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Evaluation of Hydrometeorological Characteristics in Northern Ethiopia, Gerado Catchment

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ABSTRACT

In the northern Ethiopia, land degradation together with population pressure have resulted in high surface runoff, low groundwater recharge and high evapotranspiration. All together combined become very serious challenge to agricultural production and economic growth in the region. Understanding the characteristics and dynamics of hydro-meteorological variables is important in water resources development projects that have direct impact on agricultural production. The present study was carried out to evaluate hydro-meteorological characteristics in northern Ethiopia, Gerado catchment. Long term meteorological data such as precipitation, temperature, sunshine, and other climatic factors were collected from existing meteorological stations. Thornthwaite Empirical Equation and Thornthwaite Soil Water Balance models were employed to estimate potential and actual evapotranspiration. The approach used air temperature as an index of energy available for evapotranspiration. Similarly, groundwater recharge of the area catchment was computed as a difference between outflow and change in water storage. The runoff of the area was estimated based on the rainfall coefficient, annual precipitation and aerial coverage. On the other hand, groundwater potential (GWP) of the area was mapped based on selected spatial factors. The result indicated that the annual potential and actual evapotranspiration of the catchment were was found to be 755 mm/year and 723 mm/year, respectively. The actual evapotranspiration was evaluated and weighted based on the dominant soil textures, depth root soil, and the respective land uses. As result, high evapotranspiration was observed in moderate deep rooted cereal crops and sandy loam soil texture which accounted for 48.5% of influence. But, cereal crops with moderate deep rooted and clay loam type had lower AET (42.2%). Because of the absence of gauging stations in the catchment, the volume runoff was computed using the runoff coefficient method. Accordingly, surface runoff from the catchment was calculated to be 120,581,841 cubic meter (m^3) or 326 mm. per year. However, the groundwater recharge of the area was found to be 52,208,159.5 cubic meter (141.5mm/year). Thus, out of the given mean annual precipitation, 27.6%, 12% , and 60.4% of the mean annual rainfall lost because of runoff, groundwater recharge, and evapotranspiration, respectively. Regarding GWP, the most determinant factors affecting groundwater mapping potential were suitability mapping, lithology, liniment density, and geomorphology. . The suitable GWP areas were located within lithology and geomorphology classes. Moreover, areas with flat slope and low lineament density lay in most rich groundwater areas. In general, although the study area had high amount of annual rainfall, most of it was lost in the form of evapotranspiration and thus little amount of water was recharged. Eventually, installation of metrological stations in appropriate sites was recommended for all-inclusive and consistent data availability.

Keywords: Hydro-meteorological, Gerdo Catchment, groundwater recharge, runoff, evapotranspiration, GWP

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1. INTRODUCTION

Land degradation in the form of soil erosion increases runoff, evapotranspiration, and low groundwater recharge which are serious environmental problems having negative impact on agricultural productivity and economic growth in Ethiopia. High population pressures densities, climatic change impact variability, and improper utilization of land resource are the major causes of such problems (Nyssen, 2005 and Nyssen, 2011). These, in turn, have resulted in declining of agricultural productivity, water scarcity, and persistent food insecurity. On the other hand, water resources demand grows up in order to enhance agricultural and industrial developments, create incomes, and reduce poverty of rural people. This problem is more conspicuous in least developed countries whose livelihood depends on rainfall agriculture. In these regions, most of the rain goes in the form of runoff which causes low groundwater recharge. Runoff is part of the rainfall not interrupted by vegetation but reaches on the surface of earth and flows overland into streams, lakes or and oceans (Horton, 2003). And this has a direct impact on agricultural production. Updated reliable information on the spatio-temporal variation of runoff / the aforementioned parameters are at a watershed level essential to understand its impact on watershed hydrology and monitoring of water resources. Thus, estimating surface runoff, evapotranspiration, and groundwater recharge are essential for water resources development projects (Rolland and Rangarajan, 2012; Fan et al., 2013). There are conventional techniques for runoff measurements but in most situations such techniques are very costly, time consuming, and difficult in areas of inaccessible terrains. Thus, the use of rainfall runoff model is the most commonly used approach in hydrological modeling.

In most arid and semi-arid regions where there is limited hydro-climatological data, runoff estimation modeling approach is given due emphasis (Ai-Ahmadi, 2005). It is used to estimate how much rainfall changes transform to runoffs (Jenicek, 2007). Understanding and modeling rainfall transformation into runoff is difficult and dynamic since it exhibits temporal and spatial variabilities. It has a comprehensive range of applications that include modeling of gauged catchments like flood forecasting and evaluation of water resource management. Runoff estimation of un-gauged catchments and estimation soil erosion are essential input components for water resource development projects (Džubáková, 2010). It is known that rainfall is the main sources of surface runoff although it is rare and uncommon practice to find documented rainfall particularly in developing countries like Ethiopia (Gedefaw, 2020). Studies have shown that there is a direct relationship between rainfall and surface runoff. Hydrological parameters such as rainfall, groundwater recharge, evapotranspiration, and runoff vary in space and time (Suryawanshi, et al., 2012) because of different factors. The rainfall-runoff relationship is one of the most complex hydrological spectacles to apprehend because of the tremendous spatial and temporal variability (Josh and Patel, 2011). Scholars have developed several equations to make this prediction. Of these, rational method is the simplest one. In other words, evapotranspiration process if other key factor in relation to runoff. When it rains, most of the rain water goes back to the atmosphere through evaporation and transpiration. It can be affected by different biological and physical factors. The actual and potential evapotranspiration are the most important terms used in hydrology and those can be estimated calculated using different techniques.

The other variable of hydro-metrological in relation to runoff is groundwater recharge, which is mainly controlled by land use land cover, soil texture type, and geological features. Understanding the groundwater recharge variability at a given watershed level has its own impacts on monitoring and efficiently using water resources for sustainable development. Nowadays, Geographic Information System (GIS) based hydrological modeling plays a great role in exploring, identifying, and managing groundwater resources in areas where there is scarcity of water. Hence, estimating and mapping groundwater recharge at a catchment or basin level is very essential for wise utilization of the resource. Groundwater recharge is the vertical movement of water into saturated zone of the earth surface; it percolates through the pores of the land surface. On the other hand, precipitation is the most important driving parameter in groundwater recharge process. It is also the most significant factor driving force in hydrological cycle and it can percolate into the groundwater through groundwater recharge system. But, when it rains, it changes into runoff and whose intensity and amount are affected by different features as stated above. And this has direct impact on groundwater recharge and occurrence. Groundwater recharge can be appraised by using a number of methods which depend on the availability of data and level of accuracy.

Groundwater delineation investigation and mapping is another essential hydrological variable. The existing conventional methods of mapping groundwater potential sites using in situ approaches are expensive and time consuming. Recently, the introduction of geospatial technologies to delineate groundwater make the task speedy, easy and cost effective. It has the capability to capture, merge, and integrate the remote sensing satellite data together with the in-situ field data. brings to one system of modeling. These methods significantly reduce the failure of drilling groundwater projects and thus areadopted by many users. Nowadays, Remote Sensing and Geographic Information Systems (RS and GIS) has emerged as an effective tool methods for handling huge spatial data and decision making in several field of studies. Geospatial technologies (GIS and Remote Sensing) are very important tools which have invaluable importance to map, identify, delineate, and evaluate groundwater potential by considering significant factors such as geology and topography (Syed & Satapathy, 2015; Liu et al., 2015). Moreover, Khan, et al., (2017) noted that, these methods as compare to conventional methods have the competency to accurately map the controlling parameters, integrate and model the potential suitable sites of groundwater. Therefore, assessing, investigating, and delineating groundwater potential zones through these techniques has immeasurable advantage over conventional methods.

All the aforementioned hydrometrological elements have a great impact on hydrology and agriculture in particular and economy of a given region in general. The nature, distribution, and variabilities (i.e. spatial and temporal) of these environmental and climatic factors are not well understood. This was due to lack of ground based supported stations and incompleteness of data. However, all these environmental factors are caused by land degradation. and this that are more pragmatic in northern Ethiopia. According to Derege (2012) & Abdulaziz et al. (2016) because of land degradation, most of the rainfall was lost as runoff and evapotranspiration which resulted in poor groundwater recharge in the northern Ethiopia particularly in Gerado Catchment. In general, such environmental elements have a direct impact on food security, drought, and flood in the study area. However, studies have not been carried out so far on this topic. Therefore, the present study was carried out with the aim of evaluating and understanding the different hydrometeorological characteristics (runoff, evapotranspiration, groundwater recharge and groundwater potential) in Northern Ethiopia, Gerado Catchment.

1.1 Description of the Study Area

The study area, Gerado catchment is located in the North East of Ethiopia that covers a total area of 372 km^2. The average elevation of the catchment ranges from 1965m to 3552m above mean sea level and bounded within 552428 to 572576 E and 1210451 to 1243825 N (UTM/ADINDAN) respectively. Figure 1 is the map of the study area derived from digital elevation model (DEM) with spatial resolution 30m*30m. The general topography of the catchment is characterized by undulating hills, plane, and valley. It gradually decreases its elevation to the north and north-west directions. Numerous narrow and shallow river valleys originate from the mountains, and merge to form Gerado Perennial River. Intermittent rivers like Kelina, Yito and Negeweli are among the main tributaries of Gerado River which flows to Beshlo River, the main tributary of the Blue Nile River (Abdulaziz et al., 2016).

