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Agroclimatic zonation of Tigray region of Ethiopia based on aridity index and traditional agro-climatic zones

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ABSTRACT

The aim of this study was to identify the agroclimatic zones of Tigray region based on aridity index and traditional agroclimatic zone using 37-year (1981-2017) spatial climate data downloaded for Tigray region from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) for rainfall and from Enhancing National Climate Services (ENACTS) data for temperature. Arc map 10.3 was used for mapping of all climatic variables and zonation of agro-climatic zones. Potential evapotranspiration (PET) was computed based on Hargreaves formula and the aridity index was computed. Besides, the digital elevation model was downloaded from ASTER data. The aridity map of Tigray divided into three index zones (0.03-0.2, 0.2–0.5 and 0.5–0.65) and five traditional agro-climate zones (<1500,1500-2000,2000-2500, 2500-3000, >3000 m.a.s.l.) were overlaid, which divided entire region of Tigray into fifteen agro-climatic zones. Hot semi-arid, warm semi-arid, tepid semi-arid and hot arid were the dominant zones in the region.

Keywords: Rainfall, potential evapotranspiration, aridity index, agro-climatic zone

Climate is one of the main elements that determine the suitability of an area for crop growing and its potential for agricultural production. Agro-climatic zonation scheme is a standard tool for prioritizing agricultural research because they offer relevant, available information about target environment (Corbett 1996). Proper descriptions of the target environment also enable research efforts to be more clearly focused at local issues and needs. Previous agro-climatic classification like Köppen climate classification andthe Ethiopian traditional climate classification were less detail. Their main limitation is that they heavily depend on temperature for the climatic classification. However, in the semi-arid tropics' temperature is not the main limitation for crop growth (Tilahun 2006). Hence, appropriate characterization of agro-climatic zones in the semi-arid should link the rainfall with evapotranspiration (Araya *et al.* 2010).

Combining the traditional zones with aridity index will improve the agro-climatic classification system because this approach takes rainfall, temperature and potential evapotranspiration into account. Proper agro-climatic classification will help to interpret existing cropping pattern, as well as suggest new cropping patterns (Bisht *et al.* 2013). It could help policy makers, investors and agriculturists to work on crop suitability mapping and to plan for short term and long-term development strategies. Hence, an attempt has been made for Tigray region of Ethiopia.

MATERIALS AND METHODS

Study area

Tigray region is located between latitude 12°15 2 N and 14° 572 N and longitude 36° 27 2 E and 39° 592 E in the northern part of Ethiopia. The temperature regime of the region varies from hot to very cool temperature. Most part of the region's climate is characterized as semi-arid. The geography of Tigray region constitutes lowlands, mid-highlands and highlands.

Data collection

The 37 years (1981-2017) spatial rainfall data of Tigray region were downloaded from the website of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) available at the Climate Hazards Group(CHG;ftp://ftp.chg.ucsb.edu/pub/org/chg/products) with a spatial resolution 0.05°.CHIRPS satellite data is the most accurate rainfall products, with higher correlation and lower bias in east Africa and specifically Ethiopia as well (Dinku *et al.* 2014).

