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Research Article

Assessment of Effects of Turbidity Variation on Water Temperature and Evaporation of Gilgel Gibe I Reservoir, Omo-Gibe River Basin, Ethiopia

Aduna Bekele Birmachu, Tolera Abdissa Feyissa, and Nasir Gebi Tukura

School of Hydraulic and Water Resources Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia

Correspondence should be addressed to Aduna Bekele Birmachu; adunabekele776@gmail.com

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Turbidity has a significant impact on reservoir water by raising the temperature and evaporation rates. This study provided clear and concise information about the effects of turbidity alteration on reservoir water. The main objective of this study was to assess the effects of turbidity variation on reservoir water temperature and evaporation. To determine these effects, the samples were taken from the reservoir by stratifying it randomly along the reservoir course. To evaluate the relationship between turbidity and water temperature and also to measure the vertical alteration of water temperature, ten pools were burrowed, and they were filled with turbid water. Two class A pans were installed in the field to determine the effect of turbidity on reservoir evaporation. The data were analyzed using SPSS software and MS Excel. The results depicted that turbidity has a direct, solid positive relationship with water temperature at 9:00 and 13:00 and a vigorous negative relationship at 17:00, and water temperature decreased vertically from the top to the bottom layer. There was a greater extinction of sunlight in most turbid water. The differences in water temperature between the top and bottom layers were 9.78°C and 1.53°C for most and least turbid water at 13:00 observation hour, respectively. Turbidity has a direct and strong positive relationship with reservoir evaporation. The relation was analyzed using Spearman's ranked correlation coefficient, and the vertical alteration of water temperatures was analyzed using a box and whisker plot. The tested results were statistically significant. The study concluded that an increment in reservoir turbidity immensely heightens both reservoir water temperature and evaporation.

1. Introduction

Due to the presence of numerous suspended individual particles, water becomes turbid. As a result, light rays are more likely to be scattered and absorbed in the water as opposed to traveling through it directly [1–3]. As a result of the world's unfavorable global climate change, which exposes land surfaces and causes soil erosion, it is a significant issue for the environment. Water bodies, particularly the reservoirs, which were built at a tremendous expense and are crucial to the countries' socioeconomic development, are greatly impacted by this change. Strong positive correlations exist between turbidity and suspended sediment concentration, and strong negative correlations exist between turbidity and water transparency [4].

According to several studies [5–7], the activity of LULCC (landuse-landcover change) for the expansion and intensification of farmland and the construction of infrastructure heighten the alteration of air temperature, net solar radiation, precipitation, and land surface runoff and magnify soil erosion and reservoir sedimentation. The clarity and quality of surface water bodies that are utilized for water supply, irrigation, and hydropower are impacted by these activities and events [2, 8–10]. By regulating and controlling

an activity and events that cause it, building a structure, or providing nonstructural mechanisms that regulate the entrance of the soil eroded from the upstream catchment area of the water bodies, it is possible to lower reservoir turbidity [11–13].

Due to suspended particles' ability to absorb and scatter net solar radiation as it strikes the water's surface, turbidity raises the temperature of the surrounding water. The solar energy that the suspended particles have absorbed is released into the water and amplifies the temperature of the water close to the surface. By reducing the concentration of suspended particles and eliminating the plankton that causes turbidity to increase, the temperature of turbid water can be decreased. According to several studies [1, 14–16], turbidity and water temperature both decrease along the longitudinal axis of the reservoir water course. The turbidimeter is the most widely used instrument for measuring the turbidity of the water caused by the abundant presence of suspended sediment concentrations [17].

There are three well-known methods for modeling water temperature. All three of these models are statistical, deterministic, and stochastic and have their own constraints and data sets for analyzing the temperature of various water bodies [11, 18–20]. Depending on the availability of the data, both parametric and nonparametric statistical models were used for this study.

Because of their larger surface area, a substantial quantity of water evaporates from artificial lakes and reservoirs than from other natural water bodies. This happens when there are more moving molecules that break away from the water surface and escape into the air as vapor than there are molecules that reenter the water surface from the air and become trapped in the liquid [6, 21].

According to Wurbs and Ayala [22], depending on the location, evaporative losses from a reservoir may be greater than water use. The amount of water in the air depends on the amount of water that evaporates from the surface of the reservoir. The size of the vapor pressure differential between the surface of the water and the air above it is the primary physical driver of reservoir water evaporation. The absolute humidity in the atmosphere, the water surface temperature, and the amount of turbulent air mixing all influence this gradient [14, 23–26].

Due to the significant quantity of water lost from the reservoir by evaporation, the depletion of reservoir storage occurred [27] and operating efficiency and productivity of the reservoir decreased [32, 33]. The idea of smart location and geoengineering provides a potential solution for water conservation at the source by reducing reservoir evaporation. To achieve the intended purpose of a dam, an assessment of the volume of water evaporating from a reservoir is, therefore, crucial [34].

Wolancho [7] showed that numerous Ethiopian reservoirs, including Koka, Angereb, and Gilgel Gibe I, which were built for irrigation, urban water supply, and hydroelectric generation, are accumulating disturbingly larger levels of silt than they should. In 12 years, the volume of the Gilgel Gibe I dam was cut in half due to the high rate of sedimentation, and in 24 years, it will be completely filled with sediment, with a 70-year projected monitoring period, if prompt corrective action is not taken. Gilgel Gibe I reservoir has been impacted by turbidity because of the positive association between sedimentation and turbidity. The reservoir's turbidity is increased by the buildup of suspended particle concentrations. According to Prestigiacomo et al. [15], turbidity is the most causative factor for the water temperature to rise. Hence, the primary objective of this study was to assess the effect of turbidity on the temperature and evaporation of Gilgel Gibe I reservoir water. Accordingly, in order to achieve the research goal, the turbidity of various water samples was measured, the water temperature at various pool levels was noted, and surface water evaporation was measured during experimental testing.

