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Climate analysis for agricultural improvement of the Economic Community of West African States according to Köppen and Thornthwaite

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The Economic Community of West African States (also known as ECOWAS from its name in French: *Union Économique et Monétaire Ouest-Africaine*) is composed of eight countries: Benin, Burkina Faso, Ivory Coast, Guinea-Bissau, Mali, Niger, Senegal and Togo. This study is restricted to ECOWAS because it stems from a survey mission headed by the second author and aims to characterize the climate of the territory as a basis for better land use by improving agricultural activities. The climate classification systems proposed by Köppen (1900) and Thornthwaite (1948) were used to carry out the study. As expected, most of the territory belonging to ECOWAS was classified as arid. With respect to the improvement of agricultural management, the climate classes found for the territory give a gross idea of the potential of each country for agricultural exploitation. The climate diversity over relatively short distances obligates detailed studies on land adaptability for growing food crops, which is in practice not made based on scientific criteria. This study shows that there is still room for an expansion of the area for agricultural purposes, and in this way, increasing food production.

Key words: Africa, Economic Community of West African States (ECOWAS), agriculture, crops.

INTRODUCTION

The Economic Community of West African States (ECOWAS), in French: *Union Économique et Monétaire Ouest-Africaine,* is an organization that was established to promote the economic integration among eight countries of West Africa (Benin, Burkina Faso, Ivory Coast, Guinea Bissau, Mali, Niger, Senegal and Togo) that share the use of the same language and currency, the CFA Franc. These countries appear in the lower

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Figure 1. Map of Africa and the ECOWAS territory. (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

quarter of the HDI (Human Development Index), indicating a large room for improvement, mainly in agricultural management aiming for higher food production.

Also, the West African countries have been experiencing huge climate variability in the last decades with direct impact in the groundwater (Tirogo et al., 2016), although it has been shown a resilience for short-term inter-annual variation (Lapworth et al., 2013). Climate variability has also been verified by differences on tree-rings along countries such as Ivory Coast (de Ridder et al., 2013). The ECOWAS was created on January 10, 1994, in Dakar, Senegal, through an agreement signed by Government Chief Members of Benin, Burkina Faso, Ivory Coast, Mali, Niger, Senegal and Togo. On May 2, 1997, Guinea Bissau became the eighth member of ECOWAS (Figure 1) (Wikipedia, 2014).

Many studies in the last decades were carried out in order to analyze the economic and social development challenges of ECOWAS, where food production may possess a major role influencing on Gross Domestic Product (GDP), population health and wealth, and public security (Koffi-Tessio, 1998; Decaluwé et al., 2001; Dissou, 2002; Decaluwé et al., 2004; Bakhoum, 2005; Nubukpo, 2007a, b; Ouattara, 2007; Tanimoune et al., 2008; Esso, 2009; Kablan, 2009; Keho, 2010; Bakhoum, 2011; Heubes et al., 2012; Lansana, 2012a, b; Sablah et al., 2012; Carrère, 2013; Oguntunde et al., 2017). To develop information that can improve food production in these countries that depend on imports of basic food for their subsistence and to generate energy, we assume that climate is one of the main constrains in their agriculture. We use climatic data to apply Köppen´s and Thornthwaite´s methods. Köppen developed the first quantitative climate classification in 1900 and among the numerous methods available (Kottek et al., 2006; Belda et al., 2014), this is the mostly used one. As an example, Sparovek et al. (2007) also used Köppen's classification to map Brazilian climates. Although this type of analysis has been performed before for the West Africa countries, it is known that anthropogenic actions may have severe consequences on the climate characterization in this region, with a likely impact on plant diversity (Sylla et al., 2016a, b; Heubes et al., 2013).

Therefore, this study has as objective the application of the climatic classification systems of Köppen (1900) and Thornthwaite (1948), using rainfall and air temperature data (Figure 2), to supply information for the establishment of an agricultural zoning for food crops, such as corn and soybean or sugarcane for energy, based on real and potential productivities (Tables 1 and 2).

MATERIALS AND METHODS

The methodology of this study is based on concepts already known and published (Belda et al., 2014), however, carried out with geoprocessing tools, computational programming and spatial modeling. Meteorological data were compiled from public data bases found in Hijmans et al. (2005), covering the period 1950 to 2000, with the criterion of covering the full area of the ECOWAS. A strategic methodology was adopted to equalize the availability of georeferenced information to the continental scale of operation of the model and to the need of generating information sufficiently precise for the proposed characterization. After being compiled and structured in a common format, the bases of original data were integrated and processed by computational routines to generate derived variables to feed the following stages of the model.

Air temperature data were organized in average monthly minimum temperature (T_n); average monthly maximum temperature (T_x); average monthly temperature (T_d) in a way to allow the construction of maps and cyclic water balances (CWB), and rainfall data were also organized in an adequate way to generate rainfall maps and CWBs.

Potential evapotranspiration (ET_0, mm month^{-1}) is a meteorological variable that corresponds to the evaporation and transpiration of plant water under a non-limiting soil water condition,

