

Drought Indication in Lake Hawassa Watershed, Southern Ethiopia

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Abstract
Trend analysis was conducted by using nonparametric trend tests (Mann-Kendall and Sen's slope). Lake Hawassa watershed station showed statistically significant downward trend from January to April, October, and December, and upward trend from May up to September and November. For the metrological drought severity and occurrence analysis, SPI at 3 month time scales was applied by dividing the whole period in to seven equal time periods. By analyzing the drought severity, it was observed that drought severity is increasing with time for near normal except for 2070s and 2080s, increasing with time for moderate drought, and constant for extreme droughts 2020s and 2030s and vice versa for severe drought. The drought occurrence in the study area experience mostly near normal drought that account at least 43% for all time periods, severe that account at least 27%, moderate that account at least 11% and null except for 2020s and 2030s for extreme drought. The observed inter-annual variability in the study area mostly experienced near normal inter-annual variability (about 73.33%).
Keywords: drought, Climate change, SPI and Lake Hawassa watershed
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1. Introduction

1.1. Background

Meteorological drought is the earliest explicit event in the process of occurrence and progression of drought. Rainfall is the primary driver of meteorological drought. There are numerous indicators based on rainfall that are being used for meteorological drought monitoring (Smakhtin and Hughes, 2007). Rainfall, surface temperature, sea levels, and extreme climate events, are indicators of climate change which resulted in broad changes of the global climate that has an impacts on various aspects of life (Kementrian, 2014).

Meteorological drought is a creeping phenomenon, as its effects often take time to impact which makes it challenging to determine when it begins and over. Drought indices are often used for detecting the early onset and end of droughts. Several drought indices have been used effectively as drought assessment tools in other parts of the world (Barua *et al.*, 2011). Climate change has an immediate and long-term impact on water resources in African countries. It will greatly complicate the management of water-use systems (Gleick and Shiklomanov, 1989). These effects when compounded together have devastating impacts on ecosystems and communities, ranging from economic and social impacts to health and food insecurity (Kevin and Nicholas, 2010).

Climate change is one of the global issues that would affect the sustainable development of many regions and it is induced by the increase in carbon dioxide and other radioactive trace gases in the atmosphere. This was the focus of scientific investigations due to the fact that climate change has significant implications for the environment, ecosystems, water resources and virtually every aspect of human life (IPCC, 2007 and Solomon, 2016).

Ethiopia is vulnerable to climate change that leads to different types of droughts including meteorological drought (precipitation well below average), hydrological drought (low river flows and low water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture and low water holding capacity of the soil), and Socioeconomic drought (a combination of the above) (Bates *et al.*, 2008).These droughts are caused by lack or insufficient rainfall (or precipitation), climate change, human activities, and over-exploitation of surface water resources that leads to harmful effects of droughts.

In Lake Hawassa watershed, metrological drought under climate change due to lack or insufficient rainfall is a common phenomenon that has a great impact on the economy, communities, ranging from economic and social impacts to health and food insecurity. Therefore, analysis of metrological drought under climate change in the study area is used to understand and adequately apply the results for impact studies, planning, or decision-making.

1.2. Statement of the Problem

Metrological drought due to insufficient rainfall under climate change has many negative effects on different sectors (agriculture, fisheries, health, electricity, and etc.) that ranges from economic, environmental and social impacts. Metrological drought has both direct and indirect impacts for human livelihoods. A direct impact is source for agricultural drought (crop loss), which can cause starvation if alternative food sources are not available. Indirectly, water shortages contribute to the spread of disease, because people lack water for basic hygiene (Pavel, 2003).

Metrological drought under climate change is taken as the major environmental disasters. This major environmental disaster are mainly due to climatic parameters which directly influence the occurrence and severity of metrological drought that is expected to affect society in different ways ranging from food security to water resources. Production of goods and services in the society is mainly related with that of water. Especially precipitation is affected by Climate change in the hydrological cycle. Lack of precipitation due to the changes in the climatological variations drops the production of crops due to the metrological drought under climate change(Solomon, 2016).

1.3. Objectives

1.3.1. General Objective

To analyze the metrological drought under climate change in the study area

1.3.2. Specific Objectives

- ❖ To analyses the metrological drought trend in the study area
- ❖ To identify the metrological drought severity and occurrence
- ❖ To identify the average and inter-annual variability of observed rainfall

1.4. Significance of the Study

The significances of the research with their contributions are as follows:

- ➢ Trend analysis of the metrological drought is used for the identification of any possible trends in climatic parameters which directly influence the occurrence and severity of metrological drought. Therefore, whether there is a possible trend in the risk of occurrence and severity of drought events was determined.
- ➢ Provide essential information on metrological drought which would be taken as an input for different stakeholders under the climate change and to give an overview in metrological drought related researches in the study area for other researchers.
- ➢ Metrological drought information used for different decision-makers and end-users is somewhat difficult to understand. This study aims to derive information about metrological drought in general under the climate change and its analysis.
- ➢ This research also informs early warning for different organization in the study area.

1.5. Research Questions

- ✓ What is the trend of metrological drought in the study area?
- ✓ How intense will the severity and occurrence of metrological drought in the study area?
- ✓ What will the inter-annual variability of observed rainfall in the study area looks like?

1.6. Scope of the study

The study mainly investigated the analysis of metrological drought under climate change and geographically confined only to Lake Hawassa watershed.

2. LITERATURE REVIEW

2.1. Drought Review

Droughts are generally periods that rainfall is below normal, leading to extended periods of water shortage. In a broad definition, these drought that occur when there is precipitation deficiency instigates meteorological drought, which in turn subsequently impacts soil moisture content that instigates agricultural drought and also low recharge from the soil to water features such as streams and lakes causes a delayed hydrological drought (Brian, 2012). Droughts can also be defined as temporary situations when water demands in a hydrological system surpass the income of water from other sources (Wilhite et al, 1985). Drought is fundamentally characterized with that of severity, duration, and spatial distribution, frequency, magnitude (cumulated deficit). (Salas, 1993), defined these terms as follows:

i. **Duration**: can vary between a week's up to a few years or century.
ii. **Magnitude**: The accumulated deficit of water like that of precipitation below some threshold value or period.
iii. **Intensity:** The division or ratio of drought magnitude to its duration.
iv. **Severity** : The degree of the precipitation deficit that indicates the magnitude, or the degree of impacts resultant from the deficit

v. **Length:** is the largest number of consecutive days or monthes in which a day without rain has been considered as one in which the record registers a precipitation amount below a threshold of 1 mm as the threshold (Mathugama and TSG, 2011).

vi. **Frequency:** is the occurrences of consecutive dry days which are the largest number of consecutive days in which a day without rain has been considered as one in which the record registers a precipitation amount below a threshold of 1 mm as the threshold. (Mathugama and TSG, 2011).