ENACTS were used for the spatial temperature data

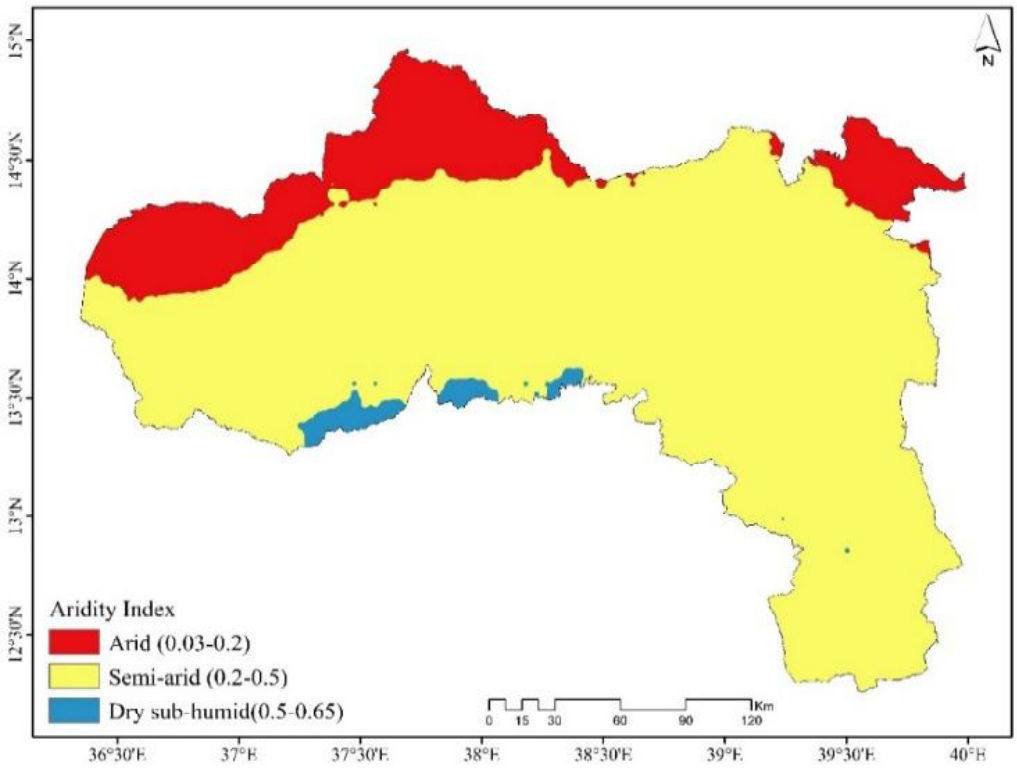

Fig 1: Aridity index in Tigray region

of the region which was obtained from Ethiopian National Meteorological Agency having a resolution of 4.17 km. ENACTS integrates the spatial information from satellite and other proxies (such as elevation maps) with measurements from quality-controlled weather stations (Dinku *et al*. 2014).

The extraterrestrial radiation (R*a*) values of 12 months were taken from Hargreaves (1994) for the latitudes ranging from 12° to 16° which covers the latitudinal range of the study area. MS excel was used to interpolate the R*a* values of 12 months to all two decimal digit latitudes found between 12° and 16°. A digital elevation model was downloaded from ASTER DEM available at https://search.earthdata.nasa.gov.

Creation of layers

We used the formula of Hargreaves (1994) to calculate the potential evapotranspiration (PET).

$$PET = 0.0023 \times Ra \times (Tmean + 17.8) \times TD^{0.5}$$

Where Tmean is the mean monthly temperature (°C), TD the mean monthly temperature range (°C), and R*a* solar radiation ($mmday^{-1}$).

The aridity index (AI) was computed as a ratio of the mean annual precipitation (P) versus the mean annual PET (UNEP 1992). This computation was made in Arc map 10.3 using raster calculator and aridity map was produced.

The DEM data were used to classify the Ethiopian traditional agro-climatic zone of the study area as compiled by Negashand and Ermias (1995) and the traditional agro-climatic map was created. Accordingly, the study area was classified in to five zones as Hot (< 1500 m.a.s.l.), Warm (1500-2000 m.a.s.l.), Tepid (2000-2500 m.a.s.l.), Cool (2500-3000 m.a.s.l.) and Very cool (>3000 m.a.s.l).

A raster calculator was used to find the intersection areas of each aridity index class and each traditional agro-climatic class. New agro-climatic zones were mapped by merging the intersection maps of newly created classes.

