



Analysis of the spatial and temporal variability of direct rainfall in Lake Tana, Ethiopia

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Abstract

The Blue Nile's source, Lake Tana, is the biggest lake in Ethiopia and offers multiple services to local, regional, and international communities. The first step to effectively, efficiently, and sustainably utilizing the services that the lake may provide is to understand its water balance using accurate estimations of its water balance parameters, including direct rainfall. Direct rainfall to Lake Tana is one of the most important water balance terms of the Lake that needs a precise estimate. This study tries to analyze the spatial and temporal variability of direct rainfall to the Lake and estimate the mean annual and mean monthly direct rainfall amount to the lake using sufficient data and appropriate methodologies. 30 years (1986–2015) monthly and mean annual data from 13 meteorological stations were collected and used to analyse the spatial and temporal variability. Spatial and statistical tools were used for data processing, analysis, and presentation. Five interpolation techniques: Thiessen polygon, spline, isohyetal, inverse distance weighting, and Kriging were considered and their performances were assessed and compared using evaluation criteria. The results indicate that the Isohytal method is slightly better than the other four methods and it is also easy to implement in a geographic information system (GIS) with Geostatic Analysis in ArcGIS. Further, the analysis has shown that the mean annual direct rainfall to Lake Tana is 1313.43 mm with a standard deviation of 259.01. Besides, it has been seen that there is a significant spatial and temporal variability of direct rainfall on Lake Tana. In terms of spatial variability, the Lake gets maximum direct rainfall in its southeastern part with an annual mean value of 1720 mm and a minimum value in its northwest parts with an annual mean value of 860 mm. In terms of Temporal variability, maximum direct rainfall is estimated in July as 374.11 mm in the Summer season and the minimum is less than 12.3 mm depth in December, January, February, and March in Winter.

Keywords Lake Tana · Direct rainfall depth · Spatial and temporal variability · Mean annual rainfall

Introduction

General

The temporal and spatial variability of the rainfall process plays an important role in many hydrological applications, such as the evaluation of hydraulic balances, management of surface water resources, and real-time runoff forecasting. The rainfall input is the most important factor in rainfall-runoff simulation models in non-snow-dominated regions. Prediction errors and bias in the rainfall-runoff simulation are the direct results of spatial and temporal variations of rainfall. Although rainfall recorders and rain gauge networks have provided numerous experimental data about spatial and temporal rainfall distribution, there is a lack of data collection networks with sufficiently small resolution and large

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area coverage, this is mainly due to the operational costs and difficult access to some locations (Yang et al. 2017).

Applying the spatial domain methods to space–time variant rainfall random field raises a problem—how to embody temporal information into the spatial space so that well-developed methods can be used. Rainfall varies from year to year and over decades, and changes in the amount, intensity, frequency, and type, e.g., snow vs. rain) affect the environment and society with its distribution system. Rainfall is of major importance to water resources assessment and management and this study has been devoted to analyzing the spatial and temporal variability of rainfall in a lake within space and time-variant and the volume depth of direct rainfall in mean annual (Habib et al. 2014).

However, the increment of surface temperature could impact the hydrologic cycle and various processes of water including changes in rainfall, runoff, nutrient enrichment, sediment loading, and evapotranspiration rates in a water system (Baron et al. 2013). No more study has been conducted on the problem of hydrological cycle impact in Ethiopia in general and Lake Tana in particular. In Ethiopia human factors, in combination with the natural conditions of spatial and temporal variability of rainfall, may influence water volume to a large extent. Some studies on hydrological dynamics in Ethiopia were very scarce. Those who have done studies mainly focus on spatial–temporal trends and variation of rainfall at the local level (Ayalew et al. 2012; Seleshi and Zanke 2004), but not in Lake Tana. The current status and ability to use the positive role of the lake and reduce the negative impact, in Ethiopia in general and the study area considered in particular, Lake Tana.

Ethiopia is known as the water tower of Africa and is blessed with a range of aquatic environments, including several lakes that are extremely valuable both economically and scientifically. Ethiopia's inland waters cover 8800 km² in total, or 0.72% of the country's total surface area (Minale and Rao 2011). Lake Tana is one of the largest freshwater bodies that represent 36% of the total inland water of Ethiopia. It provides water for consumption, fishing, irrigation, power generation, transportation, recreation, disposal of wastes, and a variety of other domestic, agricultural, and industrial purposes (Tibebe et al. 2019). The various habitats and ecosystems of the Lake and associated wetlands provide a refuge for many species of flora and fauna, many of which are known to be endemic species. There is an increasing continuous demand and development for irrigation and hydro-power in Ethiopia, particularly in the Lake Tana sub-basin. Analysis of the hydrological processes at basin, sub-basins, and catchment level is very indispensable for sustainable water resources management. Besides, understanding the temporal and spatial variability of the hydrological processes of Lake Tana plays important role in many hydrological applications (McCartney et al. 2010).

Different studies produced an aerial rainfall map of the Lake as a way to compute the direct rainfall on the Lake. Those previous study results are different and it's not studied in spatial and temporal variability of rainfall in Lake, only done mean annual rainfall of lake area in the use of water balance study and using a small number of metrological station. Some meteorological and hydrological applications require knowledge about temporal and spatial variability and deficiency of rainfall, especially in areas that have few rainfall stations or rainfall data. The reason, according to Tibebe et al. (2019), is that point rainfall data are only applicable for a relatively small area (< 4 km²). Point measurement of direct rainfall and increasing uncertainty on spatial distribution are major problems for large-scale hydrological studies.

The surface area of Lake Tana is one of the lake's key hydrologic and hydraulic characteristics. An important factor in the evaluation and assessment of the lake's water balance terms is the lake's very large surface area. It is crucial to calculate exact estimations for direct rainfall into and evaporation from Lake Tana to maintain the lake's water balance. These have just as much significance as the other inflows and outflows. These water balance concepts may be overlooked or given little thought in some other lakes or reservoirs with smaller surface sizes. This is not viable in Lake Tana, though, due to its vast surface area. Therefore, one of the most crucial water balance variables that require an accurate assessment is direct rainfall on the Lake. The assessment of the rainfall is the first step in any water balance. Therefore, it is crucial for effective, efficient, and sustainable socio-economic growth as well as the environment to continuously investigate the spatial and temporal variability of rainfall.