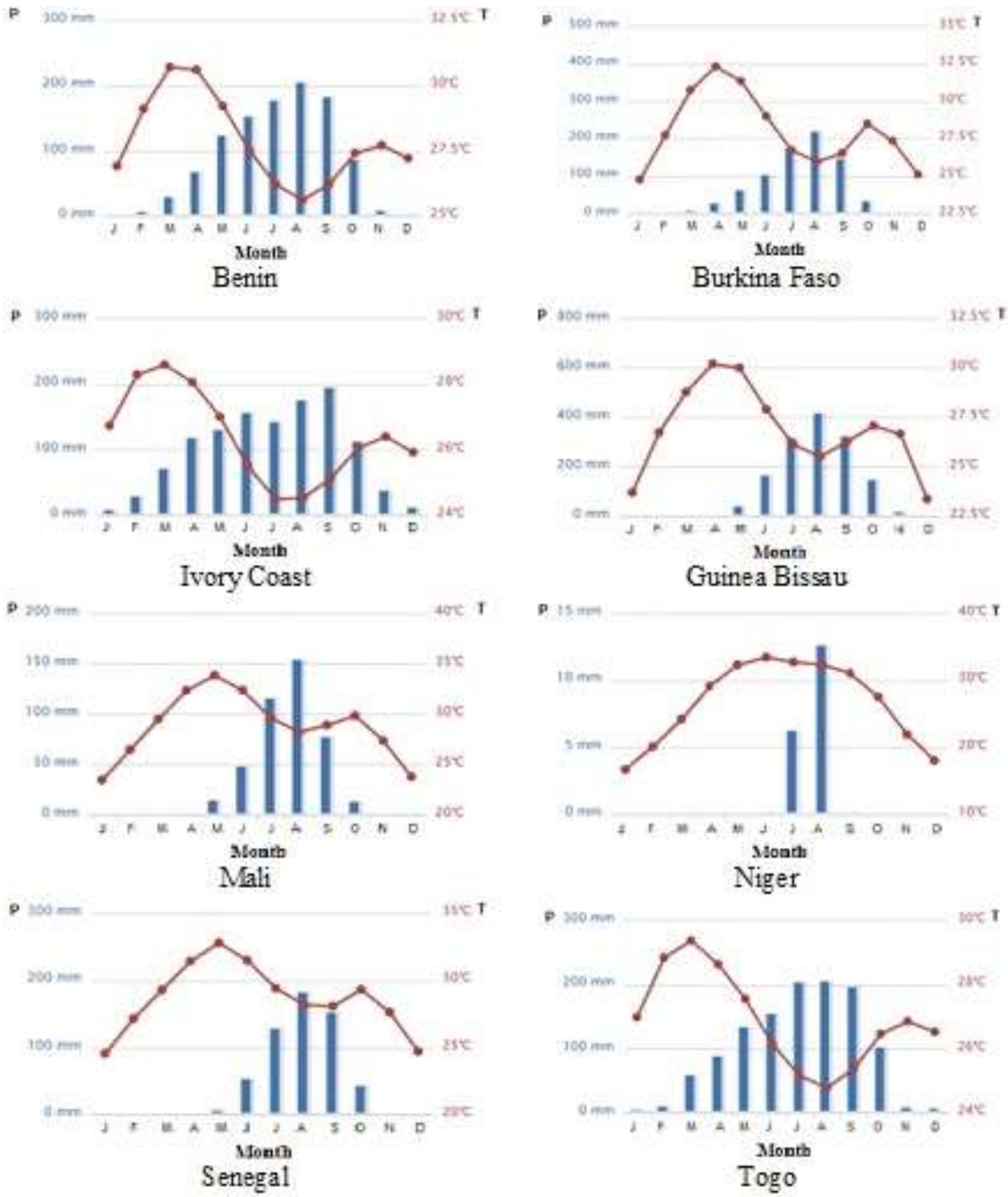

Figure 2. Country average values for rainfall (P, mm) and air temperature (T, °C) in ECOWAS countries for the period 1990 to 2009.
Source: World Bank (2014).

therefore corresponding uniquely to a response of a crop to atmospheric conditions. Several climatic variables contribute to ET_0, mainly solar radiation, air temperature, humidity and wind, but due to the lack of such records in many regions of the world, Thornthwaite (1948) developed an equation to estimate monthly ET_0 based only on air temperature data, which will be used in this

Table 1. General information for ECOWAS countries.

Country	Benin	Burkina Faso	Ivory Coast	Guinea Bissau	Mali	Niger	Senegal	Togo
Latitude	6º10' to 12°25'N	9° to 15° N	4° to 6°N	11° to 13°N	10º to 25°N	11º to 24ºN	12º e 17ºN	6º to 11ºN
Longitude	0°45' to 3°55'E	6°W to 3°E	2° to 9°W	13° to 17°W	13ºW to 5°E	0° to 16ºE	11º e 18ºW	0º to 2ºE
Area (10^3 km^2)	113	274	322	36	1,240	1,267	197	57
HDI (2013) (rank)	0.476 (165th)	0.388 (181st)	0.452 (171st)	0.396 (177th)	0.407 (176th)	0.337 (187th)	0.485 (163rd)	0.473 (166th)
Population (hab)	10.1 10^6	16.5 10^6	16.9 10^6	1.5 10^6	$15 \cdot 10^6$	$17.2 \cdot 10^6$	$13.7 \cdot 10^6$	$6.6 \cdot 10^6$
Density (hab km^{-2})	89.7	60	52	42	12	13	69	115
GIP (US$)	15 bi	22 bi	n.a.	n.a.	17 bi	n.a.	n.a.	n.a.
GIP (US$ *per capita)*	1,619	1,302	n.a.	n.a.	1,091	n.a.	n.a.	n.a.
Growth (% y^{-1})	4.4	6.5	2.3	n.a.	5.8	n.a.	2.6	2.1
Arable area (ha)	$7 \cdot 10^6$	$9 \cdot 10^6$	$21 \cdot 10^6$	n.a.	n.a.	n.a.	n.a.	n.a.

Source: World Bank (2013); FAO (2015); Wikipedia (2014); United Nations Development Programme (2015); BTI (2014a, b, c, d).

study:

$$ETo_i = 1.6\left(\frac{\sum_{i=1}^{12} 10.T_i}{I}\right)^{\sum_{j=0}^{3} a_j I^j} \quad (1)$$

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514} \quad (2)$$

in which i is the month sequential number, I the thermal index calculated from the average monthly air temperature (T_i, ºC), and a_i are empiric coefficients determined through a regression analysis using average monthly values of temperature. In our case, j defines a_0 = 0.49239, a_1 = 0.01792, a_2 = -0.0000771 and a_3 = 0.000000675 (Thornthwaite, 1948).

With rainfall and ET_0 data, the components of a cyclic water balance (CWB) can be calculated. Such a water balance allows determining periods of water deficit or excess.

The pedological database was obtained from FAO (2012). Standardization of attributes, nomenclatures and other soil data for the whole study region was based on the World Reference Base for Soil Resources (WRB) according to FAO (2006), which included the need to correlate information with the Brazilian Soil Classification System (SiBCS) based on the Brazilian Agricultural Research Corporation, EMBRAPA (2006). Soil altitude and slope data were obtained from the Shuttle Radar Topography Mission (2010).

Thornthwaite and Mather (1955, 1957) presented a basic equation for soil water depletion as a function of soil water storage (A, mm):

$$A = A_c e^{-\frac{L}{A_c}} \quad (3)$$

in which A_c (mm) is the soil water holding capacity defined as the difference between volumetric water content at field capacity (FC) and at the permanent wilting point (PWP) times 1000 mm (considering a 1 m deep soil), and L is a water balance component related to the cumulated water deficit as defined in Thornthwaite and Mather (1955, 1957), Mendonça (1958) and Dourado Neto et al. (2010).

The climate classification systems proposed by Köppen (1900) and by Thornthwaite (1948) are frequently used in the world (Kottek et al., 2006; Belda et al., 2014). The Köppen classification employs climatic values for summer and winter. Summer was considered to comprise the months of May, June and July, and the winter the months of November, December and January.

RESULTS AND DISCUSSION

Edaphic characterization

Soil water holding capacity

The soil water holding capacity (A_c, mm) of the soils of the ECOWAS countries (FAO, 2012) is illustrated in Figure 3. Such data in a country-scale manner constitute a novelty for the area. In general, fertile soils present high values of A_c, of the order of 300 mm for a 1 m deep profile. Medium values of A_c are of the order of 200 mm,

Table 2. Climatic description of the ECOWAS countries.

