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Biophysical Characteristics of Weyb Watershed, Bale Mountainous Area of the Southeastern Ethiopia

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Abstract*: Characterizing the biophysical features at a watershed level is a significant input for analyzing natural resources, for solving potential water resource management problems, for integrated water utilization assessment, for water allocation policy and management. The objective of this study was to assess the biophysical characteristics of Weyb watershed, which is recognized as a potential agricultural zone in southeastern part of Ethiopia, was considered as a case study. Relevant data were used and; ArcGIS, Microsoft Excel sheet and fundamental formulae were applied for the analysis. Accordingly, six current biophysical characteristics of Weyb watershed i.e., watershed area, land use land cover and soils, geomorphology, climate, agricultural practice and population have been analyzed and discussed briefly. The mean annual precipitation, actual evapotranspiration and mean temperature of the watershed are 1015 mm, 970.1 mm and 14 ^{0}C respectively. The study results show that the watershed is highly suitable for widespread agricultural production.

***Keywords*: ArcGIS,** *Biophysical Characteristics, Ethiopia, Potential agricultural zone, Weyb Watershed*

I. INTRODUCTION

The water and land as entry points to and support points for the natural resource base has become the main focus of development and an integral part of the water resources development for agriculture, but the question of sustainability and adaptability remains unclear unless the biophysical features of watershed are implicitly studied. The watershed's general biophysical characteristics are groups of features that distinguishes one watershed from others. These groups of features or biophysical characteristics are very important inputs or elements whenever one needs to study about watershed's resources availability, utilization and management [1] [2].

Amanuel Zenebe [1] has identified and discussed eight general basin characteristics which include population, geography, climate, geomorphology, geology, soils, wild life, and water resources. As per the Georgia environmental protection division report on water availability and use [3], the physical characteristics of the River basin investigated and discussed include its location, physiography, soils, climate, surface water and ground water resources, and natural water quality. These physical features influence the basin's biological habitats and the ways people use the watershed's land and water resources. The most important geographical, geological, hydrological, and biological features of a river basin are also general descriptive characteristics adopted [4].

In this typical study, six fundamental biophysical features of Weyb Watershed were deeply investigated. Namely; Watershed Area, LULC and Soils, geomorphology, climate, agricultural practice and population. This study result will be used by the Watershed Authority, University Students and Scholars to develop effective strategy and policy related decisions on this watershed, to gain basic knowledge about the biophysical characteristics of Watershed, and an input for future study in the watershed respectively.

II. MATERIALS AND METHODS

A. Description of Study Area

Weyb watershed was considered as the study area for this research. The watershed is located in the upper part of Weyb Subbasin, one of the three sub-basins of Genale-Dawa river basin namely; Genale, Dawa and Weyb [5]. This Weyb watershed is in south-eastern part of Ethiopia, Oromia regional state, and is located between 6° 50′ 00″ – 7° 25′ 00″N latitudes and 39° 30′ 00″ – 40° 34′ 00″E longitudes (Fig. 1). The Weyb main river starts its course from the northern margins of Bale Mountains and flows to the Indian Ocean through the Ethiopia Somali lands [6] [7].

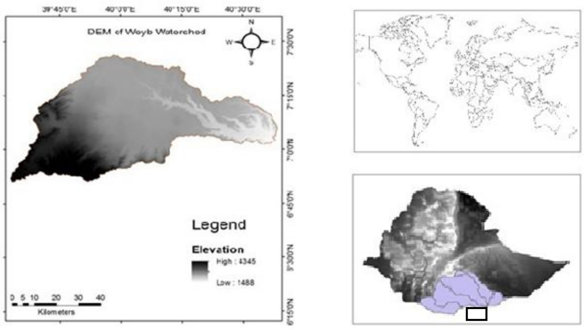

Figure 1: Location map of Weyb watershed

B. Watershed Area

The Ethiopian Digital Elevation Model (DEM) of 90 meters resolutions including the watershed's administrative map, soils data, land use/land cover data and the Genale-Dawa river basin

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master plan report of 2007 were collected from Ethiopian Ministry of Water Irrigation and Electricity (MoWIE). Before analyzing the spatial input data, these data were projected into the same projections called UTM Zone 37N in ArcGIS. ArcGIS program version 10 was used to analyze the watershed characteristics. Then, the watershed was delineated from the Ethiopian DEM, which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. The Weyb Subbasin was formerly divided into upper, middle and lower sub-basins. In line with this, this typical study concentrated on the upper part of this Subbasin (i.e., Weyb watershed).