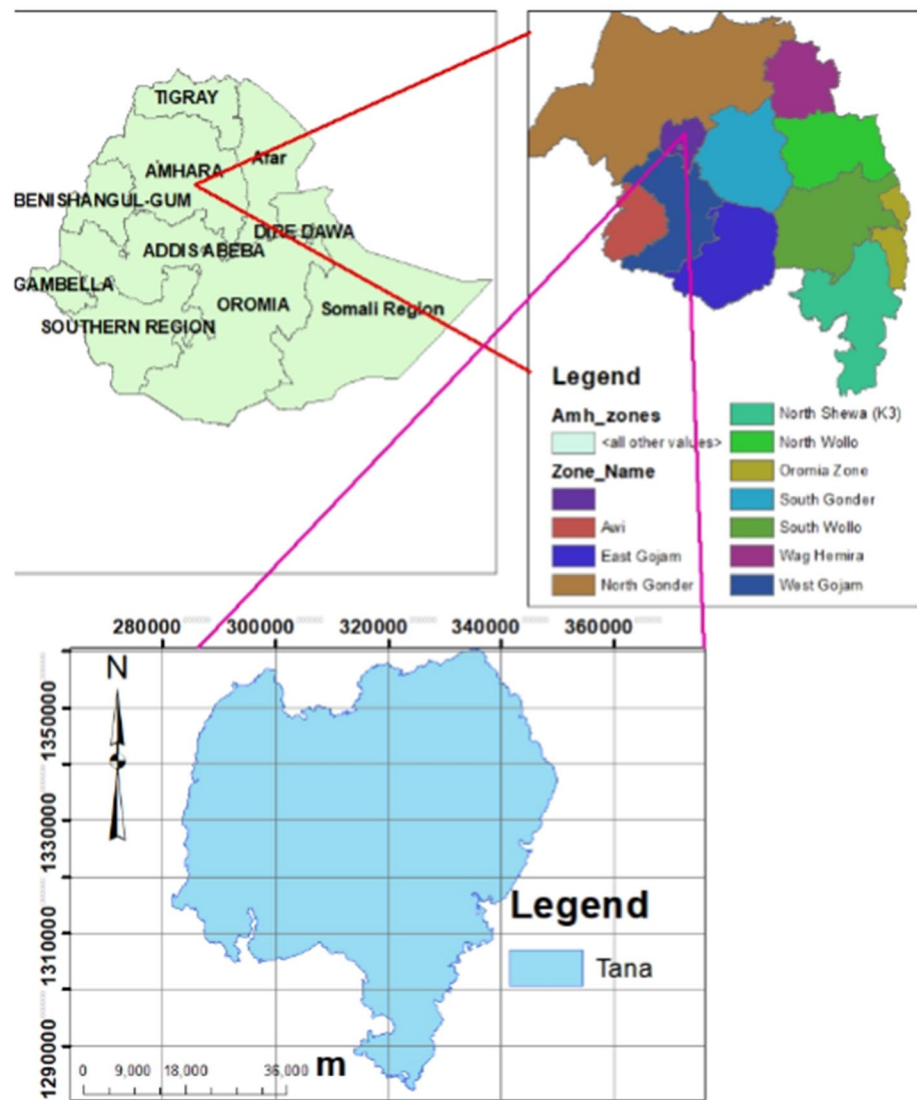
Material and methods

Description of study area

General

The largest lake in Ethiopia is Lake Tana, which also serves as the Blue Nile River's source. The approximate coordinates of the Lake are 12°N and 37°15'E. The Lake has a drainage area of approximately 15,319 km² (36% of Ethiopia's total inland water, according to Gebremedhin et al. (2018), a surface area of roughly 3066 km² (Fig. 1), a maximum length of 78 km, a maximum width of 68 km, and an elevation of 1786 m above mean sea level. There are about 37 islands in the lake, some of which have several old monasteries and churches with different religious and cultural interests (Minale and Rao 2011). The integrity of the ecological systems of Lake Tana and its surrounding wetlands is increasingly being subjected to profound

Fig. 1 Location of Lake Tana in Ethiopia



impacts on the biological, chemical, and physical processes necessary to maintain the structure and functions of the ecosystems due to anthropogenic activities and underlying socio-economic factors. Table 1 gives some information on Lake Tana.

The climate of the study area

The Lake Tana Region, despite being located near the equator, has a comparatively mild climate because of its high elevation. The annual climate may have been divided into rainy and dry seasons. The dry season occurs between November

Table 1 Facts and figures of Lake Tana

No	Description	Data
1	Location	12°00'N, 37°15'E with 1786 m amsl of altitude
2	Surface area	3066 km ²
3	catchment area	Approximately 15,319 km ²
4	depth	7.2 m mean and 14 m maximum
5	volume	Approximately 30 mm ³
6	Max. length and width	84 km and 64 km respectively
7	Major influent river	Gilgel Abbay, Ribb, Gummara, Megech
8	Effluent river	Abbay (Blue Nile) river

and April. While the wet season of the region is in the period from June to September (Marshall et al. 2011).

Topography

Lake Tana is located in a wide depression of the Ethiopian Plateau and is surrounded by high hills and mountains except where the outflow leaves the Lake by a narrow valley in the South-East. The Lake catchment has a minimum elevation of approximately 1784 m amsl, at east north, and west-south sides of the lake on the flood plain of Ribb (Fogera floodplain), Megech (Dembia floodplain), Gummara (Dera floodplain), and Gilgel Abay respectively and a maximum elevation of 4107 m amsl, at the east side of the lake at the boundary of Ribb catchment. The average elevation of the lake is 2909 m amsl (Fenta Mekonnen and Disse 2018) (Fig. 2).

Land cover

Most of the Lake Tana catchment area is characterized by cropland with scarce woodlands while only a few limited areas of highlands are forested (less than 1% of the catchment area). Figure 3 shows the land cover of the Lake Tana

basin collected from MWIER. It shows that the major land cover types are croplands (45.2%), woody savannah (18%), water (20.6%), grassland (13%), bare land (2%), and forest (1%), and urban and built-up (0.2%).

Soil

Soils in most of the Tana basin are derived from the weathered basalt profiles and are highly variable. In low-lying areas particularly north and east of Lake Tana and along with parts of Gilgel Abay, the soil has been developed as alluvial sediment. Five major soil groups in this area (Fig. 4) are Fluvisols 10%, Leptosols 20%, Luvisols 36.5%, Nitisols 21.6%, and Vertisols 11.8% in combination with four diagnostic horizon modifiers: chromic, eutric, haplic, and lithic collected from MWIE (Lemma et al. 2019).

Conceptual framework

The detail of the work is summarized in the Fig. 5 (conceptual framework of the research) and their justification is discussed in detail in separate chapters. The associated results, recommendations, and discussions are also presented in subsequent sections.

Fig. 2 DEM of Lake Tana basin

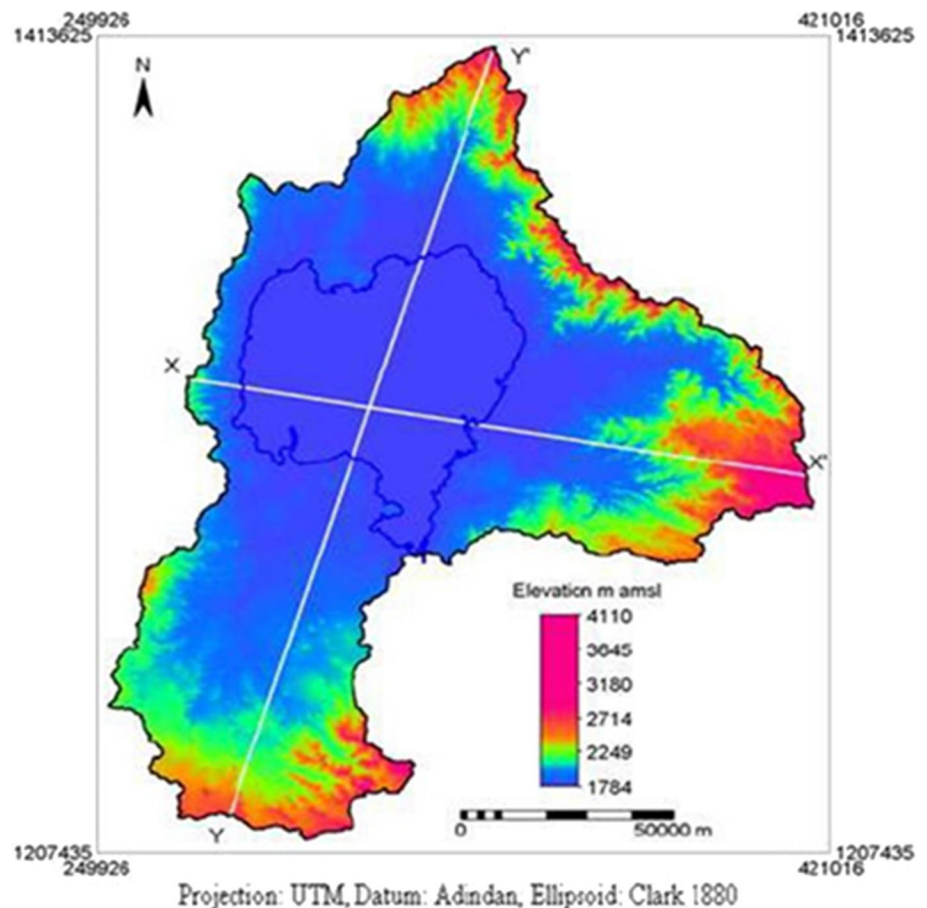
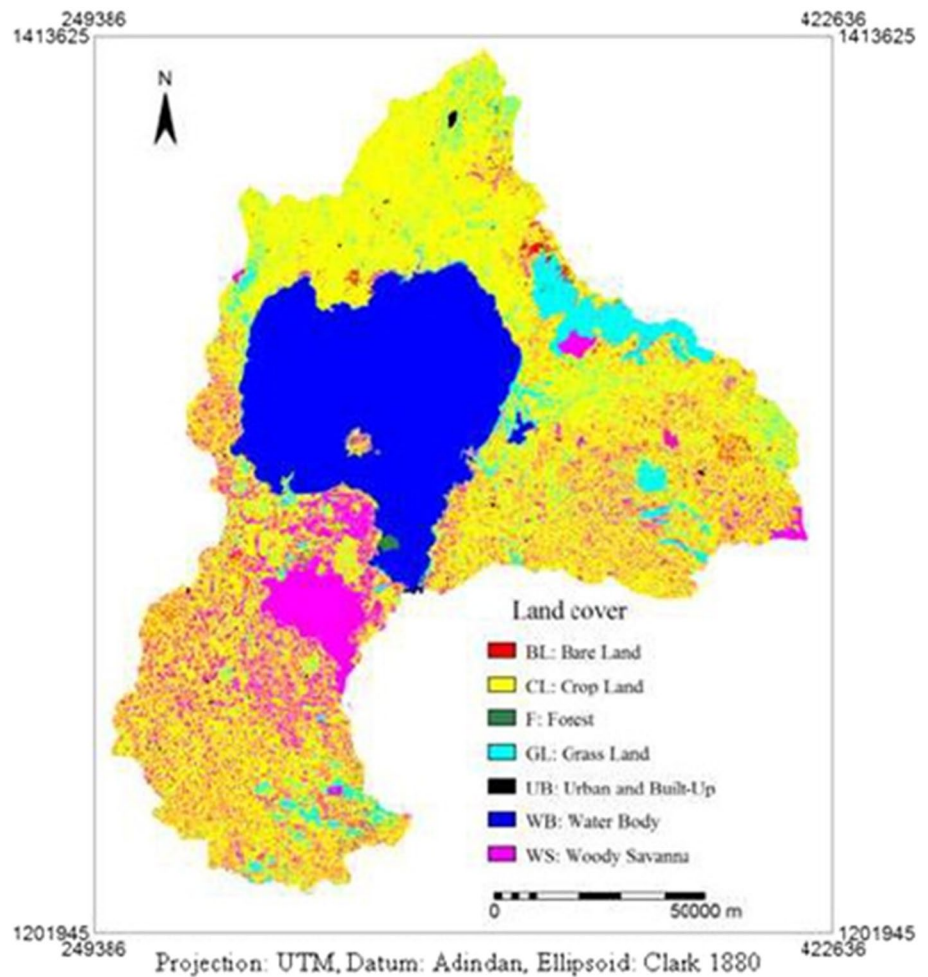