2. Materials and Methods

The Gilgel Gibe I reservoir is situated in the southwestern region of Ethiopia, in the Jimma zone of the Oromia regional state, and in the Omo-Gibe River basin as depicted in Figure 1. The reservoir's total catchment area is 4218 km^2, and its surface area at full supply level is 54 km^2. The catchment area's longitude and latitude are 36 31′42.60″ to 37 25′16.05″E and 7 19′07.15″ to 8 12′09.49″, respectively. Gilgel Gibe I reservoir is one of Ethiopia's five major reservoirs, with the main function of hydroelectric power generation [16].

Data used in the research were collected from Gilgel Gibe I reservoir water during different rainfall events using boats, plastic cans, and plastic tankers. Ten tankers were used to store turbid water taken from the reservoir with different turbidity values. To measure the turbidity of water samples, a turbidimeter was used, and the samples were taken to the field to measure pool water temperature and pan water evaporation using pools and evaporation pans, respectively. The recorded water temperature and evaporation data were used to investigate the effects of turbidity variation on water temperature and reservoir evaporation. The materials and equipment adopted during both laboratory and field tests are illustrated in Figure 2.

Both laboratory and field experiments were performed to attain the goal of the research. To determine the turbidity of the water samples taken from the reservoir water, a laboratory experiment was conducted in the laboratory room of the Environmental Health Science and Engineering Department of Jimma University. The Indian Standard Method (IS) 3025, which was updated in 2002, was used to measure the turbidity of the water sample and explained in the nephelometric turbidity unit [32, 33]. At Jimma Meteorological Institute, field experiments were conducted to measure water temperature in various pools at different layers and water evaporation using pans for the estimation of reservoir water temperature and evaporation, respectively.

2.1. Experimental Setup and Analysis. The turbidity of water samples taken from the Gilgel Gibe I reservoir was measured in a laboratory setting at Jimma University's Environmental Health Science and Engineering Department.

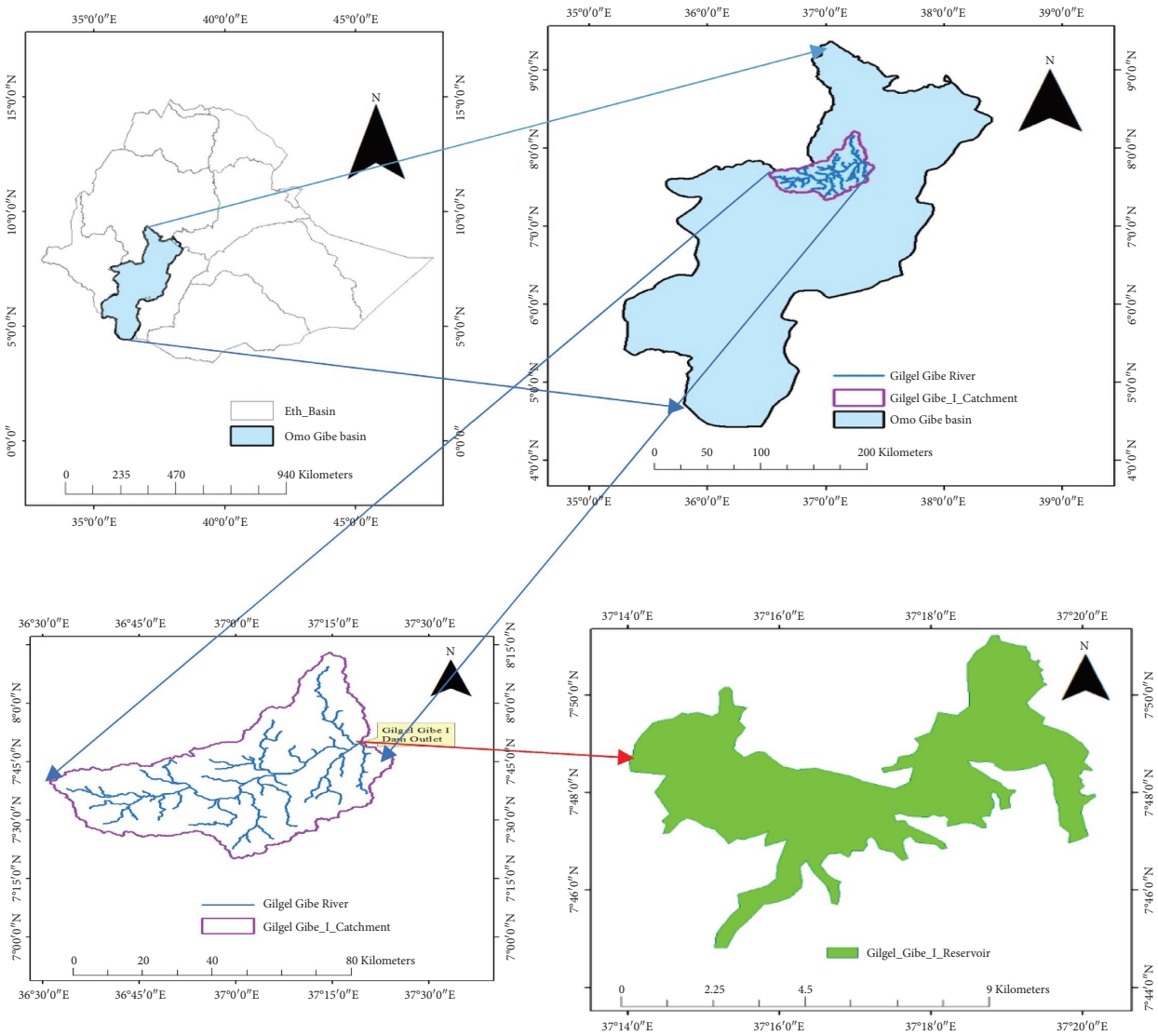

Figure 1: Study area map. Source: own study, 2021 [31].