RESULTS AND DISCUSSION

Aridity index and traditional agro-climatic zones

Based on the UNEP classification (UNEP, 1992) three classes of aridity index were identified in the study region. Those are arid, semi-arid and dry sub-humid. The aridity index value of the region ranges from 0.098 to 0.652. The aridity index values were commonly higher in areas characterized by high PET and low rainfall. Areas which have low PET and high rainfall possess lower aridity index values (Table 1). Most part of the region is covered by semi-arid climate (81.46%) followed by arid (16.91%) and dry

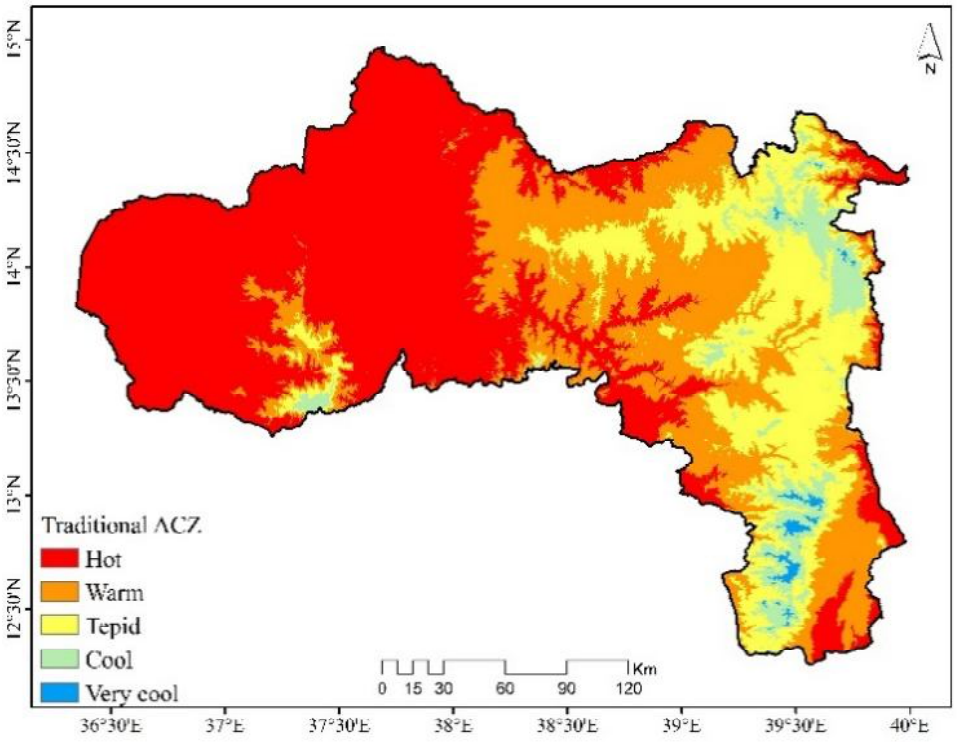

Fig 2: Traditional agro-climatic zones of Tigray region

Table 1: Climatic characteristics of aridity classes of Tigray region

Class	Daily temperature (°C)	Annual PET (mm)	Annual rainfall (mm)	Area Coverage (%)
Arid (0.03-0.2)	22.1-27.4	1910-2238	284-392	81.46
Semi-arid (0.2-0.5)	18.2-23.55	1643-1982	468-693	16.91
Dry sub-humid (0.5-0.65)	16.9-20.59	1443-1730	795-882	1.63

Table 2: Climatic characteristics of elevation classes of Tigray region

Elevation	Daily temperature (°C)	Annual PET (mm)	Annual rainfall (mm)	Area coverage (%)
<1500	21.4-28.0	1875-2175	195-628	48.36
1500–2000	19.2-21.4	1730-1858	566-597	27.37
2000–2500	17.2-19.2	1545-1731	508-567	18.7
2500–3000	15.6-17.2	1451-1581	494-568	5.09
>3000	13.8-15.6	1331-1459	546-650	0.48

sub-humid (1.63%) (Fig.1). Larger portion of Ethiopia including the northern rift valley laid under the aridity index less than 0.65. The entire Erob district, most parts of Tahtay adiyabo and Kafta humera, some parts of Gulomekeda, SaesieTsaedaEmba and LaelayAdiyabo laid under the category of arid class. However, small parts of Tsegede, Tselemti, Endamehoni and Welkaite districts were categorized under the class of dry sub-humid.