Fig. 3 Land cover of Lake Tana basin



Data sources

Data collected from the Amhara regional state bureau of water and energy development and the Ethiopian meteorological agency were utilized to attain the objectives in this paper. The main input data needed for this study involves temporal data and spatial data. The temporal data consists of precipitation, while the spatial data mainly consists of the digital elevation model (DEM), and shape file. The data used in this study comprised daily, monthly, and annual rainfall from near and over to Tana (6) and around Tana (16 Metrological stations) (Fig. 6).

Data quality

Data Quality Control was done to clean the dataset and put them in a standard format that is appropriate for analysis. The poor quality dataset is normally due to different causes and arises from the way they were acquired, transmitted from the stations to the collection center as well as achieving, i.e., A/Zemen, Chinba, and Korata. The meteorological station of Aykel, Chandiba, Gonder, Meshenti, and wanzaye

has data. But, it’s not using the data for estimating rainfall distribution in a Lake. The remaining station area covers the Lake using the interpolation method of direct rainfall distribution analysis.

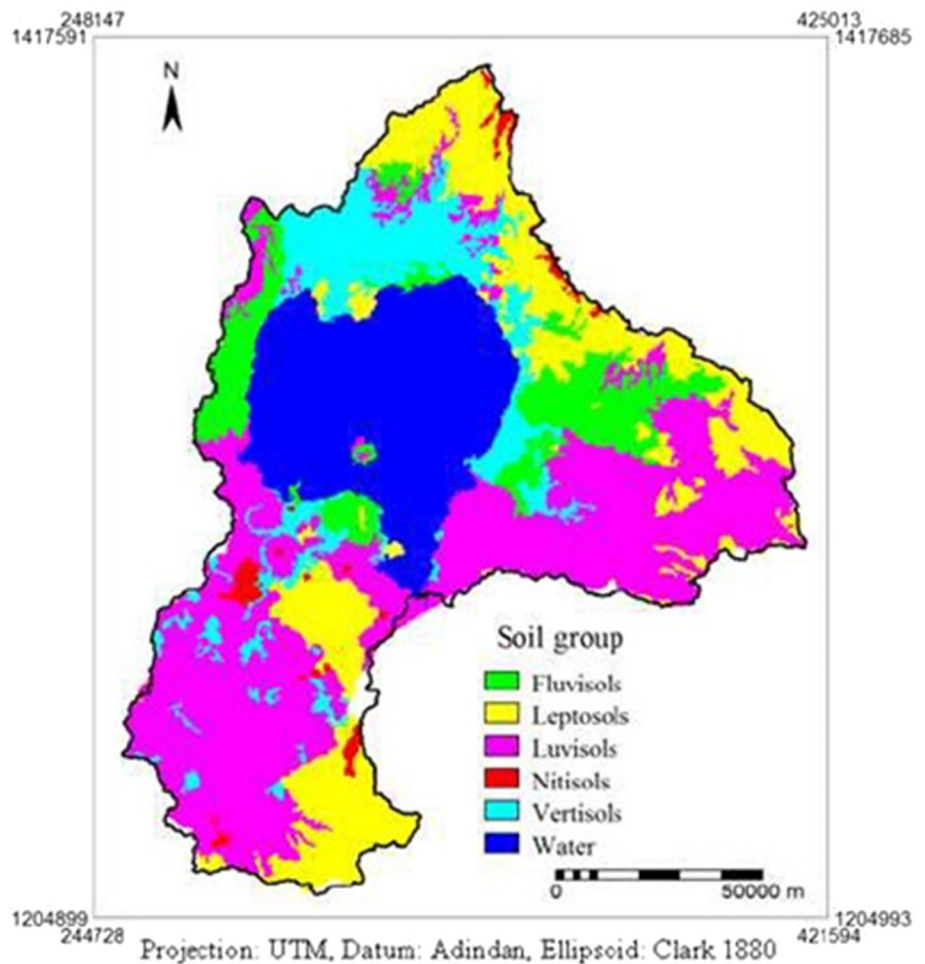
Estimation of missing data

Arithmetic mean method This method is used when: (1) the normal annual rainfall of the missing station say x is within 10% of the normal annual rainfall of the surrounding stations, (2) data of at least three surrounding stations, called index stations, are available within the basin, (3) the index stations should be evenly spaced around the missing station and should be as close as possible, (4) The missing rainfall data of station x is computed by the simple arithmetic average of the index station data in the form:

$$P_x = \frac{1}{n}(P_1 + P_2 + P_3 + \dots + P_n), \tag{1}$$

In which P_1, P_2, \dots, P_n are the precipitations of index data and P_x is that of the missing station, n is the number of

Fig. 4 Lake Tana major soil groups as FAO classification (MWIE)



index data. This is the simplest form of the equation where $a_1 + a_2 + \dots + a_n = 1$. The word normal means average of 30 years of data, i.e., 30 values of the latest records.

Normal ratio method This method is used when the normal annual precipitation of the index station data is different by more than 10% of the missing data. The rainfall of the daily index data is weighted by the ratio of normal annual rainfalls by using the following equation.

$$P_x = \frac{N_x}{n} * \left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_n}{N_n} \right), \tag{2}$$

where P_1, P_2, \dots, P_n is the rainfall data of index stations, N_1, N_2, \dots, N_n the normal annual rainfall of index stations, P_x and N_x the corresponding values for the missing station x in question, and n is the number of stations surrounding the station x .

Outlier test analysis

An outlier is an observation that lies an abnormal distance from other values in a random sample from a rainfall. In a

sense, this definition leaves it up to the analyst (or a consensus process) to decide what will be considered abnormal. Before abnormal observations can be singled out, it is necessary to characterize normal observations.

Two activities are essential for characterizing a set of data:

1. Examination of the overall shape of the graphed data for important features, including symmetry and departures from assumptions.
2. Examination of the data for unusual observations that are far removed from the mass of data. These points are often referred to as outliers.

$$\begin{aligned} xh &= \exp(\bar{x} + kn * S) \\ xl &= \exp(\bar{x} - kn * S) \end{aligned} \tag{3}$$

For data quality test as the lower and upper boundary condition (Eq. 3).