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

Figure 2: Materials and equipment used: (a) wooden boat and plastic cans used for sampling; (b) blue plastic tankers used to store samples; (c) burrowed pool used to store water for water temperature measurement; (d) evaporation pan installed and adjusted on the field for evaporation rate measurement.

This laboratory room is adequately equipped with the tools and materials needed for conducting tests. The turbidity of water samples was measured using turbidimeter, which was calibrated to a predetermined standard before each result was observed. The two knobs on the turbidimeter were used to calibrate it together with a reference standard solution

(formazin polymer). The bottom knob of an instrument, out of the three, was used to set the instrument to zero.

The sample cell was filled with turbid-free distilled water up to the horizontal mark after the standard solution, and sample water had been prepared. The cell was then gently wiped with a soft tissue to eliminate moisture from the outer part of the cell. The sample cell with distilled water was cleaned before being inserted into the turbid meter and pushed down. Covering a sample cell allowed the reading to be set to zero, and the set zero knobs to be turned on. The standard solution was produced according to our needs and added to the sample cell up to the horizontal mark after the instrument had been reset to zero. The device showed the turbidity values of the standard solution, and the procedure was repeated twice for accuracy purposes.

Turbidity readings for all samples were measured after an instrument was reset to zero and the turbidity of a prepared standard solution was recorded. The turbidity of water samples was measured, and a comparison of the intensity of light scattering between standard solution and turbid water samples was made. The relationship between the light rays scattered and the turbidity of the water samples is directly proportional to each other. The dispersion of the light rays released was very strong for the sample of water that was the most turbid. Results from laboratory testing were used as input data for field tests, and the measured turbid water samples were brought to the field.

To determine the association of turbidity with pool water temperature and pan evaporation, field tests were carried out at the Jimma Meteorological Institute. The vertical variation of the pool's water temperature was also measured here. The location of a reservoir in relation to meteorological stations in the reservoir's catchment area, the accessibility of the area for the preparation of models, and the availability of an instrument used for field tests all played a significant role in the decision of where to conduct field tests. Jimma Meteorological Institution was chosen because it fits the aforementioned criteria out of all the stations in the catchment area of Gilgel Gibe I reservoir. To reduce the insolation of incoming solar radiation, the land was cleansed before the pools were dug.

After digging test holes or pools, reservoir models were created, and thermometers were used to measure the water temperature at various levels as well as to estimate the association between turbidity and water temperature. The pools were positioned throughout the experimental area and were made by excavating holes that were 0.45 m in diameter, 0.2 m deep, and spaced 3 m apart from one another. All of these pools were dug by hand and lined with a white, transparent plastic that was pressed firmly into the ground to optimize soil-plastic contact. Thin and short metal rings held the plastic against the soil. This white, transparent material is used to preclude the entry of groundwater from nearby soil into pools as well as the penetration of murky water from pools into the ground. The white plastic was chosen to block the effects of solar radiation absorption, which could release additional energy into the pool water and increase the temperature of the water. All pits were filled with turbid water that varied in turbidity up to 12 mm below the rims of the pools. To replace the water lost by evaporation, the pools were filled at 8:00 a.m. for every 24 hours.

According to ASTM D6176-97 [34], the temperature of the water at various pool levels was monitored using handheld digital thermometers. Two thermometers were engaged, one with a short length to measure the temperature of the water at the pool's surface and the other with a longer length to measure the temperature of the water at the pool's bottom and mid-depth. To allow the sensor to stabilize and provide an accurate reading, enough time was given for the thermometer to reach thermal equilibrium with the water temperature. Data on water temperature were logged throughout the course of fifteen days at various times. A thermometer was immersed in pool water to the necessary depth in order to acquire data on water temperature, and the device's reading was recorded. To maintain the water level at the same level and to lessen the effects of water level declines on pool water temperature, the quantity of water lost due to evaporation was replenished within a 24-hour interval prior to the recording of data.

The chosen observation hours were at 9:00, 11:00, 13:00, 15:00, and 17:00 to survey how turbidity and surface water temperature relate to one another and at 9:00, 13:00, and 17:00 to observe how turbidity variation affects water temperature in a downward vertical direction. The data for all chosen observation hours were analyzed using the average value of all recorded water temperatures. The data taken at 9:00, 13:00, and 17:00 were utilized to determine the association between turbidity and surface water temperature. The data recorded at 13:00 were used to show how the temperature of the water changed vertically downward. A spreadsheet created in MS Excel 2016 and SPSS version 20 was used to analyze the recorded results to depict their relationship and vertical alteration of water temperature. The underneath Figure 3 illustrates how water temperature in different pool levels was measured during the field test.