Country	Description	Crop	Production – t.ha^{-1} (2016)
Benin	Characterized by two well defined climatic zones separated by a transition zone. South: two rainy seasons per year (March to July, September to November), humid and warm; a long dry season (December to March) with the warm and dry wind "harmattan"; Center: Transition climate with spatial and temporal fluctuations that make dryland agriculture risky; North: characterized by a single rainy season.	Maize	1,376,683
		Oil Palm Fruit	654,542
		Rice	281,428
		Seed cotton	346,935
		Sorghum	129,665
Burkina Faso	Presents an interchange of dry and wet season; wet season longer in the south; dry season determined by the "harmattan" wind; country divided in three climatic zones:. (i) South Sudan, highest rainfall amount; (ii) North Sudan, medium rainfall amount during 4 to 5 months, with presence of forest vegetation under human pressure; and (iii) Sahel, very low rainfall during 3 months, shrub vegetation.	Cotton	900,448
		Maize	1,583,421
		Sorghum	1,742,116
		Millet	1,056,931
Ivory Coast	Very warm and humid the whole year, with two distinct seasons: dry winter and wet summer. Three agroecologic zones: (i) south (50% of the area), with most of the rain and including almost all forest, four climatic seasons, dry from December to March, rainy from March to June, short dry spell from July to August, and a short rainy season from September to November; planted to coffee, cacao, palm oil, rubber and coconut; (ii) Sudan Guineans' zone (19% of the area), transition between forest region and the north, with four seasons: long dry spell from November to February, long rainy season from March to June, short dry spell from July to August, and a short rainy season from September to October; irregular rainfall that harms agricultural practices; and (iii) Sudanese zone (31% of the country): northern region with a single rainy season that enables dry land agriculture.	Rice	1,768,121
		Maize	881,733
		Millet	54,499
		Coffee (green)	102,960
		Cocoa beans	1,472,313
		Seed cotton	378,303
		Banana	330,946
		Cassava	321,614
		Coconut	142,439
		Oil Palm Fruit	1,696,078
		Cashew	607,300
		Pineapple	46,258
		Rubber tree	310,655
Guinea Bissau	Between Equator and Tropic of Cancer, warm and humid with two distinct seasons: dry (December to April) and wet (May to November); comprises an insular territory of more than 80 islands; presents three agro ecologic zones: north, with one dry season (November to March) and one wet season (July to October); southeast with a tropical humid climate, with great agricultural potential; northwest with a moderate rainy and hot climate, also presents a good agricultural potential.	Cashew nuts	153,888
		Rice	186,000
		Sorghum	17,000
		Millet	14,000
		Roots ans tubers	89,086
		Oil Palm Fruit	81,259
Mali	High average temperatures and an interchange of a wet season (June to September) with a dry season (October-November to May-June. Four climatic subtypes are found: (i) Sudan-Guinea: southern part (6%) of the territory, with forests; (ii) Sudan area (17%) with a more or less dense vegetation; (iii) Sahel (26%), northern area with very low rainfall, occupying most of the Niger delta; and (iv) sub-Saharan zone (51%) with minimum rainfall.	Rice	2,780,905
		Maize	2,811,385
		Millet	1,806,559
		Sorghum	1,393,826
		Seed cotton	597,237
		Sugarcane	365,119

Table 2. Contd.

Niger	With 2/3 of its territory occupied by the Sahara desert, Niger has an extremely dry climate. Territory with desert lowland and dunes. Presents four climatic zones: (i) sub-Saharan zone (65% of the territory) with desert climate; (ii) Sahel-Sahara (12.2%), semi-desert climate with a long dry season (October to May) followed by a low rainfall season (June to September); (iii) Sudan-Sahel (12.9%) with somewhat better precipitation and (iv) Sudanese zone (0.9%) with better rainfall.	Maize	38,022
		Sorghum	1,808,263
		Millet	3,886,079
		Rice	30,167
		Cassava	146,563
		Cow pea	1,987,100
		Groundnut	453,577
		Seed cotton	10,622
Senegal	Two well defined dry and wet seasons. Rainfall in the south is about 5 times higher than in the north. Climate is directly influenced by the sea and the harmattan winds during the dry season.	Groundnut	719,000
		Sugarcane	696,992
		Millet	612,563
		Rice	885,284
		Maize	314,703
Togo	Very well distributed rainfall during the whole year, July, August and September being the most humid. More concentrated rainfall in the north.	Cassava	1,027,476
		Yam	813,985
		Maize	826,896
		Sorghum	272,776
		Rice	137,106
		Seed cotton	69,215
		Coffee (green)	10,985
		Cocoa beans	51,627

Sources: FAO (2015); World Bank (2015) and FAOSTAT (2018).

and low values 100 mm. Even being a desert area, the north of Mali presents relatively high values of A_c, reaching 125 mm due to marine formations, calcareous soils, soils with calcium sulphate, as well as saline soils, and organosoils. Neosols from the desert area of Mali and Niger present A_c values of the magnitude order of 100 mm, which could be explained by the conjugated presence of Vertisols and Gleisoils along the Niger river crossing Niger and Mali, as well as in the Chad Lake region, extreme southeast of Niger at the border of Chad, Cameroon and Nigeria.

The highest A_c values south of parallel 15º N, however in a mosaic composition, varied from 50 mm to more than 125 mm. Guinea Bissau and Senegal present most part of their territories covered by soils of A_c greater than 100 mm.

Temperature

Figure 4 presents the average monthly temperatures for the ECOWAS territory. Since this region is located between the Equator and the