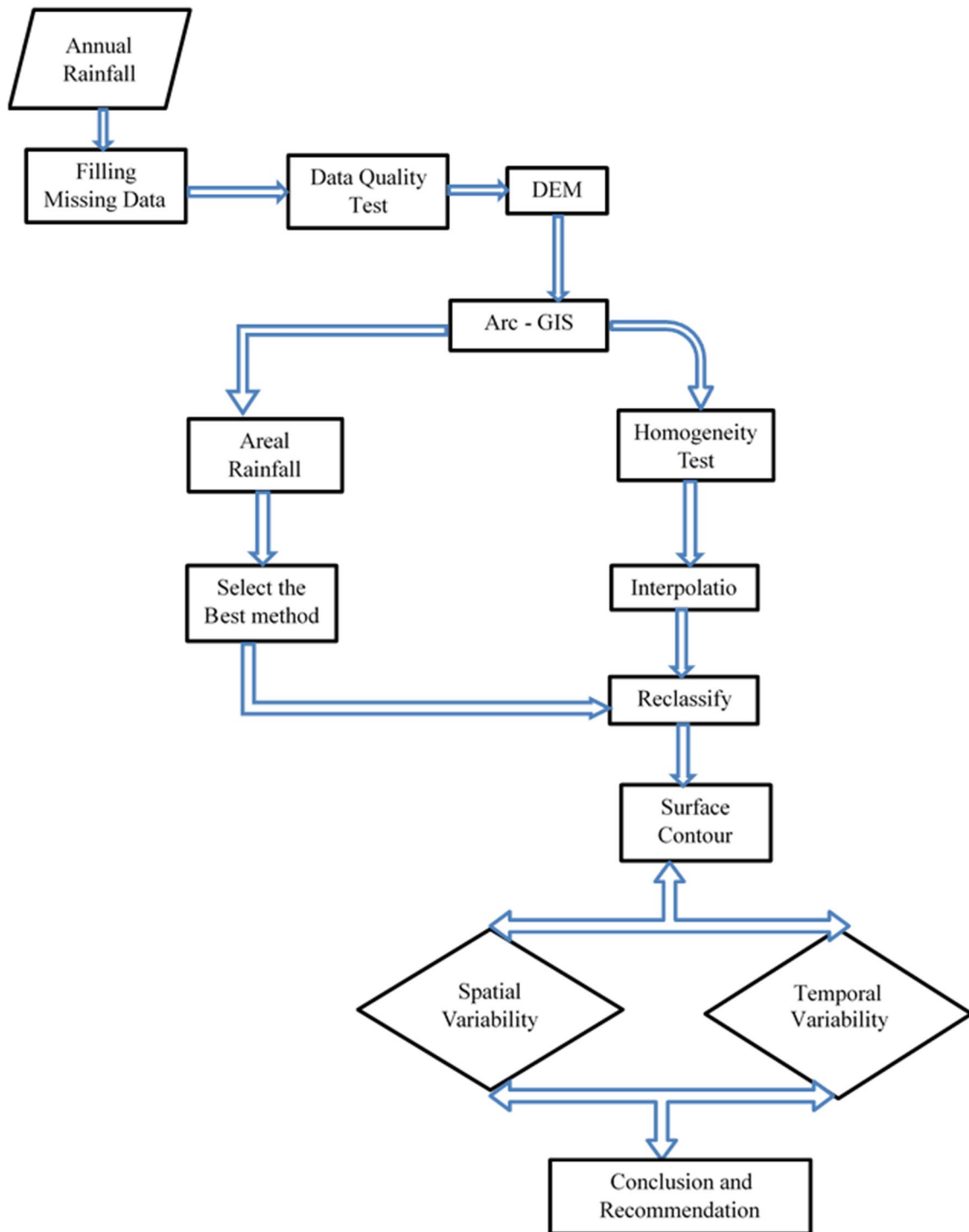


Fig. 5 Simplified methodology used in this study

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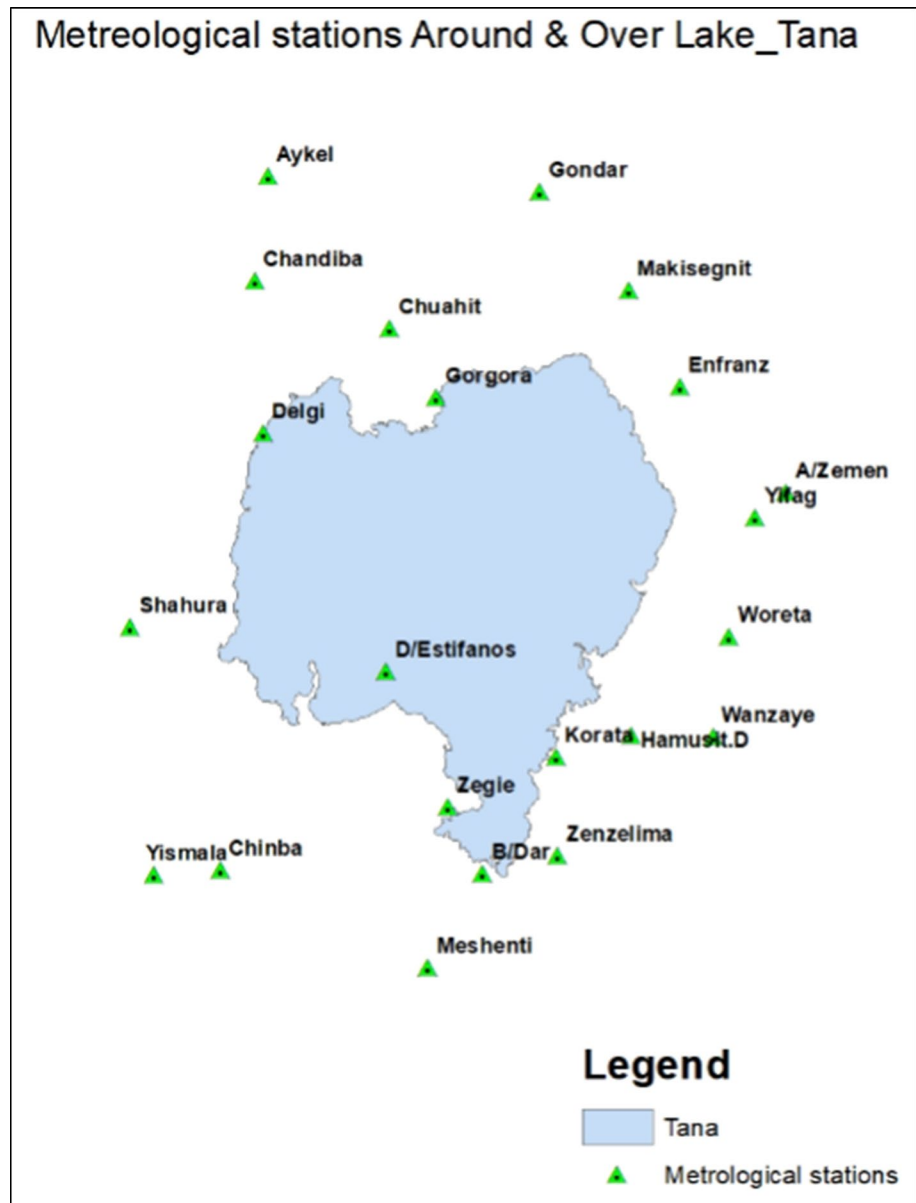
Trend significance

The significance of the observed trends for annual rainfall was tested using the student *t* test method. The equation for the student *t* test is:

$$t_l = R_{sp} * \left[\frac{n - 2}{1 - R_{sp} * R_{sp}} \right]^{0.5}$$

$$R_{sp} = 1 - \frac{6 * \sum_{i=1}^n (D_i * D_i)}{n * (n * n - 1)}$$

Fig. 6 Location of meteorology station around Lake Tana



Persistence test

Persistence is a tendency of the successive values of a time series to ‘remember’ their antecedent values and to be influenced by them.

$$r_k = \frac{\sum_{i=1}^{N-k} (x_i - \bar{x}) * (x_{i+k} - \bar{x})}{\sum_{i=1}^N (x_i - \bar{x})^2}, \tag{5}$$

Homogeneity test

Homogeneity is an important issue to detect the variability of the data. In general, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data, because it is always caused by changes in measurement techniques and observational procedures, environment characteristics and structures, and location of stations. Method for outlier identification includes the use of statistical tests like the Student *t* test (Lähnemann et al. 2020). In this study, the *t* test was

used to detect the presence of an outlier. Results of the test indicate the absence of outliers in the data series of all stations.

Consistency test

The double mass curve is used to check the consistency of many kinds of hydrologic data by comparing data for a single station with that of a pattern composed of the data from several other stations in the area. The double mass curve can be used to adjust inconsistent precipitation data.

Software using of ArcGIS 10.3.1 in geostatic analysis

Spatial coverage of each rainfall station was performed by constructing the Inverse Distance Weighing map using Geostatic analysis in the standard for extract by mask module and to draw surface contour in ArcGIS. The spatial coverage maps for each data series were prepared using spatial interpolation techniques available spatial analyst module in ArcGIS.

The input, process, and output of the isohyetal method are;

1. Input data are meteorological station coordinate and rainfall data and the data field is mean annual, average seasonal, average monthly, and annual rainfall for each as the method of IDW in power-2 and method of the standard neighborhood.
2. The process is for reclassifying, extracting, and changing the raster to the polygon area of the Lake and drawing the surface contour of a Lake depending on rainfall in a similar contour interval.
3. The output feature of a polygon area shapefile.
4. The output surface contour depends on the input rainfall data of meteorological stations.
5. Finalized output features such as the polygon area and rainfall value (contour) over Lake Tana.