2.1.1. Types of Drought

Different sets of people have different definitions of drought. The term drought may refer to a meteorological drought (precipitation well below average), hydrological drought (low river flows and low water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture), and Socioeconomic drought (a combination of the above) (Bates *et al*., 2008).

2.1.2. Causes of Droughts

Lack or insufficient rainfall (or precipitation): -is the major cause of droughts in most regions. A long-drawn-out period without rainfall can cause an area to dry out. The quantity of water vapor in the atmosphere pretty much impacts the precipitation of an area.

Climate changes: - Climate change imposes a challenge for the sustainable management of water resources and the factor influencing this phenomenon is key for water managers and policy-makers. In the world, climate change is a key concern in any time and need to be tackled. Deforestation, serious soil erosion and loss of top soil which is fertile to give high crop yield and land degradation which in turn have adversely impacted agricultural productivity are due to the burden of climate change (Loch *et al.*, 2013).

Human activities: -Forests are critical components of the water cycle. They help to store water, minimize evaporation, and contribute a great deal of atmospheric moisture in the form of transpiration. This, in essence, implies that deforestation, aimed at uplifting the economic status of a region, will expose vast quantities of water to evaporation. Cutting down trees will also take away the capability of the ground to retain water and allow desertification to occur easily. Deforestation also greatly minimizes watershed potential.

Overexploitation of surface water resources: -Specific areas are endowed with surface water resources like rivers and streams whose sources are watersheds and mountains. These surface water resources could dry out if their main sources are interfered with. Irrigation systems and hydroelectric dams are just some of the aspects that contribute to over-exploitation of surface water resources.

2.1.3. Harmful Effects of Droughts

Droughts have both direct and indirect consequences for human livelihoods (Pavel, 2003). A direct consequence is crop loss, which can cause starvation if alternative food sources are not available. Indirectly, water shortages contribute to the spread of disease, because people lack water for basic hygiene.

A. **Economic Effects: -** involve loss of money by governments, enterprises, families or individuals. Below is an outline of the main economic impacts of droughts:

- ✓ Low yields equal loss of substantial income. Low yields also lead to pay cuts and layoffs to farm workers.
- ✓ Businesses and industries that produce farm equipment may close down since farmers have no money to purchase equipment.
- ✓ Prolonged shortage of rains means drier conditions. This makes an area susceptible to wildfires.

B. **Environmental Effects**

- ✓ Droughts lead to decimation of habitats. Water bodies such as rivers, lakes, ponds, lagoons, and creeks dry out, and this leads to death of water animals.
- ✓ Soil moisture is critical to the breakdown of organic matter. Droughts compromise soil quality since there is less to zero organic activity because organisms have died.
- ✓ The quality and health of surface water bodies such as rivers, streams, lakes, and ponds are enormously impacted. This endangers living organisms depending on the water for survival.
- ✓ Wildlife walk long distances in search of water. They end up in new dangerous habitats that can lead to their demise.

C. **Social Effects**

The social effects of drought are the most potent since they directly impact humans. Many in the third world countries that have experienced drought can attest to their severity.

- ✓ Water maintains our health. Sanitation and clean drinking water are critical to a healthy body. Droughts lead to malnutrition, anemia, and hunger.
- ✓ Droughts trigger migrations. This means the area will lack young and working population, a critical ingredient to the development of any region.
- ✓ Lack of control over when the drought ends can have far-reaching psychological effects like stress, anxiety, and depression. Social interaction reduces and community networks get broken.

2.2. Metrological drought analysis

Metrological drought originates from a deficiency of precipitation over an extended period of time usually a season or more resulting in a water shortage for some activity, group, or environmental sector. Analysis of this drought is essential as droughts are becoming more common and severe due to the impact of climate change (Meehl *et al.*, 2000) and (Mishra *et al.*, 2009).

Metrological drought analysis heavily reliant on the metrological data and emission scenarios are used to explore how much humans and earths system could contribute to future climate change to analysis the risk based on frequency analysis of drought severity. The input variables like that of precipitation data are needed for meteorological drought analysis, stream flow, reservoir and lake level data for hydrologic drought analysis, and soil moisture and crop yield for agricultural drought (Mishra and Singh, 2011).

In few studies, droughts have been analyzed by different authors. (Ganguli and Reddy, 2014) established comprehensive and integrated drought management strategies, it is life-threatening to understand the nature of drought risk with appropriate management which requires knowledge of the expected frequency of drought magnitude that can be achieved by employing probabilistic approaches. Identifying the occurrence, severity patterns of droughts, and investigating the possibility of analyzing the future patterns of droughts would generate useful information to various stake holders for their decision making purposes (SC and TSG, 2011).

Different types of droughts are analyzed by using different drought indices. Different types of drought indices are used to analyses and predict different types of droughts including meteorological, hydrological, agricultural and socio-economic droughts. It has been applied in several studies for drought analysis and they give reasonably good results. From different types of drought indices, some of metrological drought indices are standard precipitation index, Reconnaissance Drought Index, deciles and Palmer Drought Severity Index (Durdu, 2010).

2.2.1. Drought indices review

The preparedness and mitigation of drought upon timely information can be obtained from drought indices. Drought indices (DIs) have also been commonly used to quantify rainfall deficits, soil moisture and water availability (Mishra and Singh, 2010).

I. Standardized Precipitation Index (SPI)

One of the most well-known and widely-used meteorological drought indices which were designed by (McKee et al., 1993) to quantify the precipitation deficit for multiple time scales (i.e. 1, 3, 6, 12, 24 and 48 months cumulative moving values). It is basically the transformation of the precipitation time series into a standardized normal distribution. The significance of this index is that it is Simple (only on precipitation), Versatile (Can be computed for any time scale), and can provide early warning of drought and help assess drought severity while its disadvantages are it access to a long, reliable temporal time series (Mishra and Singh, 2010).