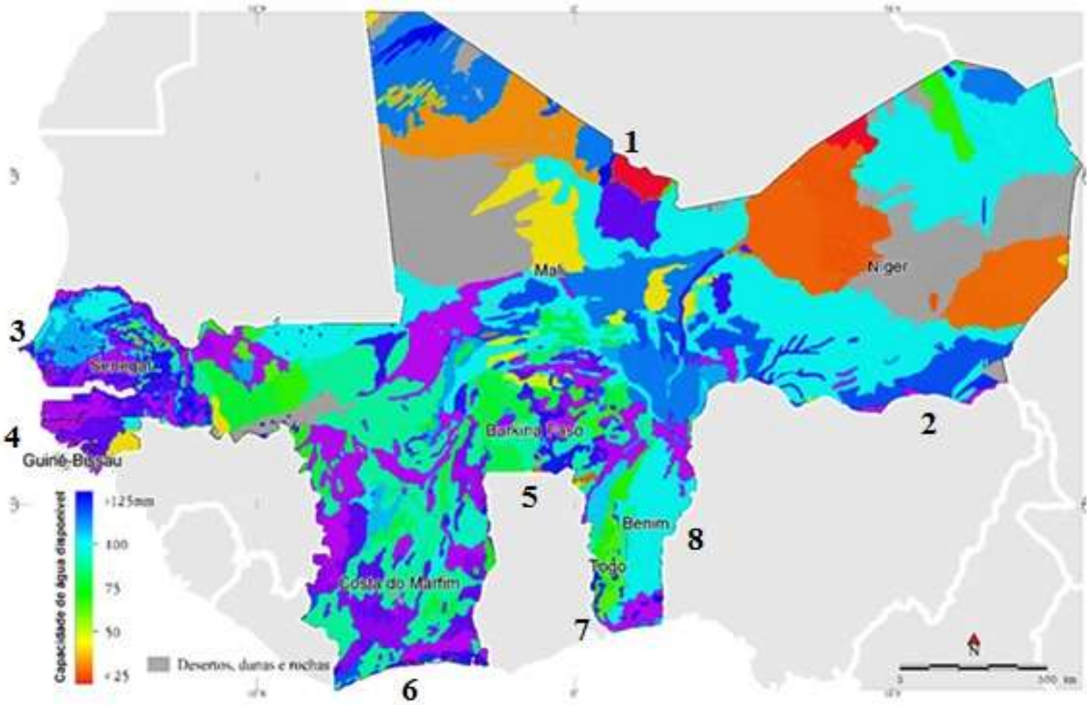

Figure 3. Soil water holding capacity (A_c, mm) of the ECOWAS territory: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

tropic of Cancer, Figure 4 shows that ECOWAS can roughly be divided into three temperature zones according to latitude: (i) from the Equator to parallel 10º N (Ivory Coast, Togo and Mali); (ii) between parallels 10º N and 15º N (Guinea Bissau, Senegal, south Mali, Burkina Faso and south Niger); and (iii) north of parallel 15º N (north central Mali and Niger). The northern part (above 15º N) including Mali and Niger, belongs to the Sahara desert including hilly regions, and presents the lowest average temperatures, reaching about 17°C in January. During May and June the temperature reaches 35ºC, while in the Northern regions of low altitude in in Mali, Niger and Burkina Faso the average winter temperature varies from 20 to 27ºC and remains in this range with the arrival of the summer. Figure 4 also shows that the coastal countries Togo, Benin, Ivory Coast, Guinea Bissau and Senegal (with exception of the northern part) present the smallest thermal amplitudes during the year, between 20 and 30ºC, as well as the highest rainfall.

Figure 5 shows that the minimum air temperatures of ECOWAS oscillate between15 and 20ºC, with the lowest values found in the more arid regions, between Sahel and the Sahara desert. The extreme north of Niger and Mali presents minimum temperatures below 17ºC, which leads to thermal amplitudes greater than 30ºC.

Figure 5 also shows that maximum air temperatures of ECOWAS are in the range 28 to 48ºC. The lowest are in the Southern part of the territory, between 28 and 33ºC; in the center, in the Sahel, temperatures are of the order of 35 to 40ºC, and north, in the desert, temperatures can reach values above 45ºC; a few points of exception with low maximum temperatures are found in the hilly regions.

With the Equator line projecting well in its center, Africa is the continent with the largest tropical area of the world. In the few mountain peaks, lower temperatures can be found even in the equatorial band. Large temperature ranges depend on the seasons and the solar radiation, which depends on latitude, altitude and proximity to the ocean.

The climate parameters that result from the thermal conditions should suffer along the seashores, the cooling provided by the sea breeze, which is actually lower in the interior, however, the influence of the sea is probably less effective over the excessively humid seashores due the similarity of the thermal parameters between ocean and coastal zone (Carter, 1948).

Rainfall

One of the main characteristics of rainfall described by several authors are the great differences among the rain volumes found in the different parts of the African continent (Carter, 1948), and the same is true for the