Table 1 Agro-climatic zone of the study area

Altitude (m)	Temperature	Classification	Local name
Below 500	25 and above	Hot	Bereha
500-1500	20-25	Hot temperature	Kola
1500-2300	15-20	Temperate	Woina dega
2300-3300	10-15	Cool temperate	Dega
3300 and above	10 or less	Cool	Kur

Source: Ethiopian Metrological Institute (EMI, 20008)

The characteristics, types, and distribution of soil for a certain area depends on geomorphology (landscape), geology, and the type of land use activity. The dominant soil type of the study area is classified into clay, sandy cay, and rocky. Clay soil covers 43.2 km^2 which is approximately 11.68% of the catchment. It is highly exposed to the left side of the river along the flat and gentle to flat. Such type of soil is mostly covered with cereal crops. . Sandy clay is the other type of soil that covers 50.1 km^2 which accounts for 13.54% of the catchment. More than 74% of the study area is covered by rocky soil type that covers 276.7km^2 of the catchment. Such soil coverage is highly vulnerable along the steeper part of the catchment. This rocky soil is especially available at the steeper part of the catchment covered with shrubs and plantations like eucalyptus and cereal crops. In line with FAO's soil classification, the dominant soil type in the study area include: cambisols, lithosols, and rock surface (Abdul Aziz et al., 2016).

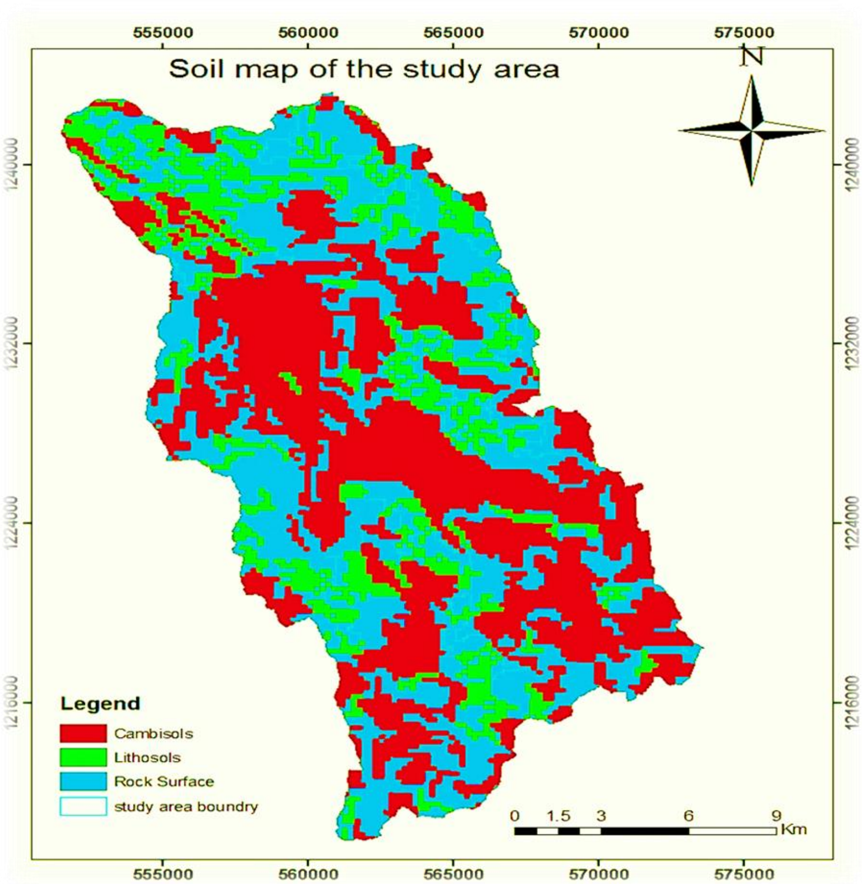

Figure 1 Soil map of the study area

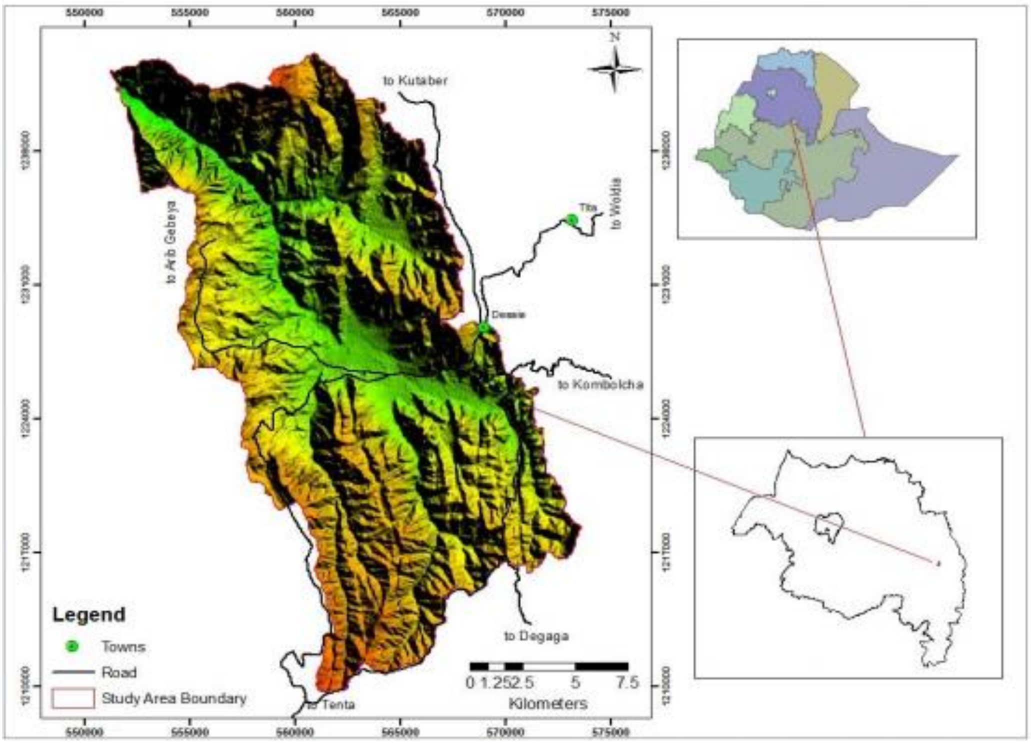

Figure 2 Location of the study area

Volcanic rocks and alluvial deposits form the main geological units of the study area. . The volcanic rocks having tertiary age covered 78.8% of the area ranging from lower basalt to Aiba basalt. On the other hand, alluvial deposits of quaternary covered 21.2% of the study area. Major and inferred faults, fractures, and lineament having an alignment of N-S, NNW-SSE, NW-SE, NNE-SSW, and NE-SW were observed. Moreover, two hydro-stratigraphic units were noticed during the hydro-geological investigations. Alluvial deposits having inter granular porosity and permeability could be found along the flat and gentle slope consisting of clay and silt. Similarly, volcanic unit also comprised highly fractured, unweather basalt, and ignimbrite. Though the fracturing and weathering rate of these formations was prominent due to topographic locations, the volcanic units were characterized by negligible groundwater potential. Gerado River Catchment is situated in the Ethiopian highland plateau adjoining the western escarpment of the Rift Valley and the Abay River Basin (Abdul Aziz etal, 2016).

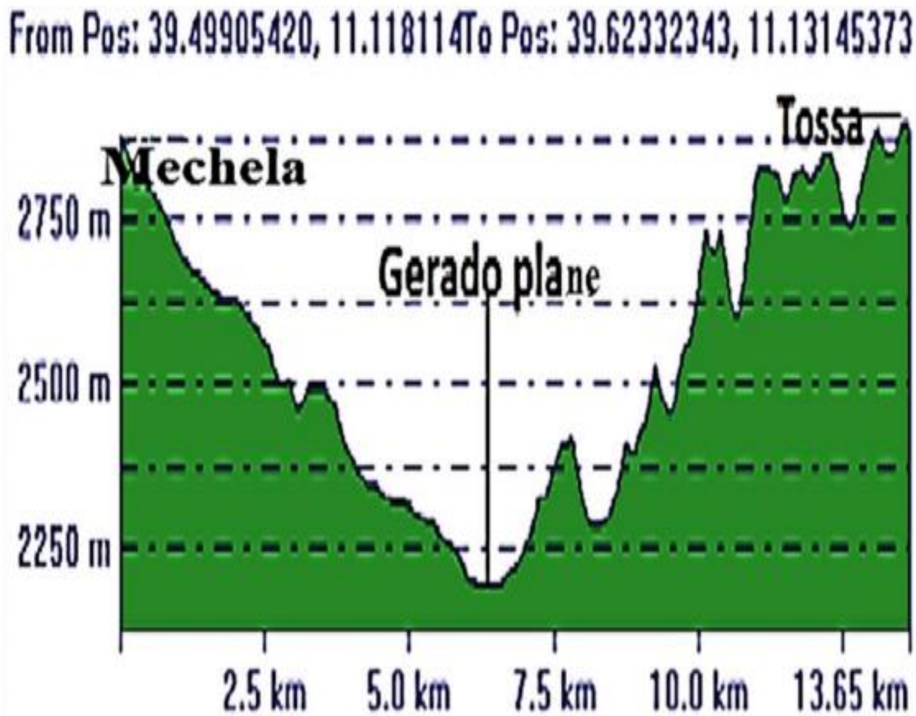

Figure 3 Cross-section of the study area (E-W) (Derege, 2012)