C. Land use/land cover and Soils

The Land use/ land cover (LULC) is one of the important spatial data that characterizes the catchment. This parameter is dynamic in nature as land use may change both spatially and temporally. The LULC map and datasets were obtained from MoWIE, which was produced in 2007. In order to make this data more recent and up-to-date, ground truth checks up has been done as well as google earth was used.

Furthermore, the relevant physio-chemical properties of major soil types in the watershed were mainly obtained from the digital soil map collected from MoWIE. This parameter is static in nature in that in cannot change both with time and space.

D. Geomorphology

Geomorphology describes the river origin, to where it flows, the maximum and minimum elevations, major tributaries of the main river, the mean annual streamflow amount and watershed's slope classes. Consequently, these features were analyzed using ArcGIS.

E. Climatic Data

Under this part of the study, the mean annual rainfall, mean annual evapotranspiration and minimum and maximum temperatures were analyzed thoroughly. For this purpose, a historical climatic data of twenty-five years was collected from the National Meteorological Service Agency (NMSA) for the six stations located in and around the watershed as presented in Table I and Fig. 7. Namely; Agarfa, Robe, Dinsho, Ginir, Homa and Sinana stations.

Table I: Meteorological data (Source: NMSA)

S No.	Station	Latitude (°N)	Longitude (°E)	Elevation (m a.s.l.)	Period of record
1	Agarfa	7° 16' 1.2"	39° 49' 1.2"	2550	1983-2017
2	Ginir	7° 7' 58.8"	40° 42' 00"	1750	1989-2016
3	Homa	7° 7' 58.8"	39°55'58.8"	1680	1987-2017
4	Sinana	7° 4' 1.20"	40° 13' 1.2"	2400	1983-2016
5	Robe	7° 7' 58.8"	40° 03' 00"	2480	1984-2017
6	Dinsho	7° 06' 00"	39° 46' 1.2"	3072	1970-2017

The historic time base selected for the hydrological analysis was fixed to be 25 years period (i.e., 1989 – 2014). In addition, the missing meteorological data was filled using normal ratio method [2] (Eq. 1), the data consistency was also checked using double-mass curve techniques [8], and the outlier detection was also conducted using the standard deviation method [9] (Eq. 2 and 3). The evapotranspiration output was also computed using FAO-Penman Monteith equation [10] (Eq. 4).

$$Px = \frac{1}{n}\sum_{i=1}^{i=n}\frac{Nx}{Ni}Pi \quad (1)$$

Where: Px is the missing rainfall for any storm at the interpolation station 'x'
Nx the normal annual rainfall value for the 'x' station and
Ni the normal annual rainfall value for 'ith' station.
Pi is the rainfall for the same period for the same storm at the "ith" station of a group of index stations

$$X_H = \bar{X} + K_N S \quad (2)$$
$$X_L = \bar{X} - K_N S \quad (3)$$

Where, X_H is high outlier threshold in log units, X_L is low outlier threshold in log units, $\bar{X}$ is mean logarithm of systemic data, S is the standard deviation in log units and K_N is critical deviate for sample size N at 10% significance level.

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (4)$$

Where: ETo = reference evapotranspiration (mm/day)
Rn = net radiation at the crop surface (MJ/m2/day)
G = soil heat flux density (MJ/m2/day)
T = air temperature at 2-meter height (°C)
U2 = wind speed at 2-meter height (m/sec)
es = saturation vapor pressure (kPa)
ea = actual vapor pressure (kPa)
es – ea = saturation vapor pressure deficit (kPa)
Δ = slope vapor pressure curve (kPa/°C)
γ = psychrometric constant (kPa/°C)

F. Agricultural Practice

The major crop types grown in the watershed both by rainfed and irrigated agriculture were assessed. In addition, areal coverage and their water sources of existing and planned irrigated agriculture were also investigated. For this specific study purpose, relevant data were collected from Oromia Irrigation Development Authority (OIDA) and FAO paper no. 56.

G. Population

Weyb watershed is located inside Oromia administrative reginal state particularly in Bale zone, and some part it exists in west Arsi zone. Subsequently, seven districts from Bale zone i.e., Agarfa, Dinsho, Sinana, Goba, Goro, Gasera and Ginir and some parts of Adaba district from west Arsi zone exists inside the watershed (Fig. 8).