As illustrated in Figure 4, class A evaporation pans were adopted to measure the rate of pan evaporation for most and least turbid water samples acquired from the reservoir. According to Kohli and Frenken [21], the pan's measurements are 1.207 m in diameter and 0.254 m in depth, and it was set on a wooden platform that is 0.15 m above the ground. Pans were properly positioned on the wooden platform so that the level of water poured into the pans was consistent across the pan's perimeter. Evaporation for the most and least turbid water samples was collected using two pans during the experiment, which took place at the Jimma Meteorological Institute for 40 days between September 10 and October 20. For the other samples, interpolation was used to calculate the values of pan evaporation for a given value of water turbidity that was measured in the laboratory.

Water lost due to evaporation was replenished when the level of the water reached 30 mm below the full level of a pan because it should not have dropped more than 50 mm below the full supply level of the pan [35]. Pan evaporation data for two pans were recorded for 40 days within 24-hour intervals in depth (mm). The data collected throughout the study

(a) (b) (c)

Figure 3: Measuring water temperature. (a) Covering the pool with a white transparent plastic sheet, (b) measuring surface water temperature, and (c) measuring water temperature at mid-depth and bottom of a pool. Source: own study, 2021.

(a) (b) (c)

Figure 4: Measuring pans evaporation. (a) Pouring turbid water to pan, (b) searching level of the water, and (c) reading current depth of water after evaporation. Source: own study, 2021.

period were averaged to determine the intensity of pan evaporation. Pan evaporation and pan coefficient were used to calculate the surface water evaporation of the reservoir.

3. Results

3.1. Reservoir Water Turbidity. The findings of the laboratory tests showed that the turbidity of the water in the Gilgel Gibe I reservoir changed dramatically during the rainy season. The intensity of rainfall and the actions that had been carried out in the reservoir's upstream catchment area affected the turbidity of the water in the reservoir. Due to soil erosion from the reservoir's upstream catchment area, a significant number of suspended particles reached the reservoir.

Throughout the study period, Gilgel Gibe I reservoir water had a maximum total suspended solid particle concentration of 75.33 mg/L. Most parts of the land upstream of the reservoir have been used for farming, and because of this, a significant quantity of sediment particles has entered the reservoir during this season. Hence, the turbidity of Gilgel Gibe I reservoir water was substantially high during the wet season. The measured turbidity values of water samples taken from reservoir water ranged from 43.7 to 226 NTU. Among the collected samples from reservoir water, the largest value of turbidity was recorded during the period of farming activity, and the intensity of rainfall confluenced. The smallest water turbidity value was recorded near the period when seasonal rainfall ceased (when rainfall intensity decreased significantly, most parts of the upstream area of the reservoir were covered with vegetation, grasses, and plants).

3.2. Surface Water Temperature. As observed from field test results, the average surface water temperature of pool water altered with the variation of both water turbidity and net solar radiation striking the surface of pool water. The data were collected at 9:00, 11:00, 13:00, 15:00, and 17:00 of each day. The variation of surface water temperature for a consecutive observation hour is rare, except at midday, and hence, only three recorded data were used among the five measured above. The data recorded at 9:00, 13:00, and 17:00 were used to analyze the relationship between turbidity and surface water temperature. At these observational hours, there is a significant difference in surface water temperature between the pools. As a result, they were applied to analyze how turbidity and surface water temperature are related. The average surface water temperature increased when the water turbidity rose during both observation hours, with the exception of the 17:00 observation hour, according to the results of the data analysis. However, at 17:00 observation hour, the relationship between water turbidity and surface water temperature was inversed.

This analysis determined that there is a strong positive relationship between water turbidity and surface water temperature of pools at 9:00 and 13:00 observation hours by

achieving a Spearman's ranked correlation coefficient of determination +1 and $P < 0.001$. This relationship was determined after carefully observing results on Spearman's ranked correlation coefficient and other different models. However, turbidity and surface water temperature have a strong negative association at 17:00 observation hour, with a Spearman's ranked correlation coefficient value of −1 and $P < 0.001$.

The relationship between turbidity and surface water temperature is statistically significant, according to the results of an ANOVA test and simple linear regression, with fixed ratios of F (1, 8) = 126.730, 28.989, and 219.301 and P values of $P < 0.001$, $P = 0.001$, and $P < 0.001$ for the three observation hours, respectively.

For the three observational data sets, R-squared values were reported as 0.9649, 0.7835, and 0.9408, respectively. The following is a list of the equations of the lines using the provided observation data during three observation hours. $T_1 = 0.0122Tu + 20.489$ $T_2 = 0.0191Tu + 27.333$ $T_3 = -0.0131Tu + 25.42$ 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.

The slopes of the lines in Figure 5 showed that changes in the amount of incoming net solar radiation reaching the water surface affected the temperature of the same turbid water in different ways. Surface water temperature increases for all samples around midday, when solar radiation striking the water surface is at its highest, with the most dramatic increases occurring for the water that is the most turbid. Turbidity and surface water temperature have a direct relationship, as shown by the positive slopes of the lines, and an indirect association, as shown by the negative slope of a line. The reason for the decrease in surface water temperature around late noon was owing to the swift release of absorbed light rays. Due to the tremendous light ray absorption and scattering capability of the most turbid water, virtually all the light rays stored near the surface of the water are promptly released from the water pool when the strength of solar radiation striking the water surface substantially decreases.

3.3. Vertical Alteration of Water Temperature. With the change in turbidity values, there was a variation in water temperature within a pool and a fluctuation in water temperature between pools at the same depth. The temperature of the water varied vertically at different levels, both within and between pools. The water temperature in each pool within a group was higher at the top layer (1 cm from the water surface) than it was at the middle and bottom layers (1 cm from the bed) for all water samples and throughout all observation hours. The data collected at 13:00 observation hour were used to analyze the vertical alteration of water temperature because there was substantial incoming solar energy at midday, which resulted in water temperature variation within a pool at different levels and between the groups of pools.