II. Reconnaissance Drought Index (RDI)

One of meteorological droughts manifest as a water deficit, the focus can be on the water balance (input - precipitation and output - potential evapotranspiration). RDI was designed by (Tsakiris and Vangelis, 2005). The significance of this index is that it is physically based, since it calculates the aggregated deficit between precipitation and the evaporative demand of the atmosphere and It can be effectively associated with agricultural and hydrological drought and while its disadvantages is it should consider actual (is the real output) and not the potential evapotranspiration

2.3. Downscaling

The objective of Downscaling is to bridge mismatch of spatial scale between the scale of global climate models (GCMs that indicate that rising concentrations of greenhouse gases) and the resolution needed for impacts assessments. It is information which is cascaded down from larger to smaller scales, with the regional climate. Two sets of techniques have emerged as a means of deriving local–scale surface climate.

Both approaches will continue to play a significant role in the assessment of potential climate change impacts arising from future increases in greenhouse–gas concentrations (Robert.and Christian, 2007).GCM boundary conditions are a main source of uncertainty for most downscaling techniques and different downscaling methods (Linda, 2009). The scenarios produced by RCMs are also sensitive to the choice of boundary conditions (such as soil moisture) used to initiate experiments (Giorgi and Mearns, 1999).

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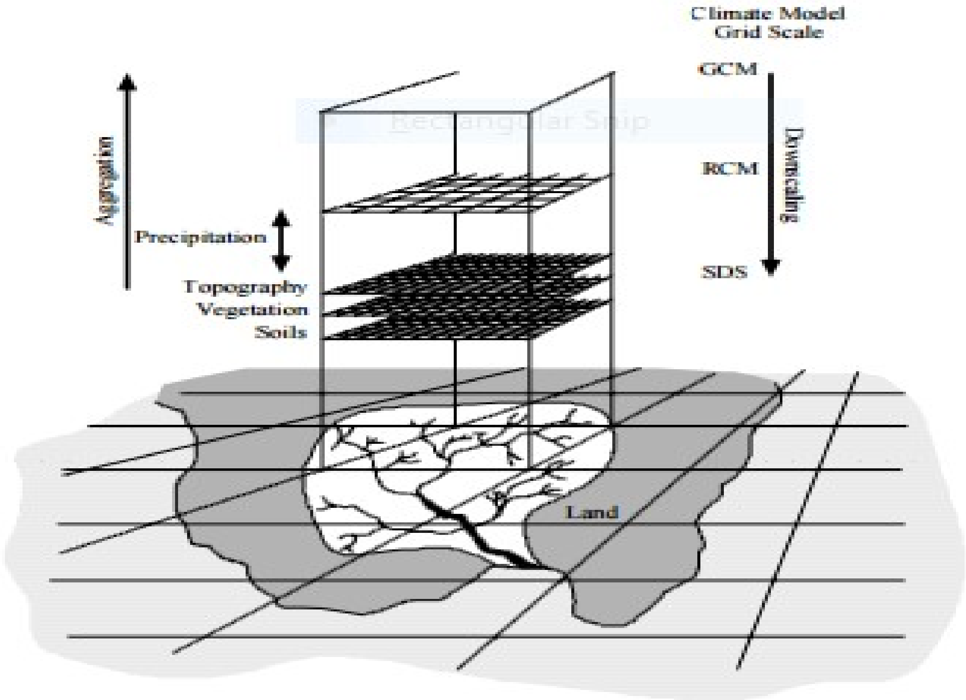

Figure 2a. The general approach to downscaling (Source W. Dawson et.al, 2007)

2.4. Statistical Downscaling Model (SDSM)

The SDSM software reduces the task of statistically downscaling daily weather series into the following discrete steps (Robert and Christian, 2015):

1) **Quality control:** used for the detection of errors in the data. It also includes maximum, minimum, mean, number of values in file, missing values, number of values ok, maximum difference and their values.
2) **Transform data:** as per the objectives of the study it may be appropriate to transform predictors and/or the predictand prior to selected transformations like logarithm, power, inverse, lag, binomial, etc.
3) **screen variables:** used to assist in the selection of appropriate downscaling predictor variables which is used for further analysis and identifying empirical relationships between gridded predictors and single site predictands (such as station precipitation) is central to all statistical downscaling methods.
4) **Calibrate Model:** used to operate the predictand along with a set of screened predictor variables. The model structures are monthly, seasonal or annual sub–models and the process is unconditional or conditional.
5) **Weather generation:** used to generate synthetic daily weather series given observed (or NCEP re–analysis) atmospheric predictor variables. The procedure enables the verification of calibrated models (using independent data) and the synthesis of artificial time series for present climate conditions.
6) **Summary statistics:** SDSM provides means of interrogating both downscaled scenarios and observed climate data. In both cases, the User must specify the sub–period, output file name and chosen statistics.
7) **Frequency analysis:** Used to plot extreme value statistics of the chosen data file by using the analyses which include Empirical, Gumbel, Stretched Exponential and Generalized Extreme Value distributions.
8) **Scenario generator:** used to produce synthetic daily weather series given predictor variables supplied by a climate model (either for present or future climate experiments), rather than observed predictors.
9) **Compare Results:** Used to plot monthly statistics produced by the Summary Statistics screen. Having specified the necessary input file, either bar or line charts may be chosen for display purposes which allows simultaneous comparison of two data sets and hence rapid assessment of downscaled versus observed, or present versus future climate scenarios.
10) **Time Series Analysis:** Used to produce time series plots for up to a maximum of five variables. The data can be analyzed as monthly, seasonal, and annual or water year periods for statistics such as Sum, Mean, Maximum, and Winter/Summer ratios, Partial Duration Series, Percentiles and Standardized Precipitation Index.

Some of the studies, for example, (Dile et al., 2013), downscaled large-scale GCM data from the HadCM3 model using the Statistical DownScaling Model (SDSM).

Table 2c. Global Climate Models used for producing future regional climate projections.

