Analysis of Drought with Respect to Water Resources Availability and Water Quality: The case of Nyangatom Woreda, Southern Ethiopia

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This is to certify that the A Thesis prepared by Tamiru Tigistu, entitled: Analysis of Drought with Respect to Water Resources Availability and Water Quality: The Case of Nyangatom Woreda, Southern Ethiopia and submitted in partial fulfillment of the requirements of the degree of master of sciences (Water Resource Management) complies with the regulations of the university and meet the accepted standards with respect to originality and quality.

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Abstract

Drought expressed in terms of failure and shortage of rainfall is the major hazard that affects the livelihood of the Nyangatom people. The objective of this study was exploring the occurrence of droughts and their impacts on water resources availability and Water Quality at Nyangatom Woreda. Based on the result of the SPEI-3 month values was used represented in (Annex4),there are a severe drought on the study area from June 1999 and November, December 2010 this implies that the soil moisture, SPEI-6 month values SPEI value may also begin to be associated with anomalous stream flow and reservoir conditions deficit occurred from March 1997 ,SPEI-12 to 24 month value , month duration were recorded in grid cells in one periods, namely in the years 1999-2003 this implies that the deficit surface water and ground water. In addition to result of the study indicated in SPEI –index, the SPEI value is less than or equal to −1 observed that the occurrence of months in which drought was detected in all severity classes within the range 72-81 and corresponds to about 19-21% of the entire time under analysis and also SPEI time series -1, 3,6,12 and 24 calculation, drought severity, duration and intensity were analysis obtained maximum duration of grid point, SPEI-24 has shown in (Figure .8) ranges between 3-7 years in category short until long duration ,the highest severity recorded at the meteorological grid point occurred SPEI result at 1999-2003 which a peak of drought with index value range -1.38 up to -6.20 (extremely dry) and Highest intensity that occurred in grid cell -1.09 in 2009 to 2012 the highest intensity for SPEI-24 was recorded in meteorology station. SPEI –index, statistically analysis used Non-parametric methods have been developed to detect trends in hydro meteorological time series. In the SPEI-3 monthly series, a drying trend occurred only in March statically significant and SPEI-6 and SPEI-24 monthly series, a drying trend occurred four month in February, March, April and June and the result is statistically significant in the representation .Therefore, the result of February up to June often drought occurrence in this month represented and time series representing longer time scales a decreasing trend. Based on this the researcher tried to recommend that carrying out capacity building training to the woreda water experts is essential to ensure the appropriate implementation of water management and biodiversity, the woreda administration should create awareness to the people to reduce or stop vegetation clearance using fire that affect the biodiversity of the area

Key words: Drought, water Resource availability, water quality, Nyangatom Woreda,

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Acronyms and Abbreviations

ARI	*Average recurrence interval*
CWBAL	*climatic water balance*
DEM	*Digital elevation model*
E	*East*
E.C	*Ethiopia Calendar*
EC	*Electrical Conductivity*
FAO	*Food Agriculture Organization*
GPS	*Global position system*
H	*cumulative of monthly index*
Ki	*correction coefficient*
LHDW	*Lokomagna hand dug well*
LSW	*Lokorlom Shallow well*
MK	*Mann Kendall*
N	*number of years of the record*
Ni	*number of days of month*
NMA	*National metrological agency*
PET	*potential evapotranspiration*
PWMs	*probability weighted moments*
Qmed	*Sen.'s slope*
r	*data ranking*
SAR	*Sodium Absorption Ratio*
Si	*maximum number of sun hours*
SMUs	*soil mapping units*
SNNP	*Sothern Nations Nationality and People*
SPEI	*standardized precipitation evapotranspiration index*
SPI	*Standardized precipitation index*
Ti	*monthly average temperature*
UTM	*Universal Transverse Mercator*
WHO	*World Health Organization*
WRB	*World Reference Base*
WRSI	*Water requirement Satisfaction index*
$^{\delta}s$	*standard deviation*
µS/cm	*micro Siemens per centimeter*
WWDSE	*Water Work Design Supervision*
EMA	*Ethiopia Meteorology Agency*

1 INTRODUCTION

1.1 Background of the study

Drought is a natural hazard causing adverse impact on vegetation, animals, people and ecosystem (Edossa et al, 2010). In recent years, it has been occurring frequently in all climatic zones and significantly affects crop yields causing shortage of food as well as animal forage (Boken , 2009). Drought is a complex phenomenon considered to be a natural hazard causing several environmental, societal and economic problems (Tallaksen and Van Lanen, 2004). Its impact on global life in the last decades is very clear. That is, the impact is due to climate change resulting from global warming which is dangerous to wide areas of the Earth. Changes in climate characteristics significantly affect the Earth's hydrological cycle.

Drought occurrence in the pastoral communities is not new. In the past, pastoral communities in Eastern Africa have suffered numerous drought events (Oba and Lusigi, 1987). The drought events lead to human, economic and environmental costs, which are mostly borne by pastoral communities who exclusively depend on livestock for their survival and livelihood (Barton *et al.*, 2001). While drought affects both farmers and pastoralists, the impacts are greatest amongst the pastoralists, since they constitute the majority of human population in arid lands where there is frequent occurrence of drought (Orindi*et al.*, 2007).

There is a concern that the ongoing global warming may increase the severity of droughts in Ethiopia (Dai, 2011) and has reported that the temperature increase of 1-3°C in 1950 to 2008. Moreover, there has been reduction of the annual rainfall in most African countries, the key factors to drought occurrence and drought severities are abnormalities in precipitation and evapotranspiration.

"Drought" may be defined as a negative deviation of water balance from the climatological normal over a given area this implies that drought is a result of deficiency in precipitation over an extended period of time, while other meteorological elements (such as temperature, wind and humidity) frequently intensify its impacts. Based on time scales and impacts, droughts may be divided into four categories: meteorological, agricultural, hydrological and socio-economic (Heim, 2002). Meteorological drought is signaled by indicators intrinsic to weather data and precedes the onset of specific impacts, i.e. additional kinds of drought. Agricultural drought may be measured in terms of duration of weeks to 6–9 months, while hydrological and socio-economic impacts usually became apparent after longer time intervals. Meteorological drought can easily be identified in the instrumental period, while drought events in the pre-instrumental period are usually based on the occurrence of significant impacts (e.g. low crop yields, low streams and loss of current in rivers, low still-water levels, and/or socio-economic difficulties). Drought episodes have important consequences for agriculture, forestry, water management and other human activities, as well as for other semi-natural ecosystems. With this regard the study of availability of water for future in the changing climate condition is unquestionable. So far especially in Africa quantification of climate change on basin scale is not studied in detail. Meeting the new challenges on water resources management, implies the quantification of climate change impact on basin-scale hydrology (Varies et al., 2004).

Currently, in Ethiopia use of intensive drought assessment tool is not common, which integrates climate, water and spatial variability of soil and land use properties as well as crop growth and root development. Such precipitation regimes are directly influenced by different climatic effects such as EL-Nino. According to (Haile, 1988), an increase in sea surface temperature in the central and equatorial Pacific Ocean and southern oscillation (SO) leads to a change in atmospheric pressure across the pacific basin. With climate change this results in an imbalance between precipitation, evaporation and transpiration .combined effect of EL-Nino and southern oscillation (ENSO) results in air and ocean phenomenon with global weather implications often associate with devastating droughts. Over the past several decades, the country has been hit by repeated droughts, famine and epidemics that may be relate to changing climate conditions (Amsalu and Adem 2009). The Ethiopian lowlands are particularly affected by these problems, which have been occurring recurrently. The people in the lowlands are among the most resource deprived and the most geographically and politically marginalized. Hence, the magnitude and impact of hazards in these areas has been intensifying.

The poor are likely to be hit hardest by climate change, and that capacity to respond to climate change is lowest in developing countries and among the poorest people in those countries. It is clear that vulnerability to climate change is closely related to poverty, as the poor are least able to respond to climatic stimuli. Furthermore, certain regions of the world are more severely affected by the effects of climate change than others. Generally speaking, vulnerability and adaptation to climate change are urgent issues among many developing countries. This study attempted to assess climate change impact and adaptation mechanisms for the pastoralist community in particular South Omo Zone, Ethiopia, Nyangatom woreda. Nyangatom woreda is major problem of meteorological drought by reason of lack of precipitation that causes a serious hydrological imbalance and has effects of a moisture deficiency with respect to water use requirements. Thus, this study tried to drought analysis and water resource availability by using of standardized precipitation evapotranspiration index method.

1.2 Statement of the problem

Drought is a major cause of poverty in pastoral communities. It results in low stocking rate and livestock deaths, which leads to reduction of assets (Illius *et al.*, 1998). Moreover, drought depletes water sources and reduces quantity and quality of forage for livestock (Orindi *et al*, 2007). Most of the population in the countries identified as experiencing high-drought frequency is agro-pastoralists whose livelihoods are constantly threatened rainfall variability. These countries are among the poorest in Africa and are extremely vulnerable to drought risks (Dilley et al., 2005) and are unable to cope with the impacts of droughts. Climate change results in changes in one or both of these factors it can be expected that drought occurrence and its severity were change as well. A change in the precipitation mean and variability obviously influences the occurrence and severity of drought.

Currently, in Ethiopia use of intensive drought assessment tool is not common, which integrates climate, water and spatial variability of soil and land use properties as well as crop growth and root development. In addition to variability in precipitation, a number of factors play a major role in the evolution of a drought. These factors include evapotranspiration, which is affected by temperature and wind, water holding capacity of soils, the depth and presence of groundwater supplies, and vegetation. Some studies undertaken at Eastern parts of Amhara Regional State have been used only vegetation indices and Standardized Precipitation Index (SPI) which cannot fully account agricultural drought severity status and meteorological drought analysis so fill these gaps, this research has detailed study metrological drought analysis and evaluation of probable risk arising out of drought in the study area have been help in developing better management plans for mitigating and adopting drought impacts by using Standardized precipitation evapotranspiration

(SPEI) and also may be solution to this practices for future drought disastrous natural phenomenon to predicting(Vicente-Serrano et al. ,2010).

Drought expressed in terms of failure and shortage of rainfall is the major hazard that affects the livelihood of the Nyangatom people. It has a negative impact on natural resources such as pasture, water sources, farmlands and trees which are directly related to the livings of the community and their livestock's. In relation to the responses of the community the availability of pasture in the area is reducing gradually due to drought and shorter rainy season. The rainy season is progressively becoming shorter starting late and finishing earlier with high rate of unpredictability. The dry season is becoming longer and leading to shortage of pasture which results in the gradual extinction of indigenous grasses. The drought is causing reduction of crop yields and the availability of water in the area and leads to shortage of food and feed for humans and livestock respectively. Furthermore, drought is causing reduction of the overflow of Omo River. Thus, this study is attempted to analysis of drought with respect to water resources availability and water quality in Nyangatom wereda.

1.3 Research question

What is the trend of water availability using climate water balance?

How to characteristics drought severity, duration and intensity

How to assess water quality in relation to drought impact mitigation

1.4 Objectives of the study

1.4.1 General Objective

The general objective of this study to analyze of drought with respect to water availability and water quality in Nyangatom wereda

1.4.2 Specific Objectives

Specific objectives of this thesis were:

To characteristics drought in Nyangatom woreda using drought severity, drought duration and drought intensity

To assess the trend of water availability using climate water balance

To assess water quality in relation to drought impact mitigation (e.g. water supply and irrigation) in Nyangatom woreda

1.5 Scope of the Study

The focus of this Research was lower south Omo zone in Nyangatom woreda, south Regional State. The area has been Chosen because for the past decades it has been seriously affected with continuous drought occurrence. Due to the high rate of drought episode and other factors the water availability. It has been decreasing water availability which illustrates the phenomenon and the negative impacts of drought to people. The result of this study could be contributing information about the drought hazard in the researcher's area developing better management plans for mitigating and drought analysis method by using standard precipitation evapotranspiration index Method.

1.6 Significance and Implications

The purpose of the study is drought analysis and water resources availability using SPEI in the case of Nyangatom woreda in study area. Drought occurrences have the effect on the availability of water for domestic and livestock use. To mitigate the problems, it can be use SPEI model SPEI model help to prediction or forecasting the future drought characteristic using by metrological data analysis such as, the PET has been calculated using the Hargraves parameterization is a simple approach for calculating PET that requires only monthly average temperature and station's latitude as input data.

This study has significant to monitor drought events and their variability, explore their Predictability, and determine how they might change under different conditions. Moreover, the information obtained from this study can be used in spatial planning to create more optimal land and water management and to eliminate or reduce the increasing drought hazard. Moreover, this study is about the hazard of drought vulnerability and Characterization. The results become an integral part of drought planning, awareness, and mitigation. Thus, the result help to handle the effect at the woreda and kebele's levels water supply problem. The task of solving water supply problems cannot be separated from solving social and economic problems of a given society. This study is important to monitor drought events and their variability, explore their predictability, and determine how they might change under different conditions.

1.7 Limitation of the study

Insufficient finance and time series data were major problems that hinders the in depth analysis of the problem. The problem could have been better explained and investigated if enough time series data and finance were available. Limitation of meteorological data gap some station was another problem encountered during implementation of the research study.

1.8 Organization of the thesis

This study was organized in five chapters. Chapter one deals with introduction, statement of problem, research questions, objectives, scope, significance, limitation and organization of the study. Chapter two deals with drought definitions, drought characterization, Drought Indicators and Drought mitigation were included. Description of the study area, method of data collection, drought characterization, trend analysis and assessment of water quality were stated in chapter three and chapter four deals about result and discussions. Finally chapter five was about conclusion and recommendation.

2 LITERATUREREVIEW

2.1 Concepts and Definitions of Drought

The absence of a consensus definition of drought makes it difficult to formulate common drought index. Droughts are defined using both conceptual and operational definitions (Wilhite and Glantz 1985). The conceptual definition of drought is more general and cannot assist in the mathematical formulation of the drought indices. An operational definition of drought tries to identify the onset, offset, severity and duration of the drought episode. Operational definitions of droughts divide droughts into four major categories namely meteorological, agricultural, hydrological and socio-economic (Wilhite and Glantz 1985). In order to understand and asses the drought phenomenon, scientists use the definitions of droughts to formulate different drought indices. A drought index is a mathematical formula that incorporates different meteorological or hydrological parameters such as rainfall, stream flow, temperatures in order to create a single value or index that can be used for decision-making processes. By using a drought index meteorologists and climatologists are able to identify the intensity, severity, duration as well as the spatial extent of a particular drought phenomenon.

Meteorological drought originates from a deficiency of precipitation over a prolonged time period, often accompanied by unusually high temperature, high winds, low humidity, and high solar radiation which result in increased evapotranspiration and is defined by the degree of dryness compared to a “normal” or long-term average (Utah Division of Water Resources, 2007). One important aspect of meteorological drought is that it stands for an early warning system of drought condition, however let alone it is not an adequate tool for water resource planning as it can produce false alarms (Vicente- Serrano and López-Moreno, 2005). Agricultural drought results from lack of precipitation plus evapotranspiration over a prolonged time period which eventually leads to extended periods of low soil moisture that would affect agriculture productivity and ecosystem rehabilitation failure (Ciais et al., 2005; Lei et al., 2015; Cunha et al., 2015).Hydrological drought mainly lags the occurrence of meteorological and agricultural droughts and it also manifests when a lack of precipitation persists for a long period, leading to over- all water supply deficiency in forms of snowpack, streamflow, groundwater and reservoir storage (Vicente-Serrano and López- Moreno, 2005; Van Loon and Van Lanen, 2012; Van Lanen et al., 2013; Joetzjer et al., 2013).

2.2 Classification of Drought

Droughts can be categorized into four types: meteorological drought, hydrological drought, agricultural drought and socio-economic drought. The meteorological drought can be observed as the general idea of drought. It occurs when there is a below Norma precipitation amount during an extended period of time (months, years, etc.) over a region. Lack of precipitation is the main cause of a meteorological drought (Mokhtari, 2005).

2.2.1 Meteorological drought

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some normal or average amount) and the duration of the dry period .definition of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. The SPI thresholds ranges, defining seven possible climatic classes, are as follows (McKee et al., 1993):

2.2.2 Agricultural drought

Agricultural drought links various characteristics of meteorological (or hydrological)drought to agricultural impacts ,focusing on precipitation shortages, differences between actual and potential evapotranspiration ,soil water deficits, and so forth .A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development from emergence to maturity. Thus, primary consequences of agricultural drought are the damage of vegetation (crops, grass, and plants), though the severity of the damage depends on the specific characteristics of both the plants and the soil in addition to weather conditions (Flood and Climate Basics, 2004). Agricultural drought can also be enhanced by human activities like over-farming, deforestation, erosion and poor water management.

2.2.3 Hydrological drought

Hydrological drought is connected with the effects of periods of precipitation on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, and ground water).the frequency and severity of hydrological drought is often defined on a watershed or river basin scale. In addition to lack of precipitation, the geology of an area also plays a crucial role on the hydrological droughts (Vogel and Kroll, 1992).

2.2.4 Socioeconomic drought

Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological and agricultural drought. it differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts .the supply of many economic goods, such as water, forage, food grains, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is full in some years, but unable to meet human and environmental needs in other years .socioeconomic drought occurs when the demand for an economic good exceeds supply as result of a weather-related shortfall in water supply.

2.2.5 Groundwater Drought

Surface water drought may progress to groundwater drought, which is less extensively studied than other drought categories, particularly its spatial distribution (peters et al., 2005:2006: Mishra and singh, 2010).It occurs when groundwater levels, evapotranspiration, low soil moisture content and thus reduce groundwater recharge. The propagation of groundwater drought from recharge to discharge and the influence of aquifer characteristics on the propagation has been studied (peters et al., 2003; peters and van lanen, 2003). Abstraction and over exploitation may create/enhance a groundwater drought.

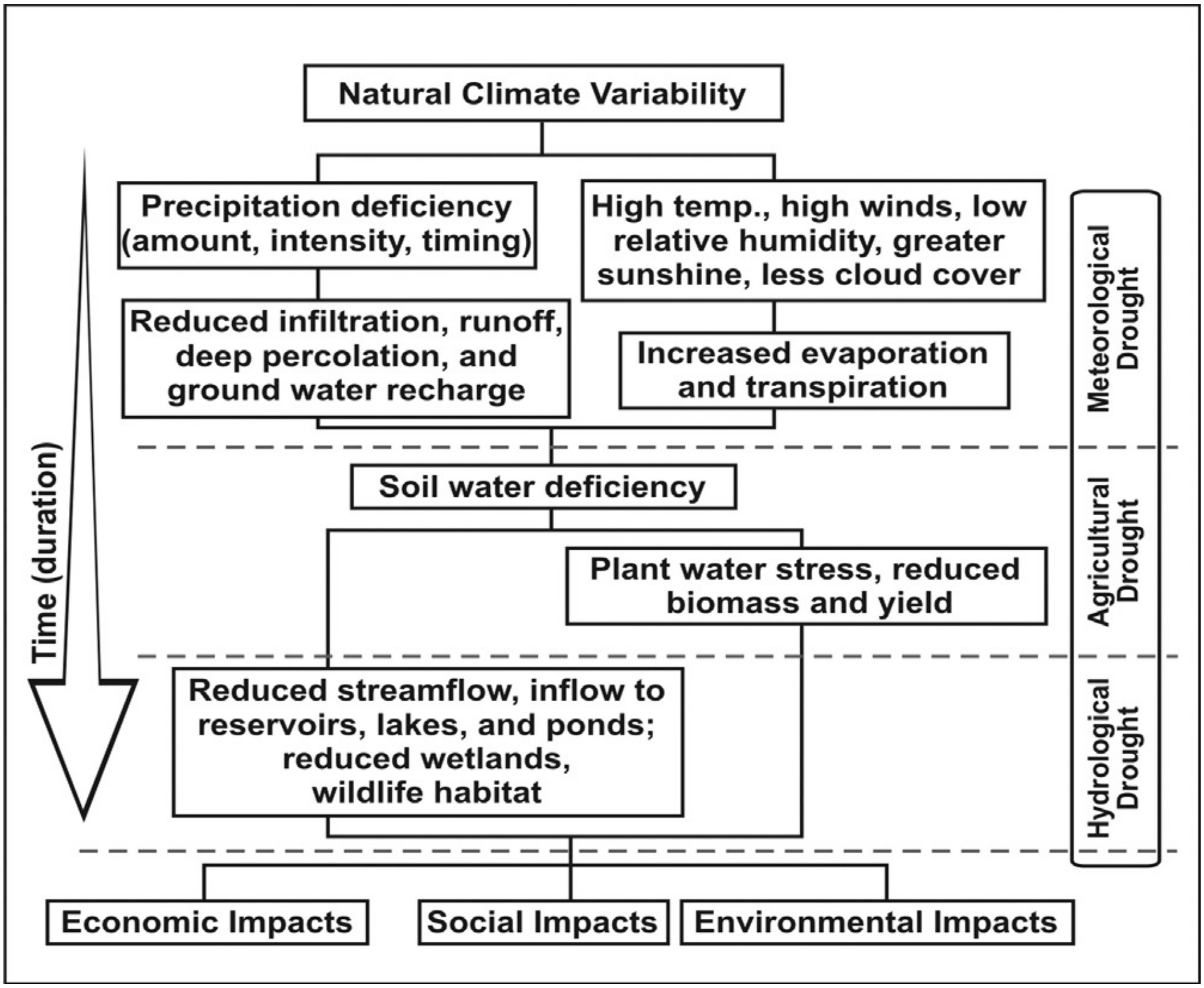


Figure 1.drought types, causal factors and their usual sequence of occurrence. Source: National Drought Mitigation Center

2.3 Drought characteristics

Describing the characteristics of drought is not a straightforward process. Unlike other natural hazards (e.g., tropical cyclones), it is challenging to notice the commencement of a drought event and more often a drought event is declared when its impacts are already taking place. Furthermore, drought characteristics can vary depending on the type of drought and the intended application (Sheffield and Wood, 2011). However, there are four important and common drought characteristics:

- **Drought Duration (D)**: refers to the number of consecutive months (or weeks) in which the precipitation (or soil moisture or runoff) is below the chosen threshold (Andreadis et al., 2005). The duration is highly dependent on the chosen threshold for the declaration of the start and end of the drought episode.

- **Drought intensity (I)**: The intensity of a drought is the severity divided by the duration. Droughts that have shorter durations and higher severities will have larger intensities:

$$I = \frac{Severity}{Duration}$$

- **Drought Severity (S)**: refers to either the value of precipitation (or any other drought indicator) at a given month during the drought event or the minimum of precipitation during the event (Thompson 1999; Vidal et al., 2010).

The severity is the cumulative sum of the index value based on the duration extent (Yang 2010):

$$S = \sum_{i=1}^{D} SPEI$$

- **Magnitude Drought (M) -** closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event.