According to Figure 6, there is a prominent vertical alteration of water temperature along with turbidity variation. These boxes indicated that the variation of water temperature at the surface and bottom layers is higher than the variation of water temperature at the middle layer for all water samples. There is one outlier that was recorded for the most turbid surface water temperature at 13:00 observation hour. Shapiro–Willk's p test value of 0.641 and visual inspection of the Q-Q plot indicated that the double-squared transformed water temperature was approximately normally distributed with a skewness of −0.003 (SE = 0.356) and a kurtosis of 0.427 (SE = 0.833). The F and P values from the univariate general linear model, which were produced after transforming the data using a double square root transformation, were used to assess the statistical significance of the finding. The model showed that there was a substantial vertical variation of water temperature along with turbidity alteration, with F (2, 27) = 39.587 and $P < 0.001$.

According to Figure 7, most turbid water was more likely to experience vertical temperature changes than least turbid water. With R-squared values of 0.9675 and 0.8194 for the most and least turbid pool water, respectively, the temperature of the water declined rapidly for the most turbid water and gradually for the least turbid water from the top to the bottom layer vertically. Due to the high rate of absorption and scattering of the net solar radiation striking the water body in most turbid water, these graphs showed that the water temperature at the bottom of most turbid water was significantly lower than that of the least turbid water. The net solar radiation received by suspended particles is released into the water, which adds additional energy that causes the surface water temperature to increase. As a result, the surface water temperature of the most turbid water is higher than that of the least turbid water.

3.4. Surface Water Evaporation. Turbidity and surface water evaporation had a direct correlation, according to the evaporation data that were collected during the field experiment and an analysis made. The findings showed that, when water turbidity rose, so did surface water evaporation of the reservoir. For the most and least turbid water samples, the average daily surface water evaporation recorded was 3.542 mm and 2.323 mm, respectively.

As reservoir water turbidity rises, so does the amount of reservoir water that evaporates from the surface, as seen in Figure 8. $E_r = 0.0067Tu + 2.0306$ where Tu and E_r represent reservoir water turbidity and an average surface water evaporation from the reservoir.

This analysis found that by achieving a Spearman's ranked correlation coefficient value of +1 and $P < 0.001$, there was a strong positive relationship between turbidity and the intensity of average reservoir water evaporation. This relationship was found by carefully observing the results of Spearman's ranked correlation coefficient and other different models. With a coefficient of determination value of +1, a fixed ratio value of F (1, 8) = 144.960, and $P < 0.001$,

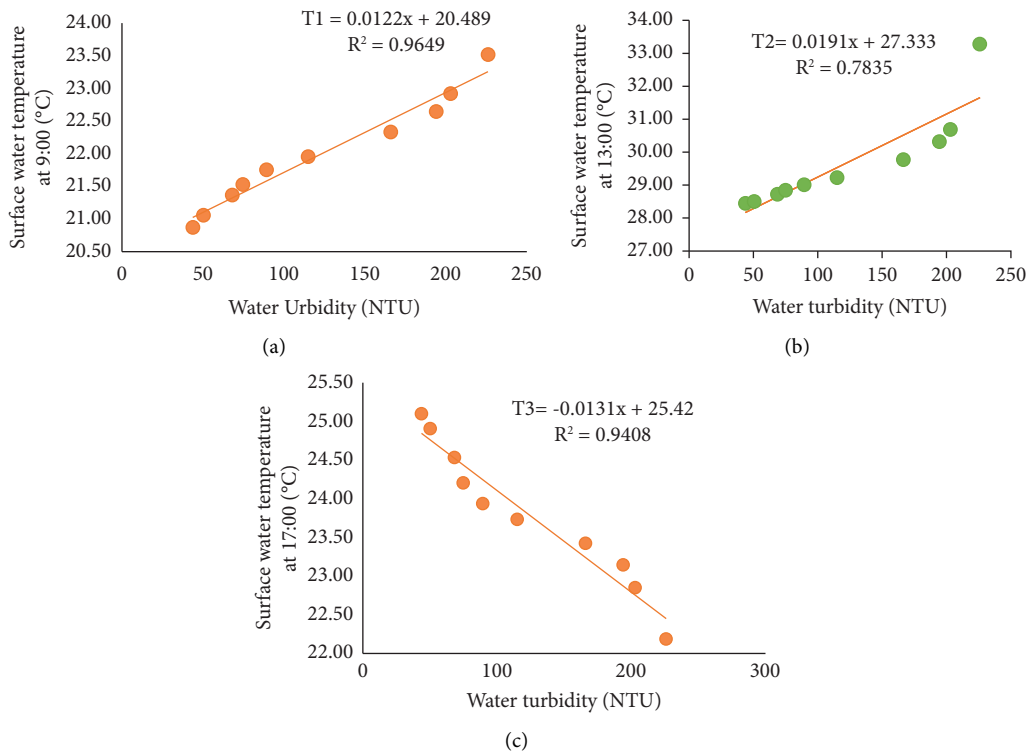

Figure 5: Turbidity and surface water temperature relationship at (a) 9:00, (b) 13:00, and (c) 17:00 observation hours.