Climate data source type	Tools	Finest readily available time scale	Approximate spatial scale
Global climate models (GCM)	PCIC Regional Analysis Tool	Daily (limited availability)	200–300 km (400,000–900,000 km^2)
GCM → Regional climate models (RCM)	To be added to PCIC Regional Analysis Tool	Daily	10–50 km (100–2,500 km^2)
GCM* → Elevation and bias corrected GCM/RCM projections	ClimateBC, ClimateWNA, Plan2Adapt	Climatological (30-year average) values: annual, seasonal, monthly	1–4 km (1–16 km^2)
GCM* → Station-based downscaling	EDS, TreeGen, SDSM, BCSD, Biosim, LARS-WG	Daily	Point (station)

Source (Murdock and D.L, 2011)

3. MATERIALS AND METHODS

3.1. The study area description

Lake Hawassa watershed is located at 7.06° latitude and 38.62 ° longitudes, and at elevation 1697 meters above sea level. It is about 275 km far from the capital city of Ethiopia (Addis Ababa) (MoWR, 2010).The study area has a tropical savanna climate that borders on a subtropical highland climate (WWI, 2016) and has two seasons: a lengthy though not intense wet season from March to October and a short dry season from November to February (NMA, 2016). The annual average magnitude of 961 mm was distributed as 50% for Kiremt (June-September); 20% for baga (October-February) and 30% for belg season (March-May) (Mulugeta, 2013). The average annual rain fall of Hawassa in this study is 1044.79mm. The location map of the study area looks like:

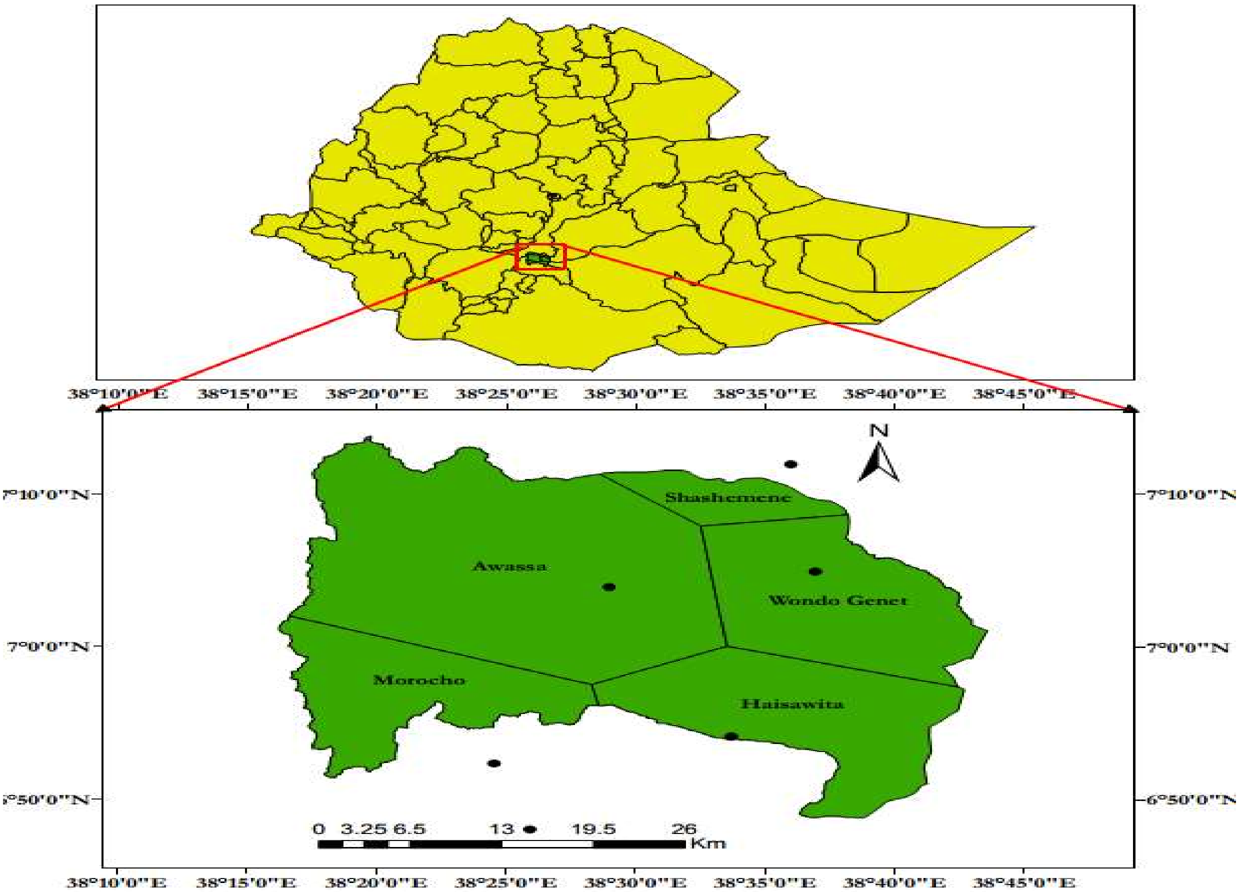

Figure 3a: - location map of Lake Hawassa watershed

3.2. Data in general

Meteorological data was collected from National Meteorology Agency of Ethiopia. The data used in this study are described below.

1. Station data (predictands): was collected from National Meteorology Agency of Ethiopia for 1987-2016 periods (30 years).
2. Large-scale atmospheric variables (predictors):Observed and modelled predictors come,respectively,from the National Centre for Environmental Prediction (NCEP) reanalysis (Kalnay *et al.*, 1996).They were extracted for the grid point closest to each climate station from the Canadian Institute for Climate Studies (CICS) website (http://www.cics.uvic.ca/scenarios). Scenarios describe plausible trajectories of different aspects of the future that are constructed to investigate the potential consequences of anthropogenic climate change. As Comparison of CO2 concentrations for the 21st century from the RCPs and SRES scenarios shown RCP8.5 is closest to A1FI, RCP6 is closest to A1B, and RCP4.5 is similar to B2 (Data from Meinshausen et al 2011 and IPCC).Therefore,B2 which is closest to RCP4.5 was used for this study. To get the data, Select the location of the study area from the African window and enter the coordinates of study area i.e. 11 to represent 38.62 $^{\circ}$ for longitude and 32 to represent 7.06° for latitude Finally, download the zip file which contains NCEP 1961-2001for baseline data and calibration purpose with others up to 2099 for scenario generation containing 26 variables in each.