The elevation of the region ranges from 500 above mean sea level (amsl) in the far west of Kaftahumera district to 3916m a.m.s.l. in the highlands of Endamehoni district. Based on traditional zoning, the region has five agroclimatic zones. The hot, warm, tepid, cool and very cool has the spatial coverage of 48.36, 27.37, 18.67, 5.09, 0.48 per cent respectively in the region (Fig.2). The lowland elevations are characterized by hot temperature and the highland elevation characterized by cool temperature (Table 2).

Agro climatic zones

Latitudinal difference together with complex topography determines the climate of the study region

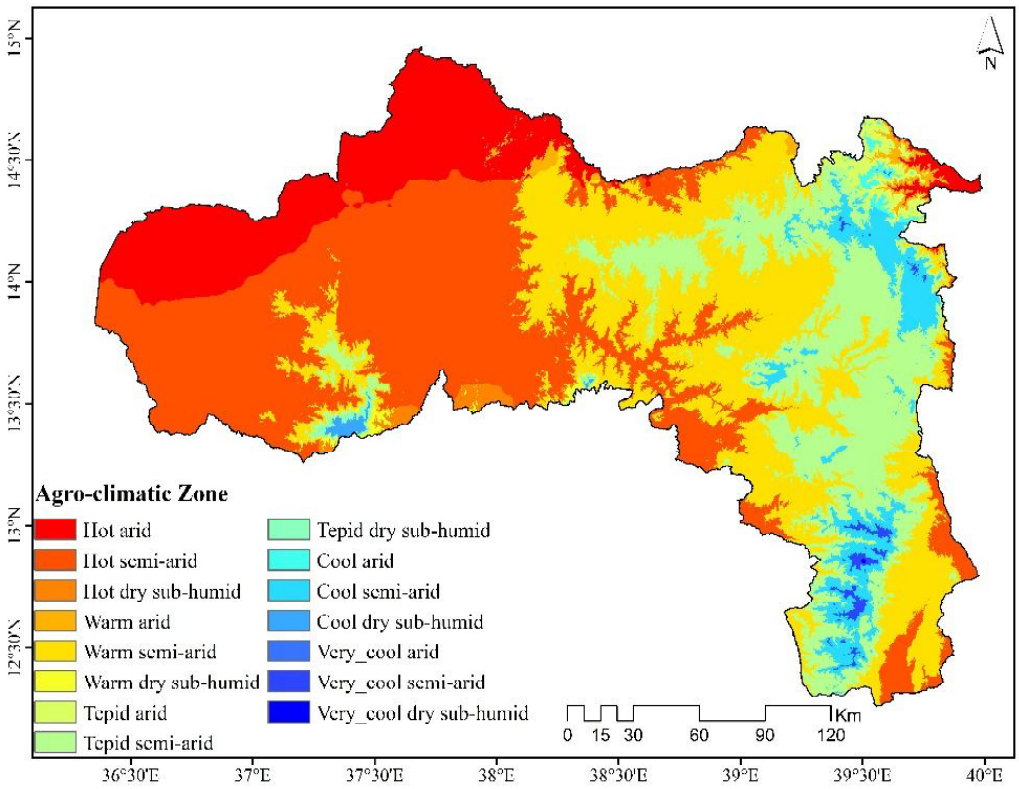

Fig 3: New agro-climatic zones of Tigray region

which brought spatially variable agro-climatic zone. Evidently there is strong relation between altitude and agro-climatic zone. Based on aridity index and altitude 15 agro-climatic zones were identified in Tigray region (Fig. 3). The general description of all agro-climatic zones is discussed and summarized in Table 3.

Hot climate

Top most western and southwestern zones of the region is mainly characterized by the hot arid climate. These areas are known for their lower altitude, lower annual rainfall (302-395 mm), higher daily temperature (24.3 -27.1°C) and higher annual PET (2047-2217mm). The arid lowlands of Tahtayadiyabo, Kaftahumera, Lealayadiyabo and Erob districts has this hot arid climate. This hot arid zone covers 14.3 per cent of Tigray region.