From the above result of interpolation data to export raster layer, for the process of an exported raster layer to reclassify, from reclassifying to extract by mask using Tana shape file, as the process of extracting to change raster to polygon (area) getting area of and from the export of IDW to raster layer to draw contour at the surface and clip surface of isohyetal interpolation as the future data of polygon shape file getting rainfall value as the given contour interval in lake Tana as spatial distribution (map/figure) and temporal variability (table) of mean monthly, annual (2008–2015), mean annual, mean seasonal rainfall in millimeter depth as the average of Lake area.

Results and discussion

The outcome of the study revealed various facts about the spatial–temporal variation of rainfall in the Lake.

The result from data quality test

The quality obtained from this study depends on the quality of data used, to ensure that results from data analysis have proper meaning and interpretation. The objective of data quality control is to detect and remove errors in the data sets. Furthermore, the data quality test involves the estimation of missing gaps and the homogeneity test.

Missing data

There are numerous reasons why rainfall data may be missing from the database; some of them are the effect of natural hazards such as floods and human-related problems such as the temporary absence of people in charge of reading gages. In this study, missing rainfall records were encountered in the observed rainfall data from 13 stations.

Homogeneity tests and trend test

The result of the homogeneity test indicates that the data series of precipitation amounts are homogenous. The methods that are normally employed to detect and correct an inconsistency in the data set are Single and double mass curves. The single mass curve was used in this study to test for the homogeneity of the data. The single mass curve is a plot of annual cumulative rainfall against time; the mass curves for most of the stations were almost straight lines indicating that data from most stations are homogeneous except for the Maksegnit station. All data have no trend as the 95% confidence interval for the degree of freedom is $n - 2$ with a 5% significance error.

Persistence test

At 5% of significance interval, the upper and lower critical region is defined as $\{-1$ and $1\}$. Between these ranges, the test is acceptable or has no persistence. The data with the given significance interval is acceptable, so has no persistence.

Estimating areal rainfall interpolation method

Rainfall analysis is usually based on data from a network of meteorological stations each of which corresponds to a

point. A well-distributed network of stations is required to extrapolate point-scale results to the area-scale (Piticar and Ristoiu 2013).

Interpolation predicts values for cells in raster from a limited number of sample data points. It can be used to predict unknown values for any geographical point data, such as coordinate (easting, northing), elevation, and rainfall. The available interpolation methods are listed in the

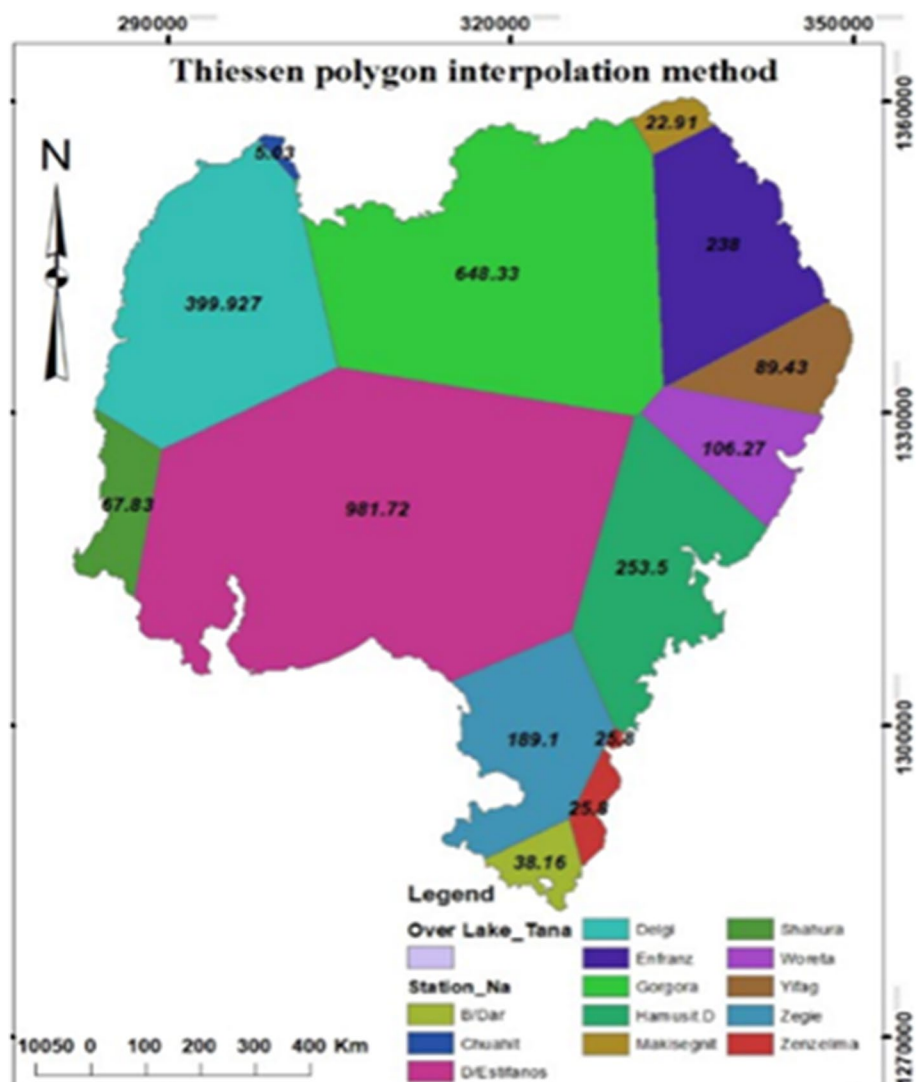
literature. D/Estifanos station will influence more than 32.35% of the study area, whereas the Chuahit station will influence 0.002% of the area depending on the grid area, see the map and Table 2 (Fig. 7).

The accuracy of areal rainfall estimation depends on the spatial variability of precipitation; thus more gauges would be required in that area where rainfall is highly

Table 2 Comparison of interpolation method

Interpolation method	Mean annual RF value	ME	MAE	RMSE	RME	PE
IDW	1314.5	-35.7	251.6	275.3	19.8	19.1
Thiessen polygon	1349.9	-72.7	254.7	282.9	19.9	18.9
Isohytal	1313.43	-35.8	249.4	274.3	19.8	19.1
Kriging	1348.1	-70.8	254.6	282.4	19.9	18.9
Spline	1372.0	-94.8	256.5	289.3	20.1	18.7

Fig. 7 Thiessen polygon interpolation methods



variable within time, Lake is, of course, one of the areas where the rainfall is highly variable with space and time.

Analysis of the Lake areal rainfall interpolation method is using the Isohytal method from the above comparison method by considering the least of RMSE, MAE, and RME. So, in this study, the isohyetal method is greatly precise the estimation of direct rainfall variability in the Lake rather than the other method. Depending on the interpolation of the isohyetal method, to estimate the direct rainfall and analysis its distribution system of rainfall in the Lake area.

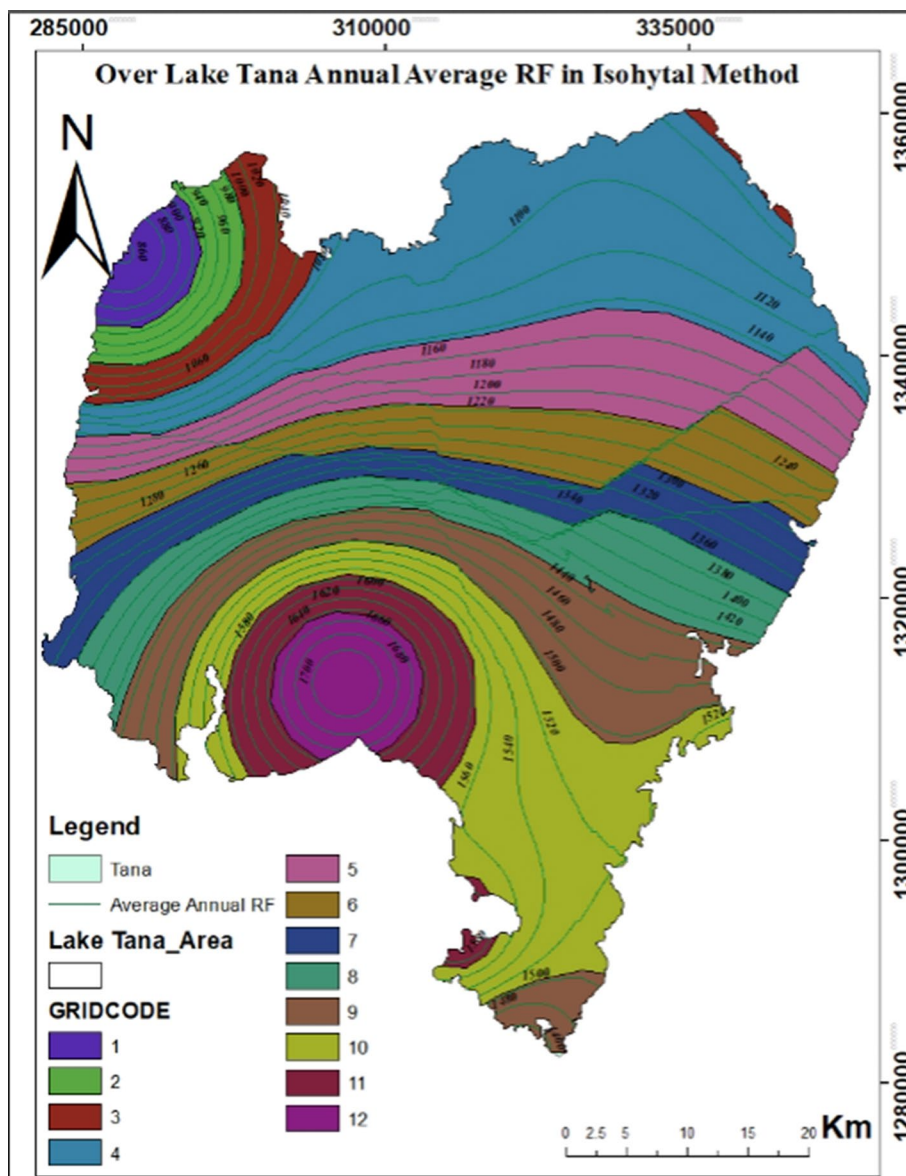
Results from spatial distribution and temporal variability of Lake Tana rainfall