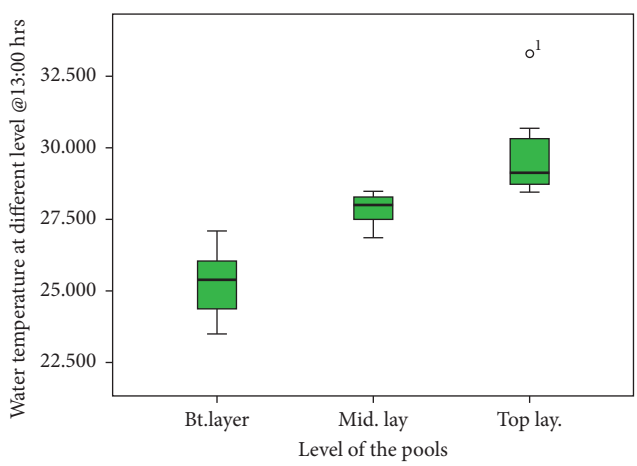

Figure 6: Box and whisker plot depicting vertical alteration of turbid water temperature.

the relationship between turbidity and average surface water evaporation was statistically significant, according to the results of simple linear regression and ANOVA tests. It was determined that the increase in water turbidity amplified the rate of surface water evaporation.

4. Discussion

During the rainy season, significant amounts of suspended particles are added to the Gilgel Gibe I reservoir. Water samples collected from reservoir water had measured turbidity values that ranged from 43.7 to 226 NTU. To acquire turbidity data, after an instrument is adjusted with distilled water and a standard solution with the help of knobs, a water sample is added to the cell. To dry the outer parts of the cell, it was wiped and inserted into the turbidimeter, and the displayed turbidity reading was recorded for all samples. The intensity of the rainfall, inadequate integrated watershed management, and human action carried out in the reservoir's catchment area were the key elements found to be the causes of reservoir water turbidity variation. Due to an increase in soil erosion from the reservoir's upstream catchment area, when the intensity of the rainfall increases, the number of suspended particles entering the reservoir has

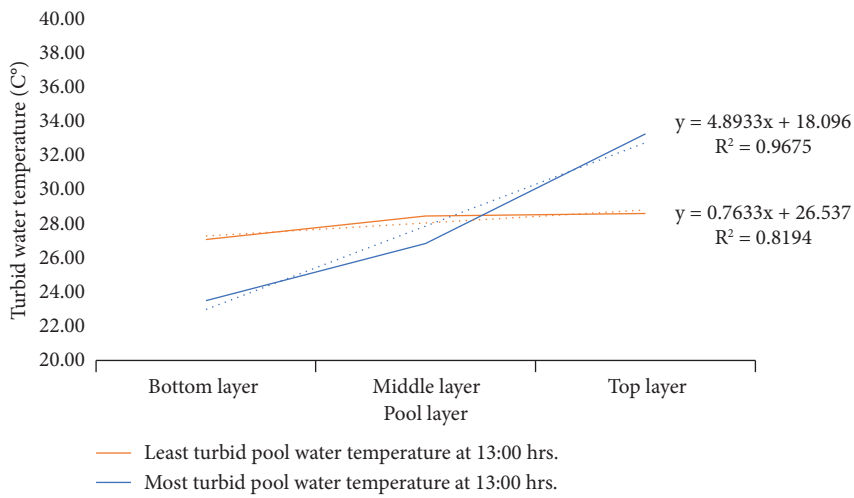

Figure 7: Difference in vertical alteration of turbid water temperature in most and least turbid water.

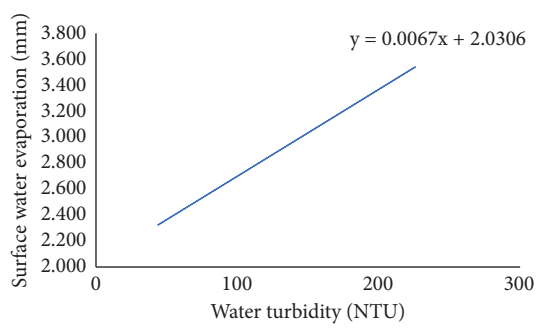

Figure 8: Turbidity and reservoir water evaporation relationship.

increased. Because they carried small-sized soil particles to the water surface, the eddies that rose from the reservoir's bed also increased the concentration of suspended particles in the water. When suspended particles enter a reservoir, the quality of the water decreases, the reservoir performs worse, and the aquatic life, primarily fish, is harmed. During the study period, Gilgel Gibe I reservoir water had a maximum total suspended solid concentration of 75.33 mg/L. This maximum value of total suspended solids was recorded when the most part of the catchment area of the reservoir was bare and rainfall intensity was high. According to the author of [36], the maximum limit of the guideline ambient environment criteria for Ethiopian reservoirs is 50 mg/L, and the highest recorded concentration of total suspended solids (TSS) in this reservoir was significantly greater than this value.

As demonstrated in earlier research by several scholars, rainfall events and changes in rainfall intensity caused a change in the turbidity of the water. For small natural puddles and rivers, Paaijmans et al. [2] and Chapman [37] showed that the turbidity of surface water bodies stepped up together with rainfall events and rainfall intensity increments. Ambelu et al. [38] measured reservoir turbidity in the range of 40–155 NTU, and Woldeab et al. [16] measured it in the range of 47.07–95.3 NTU for the Gilgel Gibe I reservoir. The results gathered by the aforementioned two researchers indicate that there is a temporal change in the turbidity of reservoir water. It was a result of the altered land use and land cover patterns in the catchment area and an inappropriate application of integrated watershed management. Near the time the rain episodes stopped, all samples were collected. The maximum turbidity measurement made in this study was higher than those recorded on the same reservoir by Ambelu et al. [38] and Woldeab et al. [16]. Thus, according to these researchers, variations in rainfall intensity in the reservoir's catchment area were the primary reason for reservoir water turbidity variation, and our investigation supported their concept. The above results assured that the Gilgel Gibe I reservoir was highly turbid, and the effects of this turbidity must be studied to take mitigation measures to decrease reservoir water turbidity and increase reservoir water performance.