2. RESEARCH METHODOLOGY

Long term meteorological data such as precipitation, temperature, relative humidity, and sunshine hours were the most essential input data employed for this study. Those data were collected from Ethiopian Meteorological Institute (EMI) branch office (Kombolcha and Dessie) as presented in table 2. Once the data were collected, data completeness and quality were checked up. Determination of water balance in a certain catchment is based on hydro-meteorological data so as to use the resource effectively in water resource management. To determine the water balance of the study area, important long term meteorological data were collected from Kombolcha Meteorological Station. The meteorological stations within and around the study area were presented in table 2 below. These data were taken from the stations based on their availability.

Table 2 Meteorological stations of the study area

No.	Stations	Location (UTM)/ADINDAN			Recording periods(years)	
		Easting	*Northing*	*Elevation*		
1	Dessie	569342	1231348	2400	1990-2010	*
2	Guguftu	553039	1203569	3450	1990-2010	**
3	Albuko	569855	1194487	2482	2006-2010	*
4	Kutaber	558212	1245405	2600	1990-2010	*
5	Kombolcha	576448	1227015	1825	1985-2007	**
6	Tita	573693	1233807	2480	2001-2006	**

* Records of rainfall only ** Records of rainfall and temperature

Since rainfall measurement is a point observation, it may not provide a representative value for the area under consideration. To get more reliable and representative result, it is essential to obtain an effective uniform depth of rainfall of the catchment. Hence, the rainfall of the catchment was computed using different interpolation techniques such as arithmetic mean, isohyetal, and thiessen polygon interpolation. . Hence, data were collected from six meteorological stations around the study area. The rainfall coefficient method was used to compute the monthly distribution of rainfall and discriminate between rainy and dry months. The rainfall coefficient method becomes complicated while calculating the rainfall of each month. Usually, it should be the ratio between the mean monthly rainfall and one-twelfth of the annual mean rainfall. However, the thornthwaite empirical formula was adopted to calculate the potential evapotranspiration for the study area as in equation (1). This method uses air temperature as an index of energy available for evapotranspiration, assuming that air temperature is correlated with net radiation and evapotranspiration. Thus, the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration (Dunne and Leopold, 1978). For this purpose, we adopted the thornthwaite empirical equation as shown below: -

$$PETm = 16Nm\,(10TI\,m)a \qquad 1$$

Where PET is potential evapotranspiration in mm/month,

m is the months 1, 2, 3…………….12

Nm is the monthly adjustment factor related to hours of daylight

It is found from standard table by dividing possible sunshine hours for the appropriate latitude (100 N) of the study area (Gerado river catchment) by twelve months. Tm, is the monthly mean temperature in ^{0}C, I is the heat index for the year.

To calculate the actual evapotranspiration, the thornthwaite soil water balance model was used. The required parameters to determine actual evapotranspiration are mean monthly precipitation and potential evapotranspiration. Moreover, water holding capacity of the dominant soil texture and monthly soil moisture storage are also determinant factors. Furthermore, to evaluate and check for the shortage or addition of moisture to the soil, the difference between precipitation and potential evapotranspiration was calculated and presented as in equation (1) below. Hence, positive values indicate the addition of moisture to the soil whereas negative values imply monthly demand of moisture by vegetation not satisfied by the monthly rainfall. The accumulated potential water loss that was calculated by cumulating the negative values of the differences between monthly precipitation and evapotranspiration and used to estimate calculate the soil moisture for the dry months.

$$SM = W * exp(-APWLW) \quad 2$$

Where, SM, is the Soil moisture during the month m (mm),

APWL, is the accumulated potential water loss and

W, is the available water capacity of the root zone (mm).

The soil moisture surplus which is in excess of soil moisture values (Sm) especially in wet season is calculated using the equation (3) as follow

$$\text{Sm} = \text{P} - \text{AET} + \Delta Sm \quad 3$$

The actual evapotranspiration (AET) for the dominant soil types and the respective land use is weighted according to the proportion of the area it represents. The actual evapotranspiration, AET, for the dominant soil types and the respective land use in the area was weighted according to the proportion of the area it represented as given here:

$$AWTw = \frac{\sum(AETi)ai}{iAt} \quad 4$$

Where $AET_{w,}$ is weighted actual evapotranspiration

AETi, is actual evapotranspiration of the dominant soil ai, is area of each soil

At, is total area of soil coverage

Runoff takes place when the rainfall not fully infiltrated forms a flow as a thin sheet across the land surface. (Tenalem and Tamiru, 2001). In the study area, there was no river with gauged hydro-meteaorological stations; so, it was difficult to determine the runoff generation of the catchment. The volume of runoff from the catchment was also computed using the runoff coefficient method as given in equation (5) below:

$$Q = K.P.A \quad (5)$$

Where: Q, is run off in m^3

K, is a constant also called runoff coefficient;

P, is precipitation (mm): and

A, is area of the catchment (m^2)

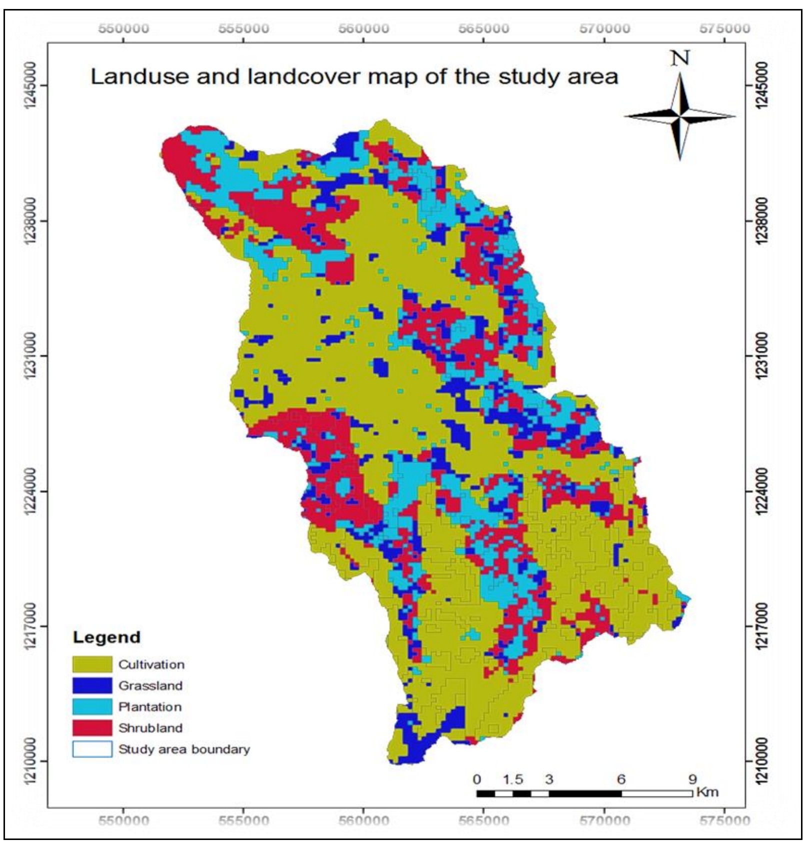

Figure 4 Soil map of the area

On the other hand, groundwater recharge flows to saturated zone as a precipitation that infiltrates into soil to a depth below the root zoned of surface vegetation where it cannot be removed by evaporation (Tesfaye, 2015). It is the downward flow of water reaching the water table, forming an addition to the groundwater reservoir (Lerner et al., 1990). Different techniques of recharge estimation have been widely applied under various climatic and hydrogeological conditions all over the world. Groundwater recharge estimation using hydrograph separation, isotopic tracers (stable isotopes of oxygen and hydrogen), lysimeters, soil moisture technique, mixing-cell models (compartment models, lumped models and black box models) and tracer techniques have been extensively experimented and used by many workers in different parts of the world. Three independent methods were used for comparative evaluation of recharge methods in the small watersheds in the rain forest belt of Nigeria. The methods included recharge estimation using water level and porosity, base flow recession analysis, and water balance method. The results showed that groundwater recharge obtained from water balance method was constantly higher than values from other methods. So, , groundwater recharge estimation of the study area was computed using water balance method formula as in equation 6:

$$Inflow \;=\; outflow \;\pm\; change\ storage \qquad 6$$

$$P + Gi = AET + SRQ + R + Go \pm \Delta S$$

Where, P – annual precipitation

AET- actual evapotranspiration

ΔS - Change in water storage

Go - Groundwater out flow

Gi - Groundwater inflow

SRO – annual surface runoff

Investigation of groundwater potential site is complicated because of the lack of common understanding of the several environmental, climatic, and topographical factors (Lentswe & Molwalefhe, 2020; Makonyo & Msabi, 2022). Moreover, demarcation of potential areas demanded evaluating many spatial factors based on scientific methods (Malczewski & Rinner, 2015). Most previous groundwater investigations had applied conventional techniques based on geophysics, geology, and hydrogeology. However, the recent introduction of geospatial technologies to water resource ^ makes it very effective and constant. For the present study, groundwater potential map of the area was developed by integrating geology, geomorphology, LULC, slope, soil, drainage, lineament density, and rainfall raster layers to one system modeling. Each layer was given a rank and weight based on their importance for groundwater occurrence. The procedure followed was based on multiplication of each factor's raster map with given factors weight which is generated in multi criteria decision analysis based analytical hieratical process and spatial analysis.