Hot semi-arid has the largest area coverage in the region which constitutes for 33.3 per cent. The mean daily temperature ranges from 21.4-25.1°C. The mean annual rainfall varies from 465-715 mm and the estimated mean annual PET ranges from 1819-2063 mm. The bottom portion of western and southwestern zones with lower altitudes are classified under this hot semi-arid category. South and central zone of Tigray which are found in an altitude less than 1500 amsl has a hot semi-arid climate. Most of the districts in the region have this type of agro-climate though it is predominantly found in the districts of Kaftahumera, Welkait, Tsegede, AsgedeTsimbla and Tselemti.

Hot dry sub-humid zone constitutes a very small area of Tigray region covering 0.7 per cent. These are found in the small portion of Tselemti and Tsegede districts where the elevation is below 1500 m.a.s.l. and annual rainfall higher than 800 mm. The mean daily temperature ranges from 19.2-20.9°C. The mean annual rainfall for this zone varies from 838-885mm and the mean annual PET range is estimated from 1618-1746 mm.

Warm climate

The warm arid agro-climatic zone covers 1 per cent of the region. This zone is scattered in the north and eastern portion of the region. Predominantly it is found in altitude of 1500 to 2000 m.a.s.l. mean annual rainfall ranging from 228-370 mm and temperature of 19.6-23.0°C. The mean annual PET is high which ranges from 1748-1978 mm. The mid lands of Erob, Lealayadiabo and SaesieTsaedaEmba are classified under this category.

Warm semi-arid zone is one of the agro-climatic zones which represented in all administrational zones of the region and all districts except Erob district. It has 26 per cent spatial coverage in the region. This entire zone is found in an

Table 3: Climatic characteristics of agro-climatic zones of Tigray region

ACZ	Daily average temperature	Annual rainfall	Annual ETo	Area coverage (%)
Hot arid	24.3-27.1	302-395	2047-2217	14.28
Hot semi-arid	21.4-25.1	465-715	1819-2063	33.33
Hot dry sub-humid	19.2-20.9	838-885	1618-1746	0.74
Warm arid	19.6-23.0	228-370	1748-1978	1.02
Warm semi-arid	19.2-21.6	484-696	1700-1904	25.99
Warm dry sub-humid	17.3-20.2	804-882	1467-1720	0.36
Tepid arid	17.9-19.6	229-302	1647-1753	1.23
Tepid semi-arid	17.3-19.4	475-645	1566-1760	17.19
Tepid dry sub-humid	16.2-19.0	752-848	1383-1622	0.27
Cool arid	17.3-18.5	246-298	1598-1690	0.36
Cool semi-arid	15.3-17.5	408-638	1443-1616	4.48
Cool dry sub-humid	15.3-17.2	781-839	1302-1470	0.24
Very cool arid	16.9-17.6	249-256	1569-1613	0.01
Very cool semi-arid	14.2-16.0	531-675	1346-1486	0.46
Very cool dry sub-humid	13.8-13.9	643-649	1314-1334	0.01

altitude between 1500 and 2000 m.a.s.l. The annual rainfall of this zone ranges from 484 mm to 696 mm. The temperature and PET ranges are 19.2-21.6 °C and 1700 mm to 1904 mm respectively.

Warm dry sub-humid consists 0.36 per cent of the total area of Tigray region confined to the elevation 1500-200 m.a.s.l. This zone is found on small mountainous areas of Tsegede and Tselemti district. The temperature in this zone ranges from 17.3-20.2 °C. the annual rainfall ranges from 804 mm-882 mm and the estimated PET varies from 167-1720 mm.

Tepid climate

Tepid arid zone is characterized by a very low annual rainfall ranging from 229-302 mm and moderate daily average temperature ranging from 17.9-19.6 °C. The estimated mean annual PET ranges from 1647-1753 mm. This zone is specifically found in the adjacent areas of Erob, Gulomekeda and SaesieTsaedaEmba districts. This area is characterized by mountainous feature having altitudinal range from 2000 to 2500 m.a.s.l. It totally covers 1.23 per cent of the region.

Tepid semi-arid has variable annual rainfall ranging from 475-645 mm, moderate temperature 17.3-19.4 °C and annual PET from 1566-1760 mm. The altitudinal range of this zone is 2000 to 2500 mm. It accounts for 17.19 per cent of the region predominantly covered HintaloWejirat, Enderta, Wukro, DeguaTemben, Hawzen, and Ofla districts.