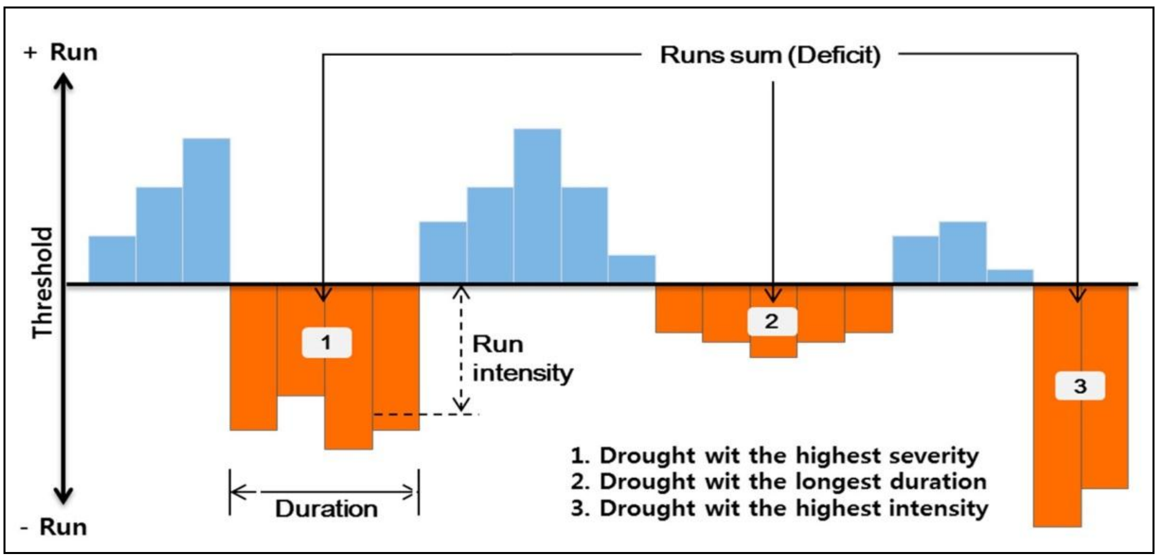


Figure 2 . Drought characteristics using the run theory for a given threshold level (Lee et al, 2017).

2.4 Drought Indices

In the process of monitoring and assessing droughts, drought indices play an essential role because their use assists the simplification of the confusing relationships between climate and climate-related parameters. A drought index is acceptable when it presents a clear, simple and qualitative analysis of the main drought characteristics namely the intensity, the duration and the special extent (Hayes, 2000). Drought indices incorporate several variables related to drought, (e.g. precipitation, temperature, potential evapotranspiration, soil moisture, snowpack) into a single number, the use of which is more efficient in the decision making process than raw data (Hayes et al., 2007).

2.4.1 Standardized Precipitation Index (SPI)

The index was developed by (Mckee et al. 1993) as an alternative to the PDSI. It has different categories that define drought intensities ranging from -2 (and less) to 2 (and above), with negative values indicating deficiency in water (see Table 1). SPI was recently considered by the World Meteorological Organization (WMO) as the reference drought index and is the most used drought index worldwide (Hayes et al. 2011; Potop et al., 2012).

The main advantage of SPI is that it is based solely on precipitation making it very easy to compute. Opposed to PDSI, the SPI can be calculated for different time-scales making the index attractive in other sectors such as meteorology and hydrology. Since the index is standardized, two different regions can be now compared in terms of dryness or wetness. The main disadvantage of the SPI is that it does not include some other variables (e.g., temperature, evapotranspiration, wind speed and soil water holding capacity) having influence on drought. Furthermore, the index assumes that other variables are stationary (Vicente-Serrano et al., 2010).

Although precipitation is the main driver of drought hazards, recent studies have shown the importance of including temperature in characterizing drought over any region (i.e. Vicente-Serrano et al. 2010, 2011; Abiodun et al. 2012). Vicente-Serrano et al. 2011) showed that drought severity is not only related to precipitation, but to other variables such as potential evapotranspiration (PET, through temperature), which may play a more crucial role under the warming climate.

Table 1: SPI Classification. Source: (Fuchs et al. 2014).

SPI	Drought Classification
2.0 and above	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately dry
-0.99 to 0.99	Near normal
-1.0 to -1.49	Severely dry
-2.00 and less	Extremely dry

2.4.2 Standardized Precipitation and Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) was developed by (Vicente-Serrano et al. 2010) with the intention of defining a drought index that would be sensitive to Climate change. (Vicente-Serrano et al. 2010) noted that the main factor influencing drought is precipitation; although other factors such as air temperature, ET, wind speed, and soil water holding capacity can also influence drought. The SPI can detect wet and dry events occurring simultaneously at different time-scales. However, the main shortcoming of SPI is that it uses only one climate variable rainfall for monitoring droughts (Sivakumar et al., 2011; Vicente-Serrano et al., 2012).

It assumes rainfall has a stronger influence on droughts than other climate variables such as temperature, wind speed and direction, and potential evapotranspiration; hence these variables are neglected. Before the early 1980s, this assumption was warranted, because precipitation seemed to be the dominant factor in terrestrial water changes; but, thereafter, other climate variables such as temperature, wind, and humidity have been shown to have equally, or even more, important than rainfall in influencing drought. For instance, if a given region received the same amount of rainfall during two different seasons under different temperatures, it was likely that the region would be drier during the warmer season owing to higher evaporation. However, to overcome the shortcomings of SPI, (Vicente-Serrano et al. 2010) recently proposed a new drought index: the Standardized Precipitation Evapotranspiration Index (SPEI), which depends on the potential evapotranspiration (PET).

Table 2: SPEI classification scale Source: (Wang et al. 2014).

Category	SPEI
Extremely wet	2.00 and above
Severely wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Near normal	−0.99 to 0.99
Moderate drought	−1.00 to −1.49
Severe drought	−1.50 to −1.99
Extreme drought	−2.00 and less

2.4.3 Palmer Drought Severity Index (PDSI)

Palmer (1965) developed this index based on the supply-and-demand concept of the water balance equation. The objective of the index is to measure the departure of the moisture supply for normal condition at a specific location. The PDSI is based on precipitation and temperature data, on the local Available Water Content (AWC) of the soil and other meteorological parameters. The Palmer Index has been widely used but it has some limitations. Among these we mention: the index is highly sensitive to the AWC of a soil type and that there are some difficulties in comparing the results obtained in regions with different water balances. The Palmer Index varies between -4.0 and +6.0. The index classification is shown in the following table:

Table 3: PDSI classification Source: (Fuchs et al.2014)

PDSI	Drought Classification
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild droughts
-2.0 to -2.99	Moderate droughts
-3.0 to -3.99	Severe droughts
-4.0 to less	Extreme Severe drought

2.4.4 Other indices

Improve indices to allow further comparisons over various timescales, climate zones and latitudes. Among other the Soil Moisture Deficit Index (SMDI) and the Evapotranspiration Deficit Index (EDI), both developed by (Narasimh and Srinivan, 2005), and based on simulated output from calibrated hydrologic models on a weekly scale. In 2009 the Soil Moisture Index (SMI) was proposed and included wilting point and field capacity (Mishra and Singh, 2010). Many indices have been developed one regional scale to monitor and analyze droughts in specific areas. For Africa, an index called Dependable Rains, based on the statistical rainfall occurring four out of five years in 1993 and a year later it was turned into the National Rainfall Index (RI). The RI was calculated from rain gauges at a national level and was mainly used for distinguishing patterns at a local scale. Another regional attempt to monitor droughts is the Australian Drought Watch System is based on consecutive months with precipitation below a threshold (Heim, 2002). In the US a Drought Monitor incorporating multiple indices and observation sets (Svoboda et al., 2002).

2.5 Drought mitigation options

The pro-active mitigating strategy of reducing vulnerability by enhancing coping mechanisms and resilience of the production systems is quite different than the disaster aid. The mitigation is also planned around normal or excessive rainfall years when there is enough precipitation for recharging soil with water, aquifers, surface storage and adequate production to acquire assets. Rainfall is the ultimate source of surface and ground water resources for managing risks and distress associated with spatial and temporal variability in the rainfall and its distribution pattern.

2.5.1 Water well for irrigation

A well is any excavation that is drilled, driven, dug and constructed when the intended use of such excavation is for the acquisition of ground water. The ultimate objective is to tap groundwater and small scale irrigation purposed. The well type can be depends on the type of aquifer containing the water. Gravity wells penetrate unconfined aquifers. As a result, the static water level in gravity well is the same as the level of the water table. If the hydrostatic pressure in a confined aquifer is sufficient to cause the water to rise above the water level in the aquifer, artesian conditions are present. A raised water level in a well indicates that the aquifer is confined and that the water at the surface of the aquifer is under pressure which is greater than atmospheric pressure. This type of well is called an artesian well (Dorota et al., 1988). Wells can also be classified based on their depth and can say shallow well or deep well. In many areas good irrigation water can be obtained from shallow aquifers. Careful investigation of the shallow water aquifers should be performed prior to well construction. In some instances, when the shallow water table is due to a perched water table, pumping for irrigation can quickly exhaust the water supply (Dorota et al., 1988).Therefore, alternative water resource for water supply proposed and mitigation water scarcity in the proposed target kebele's was carried out using an integrated approach to identify and select potential groundwater areas for water supply source and predict a groundwater level rise and change of water quality to irrigable land under the implementation of Irrigation

2.5.2 Harvest Irrigation water in Ethiopia vegetable production

In (semi-)arid areas water shortage due to droughts and erratic rainfall is a serious constraint to production and Water shortage therefore may limit agricultural production growth. Therefore, some farmers have invested in small-scale water collection and irrigation technologies, often represented as water harvesting technologies (FAO 1991). With these technologies, farmers collect and store rainwater and use it in periods with insufficient rainfall. Water harvesting technologies are thus used for supplementary irrigation. Our survey data shows that many Ethiopian farmers selectively distribute the collected water to high-value crops such as vegetables and perennials. Other farmers apply it to crops with relatively small plots so that in total not much water is required, or to crops that have a relatively short growing period.

2.5.3 Land management practices in Ethiopia

Land management in Ethiopia has developed in to different farming systems with different level of intensification (Wegayehu, 2006). In the similar way(Bogale, 2002) reported that a number of soil and water conservation techniques have been working by farmers, most of which have their origin in the traditional knowledge but adapted to the present environmental and social circumstances by experiments through generations. According to (Zeleke*et al.*2006) land management practices that have applied in Ethiopia classified into two broad categories: indigenous and introduced, with different degrees of acceptability, areal coverage and benefits. Indigenous knowledge includes the complex of practices and decisions made by local people. The introduced type of land management technologies refers to the recommended type of structures, which have standard length, width and height. In most areas of Ethiopia, new land management technologies were introduced more than two decades ago. During such span of time, the introduced technologies have been under continuous modification, which make it very difficult to trace them back to their origins to compare them with recent development (Tadesse, 2011).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The study area is located in Southern part of Ethiopia South Omo at Nyangatom woreda around kangaten town at about 980 km far from Addis and 680km from City of Hawasa town. It is bordered with Keffa zone and Konta special woreda in North, Gamo Gofa zone and Baske to special woreda in North East, Kenya in South, Segen Zuria People's zone in East, Oromiya region (Borena zone) in South East, and Bench Maji zone in West and North West directions. The project is located in Kibishi River Basin with geographic coordinates of 721809UTM Northing and 218090 UTM Easting at head and 590444UTM Northing and 123013UTM Easting at tail with a projection of UTM; Datum Addendum and zone-36 Degree

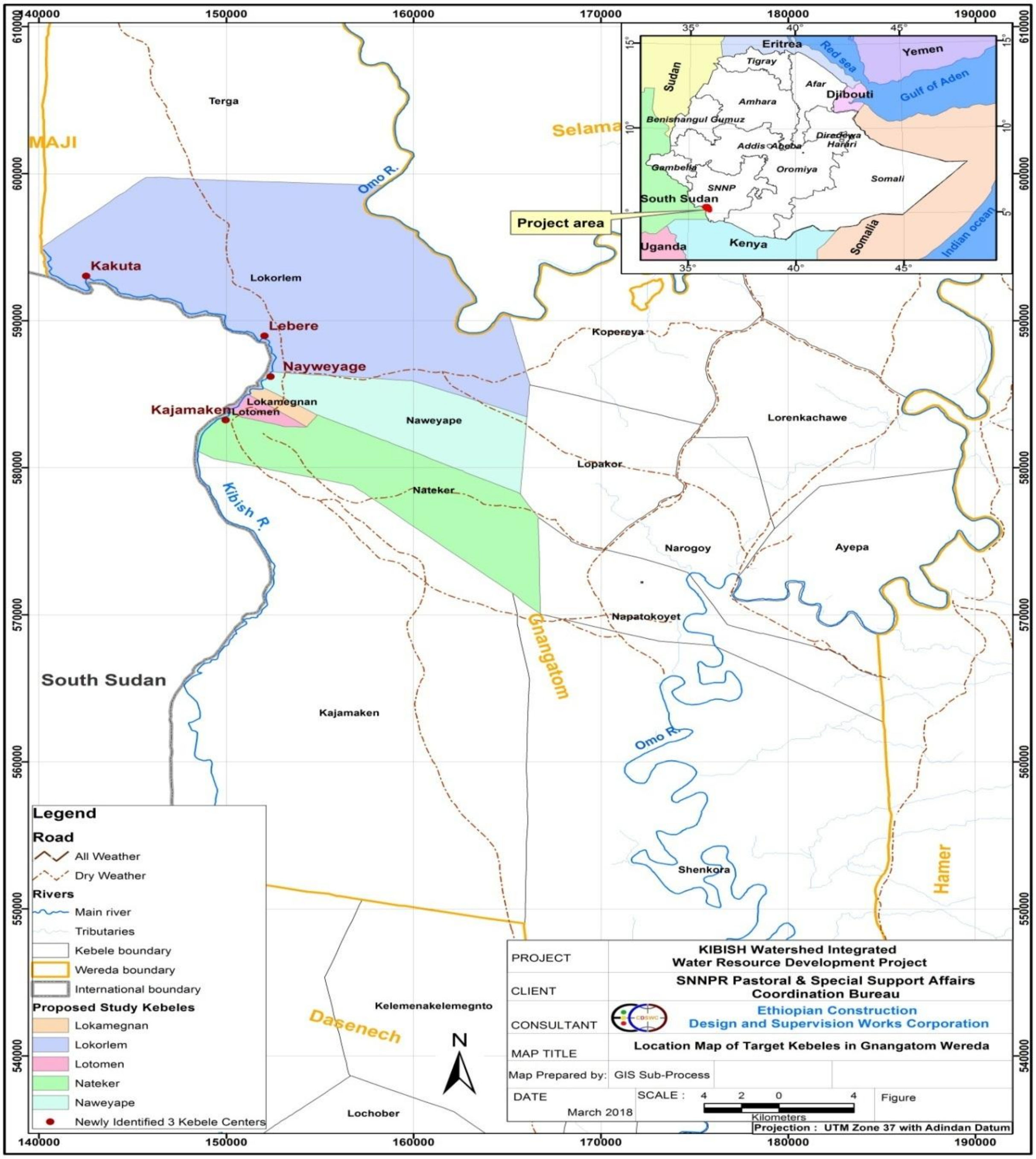


Figure 3. Study area location map source: water work design supervision

3.1.1 Topographic variation and drainage network

Topographic variation of the study catchment is derived from DEM and elevation in the study catchment varies from 405 to about 1550 m a.s.l. Topographic highs are found in Western and Eastern peripheries. In the eastern periphery, Niyalibong Range defines a magnificent linearly oriented steep ridge in NNE direction. However dismembered ridge dissected by faults mark the western side of the study site. The central portion of the catchment is a plain tract of land (possibly delta) stretching from north to south. In this topographic low, Omo River meanders and flows southward to ultimately join Turkana Lake.

Fractures and faults are manifested by arrangement of steep slopes or scarps. The land generally stretches in southern direction defining an elongated and wide plain to join Lake Turkana forming delta landform. In this wide plain is meandering River Omo with general flow direction southward to join Lake Turkana. This enabled the establishment of base level in the southern periphery of the area which has induced the drainage to be generally southern direction.

Thus, flood originating from the upstream, western and eastern directions deposits dominantly fluvial and alluvial sediments leading to formation of thick deposits of sediments. Furthermore, slope of the vast portion of catchment is less than 100 and is flat-lying which dominates the central portion of the study catchment. Steep slope areas are situated in Western periphery of the study catchment. Remarkable to this area is a linearly oriented steep slope manifesting lineament which can be interpreted as faults.

In general, Omo is an exotic stream in its lower basin and its two major affluent, the Kibish and Usno Rivers, are generally dry during the low-sun season, Minor stream networks are correspondingly poorly integrated, with radial highland drainage failing on broad piedmont slopes, Kibish River is a river of southern Ethiopia, which defines part of that country's border with South Sudan. It flows towards Lake Turkana,

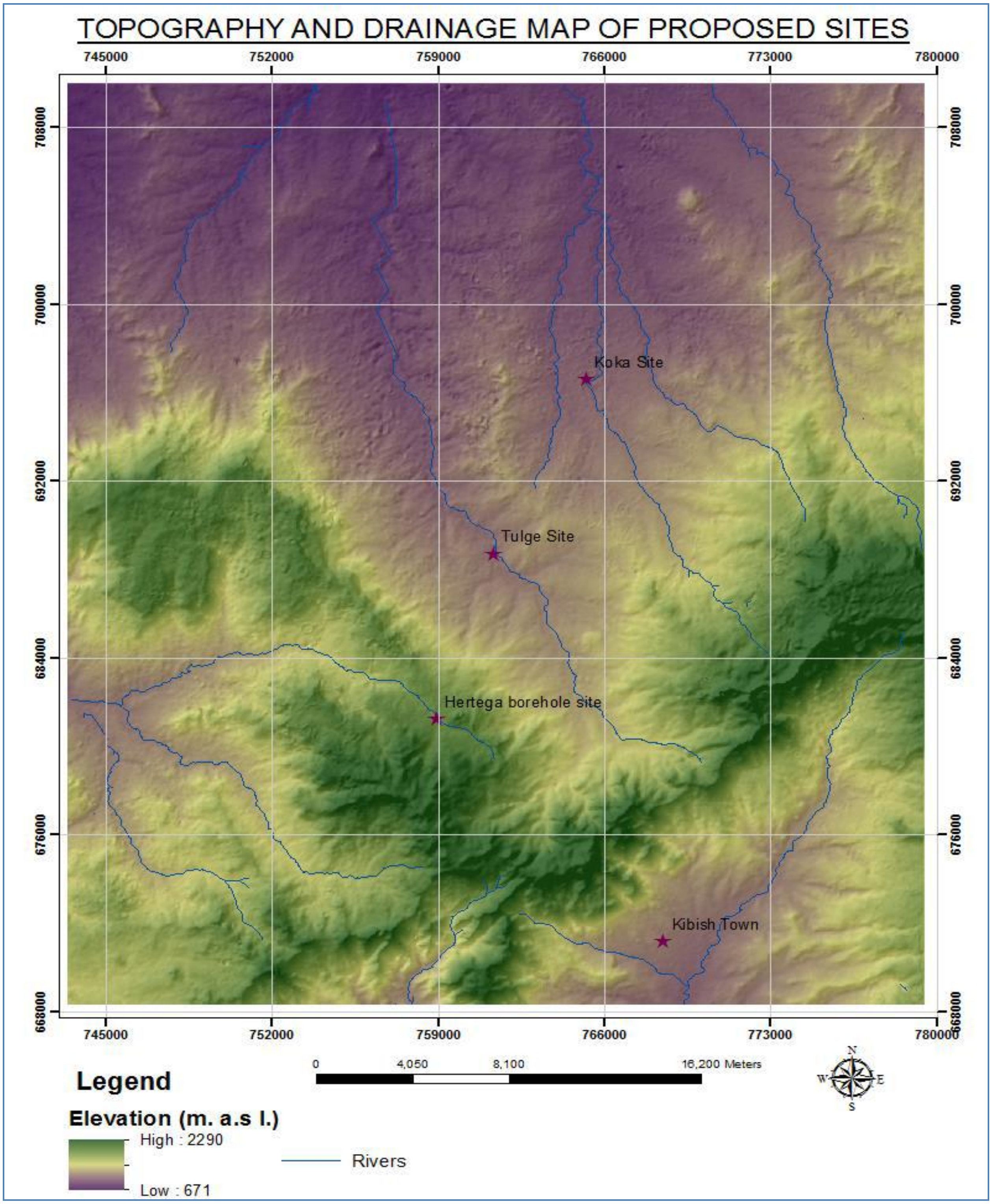


Figure 4. Topography and Drainage Map of Hertega Kebele Boreholes source: water work design supervision

3.1.2 Climate

According to the air temperature data collected by Ethiopia National Meteorological Service Agency from seven weather stations, the mean minimum and maximum annual temperature at study area was found between 33^0C and 42^0C, respectively. A bi-modal nature characterized rainfall is common in most parts of the study area. The short rainy season (*Belg*) extends from February to April while long rainy season (*Meher*) that ranges from June to September. In most cases, the highland areas (*Dega*) are mainly dependent on *Belg* rain whereas, the Woina dega and Kolla areas are *Meher* rain dependent for crop production (NMSA, 1996).The principal feature of rainfall in most parts of North Wollo Zone is its seasonal character, poor distribution and variability from year to year. For the past decades, an erratic distribution of rainfall has been the major climatic factor affecting crop yields in the study area. The traditional agro ecology of the woreda is kola with an altitude that ranges between 300 - 450m a.s.l. The mean annual rainfall ranges from 350 – 500mm.

I. Rainfall Analysis

The entire available climatic data, in association with command area rainfall forms the basic inputs for the estimation of the crop water requirement. The rainfall in the woreda is erratic in nature. The mean annual rainfall ranges from 30 – 130 mm. The highest is recorded in the month of January and February and the minimum is recorded in the month of October and November (Figure .5)

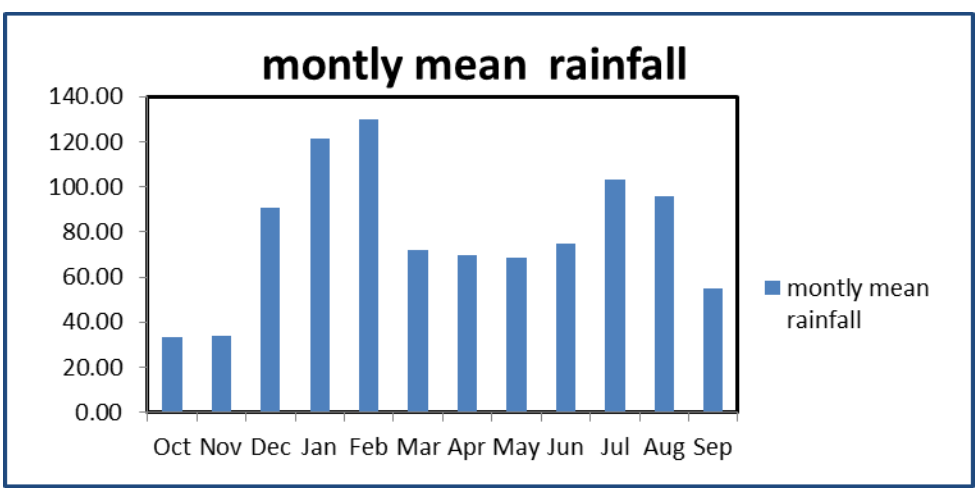


Figure 5. Monthly Rainfall millimeter, (mm)

II. **Temperature**

The minimum and maximum temperature as given in (Figure.3), exhibit the monthly minimum and maximum temperatures of 15^0C and 36^0C respectively.