3. RESULT AND DISCUSSION

3.1 Annual Rainfall Estimation:

Good understanding of the nature and characteristics of rainfall helps to conceptualize and predict its effects on runoff generation and evapotranspiration. Knowing the nature, amount, and aerial distribution of rainfall characteristics is also essential for hydrological modeling analysis. It is a significant hydrological factor and its duration and magnitude are the main cause of groundwater recharge (Champak and Dinesh, 2018). According to Tesfaye (2015), we can hypothesize and estimate its effects on runoff, infiltration, and evapotranspiration. Therefore, for better rainfall analysis, it is important to know its areal distribution and coverage. Since rainfall measurement is a point observation, it might not represent the area under consideration. In such situations, it is essential to obtain a more reliable and representative rainfall of the catchment. In the current study, simple arithmetic mean, isohyetal, and thiessen polygon interpolation methods were used to estimate the rainfall.. However, the selection of appropriate interpolation methods depends normally on the density of gauging stations, the nature of the area, the objective of the study, and the availability of time (FAO, 1997).

Arithmetic mean interpolation: This method was used to determine the mean monthly rainfall of the study area. In the study site, there were five meteorological stations: Dessie, Albuko, Guguftu, Kombolcha, and Kutaber. Arithmetic mean rainfall was computed using the interpolation technique as given below:

$$P = P^1 + P^2 + P^3 \pm \qquad +Pn/n \qquad 7$$

Where --P is the average depth of precipitation of the area, P1, P2, P3
Pn are the rainfall records at the stations 1, 2, 3 etc.
and n is the number of meteorological stations.

Hence, the mean annual rainfall of the catchment was 1251.37 mm. (table 3). Similarly, other studies in Abay Basin indicated that the annual depth rainfall was 1373.3 mm (Tesfa, et al, 2021). The highest mean monthly rainfall of the area was recorded in July, August, and September. However, the lowest mean monthly precipitation was recorded from November to January. According to Daniel (1977), the study area had two rainfall regimes (a bimodal rainfall characteristics). From March to April (Belg Season), the area got a small rainfall of 11%. While the area had annual rainfall of 70% in July, August, and September. and the rainfall in the rest of the months amounted to 18% (table 3).

Thiessen polygon interpolation: This interpolation method determines areal depth of precipitation assuming any point in the area under consideration and the rainfall the same as the nearest gauge. So, the depth recorded at a given gauge is applied to a distance halfway to the next station in any direction. The relative weights for each gauge were determined by the corresponding areas created in a thiessen polygon network. The boundaries of the polygons are formed by the perpendicular bisectors of the lines joining adjacent gauges (Chow, 1988). This interpolation provides non-uniform distribution of raingauge by determining a weighted factor for each gauge and it is generally more accurate than the arithmetic mean method. According to this interpolation, the annual mean rainfall of Gerado Catchment was computed and found to be 1180.31 mm. as in figure (3) and table (4). According to Tesfa, et al., (2021), the annual rainfall in Abay Basin was estimated to be 1399.8 mm using thiessen polygon interpolation. A similar study by Yibralem (2013) stated that this method requires a less simple division of the area than the arithmetic mean method because not all rain gauges have the same weight.

Table 3: long term mean monthly precipitation (mm.)

Stations	Long term mean monthly precipitation (mm.)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total PCP
Dessie	18.26	31.02	61.0	84.25	57.1	36.6	339.6	342.2	140.3	58.2	19.36	20.85	1208.74
Albuko	25.54	53.18	42.1	113.8	79.3	37.2	461.4	439.4	129.7	59.3	59.12	46.62	1546.66
Gugufṭu	23.22	24	64.6	59.05	55.9	59.1	439.7	405.8	101.1	33.4	16.06	17.9	1299.83
Kombolcha	24.5	31.6	74	95.5	59.1	29.5	264.5	247	112.6	43.4	21	18.1	1020.8
Kutaber	10.87	12.83	51.1	51.04	52.4	38.6	342.4	350.8	113.4	45.3	17.27	6.261	1092.27
Mean	21.64	28.09	63.3	79.62	58.9	41.9	373.4	368.3	120.8	47.7	25.1	22.57	***1251.3***

Table 4: Thiessen polygon annual rainfall interpolation

Stations	Mean rain fall (mm)	Area of influence (km^2)	Area Wtd (km^2)	Weighted Area (%)	Weighted rainfall (mm.)
Dessie	1208.74	218	0.5860215	58.60215	720.1603
Albuko	1546.66	26	0.0698924	6.98924	67.9234189
Kombolcha	1020.80	48	0.1290322	12.90322	123.323676
Kutaber	1092.27	80	0.2150537	21.50537	223.440086
Total	4868.47	372	1	100	***1180.31***

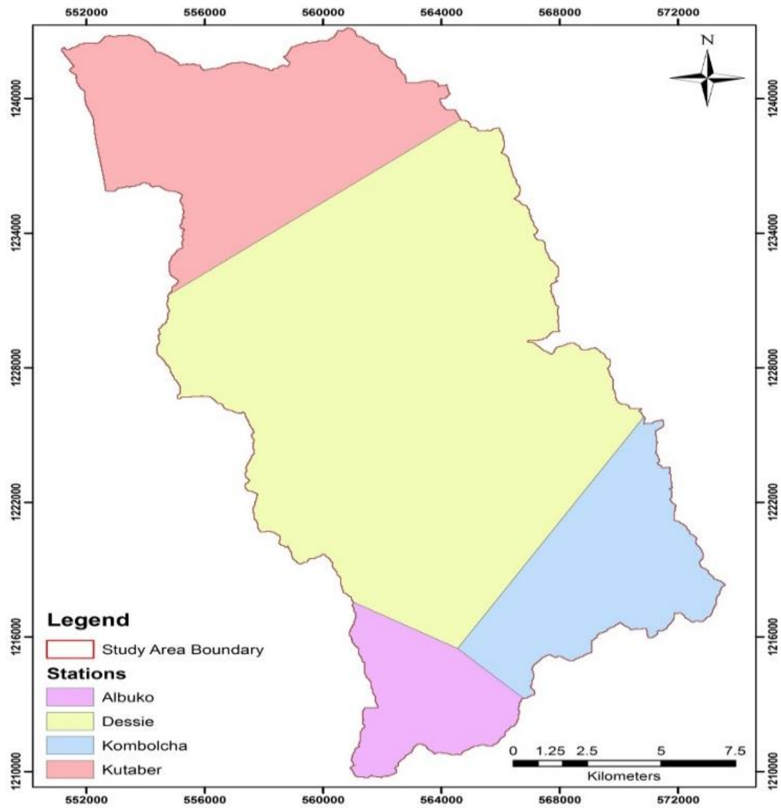

Figure 5 Thiessen polygon annual rainfall interpolation

Isohyetal interpolation: This type of interpolation takes into account the impact of physiographic parameters which include elevation, slope, distance from the coast, and exposure to rain bearing winds (Shaw, 1988). It accounts for local effects like prevailing wind and uneven topography (Wilson, 1990). It is done by drawing contours of equal areal depth of precipitation and measuring their inter-isohyetal area. For this study, the mean annual rainfall of Gerado River was found to be 1307.76 mm. (table 5). Rainfall is not evenly distributed over the study area because of topographic variations of the basin and the extreme dry and rainy seasons. In this case, the isohyetal polygon interpolation technique is the most preferable approach to estimate the areal depth rainfall over the entire catchment (Stefan and Gerd 2004). Of the three methods of interpolations to determinate mean annual rain fall, isohyetal method is the most important and preferable. This interpolation resolves actual evapotranspiration areal depth as it considers different physiography effects.

On the other hand, quantitative seasonal category of rainfall distribution can be explained by using the rainfall coefficient (R.C), which is the ratio between mean monthly rainfall and one twelfth of the annual mean of the total rainfalls (Daniel, 1977), i.e. $R.C = \frac{12\text{Pm}}{\text{Pa}}$, where R.C= rainfall coefficient,

Pa =Annual total rainfall of the area, which is 1307.76 mm, Pm = mean monthly rainfall. Runoff coefficient shows the percentage of rainfall that is converted into runoff. The runoff coefficient varies from season to season and is strongly influenced by land cover of the catchment. The rainfall coefficient of the area was found to be < 0.6 for dry months and >0.6 for rainy months respectively as shown in table 4.