Climate Scenario generation process in this study were Screen variables from NCEP data (predictor),Calibrate model for NCEP and station data ,Weather generation, and Scenario generation for 7 different 30 year running mean periods (i.e. 2010-2039 [2020s], 2020-2049 [2030s], 2030-2059 [2040s], 2040-2069 [2050s], 2050-2079 [2060s], 2060-2089 [2070s], and 2070-2099 [2080s]).

3.2.1. Missing data estimation

Precipitation is an important climatic parameter and the study on this parameter is commonly hampered due to lack of continuous data. To estimate the missing observations in data, a few selected methods including Arithmetic Mean method, Normal Ratio method and Inverse Distance method (M. D. Ratnasiri etal., 2007) were used for the estimation of missing rainfall data.

The change in observational procedure and incomplete records of the data has a great influence on both consistency and continuity of rainfall data that are very important in statistical analyses. Precipitation stations may have short breaks in the records due to absence of the observer or because of instrumental failures. It is often necessary to estimate this missing record and to fill the data. The commonly used data estimating methods are the arithmetic mean (Chow *et al.*, 1988) and the normal ratio method (Young, 1992) and Inverse Distance method were applied to calculate the missing monthly rainfall data.

Uncertainty analysis among the missing value estimation methods was done and the result shows Inverse Distance method is the most suitable method for all three Low-country zones (wet, intermediate, and dry). However, for Mid-country and Upcountry Intermediate zones, Normal Ratio method is the most suitable method. Further, Arithmetic Mean method is more appropriate for Upcountry Wet zone (M. D. Ratnasiri etal., 2007).In this study, the Inverse Distance method was used

3.2.2. Data consistency

The recorded rainfall data can be affected by non-climatic factors that make them unrepresentative of the actual climatic variations occurring over the time. It may be occurred due to change in location of the rainfall station, instruments, observing practices and station environments (Peterson et al., 1998). To test the consistency of rainfall data recorded by all the stations, double mass curve was applied. To test the consistency of station, the annual values as well as their cumulative were obtained and checked by adding trend lines in the obtained linear equations.

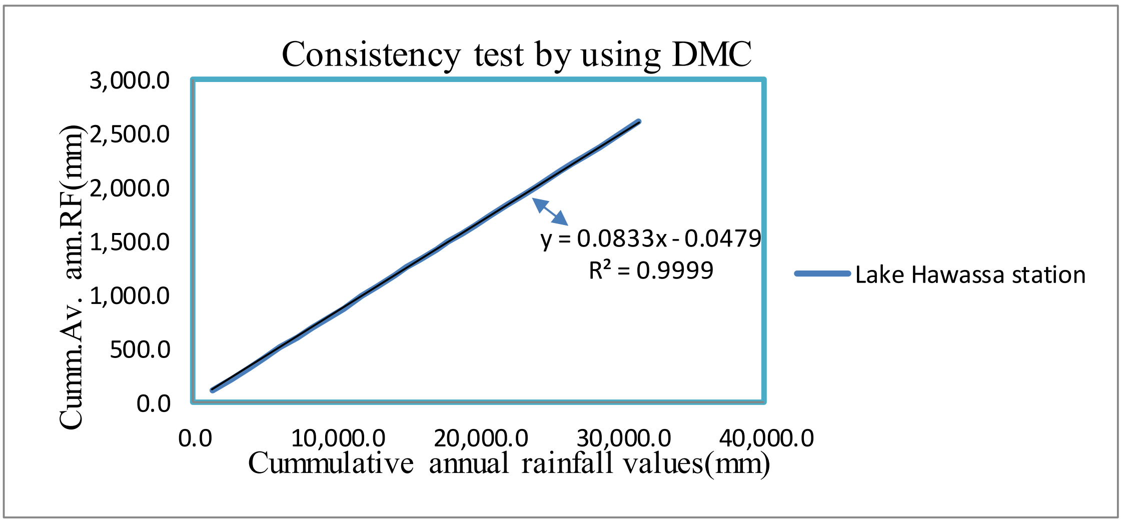

Figure 3b. Data consistencies test for Lake Hawassa watershed stations

From the result above since the plotted line shows almost similar behavior, it was concluded that the data for Lake Hawassa watershed stations were consistent and used for further analysis.

3.3. Trend analysis

The climate change impact on precipitation has received a great deal of attention by scholars worldwide. A change in precipitation is becoming evident on a global scale. Many studies have been conducted to illustrate trends precipitation. For example, for the nine states in the Northeastern United States, Mann-Kendall test at 5% significance level on time series data for each of the nine states for the time period, 1900 to 2011 was used (Karmeshu, 2012).

Statistical trend analysis depends on data characteristics to test if an existing data set is "normally" distributed or not. There are different approaches which are used for analyzing and detecting significant trends in hydro-climatologic time series. They can be classified as either parametric which is used for normally distributed data which is rarely appropriate for environmental samples without massaging data. And non-parametric methods are not as dependent on assumptions about data distribution. Generally, a non-parametric method is the safer statistics to use because it does not require the data to be normally distributed and the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari *et al.*, 2011).

Trend tests are mainly used to determine if the values of a random variable generally increase (or decrease) over some period of time in statistical terms (Helsel and Hirsch, 2002). There is an increasing trend on average air temperature on earth's global climate and the vegetation period is expected to become shorter and even more irregular distribution of rainfall is expected (IPCC , 2008). Climate time series data are not normally distributed; therefore, non-parameter tests are preferred over parameter tests. One advantage of these tests is that the data do not have to fit any particular probability distribution to validate the tests (Karpouzos *et al.*, 2010).

4. RESULTS AND DISCUSSIONS

4.1. Average aerial rainfall

The selected rainfall stations with areal coverage from Theissen polygon by using ArcGis10.2 were discussed in the Table below. Therefore, the average aerial rainfall for the study area by using Theissen polygon was 1044.79mm.