The highest is recorded in the month of January, February followed by March and. The minimum is recorded in the month of April (Figure .6)

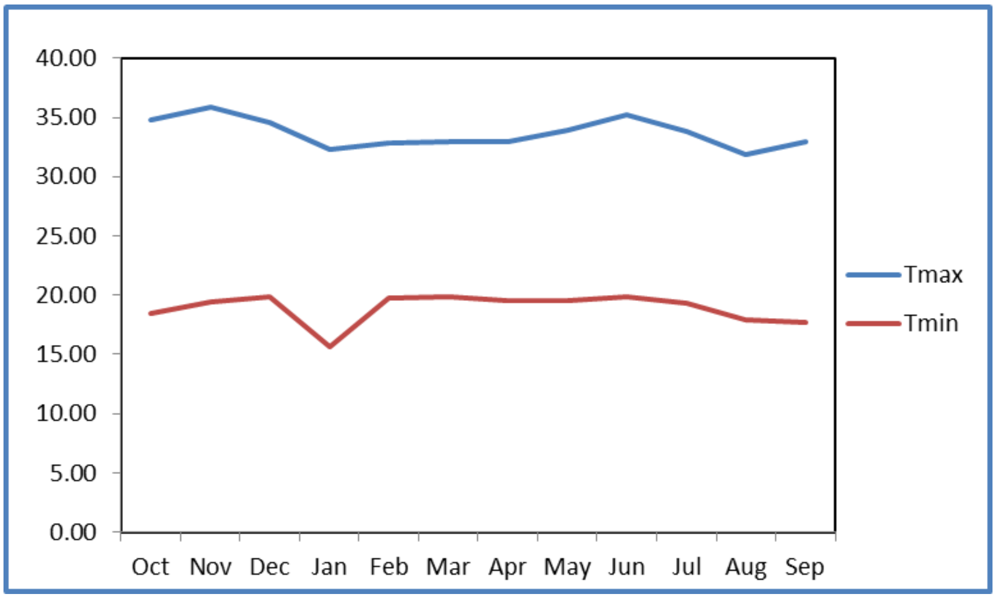


Figure 6 .Monthly Max and Min Temperature, ^oC

3.1.3 Local Geology

Some research has revealed that geology is one of the controlling factors of flow regime (Peters et al., 2003, 2005; Salinas et al., 2013). The reasons for differences in drought runoff or base flow as a result of geology are that (i) the retention capacity of groundwater differs based on geology, and (ii) the infiltration capacity of soils differs based on geology (Lacey & Grayson, 1998; Bloomfield et al., 2009). From the GLM, PR and SR (among the geological factors) were selected as controlling factors that decrease the drought runoff coefficient in high-frequency drought

The study catchment is situated in the lower Omo valley. The study kebeles and villages are situated in the plain at the southern extreme of Ethiopia very close to the Kenyan boundary in the western direction. The surface geology covering the catchment area is generally characterized by post-rift sediments, post-rift volcanics, and pre-rift volcanics (fig 7).

The Kibish formation uncomfortably overlies the Omo group which mainly comprise of four formations: Mursi formation, Nkalabong formation, Usno formation, and Shungura formation (Davidson, 1983). Davidson, 1983 outlined that Mursi formation comprises mainly sedimentary and flood basalt. The Nkalabong formation mainly consists of fluvial sediments overlaying weathered and faulted Mursi basalt and in turn overlain sand.

Omo River is exposed a succession of alternating fluvial and lacustrine sediments with thin tuff horizons (Davidson, 1983). These successions are situated beneath the Quaternary Kibish formation (Butzer, 1971a, 1976). These successions are named the Usno Formation (de Heinzelin and Brown, 1969). The Shungura Formation is exposed south of the project site and is composed of clays, silts and sands (may be resulted from fluctuating fluvial and lacustrine cycles); it uncomfortably underlies the Kibish Formation.

The lower part of the Omo valley is related to flood plain of Omo River. Thus, most of the recent sediments are closely related to fluctuations of ancestral Lake Turkana that gave rise to fluviatile and lacustrine deposit. They are composed of silt to fine sand with minor gravels. Generally, low primary porosity and permeability are expected in sediments as it contain significant amount of silt and clay fractions which represented the type of low aquifer in study area.

Accordingly, the middle reaches of the Kibish are not found to be better sites for groundwater storages in the Wadi sediments this affects lower production of groundwater occurrence or abounded groundwater resource which indication of drought occurrence in study area.

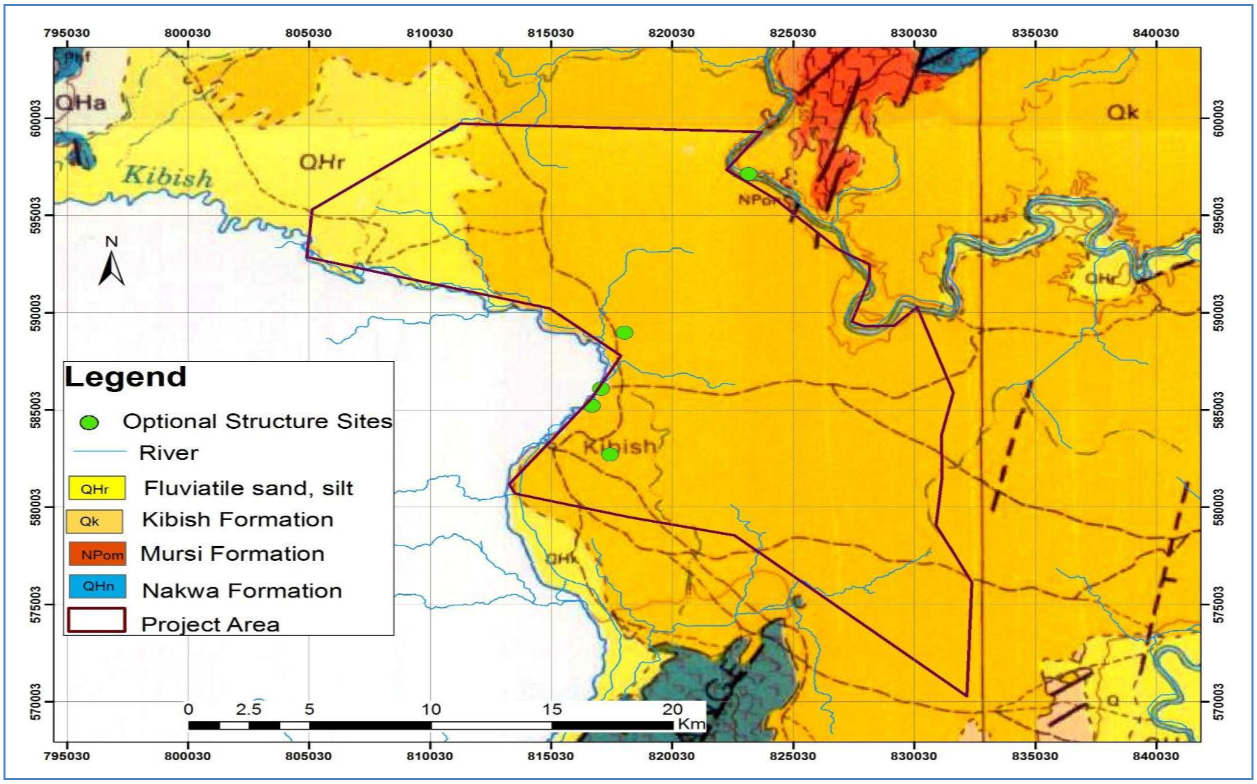


Figure 7: Geologic map of the study catchment (Cited from Nawayape and lokomongan water supply

Source: water work design supervision

The post-rift sediments cover vast portion of the central area that nearly deposited in N-S direction whereas the pre-rift and post rift volcanic cover minor portion of the catchment in the West and East, respectively (Fig.7).

The stratigraphy of the post-rift sediments (bottom to top) mainly comprises rocks members in: Mursi formation, Nkalang formation, Kibish formation and Holocene alluvia, fluviatile and lacustrine deposits (fig.7).

Water is scarce in the Omo valley in general and in the study area (Nawyape and Lokumonyi) specifically. Not only the scarcity of water, but equally crucial is the problem of water quality in the lowland of the Omo valley. Because of the acute shortage of potable water, both people and livestock are forced to use water from Omo River. In some cases, the local people inhabiting along the Omo River use root of a plant locally called Gluf (Maerua Subcordata) to physically purify the otherwise turbid water (Kebede, et al.,2013). According to (Kebede et al.,2013), of the drilled wells in the Omo delta more than 50 % are abandoned due to unsuitable salt content often for both cattle and human consumption. People in the study area also complain about the salty water in some of the shallow wells in their area. Apart from the quality, groundwater potentially occurs in the alluvial deposit in the area.

3.1.4 Soil

The primary drought effect on soil and sediment is increased sheet erosion due to the loss of plant roots and wind. In addition to the increased deposition of sediment on deltas and into rivers increases turbidity that affects fish habitat, the loss of farm soil cause long-term loss in farm production, even after the drought is over then wildfires remove vegetation, enhancing the potential for sheet erosion and soil removal and wildfire impacts create greater potential for debris floods and flows and for flash floods.

Therefore ,the result of study area soil investigation was carried out as described in the (FAO, 2006) guidelines for soil description and soils classification were done using the World Reference Base (WRB), version 2006, classification system. The soils of the project area are delineated into twenty two soil mapping units (SMUs). The SMUs were identified on the basis of slope, surface soil texture, calcium carbonate, salinity, sodicity class and dominant soil type. On the basis of morphological, physical and chemical characteristics five major soil groups were identified, namely Vertsisols (63.21%), Cambisols (15.8%), Fluvisols (13.07%), Calcisols (0.86%) and Solonchacks (0.09%) .

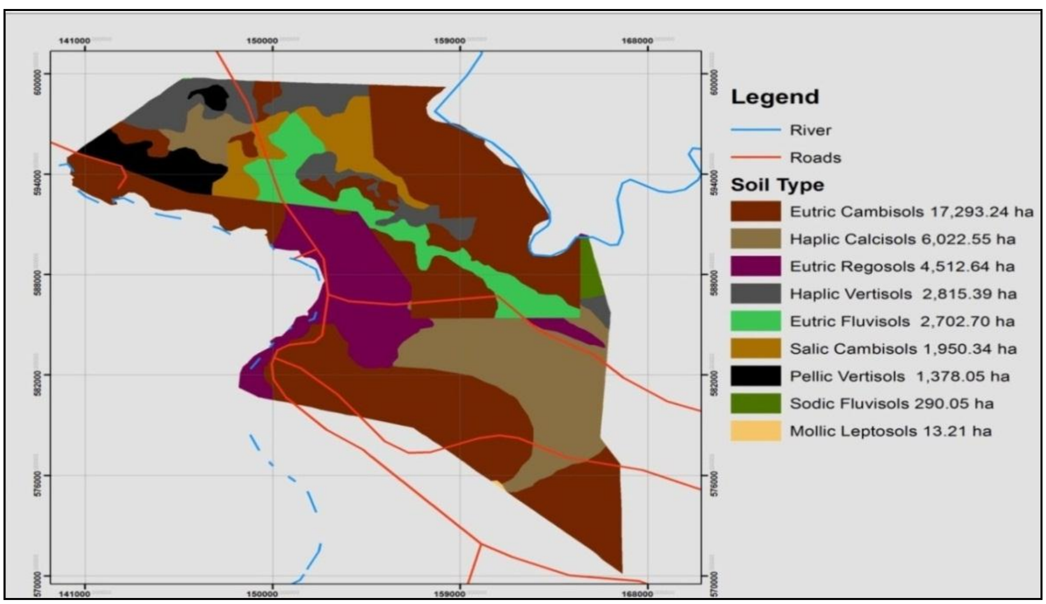


Figure 8: Study area soil map Source: water work design supervision

3.1.5 Vegetation and Wildlife

Wetland and riparian animal and plant life are displaced or die. Drier mountain slopes create vulnerability to forests from wildfire. Mountain burn areas damage game habitat and forage. Burn areas are unattractive for several years, decreasing property values and interest in development; tax bases also decrease. Dangerous animals may be attracted to developed areas for food and water. Depredation problems arise and competition between deer and elk and livestock for native forage and water increases. Deer and elk herds may migrate, affecting the hunting season. Endangered species populations are stressed further.

Stressed vegetation and wildlife are more vulnerable to disease the riverine zone in the lower Omo basin supports relatively luxuriant vegetation compared with the dry grasslands in the surrounding plains environments. The Nyangatom woreda has two discrete vegetation distributions; one is the scattered acacia dominant woody bushes and shrubs and the other is immense vast diversified riparian forest along the Omo River basins. The community woody and non-woody based products and services are potentially extracted from these forest resources (Tesfaye et.al, 2015).

Wildlife in the Omo River in forest zone includes the Nile crocodile, hippopotamus, elephant, buffalo, lion, leopard, kudu, monitor lizard, Colobus monkey, grivet monkey, baboon, bushbuck, and a host of water-loving birds, including the fish eagle (Claudia, 2017).

During the field visit fox, warthog, deer and rabbit have been observed. Vegetation in settlement area is limited to a few trees, shrubs and grasses. There is no dense forest in the project area that is proposed for wells drilling. However, there is diversified river in forest along the Omo river bank. There is no protected area in the project area.

3.1.6 Water Resources

In drought planning, it is essential to have an adequate understanding of your water supply sources. A good start would be to categorize the supply sources into surface and ground water.

Within the surface category, a further classification between storage and streams/rivers is suggested. Within the streams/rivers category, it may be significant to further divide the information between flows that are controlled by upstream structures and those that are not. If the surface water sources are located in different hydrologic basins or, in the case of groundwater, different geologic basins, this geographic distinction may be informative in terms of timing of the reduction of water supplies or different rates of recovery of supplies.

Information from previous drought events, in terms of timing, location, and duration, This information can lead to an understanding of the linkage between a drought event and the impacts on supply. Identification of trends in water supply is also important. Trends of specific concern that may have an effect on specific sources of supply might include: changes in watershed land management that affect runoff (timing, magnitude, or sediment loads); additional wells located in the aquifer or increased withdrawals; new diversions from the stream/river that might have a higher priority in times of emergency; critical habitat needs for endangered species, requiring the maintenance of minimum flows; or lower-than-normal maintenance of physical features (such as pumps and motors) that would reduce the availability of groundwater.

Nyangatom Woreda. Main source of water supply in the project Kebele's are deep well, Shallow well, hand dug well and Surface cistern for human as well as for livestock population. Accessing potable water supply to the community is among the human rights and is the matter of existence. However, the provision of safe, sufficient and accessible water is a critical challenge of the developing countries. The provision of safe drinking water and basic sanitation contributes to sustainable improvements in peoples' lives regarding their health and education situation, the preconditions for productive employment as well as for the eradication of extreme hunger and the empowerment women.

Figure 9: Sources Water supply in the Project Woreda

The source of domestic water in the Woreda ,whether trapped by pipeline or hand pumps from surface are rivers, the lakes and ground Water from spring ,boreholes, shallow and dug wells.

In 2009 E.C, according to the Zonal Water, Mineral and Energy Department the zonal Water supply access in urban areas reached 54.98% and for rural areas 39.8%. 5 Shallow Wells, 21 Hand dug wells and 4 other Water points in the Woreda. Specifically in Nyangatom Woreda the water supply access coverage of is 60%.

Table 4: Existing water point data source: water work design supervision

Easting	Northing	Elevation	KEBELE	Functional	non-Functional	Depth	Type of water
817275	588828	418	Lokorlam	X		90 m	Shallow Well
817260	588834	422	Lokorlam	X		12 m	Hund dug well
807085	594871	447	Kakuta		x	85 m	Shallow Well
807093	59889	421	Kakuta		x	90 m	Shallow Well
807631	592855	439	Kakuta	x		20m	Hund dug well
816874	592855	437	Kakuta		x	18m	Hund dug well
826924	581911	412	Kowtom		x	90 m	Shallow Well
811832	592421	402	Kajmakin	X		90 m	Shallow Well
814345	583305	419	Lebere		x	20 m	Hund dug well
804354	633020	504	Kuraz Lot-3	X		104m	Shallow Well
807420	646344	532	Kuraz Lot-2	X		110m	Shallow Well

3.2 Martials and Methods

3.2.1 Data Collection

Since, Water Availability in the dry land semi-arid areas of Ethiopia in general and study area, lower south omo in particular, are influenced and controlled by seasonal rainfall and Temperature variability. Meteorological drought analysis was carried out seasonal wise using Different drought indices with the objective of this thesis are to characterize drought with respect in Nyangatom wereda. Meteorological drought characterization was conducted by considering the entire dry and wet years because such consideration explains well drought characterization in duration, severity and intensity drought.

3.2.2 Field Investigation

The field investigation was conducted to assess ground truth by using GPS for study area weather station point data and photo capture for study area drought monitoring indices validation, and also for intensive analysis that to be used as an input to R studio software processing and interpretation of SPEI value. The major/dominant land use of study area was investigated by field observation and tap water collection

3.2.3 Meteorological data

Rainfall and temperature data was obtained from National Meteorological Service Agency (NMSA) of Ethiopia from stations of study area,32 element serious data used and analysis by Standardized Precipitation and evapotranspiration Index (SPEI) Vicente-Serrano et al.2010) proposed a new drought index called the Standardized Precipitation and Evapotranspiration Index (SPEI). The SPEI based on precipitation and temperature data, and has the advantage of combining a multi-scalar character with the capacity to include the effects of temperature variability on drought assessment. The procedure to calculate the index is detailed, and involves a climatic water balance, the accumulation of deficit/surplus a different time scales, and adjustment to a Log-logistic probability distribution.

3.2.4 Water Sample Laboratory Analyses

Eight samples were collected from shallow and hand dug wells located in the target kebeles of Nyangatom wereda as of south omo zone for physio-chemical analyses to be conducted in the water work design supervision laboratory. These sources of samples could possibly have similar signature with that of the groundwater.

3.3 Computation of Standardized precipitation evapotranspiration index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) uses the difference between precipitation and Potential Evapotranspiration (PET). The computation of the SPEI is based on the following steps: (1) computation of PET; (2) the accumulation of deficit and/or surplus climate water balance (CWB) at different time scales (i.e. P-PET); and (3) normalization of water balance into a three-parameter log-logistic probability distribution to obtain the SPEI index series. The complete description of SPEI processing steps is presented in Vicente-Serrano et al. (2010).

In this research, the PET was calculated using the Hargreaves method (Hargreaves and Samani, 1982) instead of the more data-demanding Penman–Monteith (PM) method (Allen et, 1998); (Monteith, 1965). The PM method requires large amounts of data such as solar radiation, temperature, wind speed and relative humidity. In the majority of stations in Ethiopia, long-term records of these variables are not available due to the limited first class stations, improper functioning of the existing ones, and recording errors. Therefore, due to the absence of data required for computation of PM, the Hargreaves method (Hargreaves and samani, 1982) will be applied to estimate potential evapotranspiration (PET), following the recommendation given by (Begueria et al, 2014). The Hargreaves method has been applied in Ethiopia in previous studies (e.g. Tekleab et al., 2011). PET estimates at monthly and annual timescales from the Hargreaves and PM equations are very similar (Droogers and Allen, 2002).The difference between the precipitation (P) and PET for the month i will be calculated according to:

$D_i = P_i - PET_i$

The probability distribution function of the difference series, according to the log-logistic distribution, is given by

$$\mathrm{F}(x) = \left[1 + \left(\frac{\alpha}{\chi - \gamma}\right)^{\beta}\right]^{-1}$$

Where α, β, and γ are scale, shape and location parameters, respectively, for the difference series in the range (γ < χ < ∞). The parameters can be computed using the L-moment procedure with the following equations

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2},$$

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1 + 1/\beta)\Gamma(1 - 1/\beta)}, and$$

$$\gamma = w_0 - \alpha\Gamma(1 + \frac{1}{\beta})\Gamma(1 - \frac{1}{\beta})$$

Where *Γ (β)* is gamma function of *β* and w_k the probability weighted moments (PWMs) of order *k*, *k*=0, 1, 2.

$$w_k = \frac{1}{n}\sum_{i=1}^{n}(1 - \frac{j - 0.35}{n})^s D_i$$

Where j is the range of observations in increasing order and n is the number of data points.

The SPEI will then be computed as the standardized values of F(x) using the following equation

$$SPEI = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3}$$

Where *W*=√-2ln [1-*F(x)*] for F(x) ≥ 0.5, and *W*=√-2ln [*F(x)*] for F(x) < 0.5

In this research, SPEI 1, SPEI 3, SPEI 6, SPEI 12, and SPEI 24 was used and to represent the characteristics of 1, 3, 6, 12, and 24 months, respectively. The calculation will be performed using the 'SPEI' package of R software (Beguería and Vicente-Serrano, 2017) can be downloaded free of charge from (http://cran.r-project.org/web/packages/SPEI).

3.4 Drought characterization

A drought characteristic was analyzed by applying runs theory (Yevjevich, August 1967) based on time series of SPEI. Drought parameters include duration, severity, and intensity of drought (Dracup et at, 1980). Drought duration (D_d) is the time period between the initiation and termination of a drought (i.e. SPEI < -1 is considered as drought period). Drought severity (S_d) indicates a cumulative deficiency of a drought parameter below the critical level. Drought intensity (I_d) is the average value of a drought parameter below the critical level derived as the drought severity divided by the duration.

Four important and common drought characteristics method

- **Drought Duration (D)**: refers to the number of consecutive months (or weeks) in which the precipitation (or soil moisture or runoff) is below the chosen threshold (Andreadis et al., 2005). The duration is highly dependent on the chosen threshold for the declaration of the start and end of the drought episode.
- **Drought intensity (I)**: The intensity of a drought is the severity divided by the duration. Droughts that have shorter durations and higher severities will have larger intensities:

$$I = \frac{Severity}{Duration}$$

- **Drought Severity (S)**: refers to either the value of precipitation (or any other drought indicator) at a given month during the drought event or the minimum of precipitation during the event (Thompson 1999; Vidal et al., 2010).

The severity is the cumulative sum of the index value based on the duration extent (Yang 2010):

$$S = \sum_{i=1}^{D} SPEI$$

3.5 Non-parametric Trend Tests and parametric trend test

Parametric and non-parametric methods can be used for trend detection in hydroclimate variables (Kundzewicz and Robson 2004). Parametric tests are useful where data are normally distributed;

however, hydro climatological time series rarely satisfy this requirement and trend results can be affected outliers. In tandem, distribution-free nonparametric tests are more robust compared with their parametric counterparts (Kundzewicz and Robson 2004). Mann–Kendall's test is the most widely applied non-parametric test for detecting trends in hydro climatological time series (Mann 1945; Kendall 1975).