Under the Federal Democratic Republic of Ethiopia, the Population Census Commission, Central statistical Agency provided the population data of Bale and West Arsi zones for the study which is conducted in 2007. According to the Agency's data, the total population living inside Weyb watershed in 2007 was 534,348 and its annual growth rate is assumed as the same to the national population growth rate of 2.6%.

Population Projection

For population projection of the watershed, the method used by Ethiopian Central Statistics Authority (ECSA) was applied. Among the other projection methods, this method is considered to be better for forecasting the Population of the project area. Because most of Ethiopian towns and rural areas are adopting this method and there is lack of enough data to use other forecasting techniques. In this method, the assumption is made that all towns and rural areas irrespective of size tend to grow according to the following equation [6]:

$$P_N = P_0 * e^{KN} \tag{5}$$

Where: P_N = Number of populations after N years
P_0 = Present population
N = Number of years
K = Growth rate

III. RESULTS AND DISCUSSIONS

A. Watershed Area

According to the analysis, the Weyb watershed covers a total drainage area of about 4,189 km^2. Fig 2 illustrates the outlet of Weyb main river at Sofumer, the watershed and stream network delineated based on the digital elevation model using the Hydrology tools in ArcGIS.

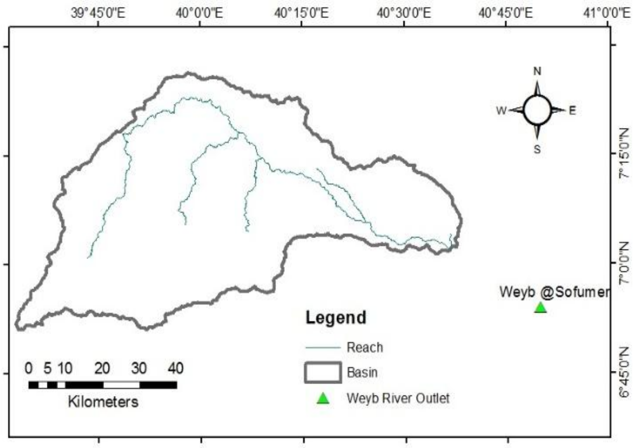

Figure 2: Weyb Watershed, Weyb river Outlet and stream networks

B. Land Use/Land Cover and Soils

Land Use/Land Cover (LULC)

From the analysis of LULC in ArcGIS, there are three major types of land uses identified and reclassified in the watershed. As shown in Table II and Fig. 3, the major land use types in the watershed are agricultural land covering 79.40% and forest covering 20.03% out of the total land use. The remaining land use type is medium residential covering 0.57% of the area.

Table II: Major land use types and areal coverage of Weyb watershed

Value	Land Use Cover	Area (km^2)	% of watershed
1	Agricultural Land	3,326	79.40
2	Forest Land	839	20.03
3	Medium residential	24	0.57
	Total	4,189	100

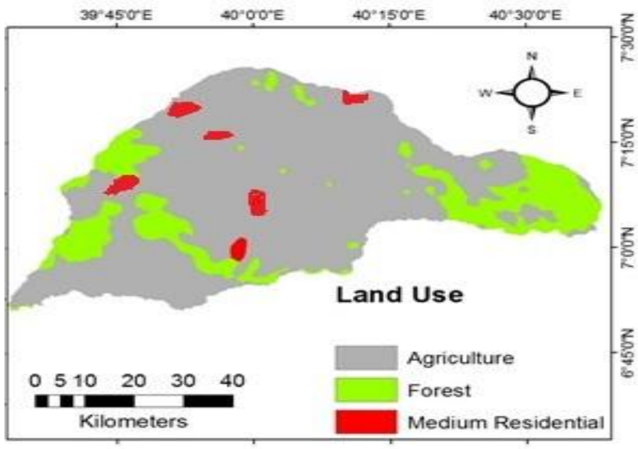

Figure 3: Land Use maps of Weyb watershed

The upper most part of the watershed is covered with the afro-alpine ecosystem that is known to be the largest area in Ethiopia [3]. Besides, dense forest is commonly found in the upper part i.e., at Dinsho (Fig. 4) and at Sannete highlands, and in the lower part of the watershed near Sofumer.

Figure 4: Dinsho forest (image was taken on December, 2018)

Soils

The soil types analyzed in ArcGIS were shown in fig. 5 and table III. Accordingly, there are five soil types available in the watershed. Namely; cambisol, luvisol, vertisol, and leptosol, regosol. Among this soil types, cambisol, luvisol and vertisol soils types are dominant soils in the watershed.