Table 4a. General description of the selected five stations by using Theissen Polygon

S.No	Station_Name	Area Ai_Km²	Annual average Pi(mm)	Weighage factor	Ai*Pi
1	Haisawita	268.03	1093.29	0.19	204.58
2	Shashemene	65.48	720.01	0.05	32.91
3	Awassa	626.02	953.98	0.44	416.94
4	Wondo Genet	268.26	1105.03	0.19	206.95
5	Morocho	204.59	1284.09	0.14	183.41
	Total	**1432.38**			**1044.79**

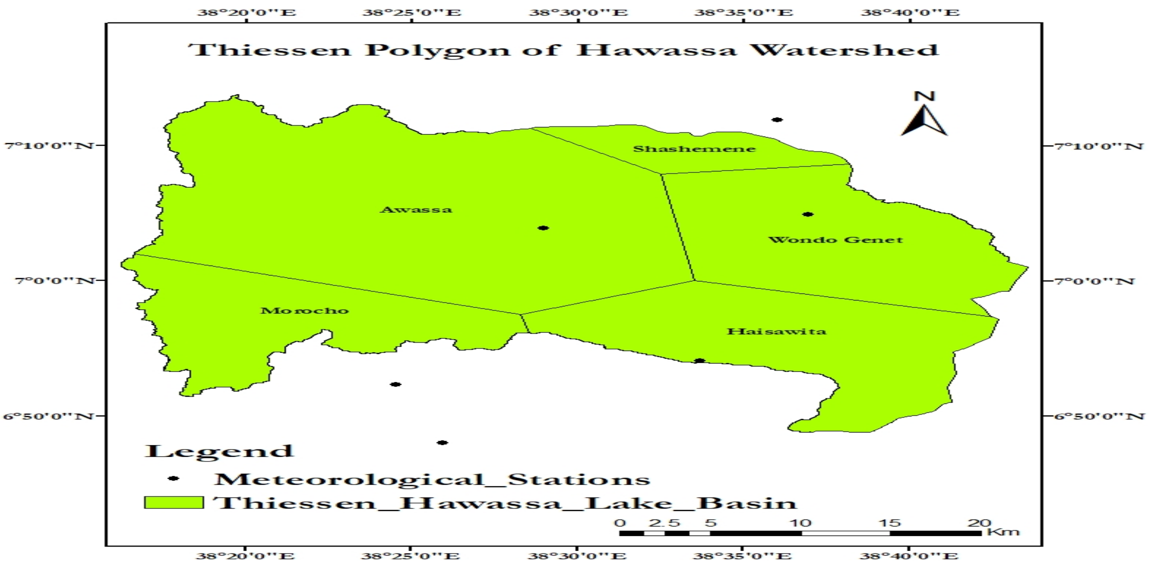

Figure 4a. Thiessen polygon of the study area

4.2. Inter-annual variability

The standardized anomaly (SA) of inter-annual variability in rainfall was shown in the table and figure below. From the computed results below, the inter-annual variability in rainfall shown out of 30 year, extreme variability was occurred in 2009 and 2015. Moderate inter-annual variability in rainfall occurred in 1999 and 2012 , near normal inter-annual variability in rainfall occurred in 1987-1995,1997, 2000-2005,2008, 2011,2013,2014 and 2016. In general, from the observed inter-annual variability the study area mostly experienced near normal inter-annual variability (about 73.33%) which indicates the departure of the annual rainfall from the mean was very small or nearly equivalent.

Table 4b. Standard anomaly analysis

Year	Annual Precipitation Lake Hawassa watershed SA	Decision	Year	Annual Precipitation Lake Hawassa watershed SA	Decision
1987	0.91	NN	2002	-0.56	NN
1988	0.75	NN	2003	-0.58	NN
1989	0.56	NN	2004	-0.42	NN
1990	-0.79	NN	2005	0.54	NN
1991	-0.28	NN	2006	1.47	MW
1992	0.84	NN	2007	1.27	MW
1993	0.25	NN	2008	-0.80	NN
1994	0.33	NN	2009	-2.00	EV
1995	0.22	NN	2010	0.59	NN
1996	1.86	VW	2011	0.04	NN
1997	-0.06	NN	2012	-1.35	MV
1998	1.24	MW	2013	0.52	NN
1999	-1.14	MV	2014	-0.28	NN
2000	-0.76	NN	2015	-2.61	EV
2001	0.78	NN	2016	-0.57	NN

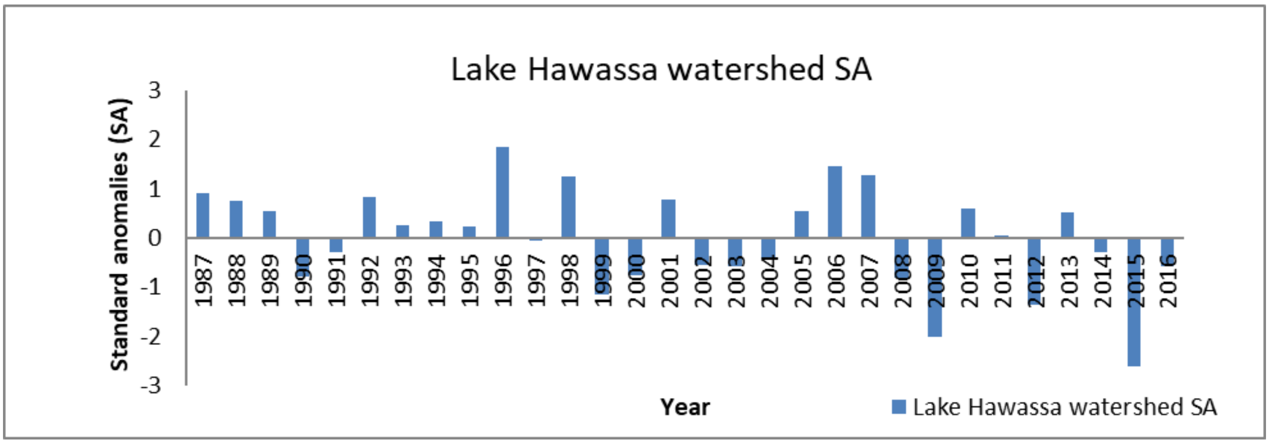

Figure4b. Inter-annual variability analyses by using standard anomalies.

4.3. Trend analysis

The trend analysis gives whether the drought patterns show increase or decrease at a particular station. There were two hypotheses represented by Ho (no trend in time series) and Ha (trend present in the time series). The rejection of Ho depends on P value as if the |P| > P1-α/2, in which P1-α/2 is obtained from the standard normal cumulative distribution tables. In this study, at the 5% significance level, the Ho was rejected if |P|>1.96. The P-value evaluated and indicated in the table below tells the presence of a statistically significant trend.