Tepid dry sub-humid covers 0.28 per cent of Tigray region. It is found in high elevation (2000 -2500 m.a.s.l.) areas in Tsegede and Tselemti districts receiving higher annual rainfall (752-848 mm), moderate temperature (16.24-19.01 °C) and lower annual PET (1383-1622 mm).

Cool climate

Cool arid zone is characterized by high elevation, cool temperature and receiving low annual rainfall. The zone has elevation of 2500-3000 m.a.s.l., daily average temperature ranges from 17.3-18.5 °C and the annual rainfall ranges from 246-298 mm. The annual PET is estimated to be 1598-1690 mm. These areas are specifically found in the districts of Erob, Gulomekeda and SaesieTsaedaEmbaIt accounts for 0.36 per cent of the total area of the region.

Cool semi-arid zone has a spatial coverage of 4.48 per cent in the region. This entire zone is found in an altitude between 2500 and 3000 m.a.s.l. The annual rainfall and PET of this zone ranges from 408-638 mm and 1443-1616 mm respectively. The temperature of this zone is cool ranging from 15.3-17.5 °C. It is mainly found in the mountainous areas of AtsbiWenberta, SaesieTsaedaEmba, Ofla, Alaje, Endamehoni and GantaAfeshum districts.

Cool dry sub-humid zone covered 0.24 per cent of total study area. The temperature is in between 15.3-17.2°C

and annual rainfall is 781-839 mm. The elevation of this zone is in between 2500-2966 m.a.s.l and its estimated annual PET rages from 1302-1470 mm. This zone is restricted to upper most hills of the Tsegede and Tselemti districts and is characterized by cool temperature and high rainfall.

Very cool climate

Very cool aridzone is characterized by a very cool temperature and very low annual rainfall. The daily average temperature, annual rainfall and annual PETvaries from 16.9-17.6 °C, 249-256 mm and 1569-1613 mm respectively. It is found in the mountainous area of Erob district where the elevation ranges from 3000 to 3215 m.a.s.l. This is the only climatic zone that is confined to only one districts. It constitutes the smallest area of all other climatic zones covering less than 0.01 per cent of the region.

Very cool semi-arid zone accounts for 0.46 per cent of the region characterized by high elevation (3000-3886 mm), cold temperature (14.2-16 °C), moderate annual rainfall (531-675 mm) and lower PET (1346-1486 mm). This zone is limited to the mountainous areas of Endamehoni, Alaje, HintaloWejirat, Ofla, AtsbiWenberta, GantaAfeshum and SaesieTsaedaEmba districts having average elevation of 3163 m.a.s.l.

Very cool dry sub-humid zone is found in the highest mountains of the region namely Tsibet and Alaje mountains. The mountains are found in the districts of Endamehoni and Alaje. This zone receives annual rainfall of 643-649 mm. The temperature in this zone is very cold (13.8-13.94 °C) resulting in low annual PET (1314-1334 mm). The elevation range of this zone is 3187 to 3916 m.a.s.l. and it accounts for less than 0.01 per cent of the total area of the region.

CONCLUSIONS

Based on aridity index and traditional agro-climatic zoning, 15 agroclimatic zones were identified for the entire Tigray region. Diversified agroclimatic were observed in the mountainous portion of the region. The agroclimatic of the region is predominantly categorized under hot semi-arid, warm semi-arid, tepid semi-arid and hot arid together having a spatial coverage of 90.8 per cent. Small portion of the region is characterized cool semi-arid, tepid arid and warm arid agroclimatic contributing to 6.7 per cent spatial coverage together. The rest agroclimatic zones such as hot dry sub-humid, very cool semi-arid, cool arid, warm dry sub-humid, tepid dry sub-humid, cool dry sub-humid, very cool dry sub-humid and very cool arid constitute a very small spatial coverage of less than 1 per cent each and 2.5 per cent together. The information about agro-climatic situations of the region is very important for interventions and development activities that may be conducted by different governmental and non-governmental organization.

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