Table III: Major soil types, hydrologic soil groups and areal coverage (Source: MoWIE, 2017)

S No.	Soil type	Hydrologic soil group	Runoff potential	Area coverage (km^2)	% of watershed
1	Cambisol	D	High	1,405	33.54
2	Leptosol	A	Low	276	6.59
3	Luvisol	B	Moderate	1,246	29.73
4	Regosol	B	Moderate	381	9.10
5	Vertisol	D	High	881	21.04
			Total	4,189	100

Cambisol soil type covers 33.54% and luvisol covers 29.73%. Cambisols are weakly to moderately developed soils characterized by minor or moderate weathering of the parent material and by absence of considerable amounts of illuviated clay, organic matter, aluminum or iron compounds. Luvisols are soils with subsurface accumulation of high activity clays. Leptosols are very shallow soils over hard rock or in unconsolidated very gravelly material and Regosols are soils with very limited soil development covering 6.59% and 9.10% respectively. On the other hand, vertisols are dark-colored cracking and swelling clays covering 21.04% (table 3). These soil types are fertile for producing cereal crops except Leptosols.

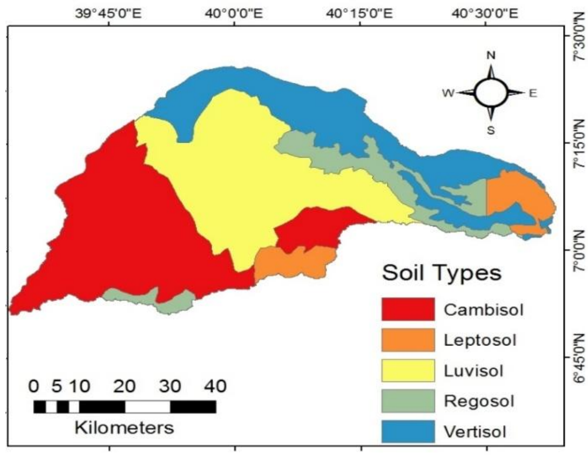

Figure 5: Soil map of Weyb watershed

C. Geomorphology

The Weyb river originates from the northern flanks of Bale Mountains and first flows to the northeastward then flows to east and southeastwards for the rest of its course. Finally, it joins with Genale and Dawa rivers near Ethio–Somalia border strengthening its journey to Indian Ocean [1] [13]. It originates from an elevation of 4345m above mean sea level, in Bale Mountains highest point locally called *Sannete* to an elevation of 1488 m at the watershed outlet near Sofumer.

The major tributaries of this Weyb watershed are Shaya, Tegona and Tebel. The Tebel River originates close to the northern Wabi-Shebelle divide near Ginir and joins Weyb Main River. The mean annual streamflow discharge of Weyb main river at Sofumer gauging station is about 16.30 m^3/s.

Table IV: Slope classes and their areal coverage

S No.	Slope class	Slope (^{o})	Area (km^2)	% of watershed
1	Gentle	0 – 7	3085	73.65
2	Moderate	7 – 25	993	23.70
3	Steep	25 – 56	111	2.65
		Total	4,189	100

Furthermore, this watershed falls from gentle to moderate slope classes which have a water holding capacity for longer time as shown in table IV. The watershed area is composed of 2.65% steep hills and mountains, 23.70% flat to undulating, and 73.65% gentle slope. Gentle sloppy areas are concentrated in the middle of the watershed i.e., covering Agarfa, Sinana, Gasera, lower parts of both Goba and Dinsho districts. From table 4 and Fig. 6, we can observe that only 2.65% out of the total area is subjected to severe erosion which are not suitable for agriculture.