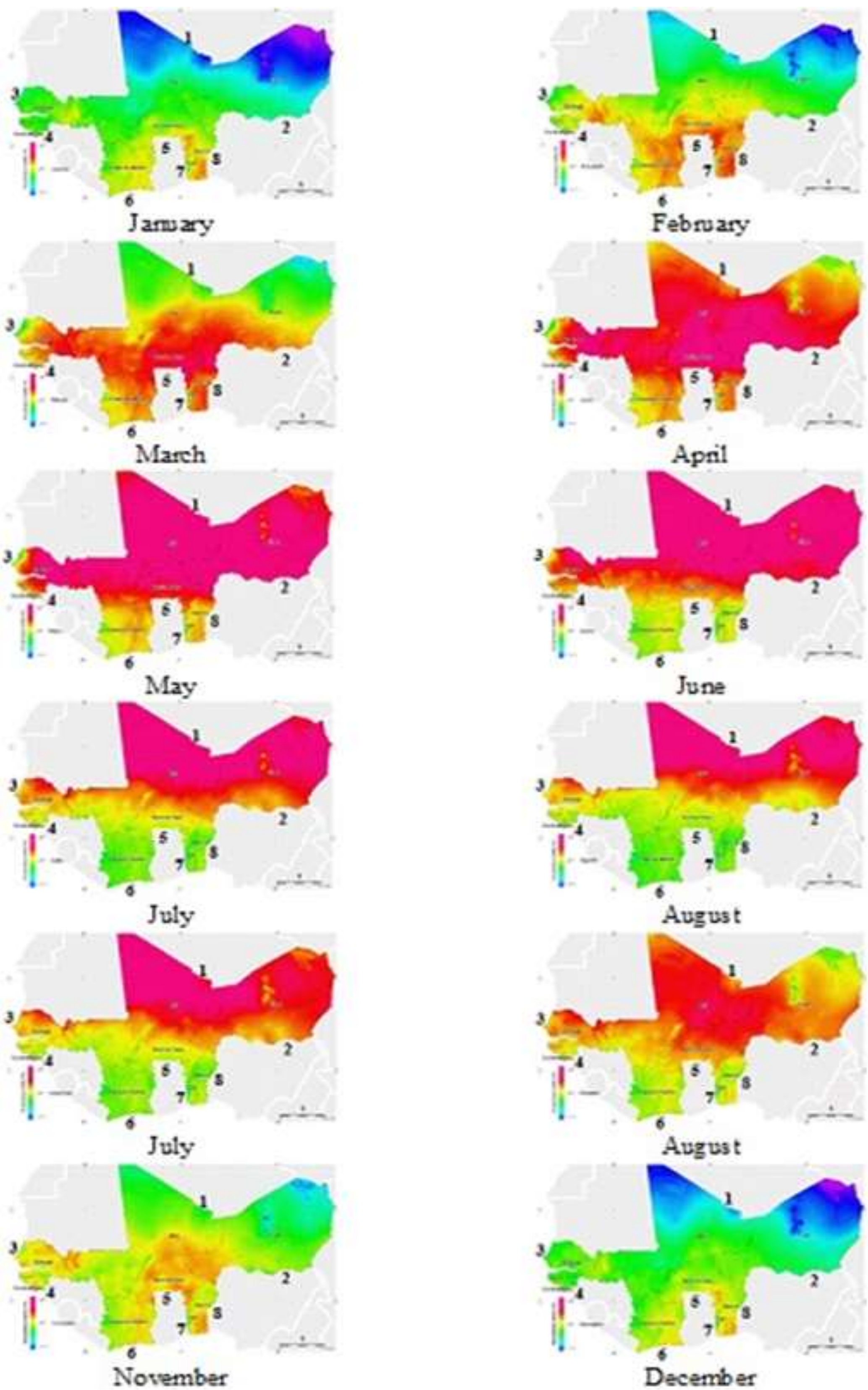

Figure 4. Mean monthly air temperature (°C) of the ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

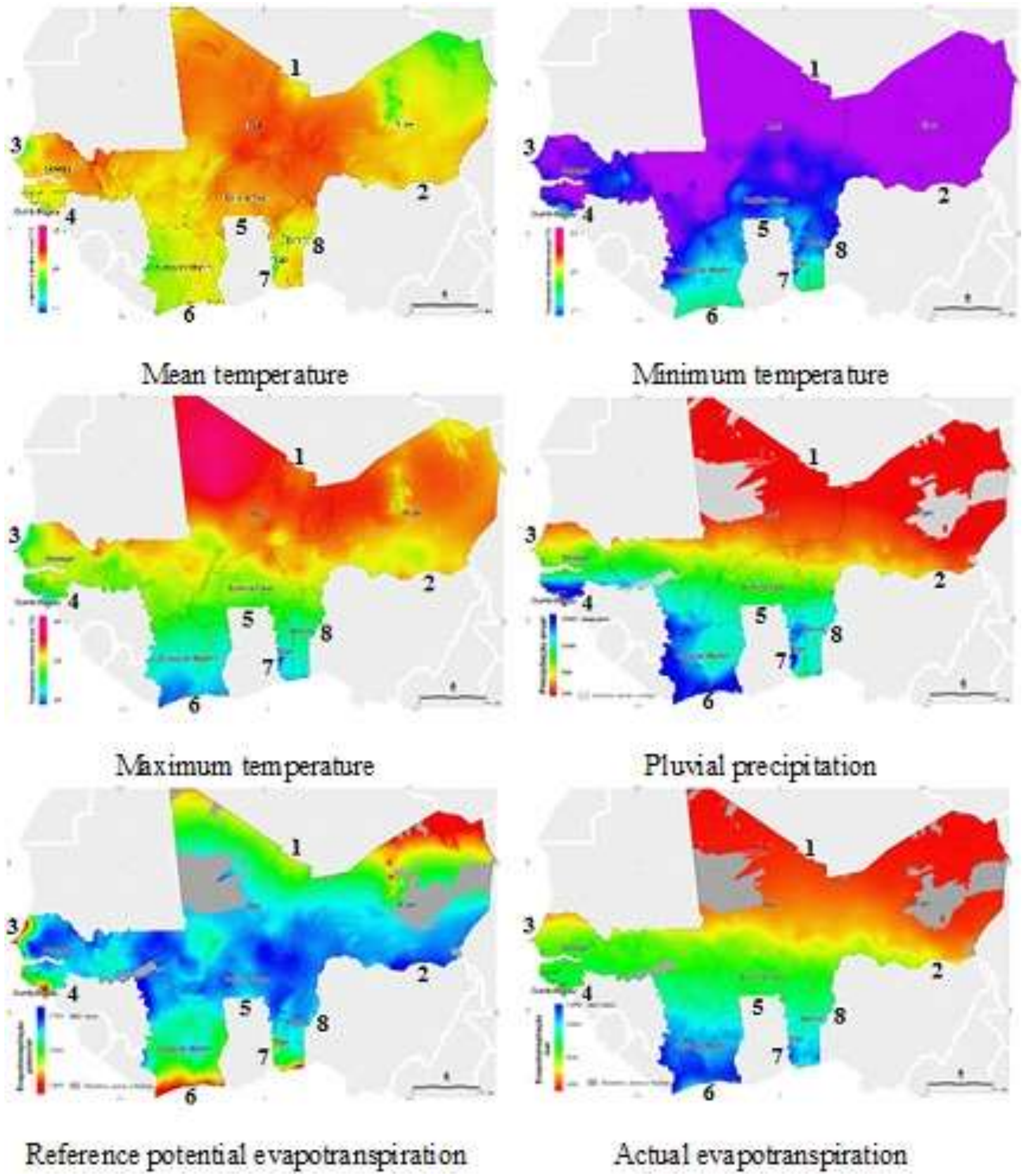

Figure 5. Mean, minimum and maximum annual air temperature (°C), mean annual pluvial precipitation (mm year^{-1}), mean annual reference potential evapotranspiration (ETo, mm year^{-1}), and mean annual actual evapotranspiration (ETa, mm year^{-1}) of the ECOWAS territory: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

countries belonging to ECOWAS. Mean annual averages of rainfall are found in Figure 5 for these countries. In the desert region of Sahara, average rainfall is below 100 mm year^{-1}, while at the coastal strip (south of the parallel 12º 30'N) of Guinea Bissau, Ivory Coast, central Togo and southeast Benin, they are above 1,500 mm year^{-1}. However, independently of the historical rainfall volumes, the majority of these countries present a rainy season limited to a few months per year. The greatest rainfall values of continental Togo are due to the presence of a mountain chain. In contrast, the region above parallel 15º N, in the Sahara desert, presents an extreme aridity with values below 100 mm $year^{-1}$; the Sahel strip somewhat below, presents averages from 400 to 500 mm $year^{-1}$.

In a general way, ECOWAS countries are faced to two well defined seasons: one rainy and the other dry. The rainy seasons coincide with the summer, but the distribution along the months is different for each country. In Ivory Coast and in Togo (Figure 5) the rainy seasons are more intense than in in the other countries, once their distributions are better spread through the year, starting from April and extending to October.

Due to rainfall, the high air temperatures of the ECOWAS countries are reduced by about 8ºC. Niger and Mali are the ECOWAS countries with lowest rainfall incidence, with very low historic average values. An exception has to be made to the extreme South of these territories that present values above 500 mm $year^{-1}$.