3.5.1 Mann-Kendall (MK) Test

The MK test is used for determining monotonic trends and is based on ranks. This is a test for correlation between sequences of pairs of values. The significance of the detected trends can be obtained at different levels of significance (generally taken as 0.05). This has been suggested by world meteorological organization to determine the existence of statistically significant trends in climate and hydrological data serious .the MK test statistics and the sign function are calculated using the formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sin(xj - xi)$$

$$\text{Where } \operatorname{sign}(xj - xi) = \begin{cases} +1; (xj - xi) > 0 \\ 0; (xj - xi) = 0 \\ -1; (xj - xi) < 0 \end{cases}$$

- The Standardized Statistic, ZMK is calculated based on the test statistic, S with the following formula: the null hypothesis of no trend is rejected with a significant trend when$|ZMK|$>$Z_{1\frac{\alpha}{2}}, Z1 - \frac{\alpha}{2}$ is a critical point of ZMK with value of 1.96 at the 5% significance level.

3.5.2 Thiel-Sen estimator

Thiel-Sen estimator (Thiel, 1950; Sen, 1968) is a non-parametric procedure that estimates the magnitude of slope of the identified trend. It is the most popular technique for linear trend estimation due to the advantage of insensitivity to outliers that limits the effect of the outliers on the slope as compared with the linear regression (Shadmani et al., 2012). The slopes of a sample of N pairs data is defined as:

$$Q_i = \frac{x_i - x_k}{j-k} \quad \text{For i=1, 2 … N}$$

- If there are n values $x_j$in the time series we get as many as N = n(n-1)/2 slope estimates Q_i. The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

$$Q_{med} = \begin{cases} \frac{Q_{N+}1}{2} & ,if\ N\ is\ odd \\ & , \\ & , \\ \frac{1}{2}\frac{Q_N}{2} + \frac{Q_N + 2}{2} & ,if\ N\ is\ even \end{cases}$$

- The values of Q_{med} indicate the steepness of trend in the data series.

3.6 Assessment of water Quality

The assessment of the water quality is essential for the effective management of the reservoir, and in consequence, for securing good quality water for irrigation practices on agricultural fields. The chemical characteristics of irrigation water affect the growth of plant directly by toxicity or deficiency, or indirectly by altering plant availability of nutrients accordingly (Ayer & Westcot, 1985; Rowe & Abdel-Magid, 1995). Water quality is determined by the quality of water entering the reservoir and processes taking place directly in the reservoir, which are susceptible to meteorological and drought conditions.

Analyses of the chemical constituents of the water help in addition to identify the water types and possibility of the water for various uses. However, water sample is taken from existing shallow wells, hand dug wells and River around the project area. For example, water sample taken from Lokorlem kebele shallow well shows that the concentration of some of the parameters (Total dissolved solids, Sodium, Potassium Alkalinity, sulphate and Boron) exceed the WHO and Ethiopian water quality standards.

Analyzed water quality with drought on surface and ground water levels rivers and lakes drop to low levels during drought, while turbidity and salinity increase, affecting fish habitat. Mountain animals have less to drink and migrate to wetter areas or to places of water concentration. Ground water levels drop and spring flow decrease. Deeper aquifers may not be affected until some years later, if at all. Wetlands can become dry until moisture returns. Soil moisture can decrease, killing even the deeper plant root systems, damaging root systems and future plant growth. Reservoir drawdown and low stream flows affect recreation

Impacts of drought on the channel pollutants and surface water quality during the drought, a decrease in the channel flow and velocity as well as the capacity of diluting and transferring is common. At the same time, the increase of the density of nutrition elements (i.e. nitrogen, phosphorus and so on), the weakening of the hydrodynamic conditions and the extension of the dwell time will provide sufficient nutrition for algae's rapid multiplication, leading to an aggravation of eutrophication, a disorder of the aquatic ecosystem, a reduction of the living species and a damage of the diversity.

A large quantity of sediments and pollutants are accumulated in the bottom of the river, which breaks the balance of the deposition and suspension of the downriver sediments and increases the oxygen consumption of suspended particles and pollutants, leading to a decrease in the pollutant carrying capacity and an increase in the density of pollutants.

The decomposition of the organics by microorganisms consumes the dissolved oxygen in the water. As a result, with the level of the dissolved oxygen decreasing, toxic materials enter the aquatic organisms, resulting in their deaths. Therefore, more dissolved oxygen is needed to decompose their bodies. The entry of nutrients into the water body causes the algae and other plankton multiply rapidly. A rise in temperature during the drought, at first, affects the physical and chemical property of the water bodies, for example, the solubility of a gas, the speed of chemical and biochemical reaction, and the impacts of water temperature on the activities of microorganism. Secondly, it affects the inner process of the water body; for instance, the process of diffusion, mineralization and vertical mixing changes the temperature between the metalimnion and the stratosphere, which can easily generate the stratification of the water body. It also speeds up the toxic reaction, leading to the decrease of the dissolved oxygen. The levels of ammonia nitrogen, nitrite and phosphate rise, while there is a drop in nitrates. Besides, it makes the algae multiply rapidly, which in turn will destroy the ecological balance of water and cause the water eutrophication.

4 RESULTS AND DISCUSSION

This section of the study deals with result and discussion the data obtained from the field survey and the result presented as follows.

4.1 Climatic water balance with respect to water availability

Standard potential evapotranspiration index (SPEI) uses the monthly difference between precipitation and potential evapotranspiration (PET). The monthly PET is calculated based on Hargreaves formula. This represents a simple climatic water balance expressed in terms of SPEI which is calculated at different time-scales (e.g., 1-, 3-, 6-, 12-, and 24-month) which allows evaluation of the effects of a precipitation deficit on different water resources components (groundwater, reservoir storage, soil moisture, and stream flow). Based on the result of the SPEI-3 month values was used represented in (Annex4),there are a severe drought on the study area from June 1999 and November, December 2010and this implies that the soil moisture, SPEI-6 month values SPEI value may also begin to be associated with anomalous stream flow and reservoir conditions deficit occurred from March 1997 and SPEI-12 to 24 month value , month duration were recorded in grid cells in one periods, namely in the years 1999-2003 this implies that the deficit surface water and ground water.

Therefore, it is characteristic, that similar wetness conditions, as evaluated by SPEI, occur over the Nyangatom simultaneously. According to the SPEI-24, the main drought episodes occurred from June, July, August, September and October 2000 the result of indication deficit surface water and ground water the results of which are represented in (Annex 4).The results indicate that drought indices respond to high variability in precipitation. As inter-annual variability in air temperature is relatively low, precipitation deficit seems to be the main factor responsible for extreme drought development. The temporal evolution of CWB at 1-, 6-, 12 and 24-month time scales selected grid cells covering the territory of the Nyangatom woreda in grid cell. A drought is considered to occur when the SPEI value is less than or equal to −1. Annexes 4 show monthly SPEI value with 32-element series can be observed that the occurrence of months in which drought was detected in all severity classes within the range 70-81 and corresponds to about 18-21% of the entire time under analysis (Table.5).

Table 5: Characteristics of drought events for different time scales in the Nyangatom Woreda, based on (Standard Potential Evapotranspiration Index (SPEI) values in the years 1983-2014

Time Scale (Months) (Standard Potential Evapotranspiration Index (SPEI)	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
Number of months with drought in 1983-2014	72	81	81	70	79
Percent of the entire time	19	21	21	18	21

Source: computed from EMA data

In addition to study area from the field survey data in water resources availability has two rivers namely; perennial Omo river and periodic kibish river. Kibish river increases in volume during the rainy seasons that has received from a number of tributaries found in the upper part of the river (surma-bench majji) through the bisects of the Kenyan and Ethiopian border until the lower parts of the river. Livestock herded around Koras Mountain and along the Kibish River are watered at the seasonally flowing kibish river. In wet season, the overflow from the river is used for crop cultivation and the river as a source of water and the perennial Omo River originates in the western Ethiopian highlands at an elevation of more than 2000 m and flows over cataracts and through gorges and an entrenched valley before its passage through the lower Omo basin, where it terminates at Lake Turkana at an altitude of 375 m.

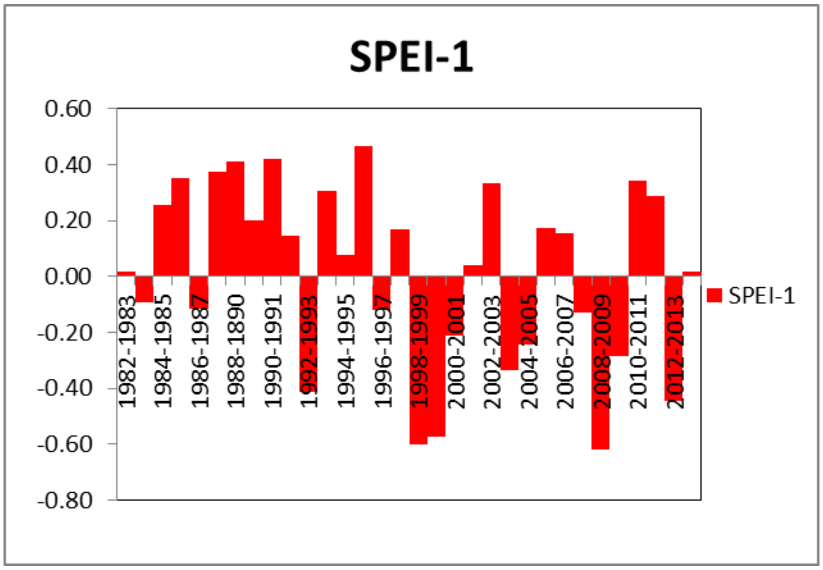
However, the result of the study which indicates during drought seasons, villagers dig water holes in the dry riverbed of the Kibish. These watering holes, frequently extends to 7 or 8 m depths. Kibish waters are the main alternative source of water for Nyangatom residents.

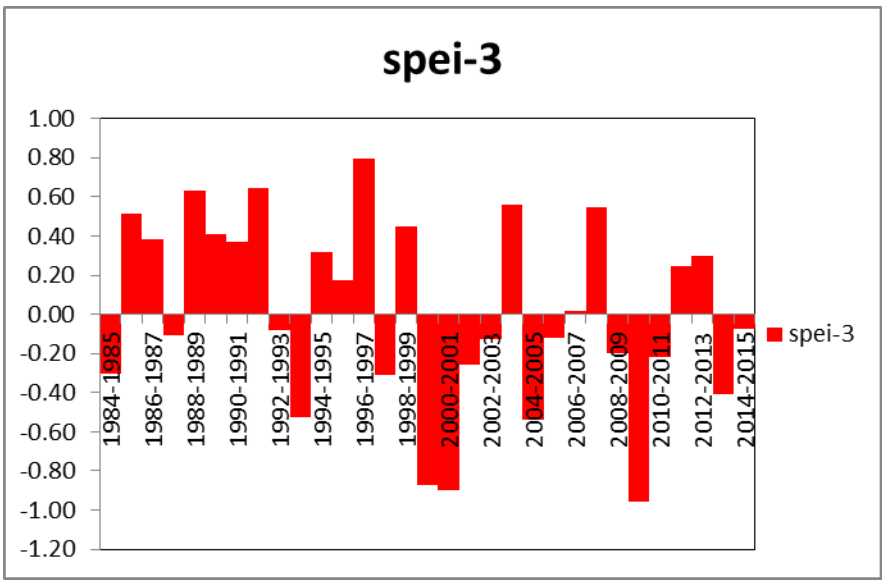
4.2 Duration, severity and intensity of drought characterization

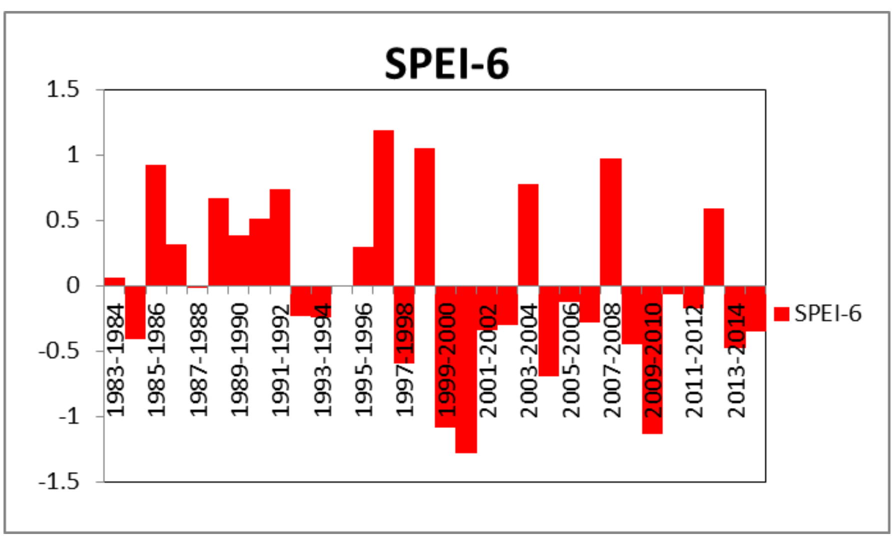
Droughts episodes also differ with regard to three main characteristics: intensity, duration and severity spatial coverage column are presented in (Figure .10) on a different time scale of hydrological drought indicators Standard Potential Evapotranspiration Index (SPEI). In this analysis, drought characteristics are considered when an event occurs at least for 3-7 successive year. Column are representing the duration of any drought event occurred in a year. Here red columns indicate the duration of moderate, severe and extreme droughts respectively. The dots show the intensity of a drought event for the given year. Figure .10 the duration of drought and intensity of SPEI on 1, 6, 12 and 24-month scale in Nyangatom Woreda. Hydrological drought mainly lags the occurrence of meteorological and agricultural droughts and it also manifests when a lack of precipitation persists for a long period, leading to over- all water supply deficiency in forms of snowpack, streamflow, groundwater and reservoir storage was occurred in 1999-2003 and 2010-2013 in the Nyangatom Woreda. Meteorological drought originates from a deficiency of precipitation over a prolonged time period, often accompanied by unusually high temperature, high winds, low humidity, and high solar radiation which result in increased evapotranspiration and is defined by the degree of dryness compared to a “normal” or long-term average and also Agricultural drought results from lack of precipitation plus evapotranspiration over a prolonged time period which eventually leads to extended periods of low soil moisture that would affect agriculture productivity and ecosystem rehabilitation failure .thus , One important aspect of meteorological drought is that it stands for an early warning system of drought condition

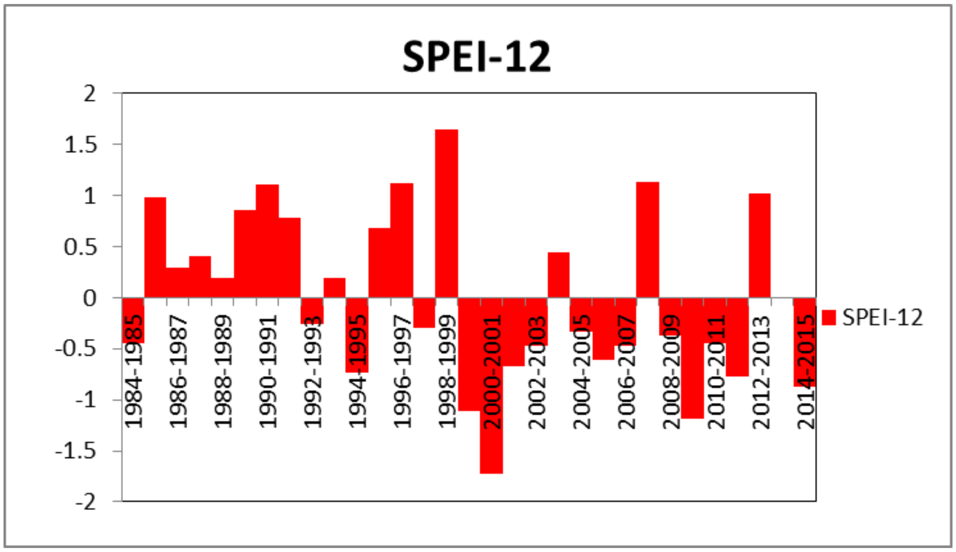
It is observed that this Nyangatom woreda experienced severe drought only in 2000-2007, and the droughts are not prolonged more than 4 year. In the other years, droughts were mostly moderate for a short duration.

Therefore, the results indicate that maximum severity of SPEI-24 calculation is shown Table.6 below result indication ranges between low and high category. The magnitude of the intensity its mean in one period of drought has a high severity and short duration. Highest intensity that occurred in grid cell -1.09 in 2009 to 2012 the highest intensity for SPEI-24 was recorded in meteorology station. And the highest intensity for SPEI-6, 12 and 24 was recorded in average value with respectively about -0.75,-1and -1.09. The hydrological impacts of a meteorological drought can sometimes be exacerbated by the overexploitation of resources. This happens particularly with groundwater resources, leading to the lowering of the groundwater table, drying up of springs and upper-river reaches, reduction in river flows, destruction of wetlands and salt intrusion (coastal areas).


SPEI-1
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
1982-1983
1984-1985
1986-1987
1988-1890
1990-1991
1992-1993
1994-1995
1996-1997
1998-1999
2000-2001
2002-2003
2004-2005
2006-2007
2008-2009
2010-2011
2012-2013
SPEI-1


spei-3
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
1984-1985
1986-1987
1988-1989
1990-1991
1992-1993
1994-1995
1996-1997
1998-1999
2000-2001
2002-2003
2004-2005
2006-2007
2008-2009
2010-2011
2012-2013
2014-2015
spei-3


SPEI-6
1.5
1
0.5
0
-0.5
-1
-1.5
1983-1984
1985-1986
1987-1988
1989-1990
1991-1992
1993-1994
1995-1996
1997-1998
1999-2000
2001-2002
2003-2004
2005-2006
2007-2008
2009-2010
2011-2012
2013-2014
SPEI-6



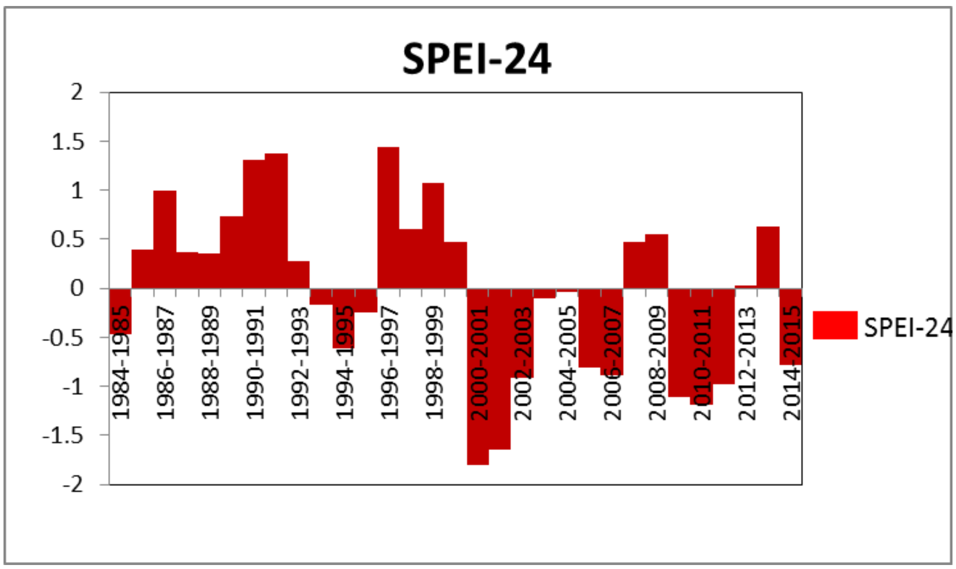


Figure 10: Temporal evolution of SPEI- 3,6,12, and SPEI-24 in the years 1983-2014 in Nyangatom Woreda.

Source: Computed from EMA data

Table.6 shows the SPEI of drought indices for Nyangatom Woreda. SPEI indicator shows that the severe drought occurred in 1999-2003 year remained until 1983 up to 1998 .The same trend was also observed on SPEI indicators. However, SPEI-24 indicated that the extreme drought in 2000-2007 with the very high Severity and long duration.

Table 6: Recapitulation of drought events the longest and strongest for SPEI time series mean value.

SPEI-1				SPEI-3			
YEAR	D	S	I	YEAR	D	S	I
1983-1984	1	-0.09	-0.09	1984-1985	1	-0.31	-0.31
1986-1987	1	-0.09	-0.09	1987-1988	1	-0.1	-0.10
1992-1993	1	-0.4	-0.40	1992-1994	2	-0.6	-0.30
1996-1997	1	-0.09	-0.09	1997-1998	1	-0.31	-0.31
1998-2001	3	-1.38	-0.46	1999-2003	4	-2.14	-0.54
2003-2005	2	-0.58	-0.29	2004-2006	2	-0.66	-0.33
2007-2010	3	-1.03	-0.34	2008-2011	3	-1.38	-0.46
2012-2013	1	-0.44	-0.44	2013-2014	1	-0.48	-0.48
SPEI-6				**SPEI-12**			
YEAR	D	S	I	YEAR	D	S	I
1984-1985	1	-0.41	-0.41	1984-1985	1	-0.44	-0.44
1987-1988	1	-0.02	-0.02	1992-1993	1	-0.26	-0.26
1992-1995	3	-0.49	-0.16	1994-1995	1	-0.74	-0.74
1997-1998	1	-0.60	-0.60	1997-1998	1	-0.30	-0.30
1999-2003	4	-3.01	-0.75	1999-2003	4	-3.99	-1.00
2004-2007	3	-1.10	-0.37	2004-2007	3	-1.41	-0.47
2008-2012	4	-1.84	-0.46	2008-2012	4	-2.78	-0.70
2013-2014	1	-0.48	-0.48	2013-2014	1	-0.88	-0.88
SPEI-24							
YEAR	D	S	I				
1984-1985	1	-0.49	-0.49				
1993-1996	3	-0.69	-0.23				
2000-2007	7	-6.20	-0.89				
2009-2012	3	-3.27	-1.09				
2013-2014	4	-0.78	-0.20				

Source: Computed from EMA data, Information: Length of drought (**D**uration) in the month; **S**: Severity; **I**: Intensity

Table 7 shows the number of drought months with different intensity classes at 1,-, 3-, 6-, 12- and 24-month timescales as calculated by the SPEI. The total number of drought months with moderate, severe and extreme intensities computed at the 1-month timescale was found to be between 45 months, 24 months and 2 months month covered at 63 %, 34 % and 3 % of the entire time series under analysis, respectively. The total number of drought months with moderate, severe and extreme intensities computed at the 3-month timescale varied between 46 months, 16 months and 4 months at grid cell point, and covered among 70 %, 24 % and 6% of the study period, respectively. The total number of drought months with moderate, severe and extreme intensities classification computed at the 6-month timescale varied among between 45 month, 25 month and 1 month at grid point, and covered at 63 %, 35% and 1.4% of the study period, respectively. The total number of drought months with moderate, severe and extreme intensities computed at the occurrence of drought at the 12-month timescale was among 34 months and 26 months at grid cell point, and the covered among 57% and 43% of the study period, respectively. The 24-month droughts with severe intensities 29 months at grid cell point, 33 months, 2 months and covered at 52 %, 45% and 3 % of the study period, respectively.