Both temporal and spatial variations in reservoir water turbidity affect the water in the reservoir. The increase in quantities of suspended particles in the reservoir degrades both the quantity and quality of reservoir water. It is a physical characteristic of water that causes a change in other physical characteristics, mostly water temperature. The average surface water temperature of the reservoir was altered due to the variation in water turbidity. It increases when the turbidity of the water rises, depending on the incoming net solar radiation striking the surface of the

water. These suspended particles flowing in the reservoir absorb the incoming net solar radiation and release it into the water, which triggers a rise in surface water temperature. It decreases the penetration depth of incoming light rays, and most solar energy is stored near the surface of the water.

The relationship between the rise in turbidity and the temperature of the surface water depends on time. Based on the analyzed data, except at 17:00, the surface water temperature rose throughout the whole observation period. However, at 17:00, water turbidity and surface water temperature were inversely proportional to one another because the most turbid water cooled more quickly than the least turbid water, through which light rays could penetrate deeply, and due to less sunlight penetration in the most turbid water. Average surface water temperature differences between pools of water with the most and least turbidity were recorded as 2.65°C, 4.84°C, and −2.91°C at 9:00, 13:00, and 17:00 observation hours, respectively. The relationship between turbidity and surface water temperature is directly proportional for the first two observation hours, but it is inversely proportional for the third. Due to the presence of a higher intensity of incoming net solar radiation, water temperature increased significantly during midday (13:00) with respect to turbidity. For a given value of water turbidity, the amount by which the surface water temperature increased depended on the strength of the net incoming solar radiation.

When surface water temperature increased, it lowered the amount of dissolved oxygen in the reservoir water, and it caused the death of aquatic life in the reservoir. Since this reservoir is rich in fish, if they are harmed by the change in water temperature, the economic growth of a country could be affected to some degree because the lives of the people around the reservoir depend on the income, they obtain from selling the fish they have hunted.

If the quality of this reservoir water degrades owing to the death of aquatic life in the reservoir, it also troubles the lives of their livestock since they use this water to drink their cattle. Most children around the reservoir have taken showers at the edges of the reservoir; therefore, if its quality declines due to the above-mentioned factors, the health of the people neighboring the reservoir could be affected. Generally, the increment of suspended particles' concertation in Gilgel Gibe I reservoir harms the lives of people neighboring it, either directly or indirectly, if it is not well managed.

Paaijmans et al. [2] showed the relationship between turbidity and surface water temperature, noting that, except in the late afternoon, as water turbidity increased, so did surface water temperature. The surface water temperature of natural water bodies was raised by an increase in the concentration of suspended particles, which also changed the daily temperature dynamics of small water collections. They claimed that, as the turbidity of the water grew, the surface water temperature of the pool increased to or exceeded 42°C. The result of this investigation was close to this value for the most turbid water at 13:00, having a surface temperature of 33.29°C. We have concluded that an increase in water turbidity raises the surface temperature of the water body. To achieve the goal of storing water in a reservoir, we should keep the water temperature at its optimum level.

Due to the absorption and dispersion of the net solar radiation hitting the water surface, there is stratification in the water temperature within a group of pool water. The depth to which this net solar radiation might penetrate was reduced by the suspended particles that were present. Water at the surface became warmer than the water in the middle and bottom layers as the water depth grew because the ability of light rays to penetrate the water was reduced. Not only light scattering and absorption but also the release of absorbed light rays into the water were the primary causes of temperature stratification. All of these components caused the water temperature to exist in various forms at various strata.

The water temperature varies between the groups as a result of various rates of net solar radiation absorption and scattering for varied turbidity values of pool water. There was a greater reduction in net solar radiation penetration in the majority of turbid water. The findings showed that different degrees of water temperature values were present in different pools at the same level with different turbidity values. Due to the large concentration of suspended particles present in most turbid water pools, the net solar radiation was strongly absorbed, and the penetration depth was poor, which also led to an increase in water temperature.

Three recorded data points at 9:00, 13:00, and 17:00 were used to highlight the variations in water temperature within and between pool groups. It showed that, during noon (13:00), compared to 9:00 and 17:00 observation hours, the temperature of the pool water differed considerably between groups as well as within them. The most and least turbid pool water had a temperature differential between the top and bottom layers of water at midday (13:00) of 9.78°C and 1.53°C, respectively. The two results of top-bottom water temperature differences indicate that the extinction of light rays was larger in the most turbid water than in the least turbid water. The most turbid water was very cold at the bottom and had a high surface temperature. The least turbid water, however, had water temperatures at the top and bottom that were almost close to each other.

From the box and whisker plot, the box indicates the interquartile range (25–75%), the range bar displays the minimum and maximum values, and the small circle denotes an outlier. The black line in the box revealed the median. A box and whisker plot depicted that there was a significant vertical alteration in water temperature along with turbidity variation. The temperature of the water declined vertically from the top surface to the bottom layer as a result of the variation in net solar radiation's absorption and scattering.

As indicated by the box and whisker plot, there was water temperature variability between the groups of water pools at the surface with respect to water turbidity alteration.