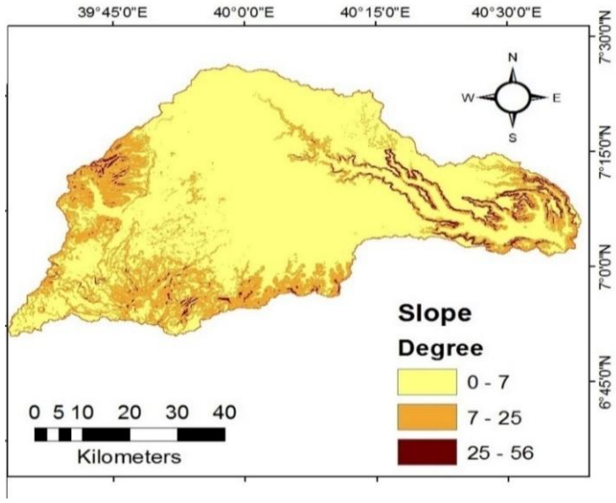

Figure 6: Weyb Watershed's slope class

D. Climate

Rainfall

The spatial and temporal distribution of rainfall at watershed scale, using GIS approaches are found to be very effective in the study area (Fig. 7). The area and influencing factors of influencing rain gauge station were calculated in ArcGIS and shown as shown in table V. Subsequently, based on the Thiessen polygon method, the mean monthly and annual areal distributions of the rainfall over the watershed has been analyzed.

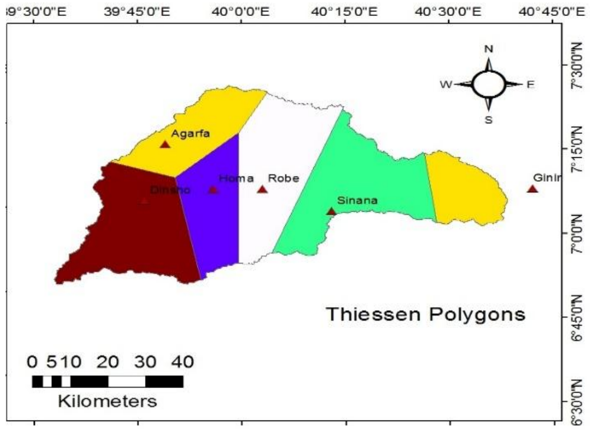

Figure 7: Thiessen polygons constructed for the watershed

Table V: Influencing factors of rain gages

Gage Name	Total area of Thiessen polygon for the watershed (km^2)	Area of influence (km^2)	Influencing factor
Agarfa	4,189	533	0.127
Ginir		368	0.088
Homa		541	0.129
Sinana		909	0.217
Robe		913	0.218
Dinsho		925	0.221
Total		4,189	1.00

The mean annual rainfall of the watershed is about 1015 mm and reaches 1688 mm at the highlands of Dinsho, western part of Weyb watershed. The catchment receives its maximum rainfall during February – April and covers 33% of the annual rainfall. The second rainfall period covers the period from June to September (Fig. 9).

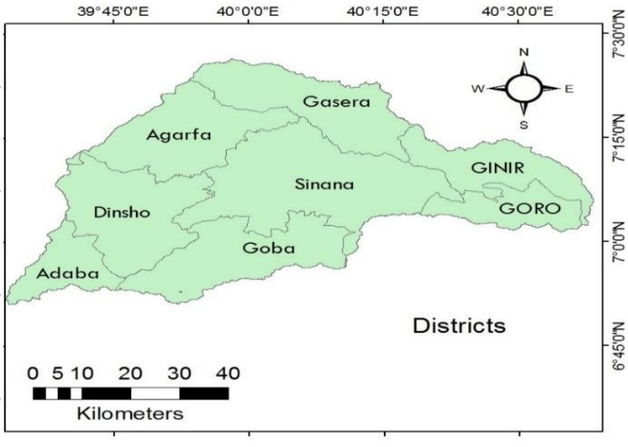

Figure 8: administrative districts of the Watershed

This watershed receives the Bi-Modal Type I rainfall (Fig. 9), in which rainfall continues through the intermediate period between the early and late season rainfall peaks [13][14]. This is reflected in the rainfall profile generated and shown in Fig. 8. Generally, the climate of the watershed is suitable for cereal crop production giving better yield than other places of the country.

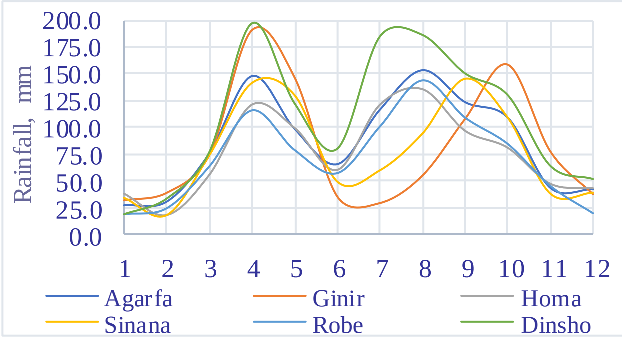

Figure 9: Mean Monthly Rainfall at different rain gauge stations of the watershed

Temperature

The watershed's annual air temperature ranges between 3.0 ^{0}C and 25 ^{0}C and the mean annual temperature is 14 ^{0}C (fig. 10). The climate of the watershed varies from humid subtropical to arid.