Table 7: Magnitude of drought episodes at 1-, 3-, 6- , 12- and 24-month time scales seasons as calculated by SPEI in 1983-2014

			Drought Classification	**Number of months with drought in 1983-2014 Standard Potential Evapotranspiration Index(SPEI)**				
Station	**Location**	**Elevation**	**Magnitude**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SPEI-24**
Grid_1	175961 , lat	390	moderate	45	46	45	34	33
	556208,Long		severity	24	16	25	26	29
			extreme severity	2	4	1		2
			Total	71	66	71	60	64

4.3 Drying trends detected in the SPEI time series

SPEI values, 32-element year series of SPEI- 1, SPEI-3, SPEI-12, and SPEI-24were prepared by metrology office used grid cell point row data for the Nyangatom Woreda, for each month a 32-element time series result was consisting of annual mean values of SPEI of different time scales. So that, the Mann-Kendall test was used the results of which are represented in (Table.8).In the

SPEI-3 monthly series, drying trend occurred only in March statistically significant. In addition to SPEI-6 and SPEI-24 monthly series, a drying trend occurred four month in February, March, April and June statistically significant, while in time series representing longer time scales a decreasing trend is obvious in considerably larger number of months. This especially concerns SPEI-6 and SPEI-24.Series of annual mean values of SPEI-1, SPEI-3, SPEI-6, SPEI-12 and SPEI-24 also show statistically significant drying trend below Table .8 sign bold color indication a drying trend monthly .It is worth mentioning that drying signals (negative values of Z Statistic) are detected in the case of their meaning series. Thus, results show that in result the analyzed time series either drying trends or drying indications are detected statically significant February up to June.

Table 8: Summary statistics of the Mann-Kendall test applied to monthly SPEI series Nyangatom Woreda in the years 1983-2014. Bold color indicates a drying trend

	SPEI-1												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Mann-Kendall ,Z Statistic	-0.36	-1.5	-0.23	0.14	-0.46	-1.59	-1.62	-0.2	-0.6	0.89	0.86	-0.6	-1.43
Significant	no	No	No	No	No	No	No	No	No	No	No	No	No
	SPEI-3												
	Oct	Nov	Dec	Jan	Feb	**Mar**	Apr	May	Jun	Jul	Aug	Sep	**Annual**
Mann-Kendall ,Z Statistic	-1.89	-1.03	-0.29	-1.18	-1.86	**-2.43**	-0.61	-1.56	-1	0.79	-0.29	-1.5	**-2.03**
Significant	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes
	SPEI-6												
	Oct	Nov	Dec	Jan	**Feb**	**Mar**	**Apr**	May	Jun	Jul	Aug	Sep	Annual
Mann-Kendall ,Z Statistic	0.62	-0.28	-0.84	-1.2	**-2.11**	**-2.66**	**-3.35**	-1.77	-2	-1.7	-0.79	-0.5	-1.36
Significant	No	No	No	No	Yes	Yes	Yes	No	Yes	No	No	No	No
	SPEI-12												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Mann-Kendall ,Z Statistic	-0.73	-1.11	-1.75	-1.03	-1.27	-1.39	-1.53	-1.57	-1.4	-1.4	-1.34	-1.6	-1.3
Significant	No	No	No	No	No	No	No	No	No	No	No	No	No
	SPEI-24												
	Oct	Nov	Dec	**Jan**	**Feb**	Mar	Apr	May	**Jun**	Jul	Aug	Sep	Annual
Mann-Kendall ,Z Statistic	**-1.96**	-1.33	-1.74	**2.34**	**-1.82**	-1.71	-1.71	-1.48	**-2.5**	-1.5	1.26	-1	-1.33
Significant	Yes	No	No	Yes	No	No	No	No	Yes	No	No	No	No

Source: Computed from EMA data result represented No=insignificant, Yes=significant

4.4 Water Quality

Rivers and lakes drop to low levels during drought, while turbidity and salinity increase, affecting fish habitat. In addition to that water salinization due to removal of vegetation thus the increase in nitrate was clearly related to the removal of vegetation, which lowered the denitrification effect. Studies of this nature are relevant to the influence of deforestation such operations may deteriorate the quality of local surface and groundwater. Thus such operations should be accompanied by hydrochemical monitoring operations.

This section focuses on the quality of water used for irrigation. Irrigation water quality has direct effects on soils and crops. Good crops can be produced by using water of excellent quality. The quality of irrigation water depends mainly on lithology and climate. The chemical characteristics of irrigation water can a fact plant growth directly by toxicity or deficiency, or indirectly by altering the plant availability of nutrients (Ayer & Westcot, 1985; Rowe & Abdel-Magid, 1995).

Therefore, nyangatom woreda was evaluated. The assessment of the water quality is essential for the effective management of the water supply, and in consequence, for securing good quality water for irrigation practices on agricultural fields and domestic purposed with challenge of drought effect on water quality problem evaluation from the result. Water quality is determined by the quality of water entering the reservoir and processes taking place directly in the reservoir, which are susceptible to meteorological and drought conditions and to monitor more frequent wildfires may burn deeply, damaging root systems and future plant growth.

In water supply the potential evaluation will not only be in terms of quantity it shall be also in terms of quality. Quantity means the amount of water resources in study and also quality means physical, chemical and biological properties of water. Water quality survey is one of the major activities to be conducted on site and through systematic water sample collection from surface water bodies, springs, shallow and deep existing wells in the study area

The water quality study involves the collection of water samples from different water bodies of interest in the study area and adjacent areas in order to:

- Characterize the chemical composition of the aquifers.

- water quality problem the impacts on crop yields and makes crops vulnerable to import limitations from study area with exact quality standards and on recreation and tourism factor
- It has environmental implications where biological and chemical contamination of water can impact on important aquatic species. Some of these impacts are clearly visible, such as major fish kills, whilst others are more insidious and long term. Combined, however, they are already having a significant negative impact on socioeconomic development in Nangatom
- Characterize the groundwater of the study area, its suitability for domestic water supply based on Ethiopian Drinking Water and WHO standards

The main groundwater quality indicators are physical and chemical constituents of water. To characterize the water quality of the area, analysis for major cations and anions were carried out for existing 8-water samples of shallow, River and hand dug well sources. Based on this, eight samples were collected from sources of springs, River and shallow wells. Total dissolved solids (TDS), Electrical conductivity (EC) increase above WHO standard in Lokerlem kebele one shallow well. OMO River, kibish river and lokomagna hand dug well is high turbidity result of water quality .but the other sample is feet quality of WHO.

The chemical analysis result of the water samples plotted in piper tri-liner diagram identified that the groundwater types are Ca-Mg-HCO_3, Ca-HCO_3, Na-Ca-Mg-HCO_3 for Hand dug well, River& shallow well respectively. In most of groundwater chemical constitutes, known standards have a direct relationship with geological formations. Comparisons of analysis results were made with WHO standard for drinking water it show Appendix 5.

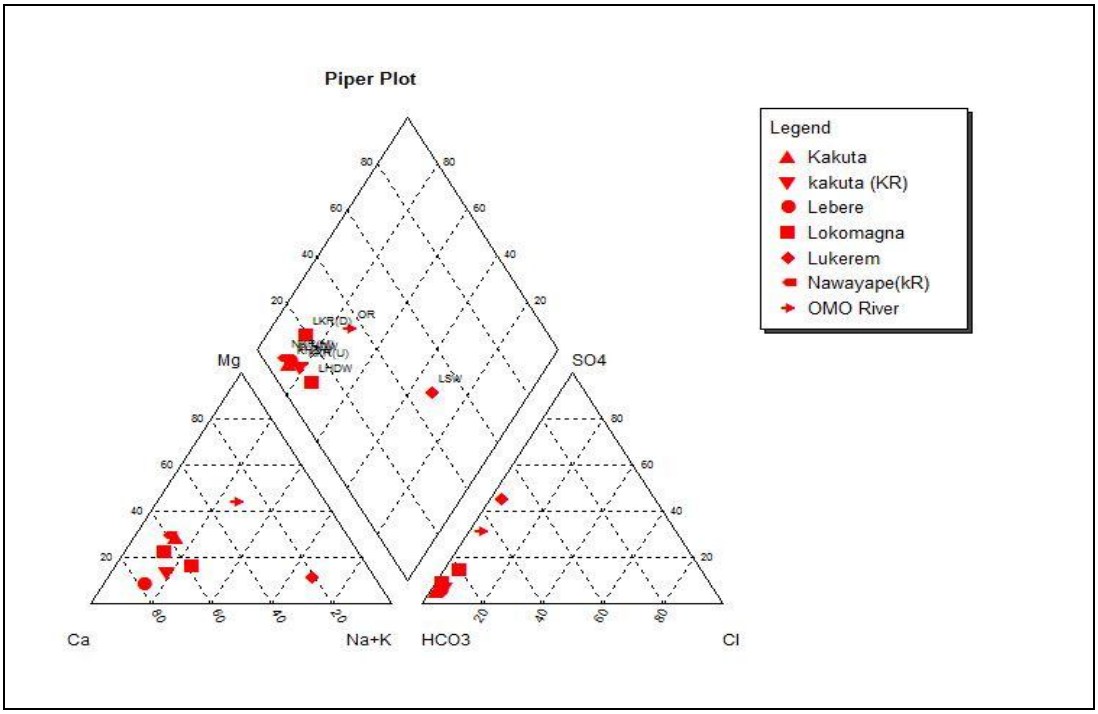


Figure 11: Piper Diagram of Kibish Area of Water Point

Source: Computed from WWDSE data

Table 9: Location and source of water sample collected and analyzed piper result

Sample ID	Sample Date	Water Type	Woreda	Kebele	Y	X	Sample source
LSW	15/03/2019	Ca-Mg-HCO_3	Nyangatom	Lukerem	588989	818457	SW
KHDW	15/03/2019	Ca-HCO_3	Nyangatom	Kakuta	592619	807556	HDW
LHDW	15/03/2019	Ca-Na-HCO_3	Nyangatom	Lebere	585952	815906	HDW
OR	15/03/2019	Ca-Mg-HCO_3	Nyangatom	OMO River kangaten	572971	177396	river
LHDW	15/03/2019	Ca-HCO_3	Nyangatom	Lokomagna	584888	816022	HDW
KKR(U)	15/03/2019	Na-Ca-HCO_3-SO_4	Nyangatom	kakuta (KR)	594457	804906	river
NKR(M)	15/03/2019	Ca-Mg-HCO3	Nyangatom	Nawayape(kR)	58114	817067	river
LKR(D)	15/03/2019	Mg-Ca-HCO_3-SO_4	Nyangatom	Lokomagna	585274	816697	River

* SW (shallow well), HDW (hand dug), RIVER

Source: Computed from WWDSE data

Apart from trilinear/piper diagram, the dominant anion and cations could be easily identified using Ludwing-Langelier plot by which the concentration of a single anion/combination of anions could be compared with a single cation/combination of cations. It is observed that NA^{+}Vs $SO4^{-}$ dominate the ionic composition of the water samples relative to all other possible combinations which is a typical characteristic of surface waters and saline groundwater at shallow depth.

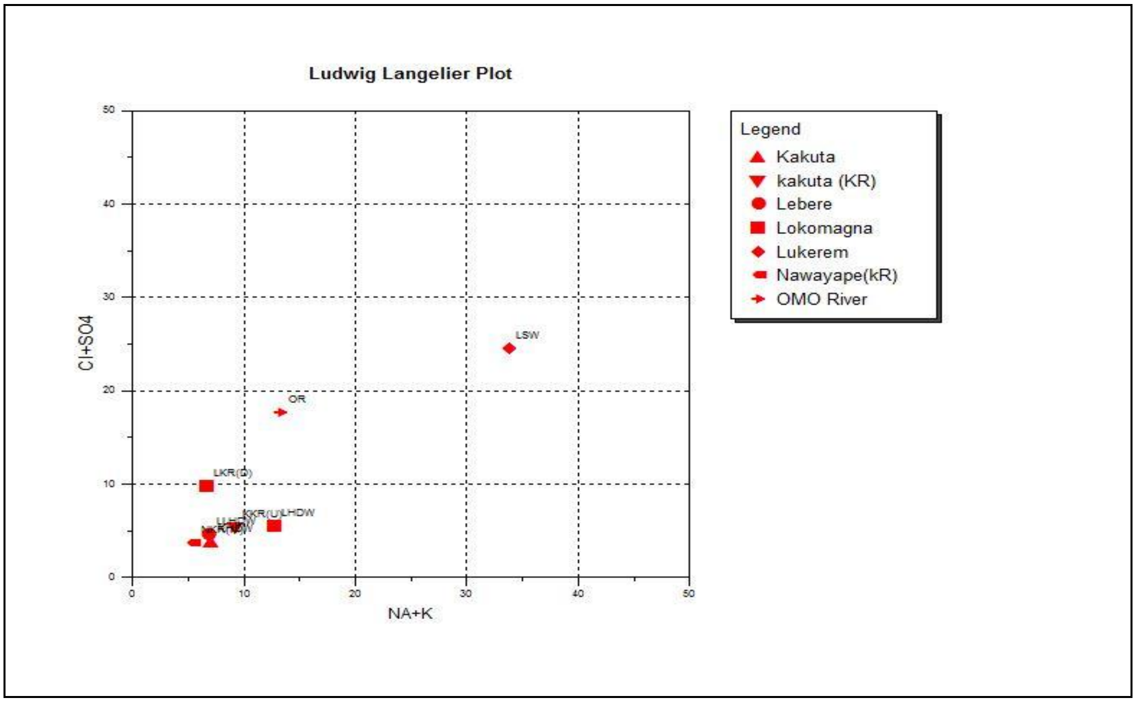


Figure 12: Ludwing-Langelier plots

Source: computed from WWDSE data

4.4.1 Salinity Hazard

A salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. In irrigated areas, these salts often originate from a saline, high water table or from salts in the applied water. Yield reductions occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time. If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought, such as wilting, or a darker, bluish-green color and sometimes thicker, waxier leaves. Symptoms vary with the growth stage, being more noticeable if the salts affect the plant during the early stages of growth. In some cases, mild salt effects may go entirely unnoticed because of a uniform reduction in growth across an entire field.

Salts that contribute to a salinity problem are water soluble and readily transported by water. A portion of the salts that accumulate from prior irrigations can be moved (leached) below the rooting depth if more irrigation water infiltrates the soil than is used by the crop during the crop season. Leaching is the key to controlling a water quality-related salinity problem. Over a period of time, salt removal by leaching must equal or exceed the salt additions from the applied water to prevent salt building up to a damaging concentration. The amount of leaching required is dependent upon the irrigation water quality and the salinity tolerance of the crop grown.

Salt content of the root zone varies with depth. It varies from approximately that of the irrigation water near the soil surface to many times that of the applied water at the bottom of the rooting depth. Salt concentration increases with depth due to plants extracting water but leaving salts behind in a greatly reduced volume of soil water

Electrical conductivity (EC) and Total dissolved solids (TDS)

A measure of the salinity hazard of water is described by its EC and TDS values and groundwater could be classified as fresh, Brackish, Salty and Brines based on these parameters. The table below shows the quality of water in terms of TDS value and it is shown that 8 samples collected from the study kebeles of KEBISH watershed are fresh water as TDS values are below 1000mg/lit for which 1000mg/lit is set as maximum WHO allowable limit. However, two samples collected from shallow and hand dug wells of Nyangatom Woreda (Lokorlem and Lokomagna kebeles) are found to be brackish water.

Similarly, EC values help to classify water quality based on permissibility status for irrigation. According to Table 10 which shows permissible limits for classes of irrigation water, all samples do not have salinity hazard for irrigation as the EC value fall in “Good and permissible” ranges with the exception of one samples which could be grouped as doubtful or unsuitable for irrigation is sample lokorlem shallow well (LSW)

Table 10: Water class based on TDS values

TDS (mg/lit)	**Water type/Quality**
0-1,000	Fresh
1,000-10,000	Brackish
10,000-100,000	Saline
>100,000	Brine

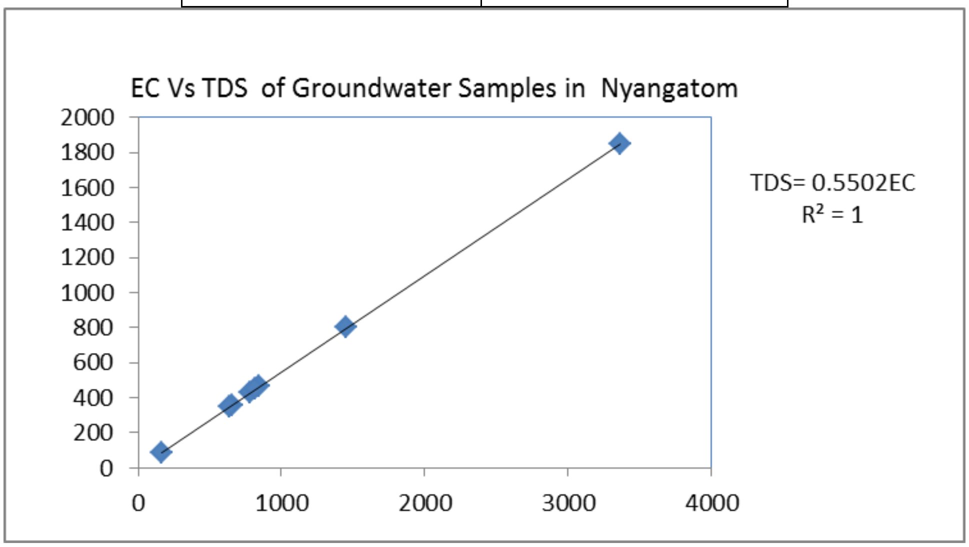


Figure 13: The relationship of EC and TDS Water Samples

Source: computed from WWDSE data

4.4.2 Water Infiltration Rate

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

The two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. Low salinity water or water with high sodium to calcium ratio will decrease infiltration. Both factors may operate at the same time. Secondary problems may also develop if irrigations must be prolonged for an extended period of time to achieve adequate infiltration. These include crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problems.

An infiltration problem related to water quality in most cases occurs in the surface few centimeters of soil and is linked to the structural stability of this surface soil and its low calcium content relative to that of sodium. When a soil is irrigated with high sodium water, a high sodium surface soil develops which weakens soil structure. The surface soil aggregates then disperse to much smaller particles which clog soil pores. The problem may also be caused by an extremely low calcium content of the surface soil. In some cases, water low in salt can cause a similar problem but this is related to the corrosive nature of the low salt water and not to the sodium content of the water or soil. In the case of the low salt water, the water dissolves and leaches most of the soluble minerals, including calcium, from the surface soil.

The suitability of water for irrigation is directly related with the concentration of Na^+ which hinders percolation of water in to the soil by reducing its permeability when it is found at high concentration. Alkali/ Na^+ hazard is expressed by sodium adsorption ration (SAR),which is the ration of the meq/lit concentration of Na^+ to the square root of half of the sum of the concentration of Ca^{2+} and Mg^{2+}. The low alkali and the medium to high salinity hazard of almost all of the samples is also clearly shown in the Wilcox Diagram (Figure 15).Exceptionally high SAR value is computed for sample LSW& LHDW which is collected from Lokorlem and Lokomagna locality of Nyangatom Woreda.

Table 11: SAR limits

SAR values	Sodium hazard	Comments
10-Jan	Low	
18-Oct	Medium	Tolerable with soil treatment with lime
18 - 26	High	Generally unsuitable for continuous use.
> 26	Very High	Generally unsuitable for use.

```
SampleID                    : LHDW
Location                    :  hand dug well
Site                        : lokomagna
Sampling Date               : 3/17/1626

Drinking Water Quality Regulations:
Element    Measured        Recommended    Maximum
---------------------------------------------------
Cond          1454          < 400          < 1250
Na            71            < 20           < 200
K             19            < 10           < 12
Ca            163.76        < 100
Fe            0.06          < .05          < .2
SO4           65.02         < 25           < 250

Irrigation water:
Conductivity =  1454 uS   (group C3: High salinity water)
Sodium Adsorption Ratio (SAR)    : 1.35
Exchangeable sodium ratio (ESR) : 0.30
Magnesium hazard (MH)            : 21.85
```

```
SampleID                    : KHDW
Location                    : KAKUTA
Site                        :
Sampling Date               : 3/17/1626

Drinking Water Quality Regulations:
Element    Measured        Recommended    Maximum
---------------------------------------------------
Cond          845           < 400          < 1250
Na            24.5          < 20           < 200
Mn            0.3           < .02          < .05

Irrigation water:
Conductivity =  845 uS   (group C3: High salinity water)
Sodium Adsorption Ratio (SAR)    : 0.55
Exchangeable sodium ratio (ESR) : 0.14
Magnesium hazard (MH)            : 33.09
```

```
SampleID                    : KKR(U)
Location                    : Kakuta kibish up stream
Site                        :
Sampling Date               : 3/17/1626

Drinking Water Quality Regulations:
Element    Measured        Recommended    Maximum
---------------------------------------------------
Cond          655           < 400          < 1250
Na            20            < 20           < 200

Irrigation water:
Conductivity =  655 uS   (group C2: Medium salinity water)
Sodium Adsorption Ratio (SAR)    : 0.57
Exchangeable sodium ratio (ESR) : 0.19
Magnesium hazard (MH)            : 16.77
```

```
SampleID                    : LSW
Location                    : shall well
Site                        :  lokorlem
Sampling Date               : 3/17/1626

Drinking Water Quality Regulations:
Element    Measured        Recommended    Maximum
---------------------------------------------------
Cond          3360          < 400          < 1250
TDS           1849                         < 1500
Na            520           < 20           < 200
K             12.9          < 10           < 12
Mg            46.99         < 30
Ca            142.4         < 100
Fe            0.31          < .05          < .2
Cl            36.07         < 25
SO4           624.35        < 25           < 250

Irrigation water:
Conductivity =  3360 uS   (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR)    : 9.66
Exchangeable sodium ratio (ESR) : 2.06
Magnesium hazard (MH)            : 35.24
```

Figure 14 : SAR values plot of collected water samples

Source: computed from WWDSE data

4.4.3 Salinity and Sodium Adsorption Ratio

To understand the water quality and functional aspects of groundwater, chemical indices like, Sodium Adsorption Ratio (SAR), and salinity were calculated and plotted on Wilcox diagram (Figure.13) based on the analytical results. It is observed that the quality of groundwater is suitable for drinking and domestic purpose in most water samples. According to the EC and SAR calculation the most dominant classes (C2-S1 and C3-S1) were found. lokorlem shallow well it show represent Sodium hazard high and Very high Salinity Hazard .But remain Sample represented Low sodium hazard and water samples collected from boreholes are categorized as medium and high sodium hazard respectively.