In Köppen´s (1900) climatic classification method, rainfall is one of the most important criterion; however, in Thornthwaite´s (1948) classification this variable is not used directly, it is compared to ET_0 and A_c during the calculation of water deficits or excesses.

Potential evapotranspiration

ET_0 calculated from Equation 1, which is based on average T measurements, is somewhat a reflection of the T distributions discussed above. It is also important to remind that the ET_0 is a climatological variable. Figure 5 illustrates the average annual potential evapotranspiration of the ECOWAS countries. The areas with lowest ET_0 levels, around 1,300 mm $year^{-1}$, coincide with the coastal areas of Senegal, Guinea Bissau, Ivory Coast, Togo and Benin, as well as the extreme north of Niger and Mali. The lower values at the coastal areas are due to the milder temperatures of this region, and in the extreme north they are influenced by the relief.

Our results are in agreement with Virmani et al. (1980), who observed that ET_0 in West Africa is inversely proportional to the rainfall distribution, with lowest values at the coastal areas and increasing in the direction of the Sahel.

The region represented by blue colors (Figure 5), ranging from parallel 10º N to 20º N, presents the highest values of ET_0, reaching volumes of 1,700 mm $year^{-1}$. This region presents the highest summer air temperatures (Figure 5), comprising the whole semi-desert and desert belt, in which ET_0 calculated by Thornthwaite (1948) surpasses by far the rainfall volumes, clearly demonstrated in Figure 5. Walker (1962) calculated ET_0 values for the Sahara desert of the order of 2,000 mm $year^{-1}$.

Actual evapotranspiration

ET_a is a measure of the evapotranspiration that occurs in real terms. It is equal or less than ET_0, that is, the maximum possible value under defined conditions and is a result of the water balance (WB) calculation, here made by Thornthwaite and Matter (1955) methodology. Figure 5 also presents average values of ET_a for the ECOWAS countries, where it is possible to see that for regions north of parallel 15º N, the values are less than 100 mm $year^{-1}$, a region where ET_0 values are above 1,500 mm $year^{-1}$, due to the condition of extreme hydric limitation. However, in the coastal belts of Ivory Coast, Togo and Benin, ET_a becomes close or equal to ET_0 of 1,300 mm $year^{-1}$, demonstrating that in a general way there is no hydric restriction. The transition between the South regions and those North of parallel 15º N, illustrated in yellow (Figure 5), is the Sahel strip, in which ET_a is between 300 and 500 mm $year^{-1}$, demonstrating clearly the reduction in water availability when we depart from the Equator in direction to parallel 20° N.

Cyclic water balance

Water deficit

In Figure 6, we see that water deficit prevails in more or less degree in the whole territory of ECOWAS, comprising also the coastal region of Ivory Coast, Togo and Benin, a region where rainfall reaches values greater than 1,500 mm $year^{-1}$. The region north of parallel 15ºN presents hydric deficiency greater than 1,000 mm $year^{-1}$. The coastal zones of Ivory Coast, Togo and Benin present a much less intense hydric deficiency, of the order of 100 mm $year^{-1}$, at least in one period of the year; in the coastal zone of Senegal and Guinea Bissau, the deficiency is greater, reaching 1,000 mm $year^{-1}$, which demonstrates that their climatic condition imposes harder climatic characteristics in relation to those areas situated close to the sea.

Water deficit is the difference between potential (ET_0) and actual (ET_a) evapotranspiration, which was not supplied by rainfall. Figure 6 demonstrates that more than half of the ECOWAS territory presents a hydric deficiency of at least 400 mm $year^{-1}$, similar to the rest of the African continent (CARTER, 1948).

As expected, the greatest hydric deficit levels occur in the Sahara desert, where more than 1,400 mm $year^{-1}$ would be necessary to correct this dry condition. This region presents an average water deficit very close to our calculated ET_0 values (1,600 to 1,700 mm $year^{-1}$).

Water excess

When a soil reaches A_c, the additional rain water is called water excess, which is lost by runoff or by deep drainage. Figure 7 shows that for the ECOWAS countries, water excess is present in greater or minor degree only in

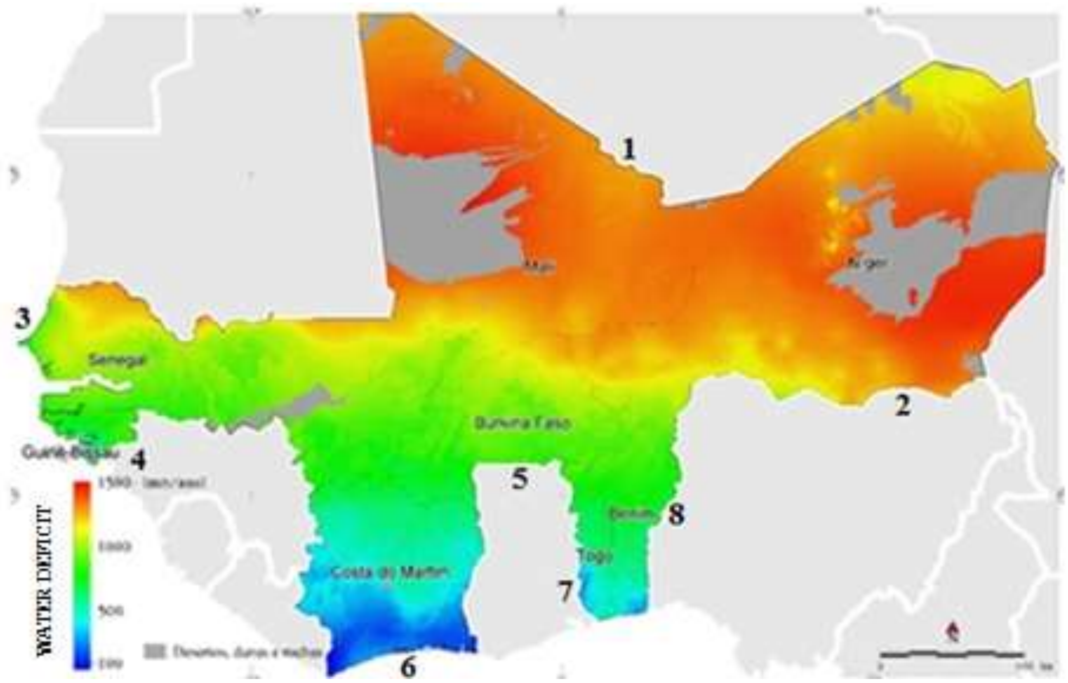

Figure 6. Average water deficit (WD, mm year^{-1}) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

latitudes below 15º N, i. e. south Senegal, Guinea Bissau, the extreme Southwest of Mali, central and south Burkina Faso, Ivory Coast, Benin and Togo. North to this area there is no excess water because rainfall values are below
100 mm year^{-1}.