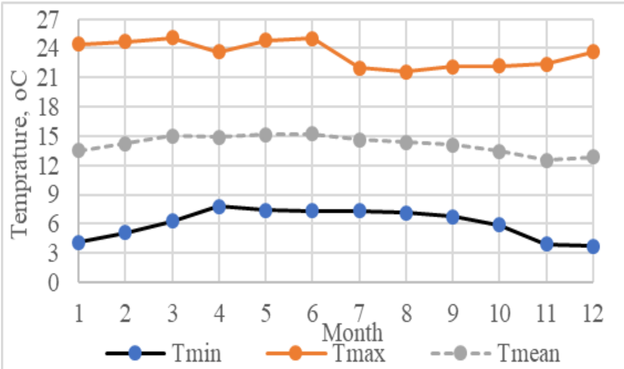

Figure 10: Temperature condition of Weyb watershed

Evapotranspiration

The mean annual reference and actual evapotranspiration are 842.7 mm and 970.1 mm respectively. The mean daily evapotranspiration ranges from 3.1 to 3.9 mm/day with the mean evapotranspiration of 3.4 mm/day (see Fig. 11).

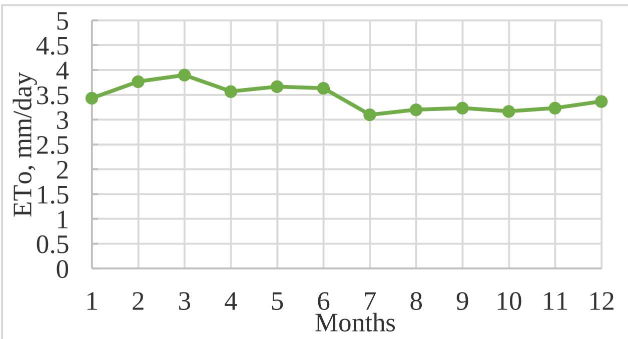

Figure 11: Watershed's Reference Evapotranspiration

E. Agricultural Practices

The major portion of the economy in the Weyb watershed is based on small-scale rain-fed subsistence farming in the highlands of the area. The major rainfed crops grown in Weyb watershed are cereal crops such as wheat (Fig. 12), barley, linseed and field pea.

Wheat is the predominant crop grown in the area followed by barley. Their

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cropping schedules are twice annually in that it is between February – April and July – September. Moreover, different types of irrigated agriculture have been practiced in the watershed producing wheat and barley. Application of water for irrigation using water pump and shallow well irrigations are also adapted in the area even though it didn't exceed irrigating around 60 ha farmland.

Several tributaries drain into Weyb river, and some of them are identified as potential sources of irrigation water, including the Shaya and Tegona rivers. According to the Genale Dawa master plan study report, the irrigation potential for this typical study watershed is identified to have about 10,000 ha of irrigable land excluding the existing irrigation schemes [9]. This existing and proposed irrigation potential accounts about 3.31% of the drainage area. Out of the total potential irrigation area of the watershed (i.e., 13,873 ha), 3,813 ha of land has been actually under irrigation which accounts about 27.60%.

Figure 12: Rainfed Wheat farm at Sinana district (image was taken on December, 2018)

F. Population

The base year (2017) population of the watershed was estimated as 693,012 and the population density was about 230 persons/km^2. By applying the same procedure, the population of the area for 20 years was projected as 1,165,665 and the population density will be about 278 persons/km^2. Knowing the population data helps, in addition to quantifying their domestic water consumption, to know their significance impact on the water resources abstraction from as well as pollution to the watershed.

IV. CONCLUSION

The assessment of biophysical characteristics of Weyb watershed gives awareness one how to significantly describe the basic features and to use them as an input for different activities to be conducted inside the watershed. Results exhibit that this watershed does have moderate climatic condition which is very suitable for massive agricultural production. The rainfall pattern is bimodal in that with little support of irrigation, crop production can be possible with rainfed system.

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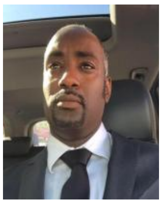
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