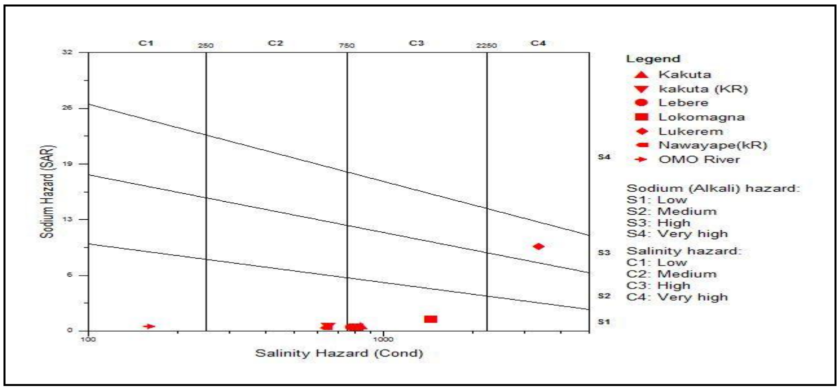


Figure 15 :*Wilcox Diagram*

Source: computed from WWDSE data

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study was tried to assess the drought conditions in Nyagatom woreda. Indices used were able to capture most of the past drought episodes in NyangatomWoreda. SPEI are useful indicators for assessing drought conditions. Spatial analysis of droughts over most parts of Nyagatom woreda has shown that elevation difference parts of the country are more likely to experience severe droughts characteristics include various drought conditions, such as duration, severity and Intensity.

Therefore, Based on the analysis drought is considered to occur when the SPEI value is less than or equal to −1 observed that the occurrence of months in which drought is detected in all severity classes within the range 72-81 and corresponds to about 19-21% of the entire time under analysis and also drought characteristics Results of SPEI time series -1, 3,6,12 and 24 calculation, obtained maximum duration of grid point, SPEI-24 is shown in (Figure .10) ranges between 3-7 years in category short until long duration ,the highest severity recorded at the meteorological grid point occurred SPEI result at 1999-2003 which a peak of drought with index value range -1.38 up to -6.20 (extremely dry) and Highest intensity that occurred in grid cell -1.09 in 2009 to 2012 the highest intensity for SPEI-24 was recorded in meteorology station.

The result of weather datasets indicates analysis that the SPEI Index analysis of Drought with respect to Water Resources Availability and Water Quality in Nyangatom Woreda. SPEI –index analysis result shows high fluctuation towards the negative indicators fluctuated largely towards the positive indicators and also statistically analysis used Non-parametric methods have been developed to detect trends in hydro meteorological time series. Methods such as Man-Kendall Test (MK) and Sen Slope estimator .The main aim of the MK Test is to evaluate if there exists a statistical monotonic upward or downward trend of the variable over time. The Mann-Kendall test was used the results of which are represented in(Table.8) different time scale the result of indication in SPEI –index , In the SPEI-1monthly series, a drying trend occurred insignificant result. However,SPEI-3 monthly series, a drying trend occurred only in March statically significant and SPEI-6 and SPEI-24 monthly series, a drying trend occurred four month in February, March, April and June significant of statically analysis result representation .therefore , the result of February up to June often drought occurrence in this month represented and time series representing longer time scales a decreasing trend is obvious in considerably larger number of months .SPEI –Index analysis the possible reason behind this is the low performance of the model during dry periods. (Figure .10) clearly shows a moderate to highly severe hydrological drought during 1999 -2003 and 2007 in Nyangatom Woreda.

In addition to study area water quality analysis of result which indicate drought characterize the chemical analysis result of the water samples plotted in piper tri-liner diagram result of Kibish Area of Water Point identified that the water types are Ca-MgHCO3, Ca-HCO3, and Na-C & Ca-Mg-HCO3 for Hand dug well, River& shallow well respectively which result indicate the area discharge and also This method is based on the conductivity of water (EC, expressed in microsiemens per centimeter, μS/cm), and the Sodium Absorption Ratio (SAR). The conductivity of water is used as an indicator of the water salinity hazard. The higher the EC, the less water is available to plants, even though the soil may appear wet which is indication drought characteristic the type of Agricultural drought and hydrological drought because impact of plant growth with less water which shows permissible limits for classes of irrigation water, all samples do not have salinity hazard for irrigation as the EC value fall in “Good and permissible” ranges with the exception of one samples which could be grouped as doubtful or unsuitable for irrigation is sample lokorlem shallow well (LSW). The future drought conditions were predicted using the Standardized precipitation evapotranspiration index. The results show significant increases in meteorological drought frequency and severity for most parts of Nyangatom woreda. In most parts of Nyangatom, the increase in the drought intensity, frequency and severity were not significant.

5.2 Recommendation

Based on the finding of the study the researchers recommend the following:

- In this study droughts were analyzed using temperature and precipitation based indices (i.e. SPEI), remotely sensed drought indices such as Normalized Difference Vegetation Index (NDVI), Vegetation Condition (TCI) and Temperature Condition Index (TCI) and can also add value to the comparison.
- Regular follow up of the implementation of environmental management and drought monitoring plans through the involvement of relevant bodies
- Carrying out capacity building training to the woreda water experts is essential to ensure the appropriate implementation of water management
- Coordinated effort should be made by relevant bodies to eradicate and control the spread of Prosopis*juliflora* weed in Kibish area to reduce its effects on livelihoods and biodiversity.
- The woreda administration should create awareness to the people to reduce or stop vegetation clearance using fire that affect the biodiversity of the area.
- As water is an important element keeping the environment unharmed in this semi-dry basin, the monitoring of water resources, water management, and water protection are prerequisites for water accessibility and its rational use.

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APPENDIX 1: Monthly rainfall row data (mm) in around Nyangatom Woreda Source of data EMA.

PRCP(1983-2014)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1983	11.3	23.6	11.9	86.5	156.7	63.7	57.3	133.7	121.4	135.1	54.3	0
1984	0	14.3	39.5	96.1	119.4	1.3	55.6	67.4	99.2	52.6	204.7	59.7
1985	29.1	3.8	86.1	218.1	150.2	95.8	90	2	54.4	51.7	38.5	3.6
1986	0	40.4	144.7	118.3	149.2	108.5	91.2	98.5	44.3	46.5	50.2	68.8
1987	7.3	35.8	131.8	85	159.4	137.7	14.8	6.3	50.7	71.7	94.7	10.2
1988	72.5	27.1	56.2	197.6	101.1	104.6	289	102.7	163.6	67.9	30.7	23.8
1989	18.3	58.2	109.1	132.6	136	21.4	151.5	49.4	154.7	72.5	61.1	139.7
1990	9.3	196.6	149.3	109	138.9	15.5	33.1	79	47.7	73.1	69.6	58.9
1991	103	74.3	119.1	104.2	165.2	107.1	28	77.3	45.7	138.5	29.3	0
1992	14.4	29.3	79	119.7	98.9	100.9	67.1	20.8	98.3	120.5	68	160.5
1993	118.5	46.9	39.5	95.2	153.4	71.8	4.8	8.2	26.3	78.5	56.4	13.5
1994	0	19.2	87.4	155.6	234.2	107.5	85	125	26.3	148.7	217.1	53
1995	0	48.1	134.8	98.6	139.6	99.3	87.6	29.3	126.1	111.4	28.8	68.2
1996	62	70.1	150	130.2	64.6	242.3	159.7	124.2	66.1	42.2	64.3	8.3
1997	0	0	0	254.2	95.2	20.2	86.7	0	14	202	322.7	251.6
1998	124.2	50	67.9	56.4	173.8	107	97	70.7	73.6	137.9	48	5.8
1999	18.9	7.2	77.7	75.4	51.1	8	77.8	93.1	49.7	132.2	52.4	19.4
2000	0	0	36.4	121.5	103.7	30.8	57.7	45.2	61	203.8	90	48.2
2001	49.1	19.6	132.4	203.1	28.9	35.8	63.2	23.5	102.4	114.7	71.2	16.1
2002	95.8	23.7	147.9	127.2	183.5	26.1	0	14.3	18.4	104.5	110	176.4
2003	20.9	23.2	73.1	154.8	189.6	48.7	66.7	195.4	16.7	46.9	84.1	85.7
2004	45.8	43.4	35	105	86.3	7.3	39.5	45.9	95.3	69.1	110.8	33.9
2005	36.6	23.2	114.1	73.8	266.6	76.4	33.1	68	51.5	105.4	51.5	0
2006	26.4	17.6	162.2	110.1	136.2	28.7	17.7	114.5	20.3	97.6	250.1	178
2007	78.7	25.4	88.3	141	117.4	239.4	29.3	86.8	84.2	44.6	83.9	6.6
2008	16.2	24.5	90.9	39.3	55.5	61.5	71.2	73.2	104.6	151.7	58.7	2.3
2009	34.8	13.2	92.2	73.5	102	17	9.5	0	89.2	117.6	23	99.2
2010	50.8	63.2	146.1	135.6	142.8	64.9	35.1	35	49	34.8	16.5	15.7
2011	0	20.6	66.9	92.7	122.2	49	152	173.1	88.9	134.6	317.2	49.6
2012	0	5.1	22.9	125.3	134	89.1	114.5	130.7	144.6	91.2	110.2	72.4
2013	23.1	4.7	85.6	199.6	63	8.6	27.8	24.4	84.7	113.3	102.8	15.3
2014	0	32.4	122.6	50.5	138.7	98.8	31.2	77.1	123.2	191	99.1	13.6

APPENDIX 2: Monthly Maximum Temperature data(^{o}C) around Nyangatom Woreda Source of data EMA.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1983	33.9	35.5	37	36.8	35.9	34.9	31.1	30.9	33.7	33.1	31.3	32.2
1984	34.8	38.2	37.5	32.3	33.7	33.6	33.1	33.9	35.3	32.9	29	29.6
1985	32.7	33.4	33.1	30.3	30.8	30.5	30.6	32.3	34.6	34.8	31.6	32.4
1986	37.1	34.7	31.8	30.8	31	28.4	31.1	33.1	34	33	30.7	30.1
1987	32.9	34.2	32.5	31.7	31.5	30.9	32.2	34.5	36.2	37	33.3	32.6
1988	32.5	35.5	35.8	32.9	33	32.3	32.2	33.3	33.6	34.7	33.5	35
1989	35.6	34.7	35	32	33.1	32.9	31.9	33.4	33	34.5	34	33.4
1990	35.2	33.8	31.6	33.2	34.1	33.3	32.9	35	35.9	33.8	32.6	32.9
1991	30.8	33.4	34.6	31.9	32.1	31.1	31.2	32.2	34.8	32.7	31.4	33.9
1992	36	36.3	35.7	32.8	33	33.6	32.4	34.4	35.6	33.5	33.2	30.9
1993	31.9	32	35.3	34.9	33.5	33.2	33.8	35	36.2	35.9	32.4	33.8
1994	36.8	37	33.8	32.7	33.5	33.5	33.2	34.6	36	31.7	29.9	31.9
1995	35.6	35.5	33.8	32.2	33.2	33.8	33.9	34.5	35.8	32.6	32	31.4
1996	31.9	32.6	31.1	30.9	32	29.8	31.8	32.7	34.6	35.2	32.7	35.9
1997	38.3	38.2	35.8	30.9	32.1	33.2	32.8	34.4	37.6	33.4	30.1	29.8
1998	30.2	34.6	34.1	33.3	31.9	31.3	31.8	32.4	36.3	35.6	32.8	35.1
1999	34.9	38	34.5	32.1	34.8	34.2	32.8	34.7	36.5	36.4	34	33.7
2000	37.5	37.7	36.7	34.3	33.1	33.9	34.3	34.7	37.5	34.8	32.6	33.6
2001	37.1	36.7	34.4	31.4	33.7	33	32.8	34.6	35.7	35.7	31.3	34.9
2002	35.9	37.3	32.6	32.5	32	34.1	34.6	35.2	36.6	31.5	31.8	31.6
2003	33	36.2	34	32.2	30.5	30.5	31.4	31.7	36	34.3	31.8	31.4
2004	33.6	36.6	37.2	31.8	33.6	33.9	34.3	34.3	35.6	34.5	31.9	32.6
2005	35.5	38.4	35.3	33.4	31.2	32.2	32.8	34.6	35.3	36	33.4	36.6
2006	36.4	35.7	34	31.8	31.5	34.3	33.8	33.1	35.1	34.5	30.5	30
2007	33.3	36.9	35.3	33	33.4	30.8	32.7	32.5	33.9	32.5	31.6	35.5
2008	36.1	36.6	34.6	30.3	34.9	34.9	32.9	34.9	34.6	31.6	32.7	35.5
2009	35.6	36.2	36	32.2	32.7	34.6	35.4	36.8	36.3	33	32.7	31.4
2010	34.1	35.1	32.5	32	31.9	33.5	34	35.2	36.3	33.9	33.7	35.4
2011	36.3	37.2	35.1	32.2	32.7	34.5	33.9	33.6	33.9	29.5	30	33.6
2012	35.2	35.6	37.8	32.5	32.2	34.2	31.7	33.8	34	32.5	31	32
2013	34.6	37.6	32.6	31.3	34.5	33.9	35.4	34	34.3	34.7	30.6	34.9
2014	36.5	36.1	34	32.4	33.9	35	34.5	34.6	34.1	31.9	30.8	32.4

APPENDIX 3: Monthly Minimum Temperature data (^oC) around Nyangatom Woreda Source of data EMA.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1983	18.2	19.1	20.5	20.2	20.6	19.4	17.9	17.6	19.1	18.4	17.2	17.1
1984	17.3	19.8	19.1	18.7	19.1	18.9	19.2	17.8	19.1	18.1	16	15.8
1985	17.3	17.8	17.9	17.1	18.1	17.7	17.9	19.3	20	19.1	18.2	17.6
1986	19.5	19.3	19	18.9	18.7	18.4	18.9	19	19.2	18.9	18.1	18.1
1987	17.7	18.2	19.5	19.7	19.6	19.9	19.9	20.8	20.8	21.3	19	17.5
1988	18.5	20.1	20.6	19.5	19.3	19.1	17.9	18	18.2	18.5	17.4	18.5
1989	18.7	18.7	20	18.7	19.9	19.3	17.2	17.5	17.2	18	16.9	18.5
1990	19.5	19.4	17.4	17.5	19	21	19	18	18	17.3	17.3	17.6
1991	17.6	18.4	19.9	18.9	19.4	19.5	18.8	19.2	19.4	18.6	17.2	17
1992	17.9	19.6	20.2	18.9	19.7	19.9	18.6	18.7	18.8	18.3	17.3	18.3
1993	17.9	18.1	20	21.5	20.6	20.6	19.7	19.4	20.5	21.1	17.9	18.5
1994	19.1	20	20.9	19.8	20.3	20.6	20.6	20.4	20.3	19.5	18	17.9
1995	18.3	19.5	20.2	20.3	20.4	20.4	20.1	20.5	20.5	19.6	18.4	17.4
1996	18.3	19.1	19.2	19.1	19.2	18.3	18.7	19.1	19.6	19.8	17.3	18
1997	19.7	19.8	21.1	18.7	19.3	20	18.9	19.7	20.5	19.5	17.9	17.4
1998	17.8	18.9	20	20.8	20.3	19.6	20	19.7	20.3	20.4	17.8	17.7
1999	18.3	20.3	19.8	19.4	20.2	20.3	19.6	20.1	20	20.5	18.1	17.7
2000	19	19.6	21.2	20.6	20.9	20.8	21.1	20.9	21.5	20.6	18.2	17.2
2001	19.1	20.3	20.3	19.8	19.8	19.8	20.7	21	20.7	20.4	17.6	18.3
2002	19.3	19.4	19.4	19.9	19.3	20.1	21	20.2	20.1	19.4	18.5	17.7
2003	17.5	19.3	19.6	19.1	19.1	18.9	19.1	18.8	19.9	19.1	18.1	16.7
2004	18.9	19.7	20.1	18.8	19.8	20.5	19.8	20.6	20.8	19.9	19.1	18.1
2005	18.8	20.7	20	19.8	18.8	19.8	19.7	19.9	20	19.8	17.5	17.8
2006	18.8	19.9	19.5	18.9	19.7	20	20.5	19.6	20.1	20.1	18.1	17.8
2007	18.7	19.4	19.7	19	20.1	19.1	19.3	19.8	19.7	19	17.9	18.1
2008	18.5	19.2	19.7	-99	20.3	20.6	19.5	20.6	20.5	18.7	18.5	18
2009	18.7	20.8	20.5	19.5	19.4	20.8	20.4	20.7	20.8	19	18.4	17.8
2010	18.2	19.3	18.7	19.5	19.6	20.4	20.7	20.1	20.2	20.1	18.6	17.6
2011	18.7	18.9	19.7	19	19.4	20.1	19.8	19.2	19.7	18.2	18.8	18.3
2012	18.3	18.7	20.6	19.2	19.1	20.2	18.9	19.4	19.9	19	18.1	18
2013	19.1	20.6	19.8	18.9	20.8	20.7	21.5	20.6	20.7	20.2	18.6	18.2
2014	18.5	19.2	20.4	20.7	21	21	20.7	20.4	20.5	19.3	18.6	16.2

APPENDIX 4: Point Data SPEI-1, 3,6,12, and SPEI-24 in the years 1983-2014 in Nyangatom Woreda

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1983	Jan	-0.00296				
1983	Feb	0.179684				
1983	Mar	-1.60927	-1.06659			
1983	Apr	-1.7436	-1.87807			
1983	May	-0.22664	-1.8195			
1983	Jun	-0.09837	-1.1248	-1.30465		
1983	July	0.482437	-0.08951	-1.15529		
1983	Aug	1.570535	0.796893	-0.53135		
1983	Sep	1.294817	1.32847	0.459982		
1983	Oct	0.961268	1.877209	1.113462		
1983	Nov	-0.10949	0.846235	0.99429		
1983	Dec	-0.46796	0.094664	0.884366	-0.41916	
1984	Jan	-0.27068	-0.45265	0.761027	-0.44769	-0.46688
1984	Feb	-1.1439	-0.75144	0.035845	-0.53784	-0.46688
1984	Mar	-1.1567	-1.20351	-0.73936	-0.36851	-0.46688
1984	Apr	-0.31331	-1.32346	-1.22584	-0.21695	-0.46688
1984	May	-0.19503	-1.03312	-1.20285	-0.13358	-0.46688
1984	Jun	-1.06569	-0.88922	-1.26403	-0.20614	-0.46688
1984	July	-0.00208	-0.66403	-1.20766	-0.28485	-0.46688
1984	Aug	0.383321	-0.32913	-0.85068	-0.56355	-0.46688
1984	Sep	0.730425	0.411819	-0.2468	-0.65941	-0.46688
1984	Oct	-0.5145	0.250384	-0.38448	-1.02332	-0.46688
1984	Nov	1.581595	1.214934	0.468636	-0.55767	-0.46688
1984	Dec	0.868748	1.106715	0.968486	-0.29756	-0.46688
1985	Jan	0.694805	1.28095	1.144507	-0.1103	-0.39259
1985	Feb	0.390139	0.738187	1.086304	0.136664	-0.33619
1985	Mar	0.427935	0.559151	1.00728	0.543733	0.077026
1985	Apr	1.858621	1.408952	1.580519	1.1167	0.668362
1985	May	0.954054	1.875943	1.393584	1.381867	0.91218
1985	Jun	1.063767	1.82849	1.509809	1.532225	1.081469
1985	July	0.960674	1.240769	1.591729	1.672105	1.243138
1985	Aug	-0.75736	0.583852	1.345949	1.452062	0.754579
1985	Sep	-0.17661	0.089005	1.171548	1.311034	0.465026
1985	Oct	-1.10003	-1.15116	0.292817	1.32967	0.136015
1985	Nov	-0.72593	-1.12753	-0.26809	0.896323	0.024016
1985	Dec	-0.50852	-1.12897	-0.77571	0.532996	0.119717
1986	Jan	-1.51442	-1.16777	-1.43888	0.08422	-0.04305

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1986	Feb	0.669805	-0.56201	-1.03672	0.171593	0.160512
1986	Mar	1.392467	0.40827	-0.48332	0.425493	0.64656
1986	Apr	0.32846	1.103401	-0.19731	-0.10548	0.746417
1986	May	0.834536	1.358976	0.287847	-0.05228	0.964205
1986	Jun	1.268738	1.232494	0.984126	0.111836	1.2963
1986	July	0.830901	1.266755	1.445979	0.113591	1.553162
1986	Aug	0.797104	1.154757	1.493312	0.43004	1.71327
1986	Sep	-0.104	0.6764	1.105812	0.43019	1.56306
1986	Oct	-0.81237	-0.05082	0.889111	0.479464	1.503319
1986	Nov	-0.24315	-0.75397	0.465283	0.544946	0.971873
1986	Dec	0.763381	-0.07109	0.243657	0.885179	0.912411
1987	Jan	0.190863	0.253872	0.06046	1.077871	0.755096
1987	Feb	0.837612	0.655794	-0.00337	1.040015	0.810065
1987	Mar	1.034034	0.82141	0.311271	0.935709	0.932426
1987	Apr	-0.61642	0.599614	0.328086	0.770206	0.517119
1987	May	0.806714	0.692899	0.711629	0.836348	0.55431
1987	Jun	1.259	0.871445	0.986647	0.771771	0.569013
1987	July	-0.73848	0.626311	0.751705	0.504627	0.226845
1987	Aug	-1.34496	-0.21247	0.195517	0.094808	0.091809
1987	Sep	-0.81391	-1.28673	-0.35115	-0.00619	-0.00835
1987	Oct	-1.68186	-1.94601	-0.70598	-0.18868	-0.09246
1987	Nov	0.09066	-1.35107	-0.98439	-0.26369	-0.03065
1987	Dec	-0.38408	-0.98494	-1.5591	-0.64467	0.09062
1988	Jan	1.20142	0.289955	-1.00299	-0.38812	0.408471
1988	Feb	0.02838	0.334034	-0.57371	-0.46079	0.345
1988	Mar	-0.9003	0.015982	-0.64386	-0.84953	0.013863
1988	Apr	1.207298	0.102156	0.085924	-0.58287	0.156219
1988	May	-0.44923	-0.15978	-0.00766	-0.80623	-0.00218
1988	Jun	0.888689	0.843248	0.487197	-0.81021	-0.137
1988	July	2.30292	1.738527	1.334465	0.293715	0.379415
1988	Aug	0.952843	1.843059	1.53362	0.710261	0.380189
1988	Sep	1.875566	2.124963	2.009964	1.103475	0.783412
1988	Oct	-0.6107	1.316883	1.924288	1.293415	0.807437
1988	Nov	-1.25969	0.268177	1.643956	1.360066	0.720766
1988	Dec	-0.74389	-1.17087	1.203398	1.450699	0.4658
1989	Jan	-0.32961	-1.00009	0.089037	0.981112	0.343343
1989	Feb	1.065098	-0.05349	0.03792	1.110296	0.397862
1989	Mar	0.174725	0.323915	-0.55301	1.291664	0.311652
1989	Apr	0.440762	0.734695	-0.36209	1.212044	0.457001
1989	May	0.080123	0.301853	-0.02654	1.33743	0.401144