In Lake Hawassa watershed stations, the evaluated P-values in all months are less than 1.96 and the hypotheses Ho (no trend in time series) was rejected or Ho was rejected if the computed p-value is lower than at the 5% significance level and Ha is accepted. The magnitude was also indicated by using Sen's slope in the above table. In general, the Sen's slope indicates that there is an increasing trend in May up to September and November as well as decreasing trend in January up to April, October and December.

Table 4c.Trend analysis by using Man-kendall

Station	Statistics	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Lake Hawassa	p-value	0.87	0.73	0.56	0.64	0.36	0.90	0.62	0.52	0.91	0.38	0.08	0.53
watershed	Sen's slope	-1.01	-1.05	-0.54	-0.43	1.23	0.37	0.58	0.79	0.40	-1.18	0.71	-0.17

4.5. Drought analysis

4.5.1. SDSM model results

The key functions of SDSM like Screening of Downscaling Predictor Variables, Model Calibration and Validation, Weather Generator and Scenario Generation has been done based on universal settings used in the model (Wilby and Dawson, 2007). Screened variables used in the selection of appropriate downscaling NCEP predictor variables were Specific humidity, 500 hpa geopotential height,and 850hpaWind direction. Accordingly 15-year period from1987-2001 was selected for the study area to represent baseline. Based on the selected predictor variables model calibration was done. The values for January, Febuary, March, April, May, June, July, Auguest, September, October, November, and December were shown below.The rainfall values for both observed and modeled shown less amount in January,Febuary,March, November,and December that indicate the presence of metrological drought in the study area.

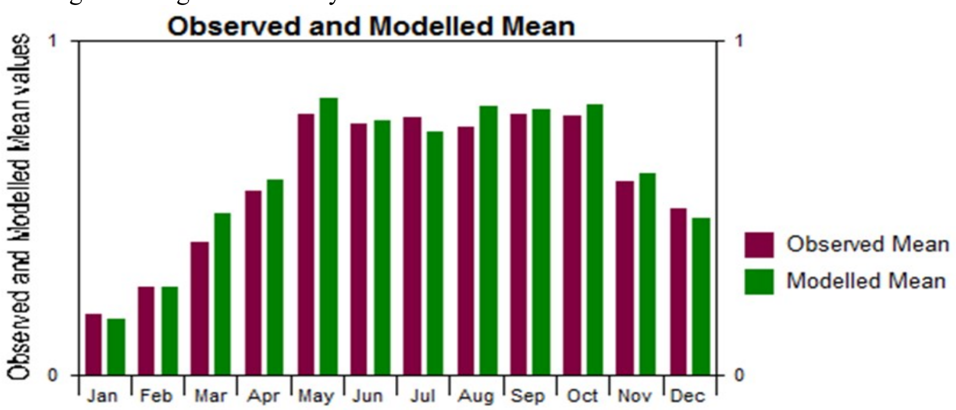

Figure 4c.Calibration and validation for the base period

SDSM model performs reasonably well in estimating the mean monthly precipitation and evaluated by using mean, standard deviation, regression coefficient (R^2), and the Nash and Suttcliffe simulation efficiency (ENS) (Nash and Suttcliffe 1970). Regression coefficient (R^2) for the sensitivity analysis requires the fulfillment of R^2 greater or equal to 0.6 suggested by (Santhi *et al,* 2001).Regression coefficient (R^2) for the sensitivity analysis was 0.97 that fulfill the result suggested by (Santhi *et al,* 2001).

4.5.2. Scenarios generated for the future period

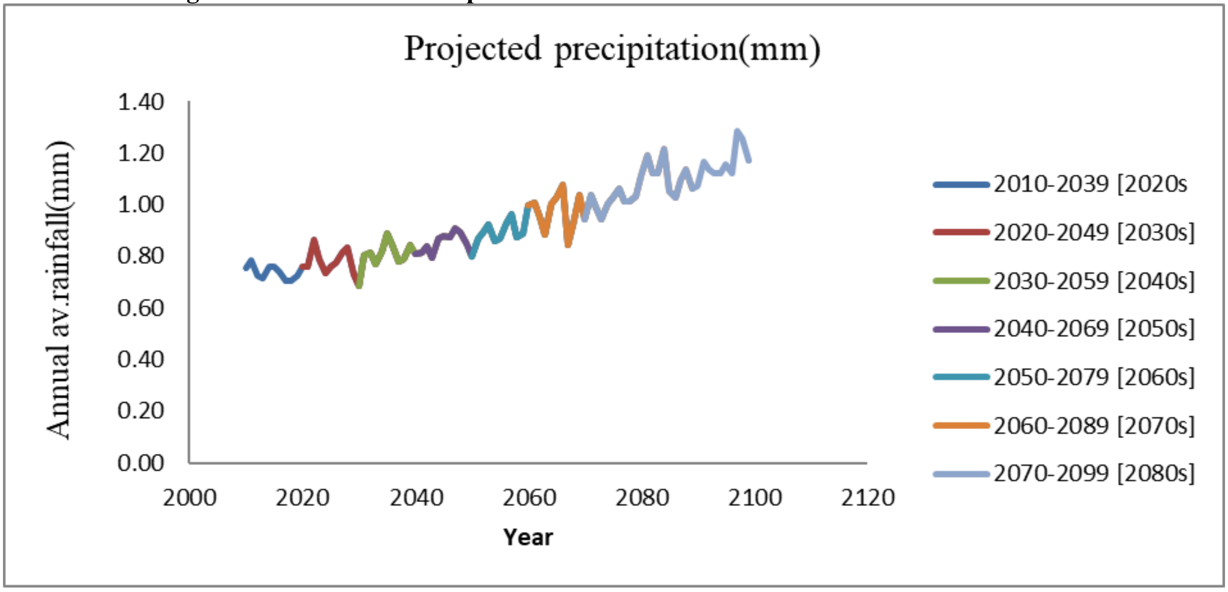

Figure 4d. Scenarios generated for the future period

The generated values of A1F1 and B2a scenarios are not significantly different. In Lake Hawassa watershed stations, precipitation scenario was generated for 2010-2039 [2020s], 2020-2049 [2030s], 2030-2059 [2040s], 2040-2069 [2050s], 2050-2079 [2060s], 2060-2089 [2070s], and 2070-2099 [2080s]) equal time periods because climate change is the one in which the changes in the behavior of climate is over longer time scales, typically 30 and above years (Pittock,2009).