The spatial and temporal distribution of rainfall over the study area was investigated; To determine the value of the large area of Lake Tana by adjusting data by time series, checking trend analysis, and persistence. And also, estimates of monthly, seasonal, and yearly rainfall for describing, spatial distribution as figure and temporal variability in the table, using 13 (thirteen) metrological stations by using the Isohytal method.

Spatial and temporal distribution of mean annual rainfall

The mean annual quantity of direct precipitation in the analyzed area for the period 1986–2015 is 1313.43 mm. They

Fig. 8 Spatial distribution of annual rainfall in Lake Tana (1986–2015)



slowly decrease from the Southeastern to the northwest area (Fig. 8) due to the volume of rainfall in the depth of a grid area within a similar contour interval. In addition to this is added a slight effect of Delgi station for minimum recording data. In large open analyzed areas to west and northwest facilities, the movement of any evidence also contributes to a general decrease of precipitation from southeast to northwest. The amount of precipitation has the highest values in D/Estifanos and B/Dar areas (1520–1720 mm), while in the northwest (860–1000 mm) is Delgi station. The minimum direct rainfall of the lake is 860 mm and the maximum rainfall is 1720 in the mean annual rainfall variability.

The contour improves in magnitude within a similar contour interval of rainfall depth. Each grid code area of the lake is divided depending on the areal rainfall and the contour passes through more than one contour in each grid area. So, we estimate the areal rainfall. Areal rainfall of the Lake (mm) = Σ (each grid code area * average of each grid code area rainfall (contour))/total area of the Lake.

Spatial and temporal distribution of mean seasonal rainfall

The spatial distribution of seasonal amounts of precipitation allows a more detailed assessment of the precipitation regime in the area. This emphasizes what has already been noticed in the spatial distribution of the annual amount of precipitation, a general decrease from summer. Winter is dry to cover the rainfall distribution of the Lake, spring is cover 9% of the total average annual rainfall, autumn covers 21% of the Lake's areal rainfall, and the summer season covers 70% of the overall direct rainfall in the Lake Tana. So, more rainfall distribution applies in summer and autumn seasons within time-variant, and spring and winter is less rainfall or no rainfall in winter. In winter, there is no rainfall distribution and variability in the Lake Tana area.

Autumn, has high rainfall distribution in the South and Southeast within the variability of rainfall is between 310 and 400 mm. In the North, Northwest, and Northeast is minimum rainfall distribution as the time rainfall variant of 190–230 mm. In the northwest and northeast is a similar distribution of rainfall (190–210 mm) and at the middle part of the lake, rainfall distribution is the average of this season rainfall with in magnitude of increasing North to Southern part. Further, this season's rainfall variability is a minimum of 190 mm in the Northwest and Northeast parts of the lake at the station of Delgie, Makseghit, and Enfranz respectively and a maximum of 400 mm in the Southern part of the lake at the station of D/Estifanos and the average season of Lake areal rainfall is 277.28 mm. In magnitude, the spatial distribution of rainfall over the lake is increasing from the region of Northwest and Northeast to the South.

The season of summer is high rainfall distribution and variability in Ethiopia compared to the other season. In Lake

Tana, the summer season covers 70% of the average annual rainfall of the area and is highly variant and distribution in time with space the average summer season rainfall of Lake Tana is 921.8 mm. The variability of rainfall is minimum in Delgi station within 570 mm rainfall and maximum in D/Estifanos station within 1200 mm rainfall depth of the Lake area. Within magnitude, the variability of rainfall in the lake is increasing from North and Northwest to Southeast and South direction. The spatial distribution of this season's rainfall is less in the Northwest and Northern parts and high rainfall distribution in the Southern part. But the middle part of the Lake is a similar value to the average (see Fig. 9).

In the spring season, the rainfall distribution is less (9% of rainfall cover) over the Lake areal rainfall. The average of this season's areal rainfall over the lake is 109.88 mm and varies within space. The rainfall variability of Tana in this season is between 90 mm (Yifag and Infarnz stations) minimum rainfall and 128 mm (Chuahit, Gorgora, Bahir Dar, and Zenzelima stations) maximum rainfall. The distribution of lake rainfall is less rainfall in the Eastern part and high rainfall in the Southeast and Northern part, but the Northwest, West, and Southwest are similar to the average of these seasons in magnitude. The spatial distribution is varying in the East and Southeast direction and the West, North, and South direction is similar distribution. The rainfall distribution of this season is increasing in magnitude from East to North, West, South, and Southeast and increases from South to Southeast. Most lake area rainfall is 110.7 mm, which covers the lake area of 60% (1823.64 km²) (Fig. 10).

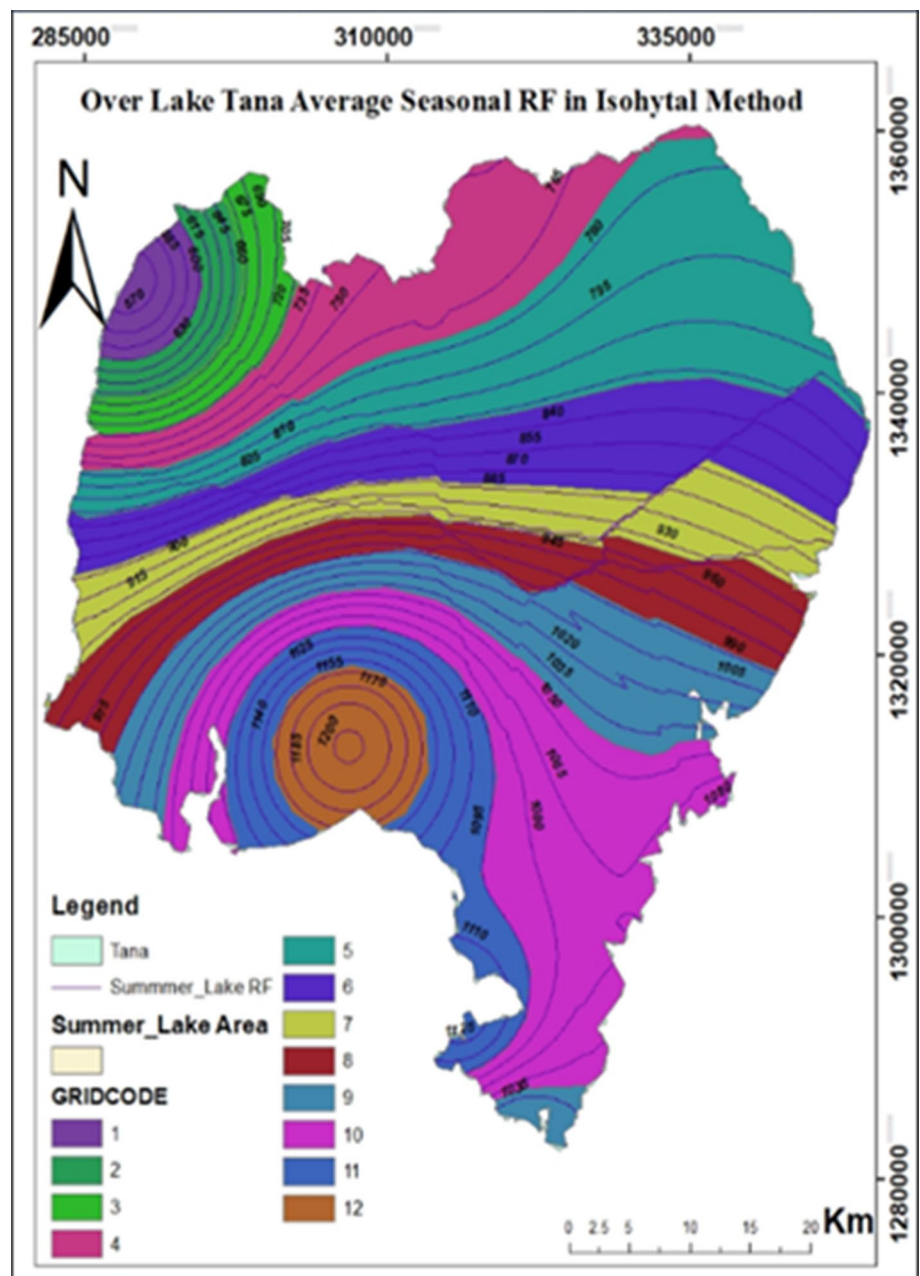
The number of precipitation changes season by season, depending on the changes that occur in the dynamic of atmospheric circulation, therefore in summer are recorded the highest values range from 560 to 1200 (mean 921.82 mm) which represents 70% of the mean annual rainfall of the area, followed by autumn as 21% and spring is 9%. The distribution of rainfall over the lake area is varying in the season as climatic conditions change.