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1989	Jun	-0.54269	-0.14878	0.06419	0.918587	-0.00084
1989	July	1.515183	0.576058	0.7932	0.550942	0.422148
1989	Aug	0.203712	0.603948	0.601461	0.38273	0.661742
1989	Sep	1.918183	1.525632	1.103794	0.388053	1.198866
1989	Oct	-0.3733	1.05294	0.95754	0.426234	1.396692
1989	Nov	-0.36275	0.644768	0.71708	0.523909	1.471406
1989	Dec	1.167989	0.343521	1.193927	1.095853	1.670193
1990	Jan	-0.66792	0.258255	0.637884	0.943519	1.277177
1990	Feb	2.304271	1.413668	1.291456	1.39312	1.724345
1990	Mar	1.668322	1.860916	1.173133	1.604345	1.970219
1990	Apr	-0.00178	2.102978	1.280023	1.737219	1.890263
1990	May	0.115996	1.010685	1.564264	1.688206	1.979595
1990	Jun	-1.14256	-0.61102	0.97458	1.383272	1.71207
1990	July	-0.34387	-0.70464	1.001099	1.027517	1.131606
1990	Aug	0.374543	-0.49809	0.170626	1.003135	1.016921
1990	Sep	-0.1729	-0.07637	-0.45041	0.604398	0.558438
1990	Oct	-0.10106	-0.02681	-0.56143	0.665542	0.630121
1990	Nov	-0.01119	-0.33326	-0.67471	0.768284	0.823592
1990	Dec	0.410496	0.063015	-0.20873	0.467385	1.011153
1991	Jan	1.719438	0.801565	0.545467	1.046276	1.321432
1991	Feb	1.449723	1.293372	0.782451	0.562561	1.348751
1991	Mar	0.431003	1.628721	0.883208	0.285618	1.357516
1991	Apr	-0.11397	0.862632	0.902661	0.185765	1.331857
1991	May	0.843527	0.592713	1.261757	0.446944	1.487998
1991	Jun	0.988314	0.852732	1.501705	0.85794	1.668128
1991	July	-0.13017	0.66209	0.922283	0.921379	1.484492
1991	Aug	0.580071	0.556482	0.703985	0.912956	1.621187
1991	Sep	-0.27861	0.07633	0.500567	0.871907	1.129299
1991	Oct	1.038636	0.672625	0.795905	1.088078	1.375077
1991	Nov	-0.73488	-0.06042	0.26842	1.149966	1.475942
1991	Dec	-0.75858	-0.16887	-0.25798	0.973333	0.928077
1992	Jan	-0.3289	-0.84038	-0.24666	0.303205	0.886245
1992	Feb	0.009614	-0.53523	-0.43296	0.009457	0.34547
1992	Mar	-0.47784	-0.49717	-0.4926	-0.15989	0.038971
1992	Apr	0.041751	-0.33548	-0.8976	-0.23233	0.030221
1992	May	-0.56031	-0.63449	-0.8527	-0.46828	-0.03245
1992	Jun	0.611174	-0.03656	-0.38052	-0.46558	0.207531
1992	July	0.379441	0.069581	-0.15582	-0.32161	0.281391
1992	Aug	-0.66908	0.06311	-0.32125	-0.52421	0.065747
1992	Sep	0.71507	0.143157	0.028012	-0.32003	0.186213

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1992	Oct	0.682599	0.253767	0.136117	-0.45993	0.30755
1992	Nov	-0.1376	0.409302	0.156471	-0.53333	0.2691
1992	Dec	1.481635	0.93858	0.649466	0.110388	0.688056
1993	Jan	1.759827	1.251224	1.114052	0.675788	0.633492
1993	Feb	1.274509	1.649712	1.418868	0.907057	0.595088
1993	Mar	-0.966	0.987223	1.063643	0.779734	0.407568
1993	Apr	-1.42718	-0.70375	0.668916	0.483384	0.233034
1993	May	0.199353	-1.17695	0.874995	0.732696	0.17926
1993	Jun	0.132723	-0.6364	0.241464	0.588518	-0.03436
1993	July	-1.22397	-0.5343	-0.78343	0.34054	-0.25258
1993	Aug	-1.13927	-1.00848	-1.38909	0.260153	-0.53931
1993	Sep	-1.27609	-1.56529	-1.42804	-0.05028	-0.6491
1993	Oct	-1.22865	-1.84261	-1.37698	-0.42935	-0.90753
1993	Nov	-0.36069	-1.56534	-1.57205	-0.63571	-0.92517
1993	Dec	-0.72542	-1.14693	-1.79056	-1.29392	-0.83425
1994	Jan	-1.28507	-1.0373	-1.78983	-1.64695	-0.90283
1994	Feb	-0.61487	-1.10768	-1.55924	-1.82262	-0.91765
1994	Mar	-0.1365	-0.80676	-1.18716	-1.76552	-0.88483
1994	Apr	0.568991	-0.04767	-0.84427	-1.4805	-0.85765
1994	May	1.534991	1.068986	-0.1842	-1.34751	-0.53996
1994	Jun	0.620494	1.229836	0.281259	-1.11671	-0.53135
1994	July	0.245343	0.919408	0.622696	-0.83571	-0.60926
1994	Aug	0.76482	0.574946	0.945001	-0.34973	-0.41557
1994	Sep	-1.18094	0.0268	0.713636	-0.31106	-0.64301
1994	Oct	1.196869	0.511444	0.896971	0.089613	-0.56829
1994	Nov	1.552298	1.189954	1.063762	0.713378	-0.17974
1994	Dec	0.406332	1.299493	0.961499	0.996578	-0.3712
1995	Jan	-0.70484	0.85883	0.83562	0.992539	-0.74703
1995	Feb	0.642001	0.130621	0.729486	1.110345	-0.8009
1995	Mar	0.77655	0.29843	1.079005	1.249867	-0.53454
1995	Apr	-0.53427	0.394967	0.727769	1.130052	-0.45731
1995	May	0.036994	0.140779	0.009763	0.823353	-0.47294
1995	Jun	0.495635	-0.08231	0.086386	0.736191	-0.40688
1995	July	0.254414	0.188957	0.337142	0.771622	-0.25645
1995	Aug	-0.86858	-0.13331	-0.04073	0.457588	-0.24946
1995	Sep	0.850453	0.06249	-0.05466	0.728341	0.032015
1995	Oct	0.458535	0.099896	0.136355	0.622521	0.272244
1995	Nov	-1.18352	0.030035	-0.21675	-0.19352	0.158209
1995	Dec	0.705177	0.111737	-0.08143	-0.18548	0.498759
1996	Jan	1.152362	0.37929	0.235691	0.195531	0.774599

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1996	Feb	1.410462	1.142301	0.790964	0.417518	1.035762
1996	Mar	1.530999	1.694278	0.950119	0.614607	1.289925
1996	Apr	0.498234	1.569688	0.990186	0.800817	1.320856
1996	May	-0.93034	0.633955	1.124457	0.667794	1.023612
1996	Jun	2.021583	1.467544	1.883349	1.212618	1.429947
1996	July	1.487409	1.762705	1.998043	1.478527	1.851748
1996	Aug	1.167347	2.000009	1.94647	1.64894	2.076222
1996	Sep	0.149513	1.255359	1.601998	1.528095	2.303173
1996	Oct	-1.52796	0.015711	1.351325	1.421455	1.791418
1996	Nov	-0.13309	-0.92756	1.366961	1.817078	1.3547
1996	Dec	-1.2386	-1.42474	0.081081	1.703637	0.991948
1997	Jan	-2.02371	-1.40954	-0.91775	1.000414	0.780001
1997	Feb	-1.69002	-1.99781	-1.62472	0.452274	0.557611
1997	Mar	-1.66257	-2.08949	-2.10332	-0.32485	0.162262
1997	Apr	2.029992	-0.22715	-1.12502	0.059417	0.651653
1997	May	-0.40554	0.04633	-1.15854	0.268352	0.651502
1997	Jun	-0.7747	0.697025	-1.00505	-0.65503	0.413857
1997	July	0.575184	-0.37076	-0.40798	-0.95695	0.441302
1997	Aug	-1.23191	-0.64233	-0.45775	-1.37471	0.345933
1997	Sep	-1.8765	-1.01157	-0.29313	-1.62233	-0.06563
1997	Oct	1.664169	-0.60029	-0.62849	-1.11868	0.176172
1997	Nov	1.955649	1.746521	0.783428	-0.26254	1.286802
1997	Dec	2.002004	2.153926	1.743585	0.987012	1.774521
1998	Jan	1.907742	2.148139	2.015513	1.801343	1.880676
1998	Feb	0.921426	1.921325	2.176755	1.918553	1.686476
1998	Mar	-0.35498	1.241777	2.295894	2.033961	1.356673
1998	Apr	-1.7342	-0.6854	1.989668	1.543356	1.132384
1998	May	0.879193	-0.61738	1.584713	1.748338	1.432498
1998	Jun	0.960947	0.186413	0.877383	1.734569	1.00266
1998	July	0.703382	1.019845	0.373137	1.739282	0.818133
1998	Aug	0.377656	0.78164	0.283665	1.804873	0.623069
1998	Sep	-0.21442	0.391909	0.329256	1.875446	0.547863
1998	Oct	0.24536	0.131038	0.777994	1.832407	0.816498
1998	Nov	-0.63505	-0.45028	0.257318	1.4167	0.78533
1998	Dec	-1.02795	-0.6536	-0.31248	0.284548	0.815044
1999	Jan	-0.05923	-0.80125	-0.53676	-0.35559	0.944209
1999	Feb	-1.53312	-1.01917	-0.91305	-0.61363	0.935548
1999	Mar	-0.22883	-0.67758	-0.87122	-0.55726	1.209445
1999	Apr	-0.83775	-1.06556	-1.27622	-0.5023	0.747227
1999	May	-1.74669	-1.44455	-1.58348	-1.01705	0.594359

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
1999	Jun	-1.38487	-2.02837	-1.5724	-1.34422	0.48022
1999	July	0.347808	-1.26504	-1.47458	-1.46486	0.402341
1999	Aug	0.308348	-0.29933	-1.10128	-1.3557	0.64074
1999	Sep	-0.71367	0.010915	-1.24304	-1.36949	0.796275
1999	Oct	-0.06844	-0.30694	-1.08916	-1.53398	0.433746
1999	Nov	-0.86782	-0.92697	-0.83802	-1.69108	-0.48291
1999	Dec	-0.41683	-0.63173	-0.57501	-1.5931	-0.98361
2000	Jan	-1.48074	-1.16165	-0.97057	-1.61641	-1.33809
2000	Feb	-1.39973	-1.27773	-1.30174	-1.57935	-1.46859
2000	Mar	-1.3837	-1.73999	-1.51341	-1.84354	-1.70641
2000	Apr	-0.5388	-1.64514	-1.78613	-1.73772	-1.65042
2000	May	-0.70763	-1.47241	-1.70789	-1.75269	-1.94711
2000	Jun	-0.87236	-1.17417	-1.71231	-1.61322	-2.02863
2000	July	-0.54844	-1.02932	-1.61666	-1.84708	-2.01856
2000	Aug	-0.69501	-0.95372	-1.53925	-1.89596	-1.97776
2000	Sep	-1.10358	-1.01591	-1.38343	-1.87364	-1.97913
2000	Oct	1.393221	-0.16377	-0.85726	-1.70519	-1.90992
2000	Nov	0.226978	0.236104	-0.67161	-1.67468	-1.84347
2000	Dec	0.210794	0.649183	-0.33392	-1.5586	-1.81774
2001	Jan	-0.06284	0.060426	-0.14473	-1.32952	-1.78561
2001	Feb	-0.60193	-0.16719	-0.04856	-1.21815	-1.75955
2001	Mar	0.619538	0.013637	0.363298	-0.80141	-1.83024
2001	Apr	1.404091	0.901794	0.367446	-0.49011	-1.64392
2001	May	-1.84423	0.107563	-0.20963	-0.70944	-1.77329
2001	Jun	-0.35747	-0.50586	-0.33667	-0.48954	-1.58545
2001	July	-0.07279	-1.17833	-0.32523	-0.36625	-1.58349
2001	Aug	-1.09346	-0.74627	-0.49855	-0.38519	-1.63451
2001	Sep	0.41496	-0.38567	-0.60283	-0.11903	-1.5293
2001	Oct	-0.24638	-0.64592	-1.18679	-0.51297	-1.54855
2001	Nov	0.155363	-0.03183	-0.68257	-0.70192	-1.49651
2001	Dec	-0.86157	-0.47821	-0.75213	-0.9696	-1.51463
2002	Jan	0.990434	0.05899	-0.40236	-0.72609	-1.3132
2002	Feb	-0.37742	-0.06985	-0.14401	-0.63588	-1.24536
2002	Mar	1.283213	0.902021	0.140488	-0.45909	-0.92747
2002	Apr	0.067042	0.582327	0.178698	-0.84437	-0.89963
2002	May	1.157724	1.354667	0.569517	-0.15803	-0.64254
2002	Jun	-0.8638	0.124751	0.604251	-0.14798	-0.62799
2002	July	-1.80375	-0.68569	-0.16306	-0.43489	-0.82409
2002	Aug	-1.22069	-1.61208	-0.41783	-0.39668	-0.8899
2002	Sep	-1.44644	-1.89291	-1.22016	-0.67041	-0.91539

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
2002	Oct	0.539428	-1.18146	-1.1274	-0.60545	-1.03185
2002	Nov	0.575054	-0.21381	-1.34299	-0.6742	-1.02808
2002	Dec	1.574252	1.153796	-0.31726	0.036444	-0.63853
2003	Jan	0.478137	1.087797	0.314976	-0.11484	-0.58368
2003	Feb	-0.05073	1.053674	0.603448	-0.02294	-0.50611
2003	Mar	-0.19011	-0.02156	0.80044	-0.32076	-0.60103
2003	Apr	0.729603	0.200171	0.868957	-0.28537	-0.76193
2003	May	1.449963	1.06999	1.241197	-0.13032	-0.22031
2003	Jun	0.380821	1.13553	0.672219	0.19595	-0.11598
2003	July	0.438914	0.845498	0.694165	0.629736	-0.08999
2003	Aug	1.972533	1.1721	1.387181	1.207116	0.543765
2003	Sep	-1.2963	0.845472	1.158731	1.184617	0.273405
2003	Oct	-1.0987	0.37984	0.771752	1.054362	0.147998
2003	Nov	0.246467	-1.19187	0.267109	1.132059	0.134434
2003	Dec	0.9511	0.156704	0.518218	0.860829	0.562309
2004	Jan	0.616498	0.644437	0.589704	0.810255	0.430902
2004	Feb	0.266752	0.727331	-0.16214	0.820547	0.508106
2004	Mar	-1.31477	-0.54305	-0.30576	0.539859	0.109127
2004	Apr	-0.06481	-0.88328	-0.12059	0.313396	0.078295
2004	May	-0.91126	-1.34448	-0.42394	-0.15775	-0.22011
2004	Jun	-1.37669	-1.25509	-1.08171	-0.37914	-0.29057
2004	July	-0.63561	-1.28624	-1.39865	-0.58317	-0.19985
2004	Aug	-0.54301	-1.0795	-1.53576	-1.19179	-0.13173
2004	Sep	0.278258	-0.44276	-1.07002	-0.88515	0.085799
2004	Oct	-0.83646	-0.69549	-1.28066	-0.93366	-0.1128
2004	Nov	0.512392	-0.14046	-0.96345	-1.04852	-0.17317
2004	Dec	-0.01805	-0.16633	-0.60105	-1.32164	-0.47131
2005	Jan	0.100304	0.153141	-0.35665	-1.31043	-0.52751
2005	Feb	-1.2624	-0.39912	-0.40185	-1.39631	-0.58093
2005	Mar	0.205761	-0.31558	-0.38856	-1.11707	-0.49999
2005	Apr	-1.1947	-0.90884	-0.57144	-1.30409	-0.78423
2005	May	2.294369	1.064168	0.197938	-0.65183	-0.5996
2005	Jun	0.466813	1.00341	0.404335	-0.1817	-0.57337
2005	July	-0.45113	1.02992	0.260553	-0.11005	-0.75496
2005	Aug	-0.06654	-0.11718	0.462473	0.018311	-1.10626
2005	Sep	-0.39312	-0.4133	0.294662	-0.07937	-1.01527
2005	Oct	-0.37368	-0.53375	0.445298	-0.04126	-0.95311
2005	Nov	-0.60553	-0.83311	-0.66471	-0.40149	-1.07327
2005	Dec	-1.62437	-1.17786	-1.12821	-0.75097	-1.26706
2006	Jan	-0.35532	-1.13645	-1.08064	-0.77569	-1.32583

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
2006	Feb	-0.23579	-0.96758	-1.09624	-0.60522	-1.34426
2006	Mar	1.28691	0.380353	-0.52268	-0.33574	-1.06865
2006	Apr	0.01988	0.605268	-0.5141	-0.22102	-1.10436
2006	May	0.390219	0.9159	-0.2052	-0.70146	-0.97589
2006	Jun	-0.82681	-0.32641	-0.00163	-0.82222	-0.8835
2006	July	-1.12387	-0.78593	-0.22202	-0.94053	-0.9711
2006	Aug	0.938949	-0.40231	0.184005	-0.61267	-0.76919
2006	Sep	-1.05814	-0.40537	-0.51431	-0.68162	-0.89763
2006	Oct	-0.27262	-0.13156	-0.67203	-0.74636	-0.84698
2006	Nov	1.680591	0.873563	0.1423	-0.07195	-0.54065
2006	Dec	1.645864	1.566838	1.081234	0.904094	0.021072
2007	Jan	1.171331	1.717294	1.53488	1.17186	0.160586
2007	Feb	-0.2081	1.282113	1.282514	1.091141	0.270615
2007	Mar	-0.17309	0.336421	1.370896	0.759506	0.264891
2007	Apr	0.392387	-0.03843	1.534898	0.834189	0.476931
2007	May	-0.36117	-0.17031	0.904773	0.746375	0.01181
2007	Jun	1.945515	1.518512	1.155892	1.404248	0.494229
2007	July	-0.43406	1.033941	0.7145	1.487937	0.467186
2007	Aug	0.599777	1.226376	0.918297	1.356048	0.563615
2007	Sep	0.604411	0.29302	1.060051	1.474415	0.703881
2007	Oct	-0.77761	0.194172	0.821215	1.518886	0.6367
2007	Nov	0.292091	-0.0923	0.857688	1.291149	0.818301
2007	Dec	-1.20598	-0.7677	-0.44736	0.43832	0.86205
2008	Jan	-0.45919	-0.59471	-0.3826	0.018259	0.773177
2008	Feb	-0.09455	-0.80457	-0.59767	0.074384	0.779227
2008	Mar	-0.01026	-0.31828	-0.72558	0.145088	0.607735
2008	Apr	0.797149	0.328748	-0.38597	0.153199	0.736423
2008	May	-1.71349	-0.60932	-0.97981	-0.08127	0.468062
2008	Jun	-0.38349	-0.86531	-0.73905	-0.83756	0.482459
2008	July	0.243618	-0.98868	-0.5414	-0.68339	0.671885
2008	Aug	-0.16346	-0.23185	-0.52612	-0.76745	0.426648
2008	Sep	0.702335	0.277485	-0.33723	-0.70702	0.679962
2008	Oct	1.33778	0.908705	-0.23103	-0.36213	0.978792
2008	Nov	-0.48157	0.635923	0.091147	-0.67522	0.284351
2008	Dec	-1.29857	-0.08581	-0.06362	-0.7692	-0.27235
2009	Jan	0.060577	-0.7906	-0.07444	-0.65386	-0.45584
2009	Feb	-0.81379	-0.85764	-0.16622	-0.66745	-0.46754
2009	Mar	-0.37411	-0.534	-0.4617	-0.71883	-0.4688
2009	Apr	-0.91468	-0.99697	-1.2323	-1.07278	-0.66995
2009	May	-0.39763	-0.91059	-1.18086	-0.83561	-0.68482

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
2009	Jun	-1.39392	-1.37609	-1.14268	-0.85766	-1.32254
2009	July	-1.64395	-1.42727	-1.55311	-1.21618	-1.42118
2009	Aug	-1.89282	-1.99048	-1.85389	-1.43894	-1.59324
2009	Sep	-0.00192	-1.59799	-1.84225	-1.49595	-1.60727
2009	Oct	0.601755	-0.87377	-1.4519	-1.77205	-1.51827
2009	Nov	-1.63833	-0.44705	-1.67986	-1.96834	-1.62248
2009	Dec	1.003422	0.28647	-1.00769	-1.56827	-1.42938
2010	Jan	0.731702	0.299534	-0.33499	-1.38413	-1.31336
2010	Feb	1.005672	0.996811	0.446141	-1.12859	-1.20571
2010	Mar	1.362352	1.258472	0.774819	-0.78084	-1.08041
2010	Apr	0.373755	1.247459	0.737434	-0.65072	-1.18251
2010	May	0.460419	1.170852	1.238617	-0.43925	-0.92657
2010	Jun	-0.00405	0.268596	0.93307	-0.08699	-0.84366
2010	July	-0.85051	-0.34322	0.523847	0.089571	-1.01348
2010	Aug	-0.82289	-0.80054	0.053189	0.308566	-1.0743
2010	Sep	-0.72915	-1.0584	-0.59651	0.199478	-1.1897
2010	Oct	-1.47196	-1.58073	-1.12459	-0.17345	-1.441
2010	Nov	-2.64757	-2.01243	-1.64119	-0.38178	-1.52707
2010	Dec	-0.82569	-2.03717	-1.84841	-0.90552	-1.49109
2011	Jan	-1.01078	-1.62155	-1.90035	-1.08884	-1.52967
2011	Feb	-0.29059	-0.93574	-1.71071	-1.20164	-1.49914
2011	Mar	-0.48396	-0.82114	-1.5543	-1.5463	-1.61923
2011	Apr	-0.41894	-0.67341	-1.45622	-1.61597	-1.62444
2011	May	-0.01824	-0.58012	-1.02836	-1.84182	-1.69371
2011	Jun	-0.4477	-0.58399	-0.88126	-1.85338	-1.51857
2011	July	1.13669	0.266693	-0.20128	-1.48671	-1.16943
2011	Aug	1.5955	1.001196	0.506507	-0.78422	-0.67759
2011	Sep	0.686857	1.397242	0.792971	-0.5032	-0.59334
2011	Oct	1.373523	1.830957	1.289328	-0.01973	-0.4725
2011	Nov	1.920986	2.080924	2.051457	1.155073	0.402868
2011	Dec	0.078301	1.570238	1.955946	1.451688	0.252308
2012	Jan	-0.60133	1.174617	1.679251	1.400031	0.033276
2012	Feb	-0.24692	-0.33092	1.256198	1.287472	-0.08932
2012	Mar	-1.60731	-1.39214	0.672173	0.961906	-0.55629
2012	Apr	0.150095	-1.205	0.324058	1.113232	-0.62248
2012	May	0.334418	-0.91541	-0.90722	1.220581	-0.64722
2012	Jun	0.315509	0.270079	-0.77047	1.196837	-0.58282
2012	July	1.044404	0.655077	-0.21398	1.191126	-0.32475
2012	Aug	1.085544	0.933682	0.252839	1.015226	-0.03043
2012	Sep	1.45883	1.388246	1.152961	1.108586	0.31988