The projected precipitation, 2010-2039 [2020s], 2020-2049 [2030s], 2030-2059 [2040s], and 2040-2069 [2050s],showed almost similar characteristics with the mean and vice versa for 2050-2079 [2060s], 2060-2089 [2070s], and 2070-2099 [2080s] .

Table 4d.Descriptive statistics for future time period

			Future time period				
Descriptive statistics	2020s	2030s	2040s	2050s	2060s	2070s	2080s
Mean	0.77	0.81	0.85	0.9	0.96	1.03	1.09
Variance	0.225	0.278	0.331	0.439	0.541	0.732	0.884
Skewness	0.311	0.336	0.354	0.428	0.411	0.449	0.442

4.5.3. Drought severity and occurrence

The drought severity and occurrence based on the SPI value was analyzed for all time periods of 2010-2039 [2020s], 2020-2049 [2030s], 2030-2059 [2040s], 2040-2069 [2050s], 2050-2079 [2060s], 2060-2089 [2070s], and 2070-2099 [2080s]). By analyzing the drought severity, it was observed that drought severity is increasing with time for moderate drought and vice versa for others (Table 4d). In 2020s, the drought severity (months) were near normal (60), moderate (14), severe (57) and extreme droughts (1) and these values were less than for period 2030s with moderate (20), extreme droughts (2) and higher than for period 2030s with near normal (60), and severe (56). In 2040s the drought severity (months) were near normal (69), moderate (24), severe (58) and extreme droughts (null) higher than for the period 2020s and2030s except for extreme droughts. In 2050s, the drought severity (months) were near normal (67), moderate (34), severe (52) and extreme droughts (null) and these values were less than for period except for severe (49) and extreme droughts (null) in 2060s. In 2070s, the drought severity (months) were near normal (73), moderate (42), severe (44) and extreme droughts (null) and these values were less than for period except for near normal (70), severe (42) and extreme droughts (null) in 2080s.In general, the drought severity (months) were near normal, moderate, severe and extreme droughts. By analyzing the drought severity, it was observed that drought severity is increasing with time for near normal except for 2070s and 2080s, moderate drought, and constant for extreme droughts except for 2020s and 2030s and vice versa for severe drought.

Table 4e.Drought classifications

				No of droght(month)				
Station	Drought classification	2010-2039	2020-2049	2030-2059	2040-2069	2050-2079	2060-2089	2070-2099
Lake Hawassa watershed	NN	60	60	69	67	78	73	70
	MD	14	20	24	34	37	42	44
	SD	57	56	58	52	49	44	42
	ED	1	2	0	0	0	0	0
	Total	132	138	151	153	164	159	156
	Mean	33	35	38	38	41	40	39

From the table below, the occurrence of drought in the study area experience mostly near normal drought that account at least 43% for all time periods, severe that account at least 27%, moderate that account at least 11% and null except for 2020s and 2030s for extreme drought.

Table 4f.Percentage of drought occurrence

					No of droght(month)									
Drought classification	2010-2039	W	2020-2049	W	2030-2059	W	2040-2069	W	2050-2079	W	2060-2089	W	2070-2099	W
NN	60	45%	60	43%	69	46%	67	44%	78	48%	73	46%	70	45%
MD	14	11%	20	14%	24	16%	34	22%	37	23%	42	26%	44	28%
SD	57	43%	56	41%	58	38%	52	34%	49	30%	44	28%	42	27%
ED	1	1%	2	1%	0	0%	0	0%	0	0%	0	0%	0	0%
Total	132		138	100%	151	100%	153	100%	164	100%	159	100%	156	100%

W= Percentage of drought occurrence calculated as the ratio of number of each drought and total multiplied by 100.

5. Conclusion and Recommendations

5.1. Conclusion

This study aimed at identifying metrological drought trends, occurrence and severity and the inter-annual variability of observed rainfall in Lake Hawassa watershed. Trend was analyzed by using the Mann-Kendall and Sen's slope. The station showed statistically significant downward trend from January up to April, October and December and upward trend from May up to September and November. For drought occurrence and severity analysis, this study analyzed the whole period of time series in to seven equal time periods of 2020s, 2030s, 2040s, 2050s, 2060s, 2070s, and 2080s at SPI 3-month time scale.

The results were compared with each other. In 2020s, the drought severity (months) were near normal (60), moderate (14), severe (57) and extreme droughts (1) and these values were less than for period 2030s with moderate (20), extreme droughts (2) and higher than for period 2030s with near normal (60), and severe (56). In 2040s the drought severity (months) were near normal (69), moderate (24), severe (58) and extreme droughts (null) higher than for the period 2020s and2030s except for extreme droughts. In 2050s, the drought severity (months) were near normal (67), moderate (34), severe (52) and extreme droughts (null) and these values were less than for period except for severe (49) and extreme droughts (null) in 2060s. In 2070s, the drought severity (months) were near normal (73), moderate (42), severe (44) and extreme droughts (null) and these values were less than for period except for near normal (70), severe (42) and extreme droughts (null) in 2080s. The drought occurrence in the study area experience mostly near normal drought that account at least 43% for all time periods, severe that account at least 27%, moderate that account at least 11% and null except for 2020s and 2030s for extreme drought.

The inter-annual variability of observed rainfall in Lake Hawassa watershed was analyzed by using standardized anomaly (SA). From the computed results, the inter-annual variability in rainfall shown out of 30 year, extreme variability was occurred in 2009 and 2015. Moderate inter-annual variability in rainfall occurred in 1999 and 2012 , near normal inter-annual variability in rainfall occurred in 1987-1995,1997, 2000-2005,2008, 2011,2013,2014 and 2016. In general, from the observed inter-annual variability the study area mostly experienced near normal inter-annual variability (about 73.33%) which indicates the departure of the annual rainfall from the mean was very small or nearly equivalent.

5.2. Recommendations

The study which was conducted to analyze the metrological drought under climate change in the lake Hawassa watershed showed the different types of droughts in different time periods. As climate change will greatly complicate the management of water-use systems and others, the result of this study including trend analysis of the metrological drought which gives valuable information for future water resources management , occurrence and severity of drought, informs early warning for different organization in the study area.Therefore, as this study has provided essential information on metrological drought under climate change, different stakeholders can use the results of this study as an input. In addition to this, the derived information about metrological drought under the climate change reduces the risk of management of water-use systems in the study area.

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