In the part of the territory where no water excess occurs, extreme levels of water deficiency occur, of the order of 1,500 mm y^{-1}, a condition that prevails in north Senegal, north Burkina Faso, and practically the whole area of Mali and Niger.

Areas with water excess higher than 500 mm y^{-1} are those of South Senegal, Guinea Bissau, the extreme south of Mali, the western and coastal part of Ivory Coast and central Togo.

The east frontier of Ivory Coast with Liberia and Guinea is covered by natural reserves, within a chain of mountains, including Mount Nimba, presenting therefore the greatest water excess. Based on these facts, water excess of more than 500 mm y^{-1}, as for Guinea Bissau, certainly present a serious local problem due to the high rainfall concentration in one single season, in this case the summer, from June to August.

Climatic classification by Köppen (1900)

Figure 8 illustrates the climatic classes as proposed by Köppen (1900) for the ECOWAS countries, represented by climate classes A (tropical) and B (arid), subdivided in six climatic types.

Classifying climates for entire Africa, Peel et al. (2007) identified three classes (A, B and C), being B (arid) the predominant one representing 52.7% of the territory, followed by A (31.0%) and the temperate C (11.8%).

For ECOWAS, the Af climate was identified only for a small region at the extreme southwest coast of the Ivory Coast; whereas Am covers a large land portion south of parallel 12º 30’ N, south Senegal and Mali, Guinea Bissau, Ivory Coast, south Burkina Faso, Togo and Benin.

From the above exposition, it can be observed that the ECOWAS region is divided in almost parallel climatic strips in relation to the Equator. Above latitude 12º 30’ N, the ECOWAS territory is classified as arid (B). The strip between parallels 12º 30’N and 15º N is represented by the arid or semiarid steppe climates (BSw), extending from the West coast of Senegal, crossing the territory of Mali, north Burkina Faso to South of Niger. This climate is characterized by being more humid than the arid climate of the desert; more north of this strip we find the climate of largest projection within ECOWAS and the complete African continent, as cited by several authors, which is the arid desert climate *(BWw),* that prevails from north of Senegal, crossing a great portion of Mali and dominating almost all territory of Niger.

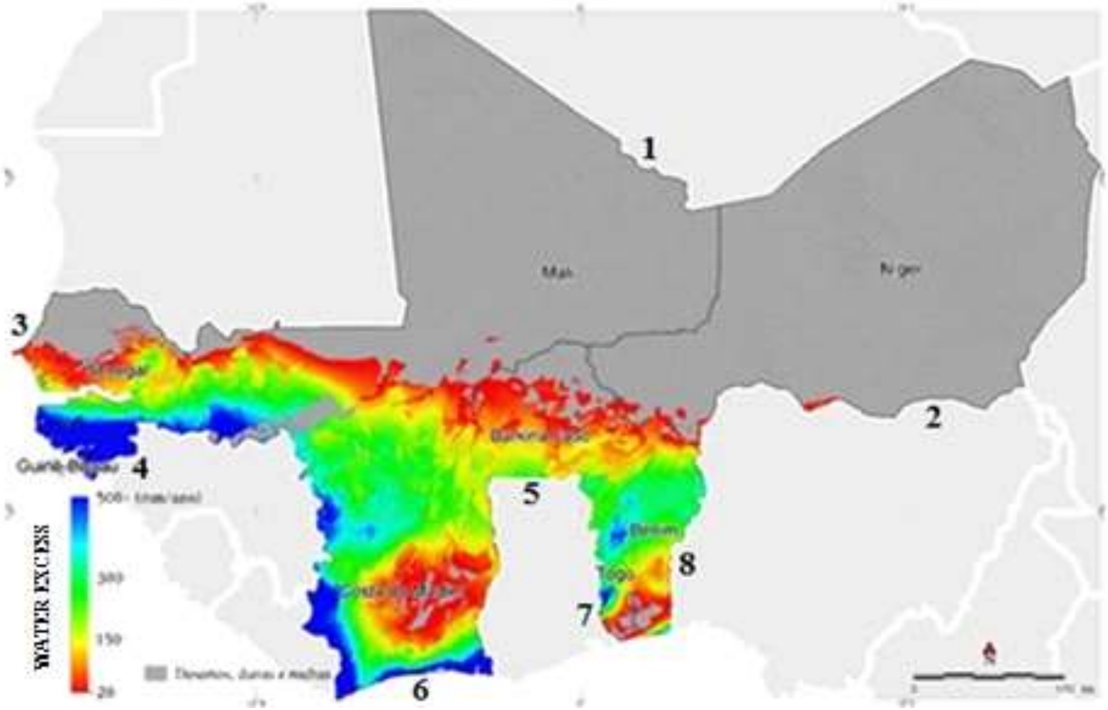

Figure 7. Average water excess (WE, mm year-1) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

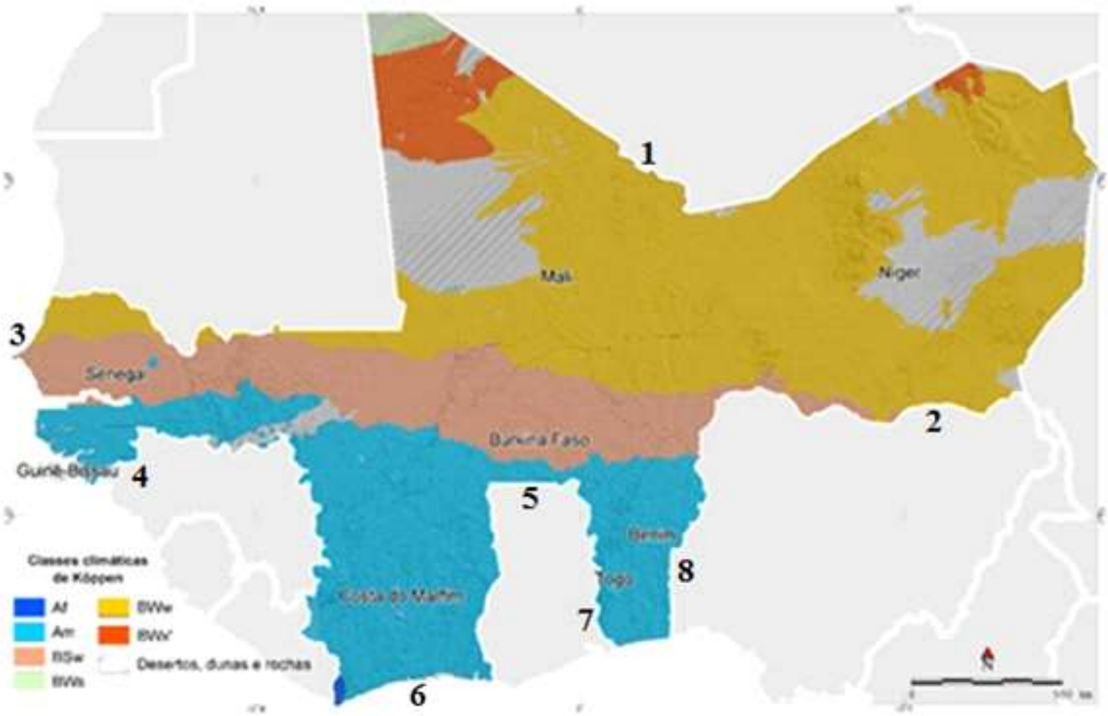

Figure 8. Climatic classes proposed by Köppen (1900) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