Table 5: Isohyetal annual rainfall interpolation

No.	Isohyetal range (mm)	Average Isohyets (mm)	Enclosed Area (km^2)	Weighted area (km^2)	Weighted RF (mm)
1	<1050	1037.5	7	0.02	21.68
2	1050-1100	1075	44	0.13	141.19
3	1100-1150	1125	41	0.12	137.69
4	1150-1175	1162.5	57	0.17	197.80
5	1175-1200	1187.5	123	0.37	436.01
6	1200-1225	1212.5	40	0.12	144.78
7	1225-1275	1250	36	0.11	134.33
8	1275-1325	1300	17	0.05	65.97
9	1325-1375	1350	6	0.02	24.18
10	>1375	1387.5	1	0.00	4.14
	Total	12087.5	372	1.11	**1307.76**

	Months												
Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Arithmetic	21.64	28.09	63.3	79.62	58.9	41.98	373.4	368.3	120.8	47.67	25.10	22.57	1251.37
Isohyet	20.47	30.5	58.6	80.72	60.8	40.2	369.5	357.0	119.4	47.92	26.56	21.94	1233.61
R.C	0.2	0.3	0.6	0.81	0.54	0.4	3.72	3.6	1.2	0.48	0.26	0.17	12.28

Table 4: Monthly rainfalls and rainfall coefficient (R.C)

Using rainfall coefficient (R.C) values, the following precipitation category can be made for dry months (October, November, December, January and February, May, June) which had R.C < 0.6 in Gerdo River Catchment. :. In contrast, R.C was found greater than or equal to 0.6 (R.C >= 0.6) for rainy seasons (March, April, July, August and September). From the six meteorological stations, only three stations Kombolcha, Guguftu, and Tita had records of monthly maximum and minimum temperatures. Since temperature is greatly influenced by altitude, only Tita Station was used for determining the mean monthly temperature.

The result showed that the study area was found at lower elevation than Tita Meteorological Station. So, the temperature data from Tita Meteorological Station was extrapolated to the study area by allowing an increment of 0.6 ºC for 100 m (Nata, 2006). The mean minimum (min) monthly, the mean maximum (max) monthly, and the mean annual temperature was presented below in table 6. Similarly, the extrapolated mean monthly max. and mean monthly min. result was given in table 7 and therewas a slight differnce between the two approaches.

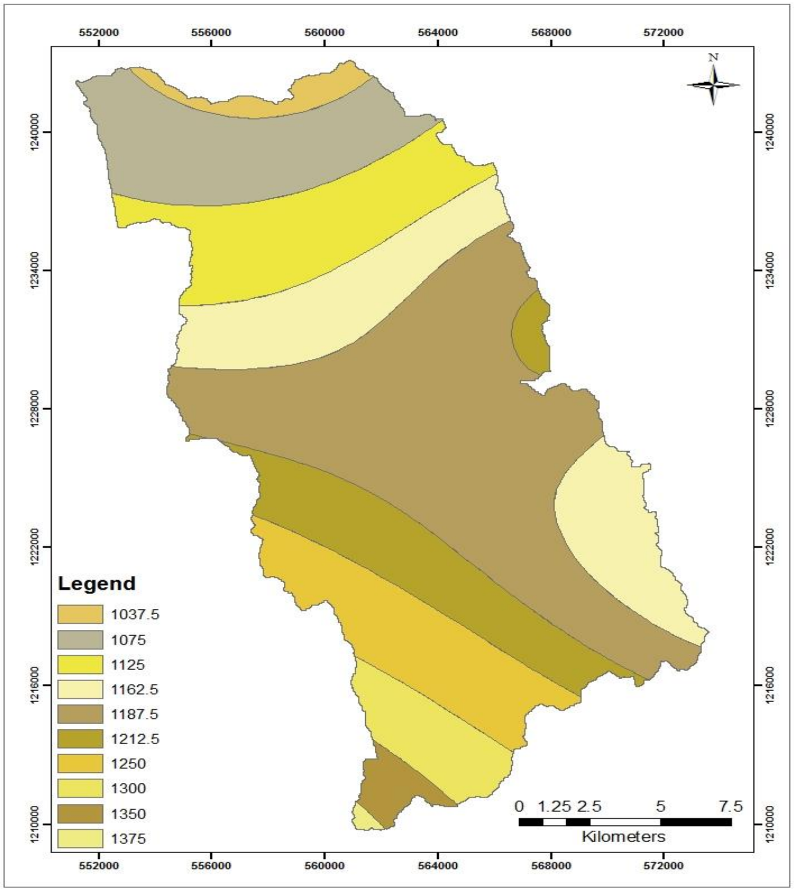

Figure 6: Isohyetal annual rainfall interpolation

Table 6: mean monthly temperature variability of Tita station

Month	Jan.	Feb.	Mar.	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max.	16.5	17.9	18.2	21.9	23.7	24.9	23.1	21.9	18.03	21.2	20.8	19.4
Min	8.4	9.2	10.3	10.8	10.6	11.5	11.9	11.8	10.7	8.1	7	7.5
Mean	12.45	13.55	14.25	16.35	17.15	18.23	17.5	16.85	14.36	14.65	13.90	13.45

Table 7 Extrapolated mean monthly temperature variability of Tita station

Month	Jan.	Feb.	Mar.	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max.	17.66	19.16	19.35	23.05	24.86	26.16	24.3	23.06	19.23	22.38	22.02	20.6
Min.	9.6	10.4	11.5	12	11.8	12.7	13.1	13	11.9	9.3	8.2	8.7
Mean	13.63	14.78	15.42	17.52	18.33	19.43	18.7	18.03	15.56	15.84	15.10	14.65

Extrapolated mean annual temperature T=16.42°c
Mean max. monthly T = 21.819 ⁰C
Mean min. monthly T = 11.01 ^{o}C

3.2 Evapotranspiration: The result indicated that the potential evapotranspiration of the study area (catchment) was found to be 755 mm/year. Nevertheless, the actual evapotranspiration of the catchment was 723 mm per year (table 8 and table 9). The value of actual evapotranspiration (AET) over a basin or a catchment is often estimated by calculating the potential evapotranspiration (PET) and then modifying the value based on the actual soil moisture content (Shaw, 1988). Similar studies in Abay Basinreported that 1300 mm. of the annual rainfall (96%) was lost due to evapotranspiration. Besides, the findings suggested that 63% of the total rainfall was lost because of environmental factor. Although these areas had similar physiographic and climatic setting, the variation in result was due to different methods employed. Similarly, a study conducted in Tigray Region showed that of the total rainfall recharge accounted for 12% while the rest 81% and 7% were due to evapotranspiration and surface runoff, respectively (Tekelebrhan, 2011). So, in general it can be concluded that very high potential evapotranspiration can result in low groundwater recharge (Portela et al., 2019).

Table 8: Calculated potenial evapotranspiration (PET) in mm.

Parameter	Month												Annua
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
N(Hrs)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.4	11.8	11.6	11.5	12.1
N_m	0.97	0.98	1	1.02	1.05	1.05	1.05	1.03	1.03	0.98	0.96	0.95	1.01
T_m(0c)	13.3	14.8	15.2	17.5	18.33	19.4	18.7	18.03	15.56	15.8	15.1	14.7	16.37
i_m		5.08	5.3	6.56	7	7.6	7.2	6.8	5.4	5.6	5.24	5.01	5.94
ta =1.62													
I=71.26							4.5						
PETm	43.92	51.12	55.87	70.7	77.62	85.31	80.1	74.16	58.39	57.2	51.89	48.9	752.2

The essential factors to determine actual evapotranspiration (AET) of a given catchment are mean monthly precipitation, mean monthly potential evapotranspiration (PET), and water holding capacity of the dominant soil (Dunne & Leopold, 1978). To calculate the actual evapotranspiration (AET) of the area, the soils should be classified into two major groups with their vegetation cover and the proportion of different types of soil and vegetation cover of the catchment. Based on the long term (20-25) years meteorological data with the exception of Tita Station, the actual evapotranspiration (AET) and potential evapotranspiration (PET) of the specific land use was estimated and summarized in table 11. The difference between monthly precipitation (Pm) and PET yielded positive value during summer and spring season and negative during winter time (table 11). This was due to very low rainfall throughout the winter season as opposed to summer and spring seasons.

To evaluate and check for shortage or addition of moisture of to the soil, the difference between PET and rainfall is very important. Accordingly, positive and negative values indicate an addition of moisture to soil and monthly demand moisture by vegetation. High amount of PET and AET values were recorded during summer and spring periods. In contrast, low AET and PET values were observed through the dry season (winter) (table 9). Relatively, high amount of AET and PET recorded during the spring season (April – June) months as compare to summer season (July – September). This could be attributed to high sun radiation energy and less cloud coverage during spring season as compare to summer season. The AET is equivalent to PET if the mean monthly rainfall is greater than respective month's evapotranspiration. The change in soil moisture showed negative values during the dry season (winter) and 0 (zero) during spring and summer rainy months (table 9). Table 10 and table 11 presented AET using soil water balance method for clayloam (200mm and 0.80m) and clayloam (250mm and 1m) with unlikely results. AET depends on climatic condition of the environment, soil moisture content, soil texture, and vegetative factors (Abebe, 2013).