Spatial and temporal distribution of average monthly rainfall

The average monthly data are observed in different meteorological stations from 1986 to 2015 years, the sum of daily rainfall in each station for the input data of simulated/result value. The monthly output result is different in time-variant and space to space depending on the magnitude of the lake polygon area and rainfall contour interval.

In April, the lake rainfall variability simulated value is minimum in the station of Woreta, Yifag, and D/Estifanos where rainfall depth is 17 mm, and the maximum result recorded in the station Delgie and Chauhit which is 28 mm depth of rainfall over the lake. The spatial distribution of rainfall over the lake in magnitude is increase from East

Fig. 9 Mean Summer season of rainfall distribution in Lake Tana



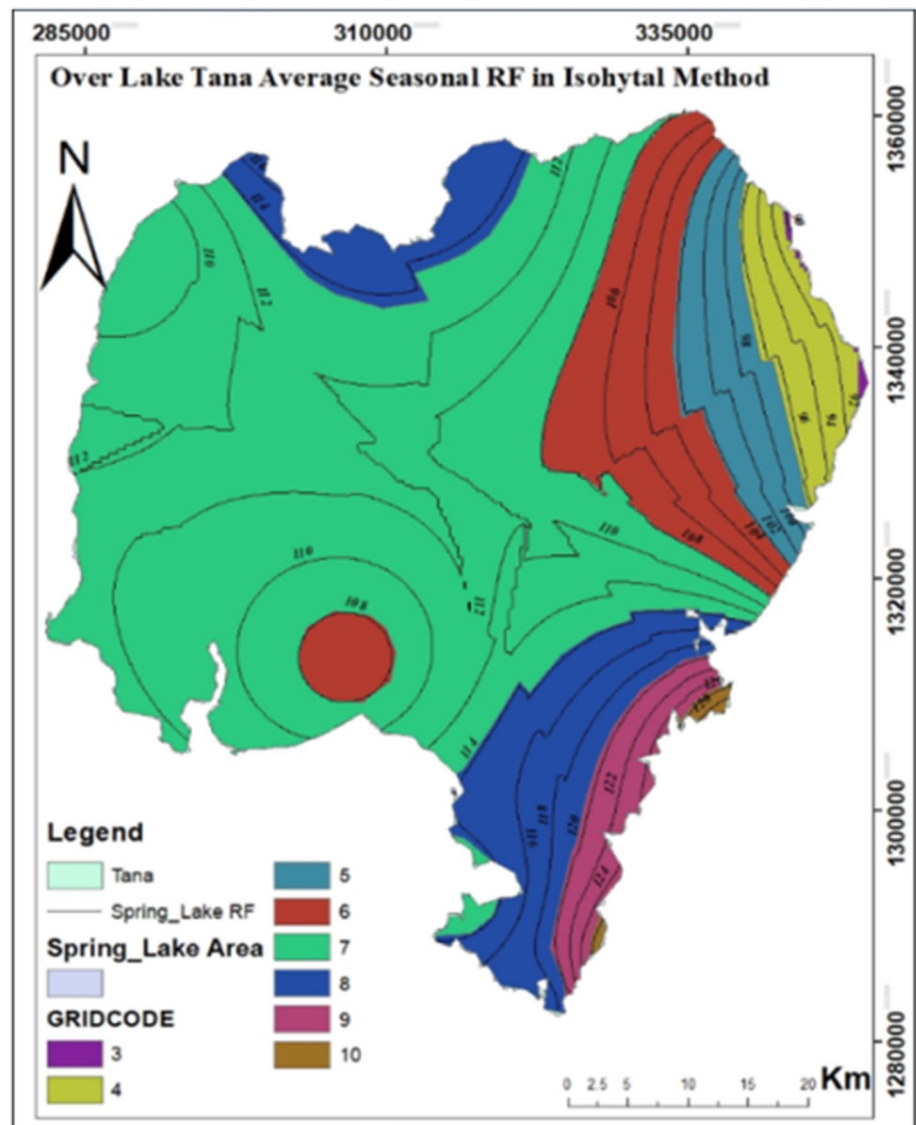
and South to Northwest. Although, from East and South to Southeast in the station of B/Dar and Zegie which output value is 24.5 mm rainfall depth.

In May, the rainfall variability of the lake is minimum in the station of Enfranz (60 mm) and maximum in Hamusit station (98 mm) as the output result of Lake Tana. During this month, the spatial distribution of rainfall is increased from Northeast (60–68 mm) to Southeast (92–98 mm) and North as the station of Gorgora and Chauhit (78 mm RF depth). From the station of Northwest Delgie to Southeast is an increase in the magnitude of rainfall. In May, the area of 1349.5 km² or 44.05% of Tana covers the rainfall depth of 78.7 mm.

In June, the variability of rainfall over the lake is the minimum result as a station of Delgie (132 mm) and maximum rainfall as a station of D/Estifanos (232 mm) and Gorgora whose rainfall depth is 196 mm. The spatial distribution of rainfall of the lake is an increase in scale from Northwest (132–148 mm), East at the station of Yifage and Enfranz (144–152 mm) to the North part (188–196 mm rainfall depth). Although, From Northwest, East, North, and Southeast (180–188 mm) to the southern region.

In July, the variability of rainfall is minimum in the surrounding Delgie station (210 mm) and maximum rainfall in the D/Estifanos station (490 mm) over the lake as the simulated result. The spatial distribution of lake rainfall

Fig. 10 Averagely spring seasonal rainfall distribution in Lake Tana (1986–2015)



this month is increasing in magnitude from the Northwest (210–280 mm) to the Southern part of the lake (450–490 mm RF depth).

In August, the variability of rainfall is low in the Delgie station (210 mm) and maximum in the D/Estifanos station (490 mm). The distribution of rainfall over the lake is similar/or the same from July. But, in the region of Southeast (400–420 mm) is low rainfall and increases in the southern region.

In September, the variability of rainfall is low in Delgie and Makisegnit station (120 mm), and maximum rainfall depth at the station of D/Estifanos (280 mm) over the lake. The spatial distribution of rainfall over the lake during this month is increased from the Northwest and Northeast to the Southern region. The distribution is low rainfall in the part of Northern (120–130 mm) and high rainfall depth in the part of Southern (240–280 mm) over the lake.

In October, the variability of rainfall over the lake is minimum in the station of Enfranz and Makisegnit (51 mm), and the maximum simulated rainfall on the station of D/Estifanos, which rainfall depth is 108 mm. The distribution of rainfall over the lake is increasing from Northeast, Northwest, and Southeast in the station of Zegie (78–84 mm rainfall depth) to the Southern region. Although, increase from Northeast to North for Gorgora station, which is 75 mm rainfall depth of simulated value. During this month, the spatial distribution of rainfall is low in the Northern part and high rainfall in the Southern part.