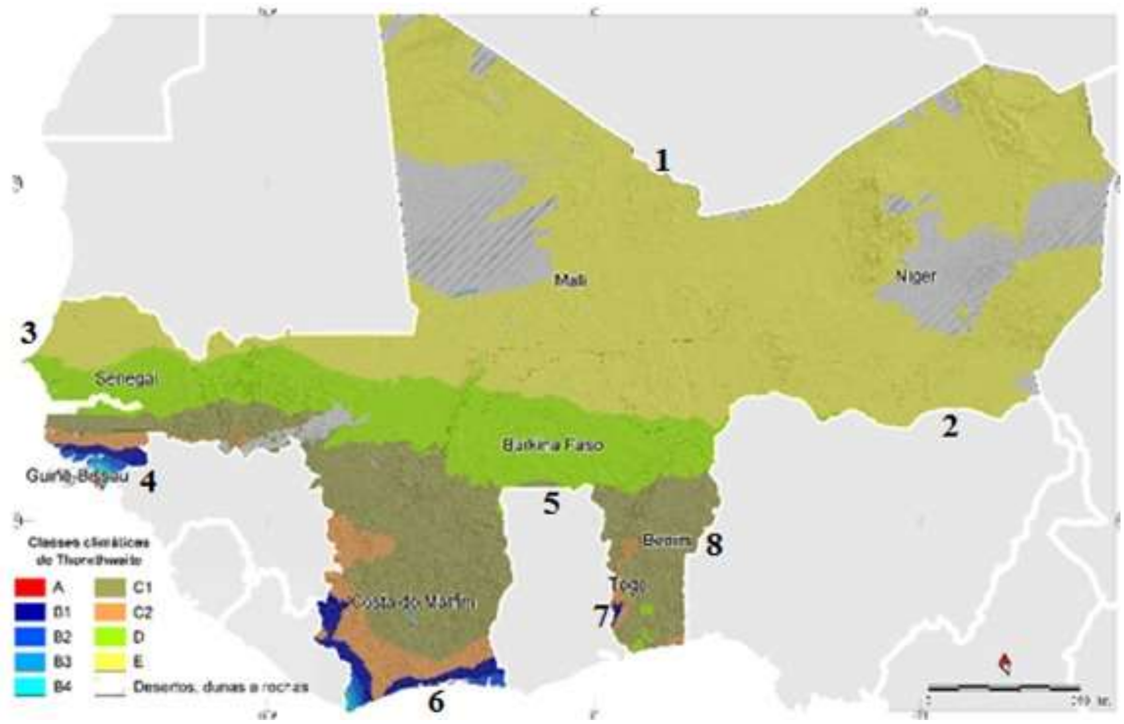

Figure 9. Climatic classes proposed by Thornthwaite (1948) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

North of parallel 20º N, two other arid climate types are found, BWx' occupying the north of Mali and a small portion of Niger, and BWs, in the extreme north of Mali.

According to the classification of Jones et al. (2013), the African continent is divided in bands parallel to the Equator, which cross the whole continent from the Atlantic Ocean to the Red Sea and more South to the Indic Ocean. In the Sahara desert, in Mali and Niger, there is a wide branch classified as hot arid, followed towards South by the semiarid climate, equatorial savanna with a dry winter, and the equatorial monsoon.

Climatic classification by Thornthwaite (1948)

Figure 9 illustrates the climatic classes according to Thornthwaite (1948) for the ECOWAS countries, where five great climatic groups are subdivided into nine types of climate. According to Rohli and Vega (2012), these climatic groups are: very humid (A), humid (B), sub humid (C), semiarid (D) and arid (E).

Climate A was detected only in a small portion of the southeast extreme of Ivory Coast, at the frontier with Liberia, surrounded by climate B areas, which characterize the neighboring areas between Ivory Coast and Liberia, the coastal region of Ivory Coast and all territory of Guinea Bissau. Other larger blocks belong to climate C, within Ivory Coast, Togo, Benin and the South of Senegal, south of parallel 12º 30' N.

Between parallels 12º 30'N and 15º N is the Sahel band with climate D, which goes from the Atlantic coast of Senegal, including the capital Dakar, to the extreme east of Burkina Faso; this is the transition zone between climates C and E, the last one covering the desert of Sahara, dominating the territories of Mali and Niger. Climates D and E form a block and occupy more than 50% of the ECOWAS countries, without climatic differentiation between low land and mountains. According to Carter (1948), the regime E also dominates the other areas of the African territory.

From the evaluation of the ECOWAS territory, it can be concluded that in relation to the climatic classification of Köppen (1900): (i) north of parallel 15°N in the north/south direction the classes: BWs, BWx´ e BWw (predominant class – arid climate), and (ii) south of parallel 15° N in the direction north/south, the following climatologic classes are found: BSw (semiarid), Am (predominant class – tropical climate of monsoons) and Af (climate of the tropical forest – small area); and (B) in relation to the climatic classification of Thornthwaite (1948): (i) north of parallel 15°N, we find in the direction north/South the following classes: E (predominant class - arid climate), and (ii) south of parallel 15° N, also from north to south, the following classes: D (semiarid climate), C (sub humid climate), B (humid climate) and A (very humid climate – small area).

Conclusions

With respect to agricultural management improvement, the climate classes found for the ECOWAS territory give a gross idea of the potential of each country for agricultural exploitation. The climate diversity over relatively short distances obligates detailed studies on land adaptability for growing food crops, which is actually not done based on scientific criteria. This study shows that there is still room for an increase in agricultural area, and in this way, an increasing food production.

The following integrated agrarian policies can be useful for extending agricultural area: (i) technological advancements in agro-genetics and machinery, (ii) strengthening the secondary and vocational agricultural education, (iii) crops' intensification and yields' maximization, and (iv) governmental subsidies and policy initiatives taken towards a stable and viable agricultural production within the countries examined.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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