Accordingly, all hydrometerological factors values were similar except for soil moisture of clayloam. Soil moisture deficency showed an increament within 250mm and 1m as compare to 200mm and 0.80m (table 10 and 11). Based on soil water balance method for clayloam (200mm and 0.80m), AET and PET values were estimated 723mm. and 755 mm., respectively. For similar soil type and cereal crops with 250mm water holding capacity root zone and 1meter (m) depth, AET and PET were estimated 728 mm/year and 755 mm/year, respectively. The annual PET values in all circumstances yielded similar values i.e 755 mm/year. But, the actual evapotranspiration results slightly deviated from each as other as it considered certain correlated environmental elements affecting it as given in table 9, 10, 11 and 12. Therefore, the real annual AET value was found 722 mm/year since it showed impacts of land use, land cover, soil texture, and depth root (table12).

The actual evapotranspiration for the dominant soil types and the respective land uses of the area was computed based on the proportion of the area and the weighted actual evapotranspiration. Besides, more AET resulted from sand loam and clay loam with root depth 1m and o.8m with 357 mm/year and 302 mm/year, respectively. But, deep rooted grasses with similar soil texture and 1m soil depth was estimated to be 64 mm/year as the aerial covergae was very small in comparison to the others. Sandy loam (49%) and clay loam (42.2%) had an impact on actual evapotranspiration (AEP) process. Based on table 12, weighted AET, high evapotranspiration (48.5%) was observed in moderate deep rooted cereal crops with sandy loam. . In other words, cereal crops with moderate deep root and clay loam have low AET relatively with 42.2% percentage influence. However, deep rooted grasses are found to have the least weighted impact on AET as compare to moderate cereal crops. Cereal crops under sandy soils are more vulnerable to evapotranspiration as radiation energy easily penetrates them. At the same time, deep rooted grasses in clay loam soil texture are less likely exposed because of less sun radiation penetration. So, taking all these essential elements into account, AET was estimated to be 722 mm/year. However, PET theoretically hardly takes all aforementioned factors into consideration..

Accordingly, the annual actual evapotranspiration of the catchment was estimated to be 722.27 mm. Table 9 and 10 presented AET (in mm) using Soil Water Balance Method for sandy and clay covered with cereal crops having rooting depth of 1m and available water capacity of the root zone 150 mm. Yibralem (2013) reported that the water inflow into the catchment area was coming only from rainfall and the water leaving the catchment area were only surface runoff (R) and actual evapotranspiration ^ (ETa). The difference between them constitutes the change both in groundwater and soil moisture storage (ΔS). The actual evapotranspiration of the catchment can easily be obtained by satellite technologies., the progressive reduction in the cost of images and the development of computer technology and associated software's and models. Hence, this opened the opportunity to extract fundamental hydrological parameters like actual evapotranspiration and others on pixel basis.

Generally, this study showed that the potential and actual evapotranspiration of the area was estimated statistically to be 755 mm/year and 722 mm/year, respectively. Simultaneously, the runoff and groundwater recharge of the area was 120,581,841m3 (326 mm) and 52,208,159.5 meter cubic (m3) or 141.5 mm., respectively. Hence, 27.6% and 12% of the mean annual rainfall was lost because of surface runoff and groundwater recharge and the rest 67% was due to evapotranspiration. The high amount of evapotranspiration was mainly due to the bimodal rainfall pattern. Moreover, the study further disclosed that rainfall coefficient was greater than 0.6 (>0.6) but less than 0.6 (< 0.6) during rainy and dry seasons (table 4).

Table 9 : Calculated potenail evapotraspiration in m

Parameters	Months												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
P	20.47	30.52	58.57	80.72	60.76	40.2	369.5	357.0	119.4	48.4	26.56	21.94	1234.04
PET	43.9	51.12	55.87	70.77	77.62	85.31	80.18	74.16	58.39	57.19	51.89	48.85	755.25
P-PET	-23.5	-20.6	2.7	9.95	-16.9	-45.1	289.3	282.9	61.03	-8.79	-25.3	-26.9	478.79
APWl	-84.5	-105	0	0	-16.9	-62	0	0	0	-8.79	-34.1	-61.0	-372.3
Sm	85.48	74.45	150	150	134.1	99.24	150	150	150	141.5	119.5	99.86	1504.1
AET	34.9	41.48	55.87	70.77	76.71	75.02	80.18	74.16	58.39	56.93	48.54	41.56	714.5
∆Sm	-14.4	-10.9	75.55	0	-15.9	-34.8	50.76	0	0	-8.53	-21.9	-19.6	0.23
SMD	-8.99	-9.64	0	0	-0.91	-10.3	0	0	0	-0.25	-3.34	-7.28	-37.71
S	0	0	78.25	9.95	0	0	340.1	282.9	61.03	0	0	0	772.1

Table 10 : AET (in mm.) Using soil water balance method for clayloam (200mm and 0.80m)

Param.	Months												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
P	20.47	30.52	58.5	80.7	60.76	40.2	369.5	357.0	119.4	48.4	26.56	21.94	1233.95
PET	43.92	51.12	55.8	70.7	77.62	85.3	80.18	74.16	58.39	57.19	51.89	48.85	755.12
P-PET	-23.4	-20.6	2.7	9.95	-16.86	-45.1	289.3	282.9	61.03	-8.79	-25.3	-26.9	478.93
APWl	-84.5	-105	0	0	-16.86	-62	0	0	0	-8.79	-34.1	-61.0	-372.25
Sm	131.1	118.3	200	200	183.8	146.7	200	200	200	191.4	168.6	147.4	2087.3
AET	36.77	43.35	55.8	70.7	76.92	77.3	80.18	74.16	58.39	57.00	49.33	43.17	723.07
∆Sm	-16.3	-12.8	81.74	0	-16.17	-37.1	53.28	0	0	-8.59	-22.8	-21.2	0.06
SMD	-7.14	-7.77	0	0	-0.69	-7.99	0	0	0	-0.19	-2.56	-5.68	-32.02
S	0	0	84.4	9.95	0	0	342.6	282.9	61.03	0	0	0	780.88

** for clay loam soil covered with cereal crops having root depth 0.8m and available water capacitym 200mm*

Table 11: AET (in mm) using soil water balance method. for clayloam (250mm and 1m)

Parameter	Months												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
P	20.47	30.52	58.57	80.72	60.76	40.2	369.52	357.03	119.42	48.4	26.56	21.94	1234.11
PET	43.92	51.12	55.87	70.77	77.62	85.31	80.18	74.16	58.39	57.19	51.89	48.85	755.27
P-PET	-23.45	-20.6	2.7	9.95	-16.86	-45.1	289.34	282.9	61.03	-8.79	-25.33	-26.91	478.88
APWL	-84.48	-105	0	0	-16.86	-62	0	0		-8.79	34.12	-61.03	-372.28
Sm	178.31	164.2	250	250	233.69	195.1	250	250	250	241.3	218.1	195.85	2676.55
AET	38.005	44.62	55.87	70.77	77.06	78.78	80.18	74.16	58.39	57.03	49.81	44.198	728.87
ΔSm	-17.54	-14.1	85.7	0	-6.304	-38.6	54.88	0	0	-8.63	-23.25	-22.2	10.03
SMD	-5.915	-6.49	0	0	-0.556	-6.53	0	0	0	-0.15	-2.07	-4.654	-26.37
S	0	0	88.4	9.95	0	0	344.2	282.9	61.03	0	0	0	786.6

* *the root depth of 1m and available water capacity of the root zone 250 mm.*

Table 12: Weighted AET calculated for each soil texture and land use

Soil texture	Land use/land cover	Root Depth (m)	W (mm)	Coverage (km^2)	Wtd	%	AET	Wtd. AET
Sandy loam	Moderately deep rooted (cereal crops)	1	150	50.1	0.4895	48.95	728.8	356.75
Clay loam	Moderately deep rooted (cereal crops)	0.8	200	43.2	0.422	42.2	714.5	301.58
Clay loam	Deep rooted (grass)	1	250	9.05	0.0884	8.84	723.2	63.947
	Total	2.8	600	102.4	1	100	2166.5	722.27

3.3 Surface Runoff Estimation: -

Runoff results from rainfall that does not infiltrate but forms flows as thin sheet of across the land surface. (Tenalem & Tamiru, 2001). In this study area, the absence of gauged hydro-meteorological stations posed difficulty to work out a model for the runoff generation of the catchment. The volume runoff of the study area was computed using the runoff coefficient model as given in Equation (6). Based on the model, the study revealed that the volume of runoff was projected to be 120,581,841 m^3 which is 326 mm. (table 11). Of the total rainfall, 27.62% of the mean annual rainfall of the catchment was lost through surface runoff. A study at Illala Catchment in North Ethopia identified that about 93% of the surface runoff occured during the wet months while the remaining 7% happened during the dry seasons (Tekelebrhan, et al., 2011). He added that groundwater recharge accounted for 12% of the precipitation while the rest 81% and 7% were converted into evapotranspiration and surface runoff, respectively. Runoff generation is significantly affected by various factors such as land use, land cover (LULC), topography (slope and elevation), and soil textures. Furthermore, Table 11 clearly disclosed that the type of land use, land cover, soil type, and slope type were very essential environmental agents that directly controlled runoff formation. The amount of rainfall, runoff coefficient factor, and depth of soil were also found to be significant factors in affecting surface runoff formation.