The upper and lower edges of the box and whisker plot for the top layer represent the surface water temperature for most and least turbid pool water. However, the surface water temperature for the most turbid pool water was very high and was represented by an outlier. The larger the box at the top layer depicted, the greater the variability of surface water temperature with respect to the change in water turbidity. In 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. The smaller size of this box revealed that water temperature variability in the middle of the pools was low with respect to turbidity variation. At the bottom layer of the pool water, there was a greater variability of water temperature with respect to turbidity alteration. The upper and lower edges of the box and whisker plot represented the water temperature at the bottom layer for both the least and most turbid pool water. Generally, these two boxes indicated that, at the top layer, due to the existence of extreme absorption and scattering, as well as the release of absorbed light rays into the water, there was a great variation in surface water temperature with respect to turbidity alteration. But, at the bottom, high variability in water temperature occurred due to the greater extinction of light rays in most turbid water.

According to Paaijmans et al. [2], the most turbid water had a higher stratification of water temperature than the least turbid water. This investigation established that the water temperature changed significantly during the midday, which was also demonstrated by them. Sunlight could only reach a limited depth through the turbid water column, depending on both the turbidity of the water and the intensity of the incoming sunshine. The deep water was not reached by the light rays which resulted in the lowering in water temperature in most turbid water near late afternoon. 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.

There was a direct relationship between turbidity and surface water evaporation of the reservoir water. Pans evaporation data were recorded for 40 days, and an average value was taken to estimate daily pans water evaporation for two samples. Measurements were carried out for both the most and least turbid water samples. During the experimental period, water lost by evaporation was replenished by pouring water into each pan, when the pans' water level reached 30 cm beneath the rims of the pans. The recorded water evaporation for both samples was 4.722 mm/day and 3.097 mm/day for the most and least turbid water, respectively. These measurements were carried out at the same time in different pans. Pans water evaporation was determined for the other samples by interpolating them with recorded turbidity data. Only two pans were used due to the scarcity of equipment. It may be taken as a limitation of this research, but careful interpolation was carried out to estimate the pans evaporation of the other samples. Surface water evaporation of reservoir water was obtained from pan evaporation recorded for each pan during the field experiment and the class A pan coefficient value (0.75). Reservoir water evaporations, for reservoir surface area equal to pan area, were estimated as 3.542 mm/day and 2.323 mm/day for most and least turbid water samples, respectively. They reflected that the surface water evaporation of the reservoir water was less than pan evaporation, owing to the additional energy supplied by the pan that aggravates surface water evaporation of pan water.

An alteration in reservoir water turbidity caused variations in the surface water evaporation of the pans and the reservoir. When reservoir water turbidity increased, surface water evaporation also increased. Turbidity caused an increase in surface water temperature, which resulted in an increase in the amount of water particles escaping from the surface of reservoir water.

As reported by Paaijmans et al. [2], a rise in water turbidity caused an increment in both water temperature and reservoir water evaporation. According to them, variation in the turbidity of pool water changes the rate of surface water evaporation by intensifying it. The report of their measurements in a similar clear water pool showed an average evaporation rate of 3.8 mm/day, but, for more turbid water, it may be greater because turbidity causes a rise in both water temperature and evaporation. 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 paper deviated from the output observed by them due to temporal variation of the experimental period, spatial variation of the study area, and differences in concentration of suspended particles in water samples, but they were within the limited range of 1.6–5 mm/day. Generally, we concluded that the intensification of suspended particle concentrations amplified surface water evaporation in the pan and reservoir water.

5. Conclusion

The study objectives were described succinctly. This study concluded that variation in reservoir water turbidity resulted in an increment in surface water temperature, which also caused the rise in reservoir water evaporation. The significance of this study was that it provided clear and precise information about the relationship between turbidity and reservoir water temperature at the surface and vertical alteration of water temperature; it elaborated explicitly on the relationship between turbidity and reservoir water evaporation; it added new data on the effects of reservoir water turbidity variation on stored water in Gilgel Gibe I reservoir; it described factors that trigger reservoir water turbidity amplification; it also described mitigation measures to be carried out to reduce reservoir water turbidity and its outputs. It vigorously declared the ways we must follow to retain stored water in reservoirs and to attain the planned goal of reservoirs. To keep a substantial quantity of stored water in reservoirs, it requires attention to the factors that cause an amplification of reservoir water turbidity. Since the recorded turbidity of this reservoir was higher than the recommended turbidity of Ethiopian reservoirs, "mitigation

measures are needed" to attain the objective of reservoir water in a sustainable manner. The main achievement of this study was the assessment of the effects of turbidity variation on reservoir water temperature and evaporation, which had not been carried out before by any scholar.

The research found a high positive association between turbidity and surface water temperature at 9:00 and 13:00 observation hours with a Spearman's ranked correlation coefficient of $r + 1$ and a strong negative correlation at 17:00 with a Spearman's ranked correlation coefficient of $r - 1$. It revealed that, as reservoir turbidity rose, so did the temperature of the water near the surface. Due to the net solar radiation's absorption and scattering, which reduced its penetration depth, the vertical variation in water temperature occurred both within the group and between groups of pool(s).

As shown in this study, with Spearman's ranked correlation coefficient of $r + 1$, there was a substantial positive association between reservoir water turbidity and surface water evaporation. This resulted from a rise in surface water temperature along with a water turbidity increment. As a result of the increased mobility of reservoir water particles brought on by the rise in surface water temperature, reservoir water evaporation rose significantly. When reservoir turbidity rose, so did the temperature of the surface water and the rate of evaporation. Generally, the main importance of this study was that it provided explicit information about the effects of turbidity on water temperature and the evaporation of reservoir water in Gilgel Gibe I.

Data Availability

The data supporting the results of the research are confidential, and if needed, we will provide them as soon as you inquire us.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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