Gird-1						
Year	Month	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
2012	Oct	0.193619	1.395689	1.224425	0.982946	0.565055
2012	Nov	0.688425	0.985725	1.188905	0.311108	1.023028
2012	Dec	0.64406	0.586719	1.220145	0.434125	1.234891
2013	Jan	-0.07212	0.47923	0.972765	0.469884	1.24588
2013	Feb	-1.5886	-0.14321	0.44388	0.321248	1.102305
2013	Mar	0.209381	-0.45996	0.067555	0.800622	1.205502
2013	Apr	1.459013	0.496995	0.446704	1.158022	1.51567
2013	May	-1.61725	0.065052	-0.21812	0.781025	1.35868
2013	Jun	-1.39582	-0.74483	-0.75556	0.462447	1.21536
2013	July	-1.5202	-1.84623	-1.12642	-0.0287	0.818829
2013	Aug	-0.88111	-1.53842	-1.07414	-0.41845	0.275349
2013	Sep	0.358662	-0.91851	-1.08393	-0.63469	0.203068
2013	Oct	-0.0113	-0.44074	-1.55004	-0.75154	-0.04672
2013	Nov	0.590127	0.309447	-1.0245	-0.96165	-0.66582
2013	Dec	-0.85825	-0.1217	-0.87169	-1.28623	-0.66721
2014	Jan	-1.01078	-0.46365	-0.64903	-1.30438	-0.70351
2014	Feb	0.235621	-0.74362	-0.32278	-1.09093	-0.62981
2014	Mar	0.507023	-0.10871	-0.24561	-1.03476	-0.24111
2014	Apr	-1.65889	-0.47147	-0.75444	-1.53596	-0.50165
2014	May	-0.23196	-0.67893	-0.98882	-1.43372	-0.58273
2014	Jun	0.202446	-0.92577	-0.64928	-1.0635	-0.59198
2014	July	-1.04133	-0.61272	-0.7126	-0.98571	-0.94892
2014	Aug	0.000945	-0.43497	-0.71162	-0.71249	-1.0874
2014	Sep	1.079281	0.013114	-0.56726	-0.52717	-1.12664
2014	Oct	1.710143	1.411134	0.401381	-0.18921	-0.93533
2014	Nov	0.523071	1.349548	0.517595	-0.35314	-1.006
2014	Dec	-0.08942	0.808084	0.447865	-0.29657	-1.02524

APPENDIX 5: Laboratory Testing Water quality data

Company Name:

Ethiopian Construction Design & Supervision Works Corporation
Research, Laboratory & Training Center
Laboratory Testing Process

Tel 0116 - 61 45 01 / 0116 - 61 01 05 ; Fax. 251 - 116 - 61 53 71/61 08 98; e-mail w.w.d.s.e@ethionet.et ; P.O.Box 2561

Title: Water Quality Testing Report	Document No: OF/RLTC/605	Issue No. 1	Page No. 1 of 1

Lab No.:- 1114/2011 — Client Ref: - Lab./06/Wq/47/19
Client/Project: Kibish Integration Water Resource Development — Date of Collection: - 11/2/2019
Client ID:- LSW, Lukerem Shallow Well — Source of Sample:- Shallow Well
Location:- Nyangatom woreda, Lukerlem village near school kebele Gps Location X-0818457, Y-0588989 & Z-435 m — Date of Received:- 6/3/2019
Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	25.00	True Color as Pt-Co	
2	pH	7.10	Potentiometric	**6.5-8.5**
3	Electrical Conductivity (µS/cm)	3360.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	1858.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	1849.00	Potentiometric	**1000.0**
6	Turbidity (NTU)	5.00	Turibidimetric	**5.0**
7	Sodium (mg/L Na^+)	520.00	Flame photometric	**200.0**
8	Potassium (mg/L K^+)	12.90	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & $Fe^{3+)}$	0.31	1,10-Phenothroline	**0.3**
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	**0.1**
11	Ammonia (mg/L NH_3-N)	0.14	Nessler	
12	Total Hardness (mg/L Ca CO_3)	551.80	Titrimetric	**500.0**
13	Calcium (mg/L $Ca^{2+)}$	142.40	Titrimetric	**200.0**
14	Magnesium (mg/L $Mg^{2+)}$	46.99	Titrimetric	**150.0**
15	Alkalinity (mg/L $CaCO_3$)	730.80	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	891.58	Titrimetric	
18	Chloride (mg/L Cl^-)	36.07	Mohr Argentometric	**250.0**
19	Sulphate (mg/L SO^{2-}_4)	624.35	Turibidimetric	**400.0**
20	Fluoride (mg/L F^-)	0.45	Ion-Selective Electrode	**1.5**
21	Phosphate (mg/L PO_4^{3-}-P)	0.18	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	**0.2**
23	Barium (mg/L)	Trace	Turibidimetric	**0.7**
24	Copper(mg/L Cu)	0.01	Bicinchoninate	**1.5**
25	Chromium(mg/L Cr^{+6})	0.01	1,5-Diphenylcarbonohydrazide	**0.05**
26	Boron(mg/L B)	0.40	Curcumin	**0.3**
27	Zinc (mg/L)	0.01	Zincon	**15**
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	–
29	Nickel (mg/L)	Trace	Heptoxime	–

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by ______ Lab Expert — Checked by ______ Senior Water Quality Expert — Approved by ______ Water Quality S/P Manager

Among the major services rendered by the Water Quality Laboratory Testing S/Process of Ethiopian Construction Design & Supervision Works Corporation are: Testing all the Physico-Chemical and Bacteriological analysis of potable or drinking water/ Bottled drinking water/, waste water, water for construction and irrigation uses and sampling of water and waste water.

Central Laboratory E.C.D.S.W.Co. Research, Laboratory & Training Center

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Lab No.:- 1115/2011 Client Ref: - Lab./06/Wq/47/19

Client/Project: Kibish Integration Water Resource Development Date of Collection: - 14/02/2019

Client ID:- Kakuta, Hand Dug Well Source of Sample:- HDW

Location:- South Omo zone, Kakuta kebele, Nyangatom woreda Date of Received:- 6/3/2019

Gps Location X-0807556, Y-0592619 & Z-438 m

Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	Trace	True Color as Pt-Co	
2	pH	7.15	Potentiometric	**6.5-8.5**
3	Electrical Conductivity (μS/cm)	845.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	474.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	464.00	Potentiometric	**1000.0**
6	Turbidity (NTU)	2.00	Turibidimetric	**5.0**
7	Sodium (mg/L Na^+)	24.50	Flame photometric	**200.0**
8	Potassium (mg/L K^+)	6.50	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & $Fe^{3+)}$)	0.04	1,10-Phenothroline	**0.3**
10	Manganese (mg/L Mn)	0.30	Periodate oxidation	**0.1**
11	Ammonia (mg/L NH_3-N)	0.14	Nessler	
12	Total Hardness (mg/L Ca CO_3)	373.80	Titrimetric	**500.0**
13	Calcium (mg/L $Ca^{2+)}$)	99.68	Titrimetric	**200.0**
14	Magnesium (mg/L $Mg^{2+)}$)	29.90	Titrimetric	**150.0**
15	Alkalinity (mg/L $CaCO_3$)	420.00	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	512.40	Titrimetric	
18	Chloride (mg/L Cl^-)	7.21	Mohr Argentometric	**250.0**
19	Sulphate (mg/L SO^{2-}_4)	22.94	Turibidimetric	**400.0**
20	Fluoride (mg/L F^-)	0.33	Ion-Selective Electrode	**1.5**
21	Phosphate (mg/L PO_4^{3-}-P)	0.55	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	**0.2**
23	Barium (mg/L)	Trace	Turibidimetric	**0.7**
24	Copper(mg/L Cu)	Trace	Bicinchoninate	**1.5**
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	**0.05**
26	Boron(mg/L B)	0.30	Curcumin	**0.3**
27	Zinc (mg/L)	Trace	Zincon	**15**
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	**_**
29	Nickel (mg/L)	Trace	Heptoxime	**_**

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by________ Checked by ________ Approved by ________

Lab Expert Senior Water Quality Expert Water Quality S/P Manager

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Lab No.:- 1116/2011 Client Ref: - Lab./06/Wq/47/19
Client/Project: Kibish Integration Water Resource Development Date of Collection: - 9/2/2019
Client ID:- Hand Dug Well, HDW Source of Sample:- HDW
Location:- South Omo zone, Lebere kebele, Nyangatom woreda Date of Received:- 6/3/2019
Gps Location X-0815906, Y-0585952
Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	61.00	True Color as Pt-Co	
2	pH	7.01	Potentiometric	6.5-8.5
3	Electrical Conductivity (µS/cm)	780.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	1086.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	429.00	Potentiometric	1000.0
6	Turbidity (NTU)	590.00	Turibidimetric	5.0
7	Sodium (mg/L Na^+)	18.00	Flame photometric	200.0
8	Potassium (mg/L K^+)	10.80	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & $Fe^{3+)}$	0.06	1,10-Phenothroline	0.3
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	0.1
11	Ammonia (mg/L NH_3-N)	0.23	Nessler	
12	Total Hardness (mg/L Ca CO_3)	331.08	Titrimetric	500.0
13	Calcium (mg/L $Ca^{2+)}$	119.62	Titrimetric	200.0
14	Magnesium (mg/L $Mg^{2+)}$	7.69	Titrimetric	150.0
15	Alkalinity (mg/L $CaCO_3$)	394.80	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	481.66	Titrimetric	
18	Chloride (mg/L Cl^-)	10.82	Mohr Argentometric	250.0
19	Sulphate (mg/L SO^{2-}_4)	23.93	Turibidimetric	400.0
20	Fluoride (mg/L F^-)	0.25	Ion-Selective Electrode	1.5
21	Phosphate (mg/L PO_4^{3-}-P)	0.63	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	0.2
23	Barium (mg/L)	Trace	Turibidimetric	0.7
24	Copper(mg/L Cu)	0.01	Bicinchoninate	1.5
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	0.05
26	Boron(mg/L B)	0.20	Curcumin	0.3
27	Zinc (mg/L)	Trace	Zincon	15
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	_
29	Nickel (mg/L)	Trace	Heptoxime	_

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by______ Checked by______ Approved by ______
Lab Expert Senior Water Quality Expert Water Quality S/P Manager

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Lab No.:- 1117/2011 — Client Ref: - Lab./06/Wq/47/19
Client/Project: Kibish Integration Water Resource Development — Date of Collection: - 14/02/2019
Client ID:- Omo river — Source of Sample:- River
Location:- South Omo zone, Kangaton kebele, Nyangatom woreda — Date of Received:- 6/3/2019
Gps Location X-0177396, Y-0572971 & Z-362m
Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	870.00	True Color as Pt-Co	
2	pH	7.23	Potentiometric	**6.5-8.5**
3	Electrical Conductivity (µS/cm)	161.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	400.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	88.60	Potentiometric	**1000.0**
6	Turbidity (NTU)	303.00	Turibidimetric	**5.0**
7	Sodium (mg/L Na^{+})	9.30	Flame photometric	**200.0**
8	Potassium (mg/L K^{+})	4.30	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & Fe^{3+})	2.20	1,10-Phenothroline	**0.3**
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	**0.1**
11	Ammonia (mg/L NH_3-N)	1.53	Nessler	
12	Total Hardness (mg/L Ca CO_3)	71.20	Titrimetric	**500.0**
13	Calcium (mg/L Ca^{2+})	11.39	Titrimetric	**200.0**
14	Magnesium (mg/L Mg^{2+})	10.25	Titrimetric	**150.0**
15	Alkalinity (mg/L $CaCO_3$)	73.50	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^{-})	89.67	Titrimetric	
18	Chloride (mg/L Cl^{-})	3.61	Mohr Argentometric	**250.0**
19	Sulphate (mg/L SO_4^{2-})	34.18	Turibidimetric	**400.0**
20	Fluoride (mg/L F^{-})	0.33	Ion-Selective Electrode	**1.5**
21	Phosphate (mg/L PO_4^{3-}-P)	0.25	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	0.03	Aluminion	**0.2**
23	Barium (mg/L)	Trace	Turibidimetric	**0.7**
24	Copper(mg/L Cu)	Trace	Bicinchoninate	**1.5**
25	Chromium(mg/L Cr^{+6})	0.01	1,5-Diphenylcarbonohydrazide	**0.05**
26	Boron(mg/L B)	0.10	Curcumin	**0.3**
27	Zinc (mg/L)	Trace	Zincon	**15**
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	_
29	Nickel (mg/L)	Trace	Heptoxime	_

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by________ Checked by________ Approved by ________
Lab Expert — Senior Water Quality Expert — Water Quality S/P Manager

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Lab No.:- 1118/2011 Client Ref: - Lab./06/Wq/47/19
Client/Project: Kibish Integration Water Resource Development Date of Collection: - 8/2/2019
Client ID:- LHDW Source of Sample:- HDW
Location:- South Omo zone, Kangaton kebele, Nyangatom woreda Date of Received:- 6/3/2019
Gps Location X-0816022, Y-0584888 & Z-417m
Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	Trace	True Color as Pt-Co	
2	pH	7.10	Potentiometric	6.5-8.5
3	Electrical Conductivity (µS/cm)	1454.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	884.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	800.00	Potentiometric	1000.0
6	Turbidity (NTU)	76.00	Turibidimetric	5.0
7	Sodium (mg/L Na^+)	71.00	Flame photometric	200.0
8	Potassium (mg/L K^+)	19.00	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & Fe^{3+})	0.06	1,10-Phenothroline	0.3
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	0.1
11	Ammonia (mg/L NH_3-N)	0.21	Nessler	
12	Total Hardness (mg/L Ca CO_3)	525.10	Titrimetric	500.0
13	Calcium (mg/L Ca^{2+})	163.76	Titrimetric	200.0
14	Magnesium (mg/L Mg^{2+})	27.77	Titrimetric	150.0
15	Alkalinity (mg/L $CaCO_3$)	672.00	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	819.84	Titrimetric	
18	Chloride (mg/L Cl^-)	10.82	Mohr Argentometric	250.0
19	Sulphate (mg/L SO^{2-}_4)	65.02	Turibidimetric	400.0
20	Fluoride (mg/L F^-)	0.22	Ion-Selective Electrode	1.5
21	Phosphate (mg/L PO_4^{3-}-P)	0.31	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	0.2
23	Barium (mg/L)	Trace	Turibidimetric	0.7
24	Copper(mg/L Cu)	0.01	Bicinchoninate	1.5
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	0.05
26	Boron(mg/L B)	0.20	Curcumin	0.3
27	Zinc (mg/L)	Trace	Zincon	15
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	_
29	Nickel (mg/L)	Trace	Heptoxime	_

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by________ Checked by________ Approved by________
Lab Expert Senior Water Quality Expert Water Quality S/P Manager

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Lab No.:- 1119/2011 Client Ref: - Lab./06/Wq/47/19
Client/Project: Kibish Integration Water Resource Development Date of Collection: - 17/02/2019
Client ID:- Kibish River Source of Sample:- River
Location:- South Omo zone, Kangaton kebele, Nyangatom woreda Date of Received:- 6/3/2019
Gps Location X-0804906, Y-0594457 & Z-443m
Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	Trace	True Color as Pt-Co	
2	pH	7.21	Potentiometric	**6.5-8.5**
3	Electrical Conductivity (µS/cm)	655.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	880.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	360.00	Potentiometric	**1000.0**
6	Turbidity (NTU)	510.00	Turibidimetric	**5.0**
7	Sodium (mg/L Na^+)	20.00	Flame photometric	**200.0**
8	Potassium (mg/L K^+)	7.10	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & Fe^{3+})	0.04	1,10-Phenothroline	**0.3**
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	**0.1**
11	Ammonia (mg/L NH_3-N)	0.27	Nessler	
12	Total Hardness (mg/L Ca CO_3)	231.40	Titrimetric	**500.0**
13	Calcium (mg/L Ca^{2+})	76.90	Titrimetric	**200.0**
14	Magnesium (mg/L Mg^{2+})	9.40	Titrimetric	**150.0**
15	Alkalinity (mg/L $CaCO_3$)	268.80	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	327.94	Titrimetric	
18	Chloride (mg/L Cl^-)	9.02	Mohr Argentometric	**250.0**
19	Sulphate (mg/L SO^{2-}_4)	19.07	Turibidimetric	**400.0**
20	Fluoride (mg/L F^-)	0.20	Ion-Selective Electrode	**1.5**
21	Phosphate (mg/L PO_4^{3-}-P)	0.60	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	**0.2**
23	Barium (mg/L)	Trace	Turibidimetric	**0.7**
24	Copper(mg/L Cu)	Trace	Bicinchoninate	**1.5**
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	**0.05**
26	Boron(mg/L B)	0.20	Curcumin	**0.3**
27	Zinc (mg/L)	Trace	Zincon	**15**
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	—
29	Nickel (mg/L)	Trace	Heptoxime	—

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by______ Checked by______ Approved by ______
Lab Expert Senior Water Quality Expert Water Quality S/P Manager

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Research Laboratory E.C.D.S.W.C. Central Laboratory

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Lab No.:- 1120/2011 | Client Ref: - Lab./06/Wq/47/19

Client/Project: Kibish Integration Water Resource Development | Date of Collection: - 8/2/2019

Client ID:- Nawayape Kibish River, NKR | Source of Sample:- River

Location:- South Omo zone, Nawayape kebele, Nyangatom woreda | Date of Received:- 6/3/2019

Gps Location X-0817067, Y-0586114 & Z-419m

Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	10.00	True Color as Pt-Co	
2	pH	7.43	Potentiometric	**6.5-8.5**
3	Electrical Conductivity (μS/cm)	635.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	524.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	349.00	Potentiometric	**1000.0**
6	Turbidity (NTU)	168.00	Turibidimetric	**5.0**
7	Sodium (mg/L Na^+)	11.50	Flame photometric	**200.0**
8	Potassium (mg/L K^+)	8.00	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & $Fe^{3+)}$)	0.05	1,10-Phenothroline	**0.3**
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	**0.1**
11	Ammonia (mg/L NH_3-N)	0.14	Nessler	
12	Total Hardness (mg/L Ca CO_3)	284.80	Titrimetric	**500.0**
13	Calcium (mg/L $Ca^{2+)}$)	75.47	Titrimetric	**200.0**
14	Magnesium (mg/L $Mg^{2+)}$)	23.07	Titrimetric	**150.0**
15	Alkalinity (mg/L $CaCO_3$)	312.90	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	381.74	Titrimetric	
18	Chloride (mg/L Cl^-)	5.41	Mohr Argentometric	**250.0**
19	Sulphate (mg/L SO^{2-}_4)	16.11	Turibidimetric	**400.0**
20	Fluoride (mg/L F^-)	0.24	Ion-Selective Electrode	**1.5**
21	Phosphate (mg/L PO_4^{3-}-P)	0.49	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	**0.2**
23	Barium (mg/L)	Trace	Turibidimetric	**0.7**
24	Copper(mg/L Cu)	Trace	Bicinchoninate	**1.5**
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	**0.05**
26	Boron(mg/L B)	0.10	Curcumin	**0.3**
27	Zinc (mg/L)	Trace	Zincon	**15**
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	_
29	Nickel (mg/L)	Trace	Heptoxime	_

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by______ Lab Expert | Checked by______ Senior Water Quality Expert | Approved by ______ Water Quality S/P Manager

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Lab No.:- 1121/2011 | Client Ref: - Lab./06/Wq/47/19

Client/Project: Kibish Integration Water Resource Development | Date of Collection: - 8/2/2019

Client ID:- Kibish River, NR Down Stream | Source of Sample:- River

Location:- South Omo zone,Lokomaga kebele, Nyangatom woreda | Date of Received:- 6/3/2019

Gps Location X-0816697, Y-0585274 & Z-419m

Reported Date: 15/03/2019

No	Tests	Test Results	Test Method	WHO maximum allowable Concentration (mg/L)
1	Colour (True)	8.00	True Color as Pt-Co	
2	pH	7.26	Potentiometric	6.5-8.5
3	Electrical Conductivity (µS/cm)	816.00	Potentiometric	
4	Total Solids 105 ^{0}C (mg/L)	696.00	Total Solids 105 ^{0}C	
5	T. Dissolved Solid 105^{0}C (mg/L)	449.00	Potentiometric	1000.0
6	Turbidity (NTU)	236.00	Turibidimetric	5.0
7	Sodium (mg/L Na^+)	18.00	Flame photometric	200.0
8	Potassium (mg/L K^+)	9.70	Flame photometeric	
9	Total Iron (mg/L Fe^{2+} & Fe^{3+})	0.04	1,10-Phenothroline	0.3
10	Manganese (mg/L Mn)	Trace	Periodate oxidation	0.1
11	Ammonia (mg/L NH_3-N)	0.30	Nessler	
12	Total Hardness (mg/L Ca CO_3)	338.20	Titrimetric	500.0
13	Calcium (mg/L Ca^{2+})	99.68	Titrimetric	200.0
14	Magnesium (mg/L Mg^{2+})	21.36	Titrimetric	150.0
15	Alkalinity (mg/L $CaCO_3$)	336.00	Titrimetric	
16	Carbonate (mg/LCO_3^{2-})	Nil	Titrimetric	
17	Bicarbonate (mg/L HCO_3^-)	409.92	Titrimetric	
18	Chloride (mg/L Cl^-)	14.43	Mohr Argentometric	250.0
19	Sulphate (mg/L SO^{2-}_4)	58.94	Turibidimetric	400.0
20	Fluoride (mg/L F^-)	0.16	Ion-Selective Electrode	1.5
21	Phosphate (mg/L PO_4^{3-}-P)	0.71	Ascorbic acid ,Molybdate blue	
22	Aluminum(mg/L Al)	Trace	Aluminion	0.2
23	Barium (mg/L)	Trace	Turibidimetric	0.7
24	Copper(mg/L Cu)	Trace	Bicinchoninate	1.5
25	Chromium(mg/L Cr^{+6})	Trace	1,5-Diphenylcarbonohydrazide	0.05
26	Boron(mg/L B)	0.20	Curcumin	0.3
27	Zinc (mg/L)	Trace	Zincon	15
28	Molybedum (mg/L Mo)	Trace	Mercaptoacetic Acid	_
29	Nickel (mg/L)	Trace	Heptoxime	_

REMARK:- The test result can be compared with the WHO maximum allowable concentration (mg/L) presented on the right column. The water sample is collected and submitted to the laboratory by the client.

Reported by ________ Lab Expert | Checked by ________ Senior Water Quality Expert | Approved by ________ Water Quality S/P Manager

Among the major services rendered by the Water Quality Laboratory Testing S/Process of Ethiopian Construction Design & Supervision Works Corporation are: Testing all the Physico-Chemical and Bacteriological analysis of potable or drinking water/ Bottled drinking water/, waste water, water for construction and irrigation uses and sampling of water and waste water.

Source: Computed from WWDSE data