In hydrological cycle, natural vegetation regulates influence on runoff and it protects from erosion (Abebe, 2013). Among the land uses, grazing and cultivated lands are more prominent in surface runoff generation. On the other hand, cultivation, plantation, and shrubs played less role in surface runoff creation. In terms of topography, flat and gentle sites are less vulnerable to runoff as compare to steepy areas. Soil texture is also other determinant element controlling runoff generation. In this study, clay and sandy clay soils were less likely exposed as compare to rocky and silty soils. The highest amount of runoff was generated from shrubs, plantation, and cultivation because of large area coverage but with slight difference in K values. In other words, grazing and cultivating lands have less impact on surface runoff generation. The highest and lowest runoff were 120,581,841 m^3 ; 43,959,708 m^3 and 11,913,780 m^3 ; 11,913,780 m^3 respectively (table 11). Runoff has a direct relationship with area and runoff coefficient. Hence, the total amount of runoff genearted from the study area was 1189mm. (1.189 m) as in table 11. The modeling of surface runoff in arid and semi-arid area is hardly possible as the mean annual rainfall and evapotranspiration are very difficult to determine (Yongxin & Beekman, 2003).

In this study, aerial coverage and runoff coefficient were found the most influential in estimating surface runoff creation. However, this method of estimation had some drawbacks as it hardly represented the space and time vulnerability. The mean annual rainfall was taken as constant but precipitation greatly varied during winter and summer season. In arid and semi-arid areas, in situ measurement of surface runoff is considered to be more accurate and explanatory. But, this cannot happen anytime and anywhere as it requires labor, material, and other constraints. It is more expensive and demanded more time and resources (Ybralem, 2013). Nowadays, satellite remote sensing technologies provide spatial and temporal hydro-meteorological data such as precipitation and evapotranspiration.

Table 13: Runoff values using the runoff coefficient method

S.N	Land use	Soil	Slope	Area(m^2)	PPT(m)	K	Runoff (m^3)
1	Grazing	Clay	Flat	9,050,000	1.189	0.16	1,721,672
2	Cultivation	Clay	Gentle to flat	65,210,000	1.189	0.25	19,383,673
3	Cultivation	Sandy clay	Gentle-Gentle to flat	50,100,000	1.189	0.2	11,913,780
4	Shrubs	Rocky*	Steep	123,240,000	1.189	0.3	43,959,708
5	Plantation	Rocky*	Steep	122,240,000	1.189	0.3	43,603,008
	Total			370,000,000	1.189		120,581,841

3.4 Groundwater Recharge:

Groundwater recharge areas are mostly located at higher topography of a given basin. In this study area, recharge areas had negligible groundwater potential zone. A hydro Geological map in fig. 7 , it was indicated that the main recharge sites were in the upper, left, and right side of Gerado Catchment. These areas were valleys and ridges on the way to Kombolcha, Albuko, Mekaneselam, and Kedijo and they covered a relatively large part of study area in comparison to the discharge area (figure 7). The lower elevated land of the study area got recharge not only from precipitation but also from groundwater flow from the upstream. However, the left and right side of the catchments had high recharge because of fractures and faults. . These areas were mostly located in the lower topography of the basin. The discharge areas in the study were low lands of Gerado well fields. They covered a relatively small area than the recharge area, which made the Gerado well field to have high groundwater potential. Identifying the recharge and discharge area of a certain basin is important for identifying potential sites and utilizing water resource management.. In the study area, recharge areas had a negligible groundwater potential zone.

There are various methods of estimating groundwater recharge; for example, water level and porosity, base flow recession analysis and water balance method. Different studies suggested that recharge values obtained from water balance method were constantly higher than values from other methods. However, these methods complemented each other and thus can be used depending on the availability of data (Simmers, 1988). The CMB (chloride mass balance) approach has been extensively used in estimating low recharge rates mainly because of the lack of other suitable methods. Low water fluxes ranging from 0.05 to 0.1 mm/ year have been estimated in arid regions in Australia and in the USA. The storage concept method using water table fluctuation has been used in various climatic conditions (Scanlon et al., 2003). Recharge rates estimated by this technique range from 5 mm/year in the Tabalah Basin of Saudi Arabia (Abdulrazzak et al. 1989) to 247 mm/ year in a small basin in a humid region of the eastern USA (Rasmussen & Andreasen, 1959). Identifying the recharge and discharge area of a certain basin is important for identifying potential sites and for water resource management and utilization. The amount of water extracted from an aquifer without causing depletion is primarily dependent upon groundwater recharge. Quantification of the rate of natural ground water recharge is basic for efficient groundwater resource development and management. It is particularly important in areas with large demand for groundwater supplies. Such resources are the key to economic development. The main purpose of this computation is to make a quantitative evaluation of the amount of water that infiltrates into the ground to recharge the ground water circulation occurring in the study area. The most important terms of the factors in water balance are precipitation, evapotranspiration, and discharge (Claudia, 2007). As the result, the change in water storage on water balance depends on the period over which the water balance was computed. The important method to determine water that recharges the ground water is water balance method, which is based on the law of conservation of energy.

The finding of this study showed that the volume of water that recharged the groundwater of the catchment was found to be 52,208,159.5m^3(141.5 mm) per year. Table 14 showed that 60. 4% of precipitation was lost as evapotranspiration; 27.6 % as surface runoff and the amount of water that recharges the groundwater was only 12% of the annual precipitation. Recharge areas were mostly found at higher topography of the basin. The finding of the current study conformed with a study done in north Ethiopia and it was found that 12% of the annual rainfall was lost in the form of ground recharge (Tekelebrhan, et al., 2012). Similarly, Tesfa et al., (2021) found that the annual groundwater recharge was found to be 197.23 mm/year. Again within the basin, two watersheds (Ribb and Gumara) had recharge of 204.76 mm and 184.83 mm., respectively. This difference was due to physiographic and climate settings. A similar study in the semi-arid of North Ethiopia by Esayas, et al., (2019) showed that more than 83% of the total annual rainfall was converted into evapotranspiration and the rest 7.4 % and 7.1% were lost as recharge and runoff. This result deviated from the current finding because of the method employed and climate settings. The current study had a bimodal rainfall while that site was in semiarid zone.

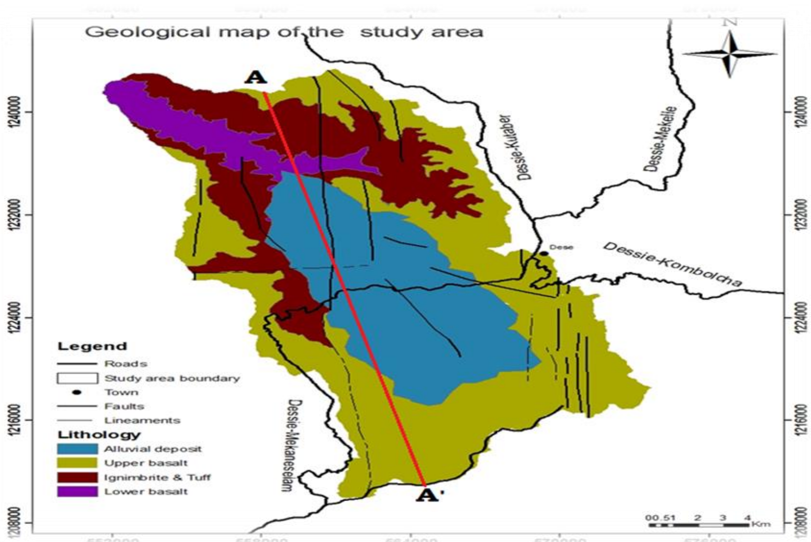

Figure 7: Geology map of Gerado Catchment

Table 14: Summary of water balance components

PPT (MM)	AET (MM)	RUNOFF (MM)	RECHARGE (MM)
1307.76	722.3	327	145.5

3.5 Groundwater Potential Mapping

For this research, the groundwater prospect map of the area was prepared by integrating eight thematic layers using spatial model analysis. Based on the multi-criteria evaluation technique, each layer and field value were assigned a rank and weighting (Arivalagan, et al., 2015**)** as all variables hardly had the same impact in determining groundwater occurrence and movement (Satty, 1980). Table 15 showed that the three factors affecting groundwater occurrence were lithology (34.5%), lineament (23.4%), and geomorphology (15.5%). On the other hand, the five least influencing factors were slope, soil, drainage density, rainfall, and land use/cover. The pair wise comparison (table 15) of groundwater potential mapping (GWP) and controlling weighted factors were shown in table 15.