In November, the variability of rainfall is minimum in eastern the station of Hamusit and the Northwest station of Delgie, where rainfall is 9 mm, and maximum rainfall in depth of 18.5 mm. The distribution of rainfall is less/low rainfall distribution of the month and the divide polygon

Table 3 Average monthly estimated value of areal rainfall over Lake Tana

Month	April	May	June	July	August	September	October	November	Others
Minimum RF (mm)	17	60	132	210	210	120	51	9	
Maximum RF (mm)	28	98	232	490	490	280	108	18.5	
Average monthly RF (mm)	21.89	77.23	187.3	374.11	357.6	186.8	77.83	12.33	18.38

area is small because it depends on the magnitude of the rainfall. The spatial distribution of rainfall is low in the East and Northwest and high in the Southeast. During this month, the distribution of rainfall is increase from East, Northwest to Southeast. Although, increase East to Northeast as the station of Makisegnit. The lake area of 1714.1 km² or 56% of the overall area of the lake covers a rainfall depth of 12 mm and 1005.2 km² or 32.82% of the lake area covers 13 mm rainfall depth (Table 3).

The temporal variability of rainfall over Lake Tana in mean monthly data is dry as January, February, and December as the sum of value is less than 12.0 mm rainfall depth. And the highest rainfall value is in July and August, the value is greater than the 210 mm minimum value of these two months and the maximum of the other month's rainfall depth over the lake. In comparison to the recorded data, mean monthly rainfall is near similar for January, February, and December, but the recorded value for September, October, November, and December are higher than of estimated mean monthly data, because the control person is not recorded perfectly to write the data randomly and having data gap and the remaining month rainfall value of recorded data is minimum. In this figure, the variability of areal rainfall is different monthly to monthly because it's a conditional case. In Ethiopia condition have four seasons, from this summer season more place has high rainfall, i.e., June, July, and August, the figure below also describe lake areal rainfall distribution.

The month of July covers 29% of Areal rainfall of the lake depending on the mean annual rainfall of the lake. The two months July and August cover more than half of (56% of) the lake areal rainfall. The variability of rainfall in September and June is similar and also October and May. So, the lake rainfall distribution is high from June to September and the variability is differing from month to month. The other months are December, January, February, and March cover 1% of the lake area, as it's dry and the month of April and November covers 2% and 1%, respectively, of the lake area rainfall from the mean annual rainfall of the lake.

Spatial and temporal distribution of annual rainfall (2008–2015)

The distribution and variability of rainfall in annual time-scale are discussed below as the result of Lake Tana,

depending on the lake polygon area and contour rainfall interval in magnitude.

The distribution of rainfall over Lake Tana in the year 2008 is low rainfall at the station of Delgie which is estimated value is 890 mm and the station of D/Estifanos is the highest estimated rainfall of 1910 mm over Lake Tana considering of the other stations. This year the part of the Northwest and Northern regions is low rainfall distribution (890–1225 mm) which is at the Southern region is high rainfall (1615–1910 mm) distribution. So, the spatial distribution of rainfall over the lake is an increase in magnitude from Northwest to South, but at the end of outlet or Southeast direction in B/Dar station is low simulated rainfall and in magnitude, the rainfall is high in the northern part with in the same contour intervals in the grid code area.

In the year 2009, the rainfall distribution and variability of Lake Tana's estimated value is low at the station of Maksignit (880 mm) and high at the station of D/Estifanos (1718 mm). The rainfall distribution is low in the Northeast (880–1075 mm) and high in the Southern region (1500–1718 mm). In magnitude, the distribution of rainfall this year is increase from Northeast to South, Northwest to South, and Southeast to South at the outlet region or which covers the simulated value of the B/Dar station).

In the year 2010, the rainfall distribution and variability over Lake Tana is low at the station of Delgie (888 mm) and high in Zegie stations (2245 mm) in simulated value. The distribution of rainfall is low in the northern part (888–1100 mm) and high in the Southeast (1710–2245 mm). As the spatial distribution of rainfall, this year is increasing in magnitude from Northwest to Southeast and Northeast to Southeast, and also East to Southeast depending on the contour.

In the year 2011, the distribution and variability of rainfall over the lake are minimum for the estimated value in Gorgora station (740 mm) and maximum in Zegie station (1980 mm). This year, low distribution rainfall in the North and Northwest region (740–920 mm depth) and maximum rainfall in the Southeast (1640–1980 mm). The spatial distribution of rainfall in magnitude is increasing from North to Southeast, Northwest to Southeast, and from Southeast of B/Dar and Zenzelima stations which cover the area of the lake is 56 km² is low rainfall (1280–1480 mm) and increase in South direction /Zegie station.

Table 4 Annual variability of RF over Lake Tana (2008–2015)

Years	Annual rainfall (2008–2015) data over lake Tana							
	2008	2009	2010	2011	2012	2013	2014	2015
Minimum	890	880	888	740	858	664	880	780
Maximum	1910	1718	2245	1980	1820	2200	1960	1758
Estimated mean RF (mm)	1415.9	1237	1353.8	1230.8	1309.8	1369.6	1404.6	1282.6
Mean annual RF (mm)	1313.43							

In the year 2012, the rainfall distribution and variability over the lake for estimated value are low in the station of Delgie (858 mm) and maximum in Zegie station (1820 mm). the spatial rainfall distribution is low in the Northwest and Northern part where the variability of rainfall is (858–1020 mm) and high rainfall distribution in the South and Southeast region (1500–1820 mm), but this region has low rainfall (1410–1440) in the station of B/Dar which covers the area of the lake is 30 km² and increase in magnitude to South region of Zegie station.

In the year 2013, the rainfall variability and distribution of the estimated value over Lake Tana are low at the station of Delgie and maximum in Zegie where variability is 664 mm and 2200 mm, respectively. The spatial distribution of rainfall this year is low in the region of Northwest (664–1000 mm) and increases in magnitude to Southeast of higher rainfall distribution (1720–2200 mm), but in the station of B/Dar cover of the area 17 km² is low (1560–1640 mm) to increase Zegie stations.

In the year 2014, the variability and distribution of rainfall over the lake area estimated value is low in the station of Delgie and maximum in Hamusit station at 880 mm and 1960 mm, respectively. The spatial distribution rainfall of this year is low in the Northwest (880–1080 mm) and maximum in the Southeast region (1680–1960 mm) and the magnitude of rainfall distribution is increasing from Northwest to Southeast and from Northeast to Southeast. Most of the lake area rainfall depth covers 1280 mm and 1600 mm an area of 792.5 km² in the northern part and 760 km² in the south and southeast part respectively.

In the year 2015, the distribution and variability of rainfall over the lake's estimated value is low rainfall at the station of Delgie (780 mm) and maximum value at the station of D/Estifanos (1758 mm). This year, the highest grid-divided area of 666.4 km² of the lake covers the rainfall distribution of 1220 mm. Generally, in the above selected year annual direct rainfall is high in the South and Southeast direction and low rainfall in the North and Northwest. And also, the distribution of rainfall in Lake Tana is increasing from the northern region to the Southeastern region (Table 4).

The variability of rainfall is different from year to year. As the figure shows, the difference in rainfall variability is between the estimated mean annual rainfall and estimated

annual rainfall, likely wavelength of up and down with the reference of mean annual rainfall.

Conclusion

To provide updated maps for the estimation of direct rainfall in the lake for mean annual, mean seasonal, mean monthly, and mean annual rainfall periods of Lake Volume in-depth, geostatistical approaches were used. In Lake Tana, the distribution of direct precipitation varies throughout both time and space. Due to the size of the Lake and the irregularity of the natural rainfall from month to month and season to season.

The study shows that the mean annual direct rainfall in the Lake Tana area is about 1313.43 mm in-depth, and there is wide spatial distribution and variability of rainfall in the lake. The mean annual rainfall of the lake in the surrounding Delgie station or northwest direction is minimum and in D/Estifanos and B/Dar station or Southeast direction is maximum rainfall which the value is (820–1000 mm) and (1520–1720 mm) rainfall depth, respectively, with in the same contour interval. The spatial variability of rainfall is increase from Northwest to Southeast and the distribution system is also different, i.e., low rainfall in Northwest and high rainfall in Southeast.

The maximum monthly direct rainfall of the Lake is July about 374.1 mm volume depth and the minimum month is December, January, February, and March which a value is less than 12.3 mm (dry) rainfall depth. The season of direct rainfall is maximum in summer and minimum in winter which a value is 921.82 and 4.44 mm rainfall depth, respectively. The result shows that a single meteorological station of recorded rainfall data does not directly estimate the Lake Tana areal rainfall, because it has a variability of rainfall within space and time. Since, to use several surrounding meteorological stations of recorded rainfall data, we estimate the spatial and temporal variability of rainfall in the lake by using the Lake area shape file.

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Data availability All available data that was used for this study is included in the manuscript or all data generated or analyzed during this study are included in this article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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