The groundwater potential (GWP) of the area was computed using mathematical equation given below:

$$\mathrm{GP} = \sum_{i=1}^{n} \mathrm{WiXi} \qquad 8$$

Where GP = Groundwater potential, WI = weight for each thematic layer and

Xi = Rates for the classes with in the thematic layer.

*GWP=0.3456*LT+0.2339*LD+0.1548*GM+0.1033*SL+0.0689*SOL+0.0449*DD+0.0286*RF+0.0203*LULC*

Were GWP = Groundwater potential, LT = lithology, LD = lineament density, GM = geomorphology, SL = slope, SOL= soil, DD = drainage density, RF = rainfall, and LULC = Land Use Land Cover.

Table 15: Pairwise Comparison Matrix among GWP Thematic Layers (CR = 0.0805)

	LT	LD	GM	SL	SDL	DD	RF	L	WEIGHT	%
LT	1	2	4	5	6	7	8	9	0.3453	34.53
LD	½	1	2	4	5	6	7	8	0.2339	23.39
GM	¼	½	1	2	4	5	6	7	0.1548	15.48
SL	1/5	¼	½	1	2	4	5	6	0.1033	10.33
SOL	1/6	1/5	¼	½	1	2	4	5	0.0689	6.89
DD	1/7	1/6	1/5	¼	½	1	2	4	0.0449	4.49
RF	1/8	1/7	1/6	1/5	¼	1/2	1	2	0.0286	2.86
LULC	1/9	1/8	1/7	1/6	1/5	1/4	½	1	0.0203	2.03

The potential groundwater areas lay within lithology class of alluvia deposits and geomorphology class of alluvia plain (figure 5 &6). Moreover, areas with flat slope and low lineament density were found in most potential areas of groundwater. If we observe the spatial distribution of the groundwater suitability map, the least potential areas are located in the western, northern, and southern parts of the study area. And these are characterized by steep slope and high drainage density which facilitate high run off creation and hence result in low groundwater potential. Thus, areas with good classes of groundwater map account for small areal coverage. Hence, it can be generalized that the study area had little groundwater potential suitability as compared to its total areal coverage. Furthermore, geospatial techniques with the help of multi-criteria decision analysis (MCDA) were good to investigate the relationship between different geomorphological and environmental factors. Therefore, those tools were very effective and indispensable for planning and managing groundwater in watershed areas.

The groundwater prospect map of the area was classified into four zones: very good, good, moderate, and poor. The very good groundwater prospect zones were mostly found within alluvial plains/valleys with smooth and irregular plain geomorphological classes. Moreover, it overlaps with flat to moderate slope classes. Groundwater zones were compared with borehole yield data to check the validity of the result. Similar studies by Olutoyin, (2013), Singh et al, (2014), and Soumen (2014) stated that validation of the groundwater potential zones should be done using existing data (dung wells and bores). Thus, out of the collected and reviewed 60 water points, 57 were measured and estimated actual yield data. In general, the data indicated high yield (≥30 l/s) in the very good potential areas while very low yield (<5 l/s) in the very poor potential areas. Intermediate values appeared in the zones between these extremes. Water points with yield 5-<12 l/s occurred in the poor, 12-17 l/s in the moderate, and 18.5-20 l/s in the good zones of groundwater potential. As shown in figure 6, 5, most of the suitable groundwater areas were found in the central and eastern part of the study area. In contrast, the northern and western part of the Gerado Catchment had less potential groundwater.

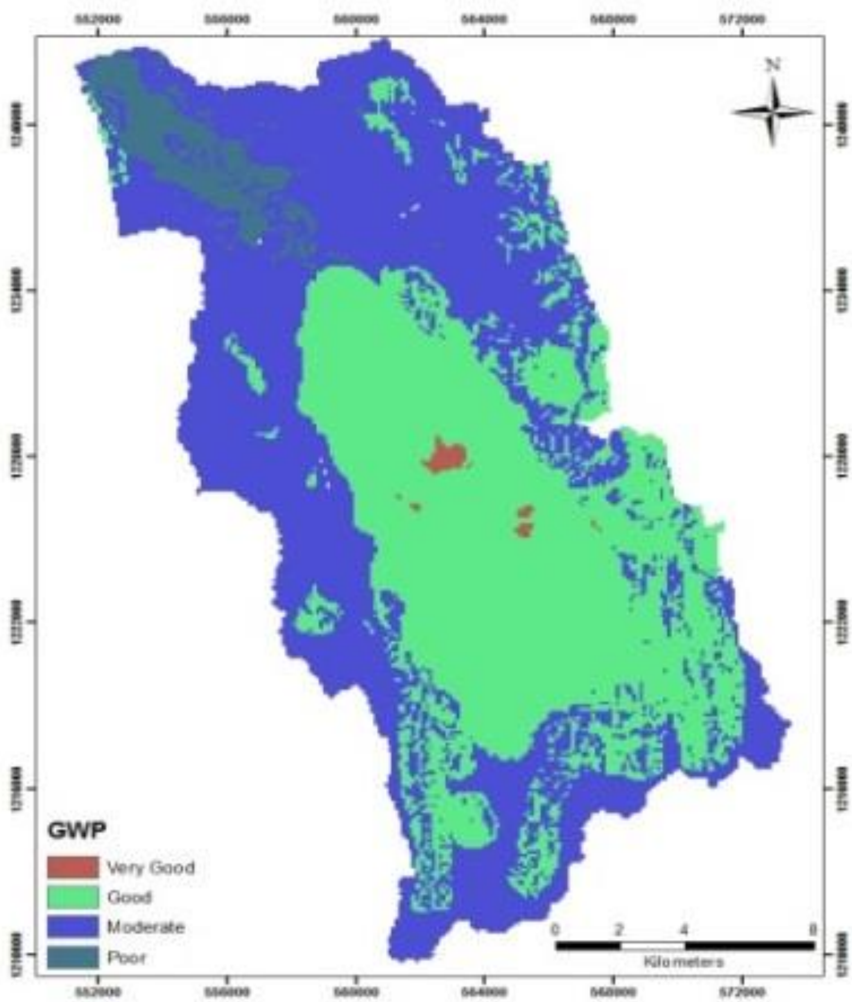

Figure 8: Groundwater potential map

4 CONCLUSIONS AND RECOMMENDATIONS

In the Northern Ethiopia owing to the absence of gauged metrological stations and continuous land degradation, understanding hydro-metrological nature and characteristics was difficult. And this had a direct impact on agriculture in particular and the economy of the region in general. However, in such circumstances understanding, evaluating, and analyzing the hydro-metrological characteristics of these factors using the existing traditional conventional methods was very essential. This was more appropriate in remote areas which hardly had ground based installed stations data. The present study was carried out in the Gerado Catchment, in the Northern Ethiopia to investigate and understand the hydro-meteorological characteristics (runoff, evapotranspiration, groundwater recharge, and mapping groundwater potential). Meteorological data were collected from existing metrological station (Dessie, Guguftu, Albuko, Kutaber, Kombolcha, and Tita). since some of the data were missing, an appropriate technique was used to fill the gaps. Once the data quality was checked, spatial interpolation methods were applied to create surface map climatic data. Thornthwaite Empirical Modeling was used to calculate the potential evapotranspiration of the catchment. This method used air temperature as an index of energy available for evapotranspiration. On the other hand, the volume of runoff from the catchment was also computed using the runoff coefficient scheme. Mapping the groundwater sites were done through the application of geographic information sciences. The finding of the study indicated high potential groundwater areas were found in the central part of the study area with alluvial geological unit. The central and eastern of the area lay within good groundwater prospect areas. In contrast, the western, northern, and southern parts were located under moderate and poor water potential zones. The result further disclosed that the potential and actual evapotranspiration of the area had about 755 mm/year and 722 mm/year. This suggested that the actual evapotranspiration result was less than the potential evapotranspiration because it considered various factors like soil and land use cover. At the same time, the runoff and groundwater recharge of the area were estimated to be 120,581,841m^3 (326 mm.) and 52,208,159.5 m^3 (141.5 mm.), respectively. Hence, out of the total rainfall, 27.6% of the mean annual rainfall was lost because of runoff. Nevertheless, the remaining 40% was wasted owing to evapotranspiration and only 12% was recharged to the ground. Therefore, having updated information on hydro-meteorological ^ of the catchment would be significant in water resource development projects such as dams and reservoirs. However, this study didn't show the spatial and temporal dynamics and trend of the aforementioned hydrological variables. So, further studies should be carried out using Remote Sensing and Geographic Information System (Geo-Spatial Technologies) as it covered large area but less costly. But, they have to consider using updated and high quality data for better outcome and findings. Moreover, such studies have to be supported through extensive ground field survey for better and accurate outputs. Installation of hydrological stations in the study area should be undertaken for better understanding of hydrological conditions.

Conflict of Interest: on the behalf the corresponding author, I can assure you that there is no conflict of interest among the authors of this research work.

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