Journal of Agriculture and Environment for International Development - JAEID 2018, 112 (1): 35-78
DOI: 10.12895/jaeid.20191.916

Climate Change Impact Chain Factors in ECOWAS

EDWARD R. RHODES[1] AND CALVIN ATEWAMBA[2]

[1] *Njala University, PMB. Freetown, Sierra Leone*
[2] *United Nations University Institute for Natural Resources in Africa, Toronto, Canada*

**Correspondence: errhodes2009@gmail.com; erhodes@njala.edu.sl*

Submitted on 2018, 13 December; accepted on 2019, 12 March. Section: Reviews

Abstract : Appropriate responses to climate change in the agriculture sector are dependent on knowledge of the status and trends of the factors of the climate change impact chain in the sector. The objective of the study was to broadly assess key human, environmental, and biophysical factors in the Economic Community of West African States (ECOWAS), mainly within the decade following the launching of the Comprehensive Africa Agricultural Development Programme (CAADP). This was done through a review of literature and analysis of data mainly from World Bank and FAO sources. The status of and changes in these factors were generally unsatisfactory. Population growth rate was high. Average daily maximum temperatures were projected to rise by up to 3.5^{o}C by 2050. Up to 35% of the lands were estimated to be severely to very severely degraded. Total Internal Renewable Water resources per capita were below international requirements in many countries of ECOWAS. Total Renewable Water resources per capita were more abundant but decreased over years. The substantial arable land and renewable water resources and carbon stored in soil (23.5 Gt) and forest biomass (6.3 Gt) are attributes of ECOWAS. Agricultural production was higher in the Gulf of Guinea Zone compared to the Sudano-Sahelian Zone but yields of rice, maize and yam were higher in the Sudano-Sahelian Zone. Food security status was unsatisfactory across ECOWAS although the production of rice, maize, cassava, yam, groundnut, cocoa, and palm oil (in most cases), and livestock, fisheries and aquaculture increased. The increase between 2003 and 2013 for aquaculture was dramatic (847%). Overall increases in the production of rice, maize, sorghum, cassava, yam and groundnut and cattle, sheep and goats were mainly due to increased crop area harvested (42%) and livestock numbers (44%). Policies should be revisited, institutions strengthened and financial investments made for ECOWAS to realize its potential to significantly contribute to food security and carbon storage.

Keywords: agriculture, CAADP, climate change, ECOWAS.

Introduction

The Economic Community of West African States (ECOWAS) was founded in 1975. Because of its large population (349.1 million in 2015), surface area (5,115,500 km^2) as reported by World Bank (2017) and significant contribution of agriculture, fisheries and forestry to Gross Domestic Product, ECOWAS has a potential of being an important regional-group in global trade, food security and mitigation of climate change through carbon storage. Membership of ECOWAS consists of Burkina Faso, Cape Verde, Gambia, Mali, Niger, Senegal, Benin, Cote d'Ivoire, Ghana, Guinea, Guinea Bissau, Liberia, Nigeria, Sierra Leone and Togo. Mauritania was a member but it withdrew in 2000. Four major agro-ecological zones span the ECOWAS region. These are the Sahelian Zone (Length of Growing Period (LGP) about 90 days or less); Sudan Savannah Zone (LGP about 90 to 165 days); Guinea Savannah Zone (LGP about 165 to 210 days) and Forest Zone (LGP about 270 days or more) (Figure 1). At a broader level, ECOWAS has been grouped into a Gulf of Guinea Zone and a Sudano-Sahelian Zone based on geographical and climatic homogeneity (FAO, 2005). All the Gulf of Guinea countries have shorelines with the Atlantic Ocean. The Sudano-Sahelian Zone as a whole experiences a hotter and drier climate than the Gulf of Guinea Zone. These groupings are utilized by CORAF/WECARD to focus its research and development programmes. The countries in the former zone (Gulf of Guinea) are Benin, Cote d'Ivoire, Ghana, Guinea, Guinea Bissau, Liberia, Nigeria, Sierra Leone and Togo. Burkina Faso, Cape Verde, Gambia, Mali, Niger and Senegal are in the latter zone (Sudano-Sahelian Zone). While the savannah spreads through both zones, the humid forest is mainly restricted to the Gulf of Guinea Zone (Figure 1).

The Comprehensive Africa Agricultural Development Programme CAADP (AU-NEPAD, 2003) promoted investment on the expansion of the area under sustainable land and water management, increased food supply and agricultural research and technology dissemination in sub-Saharan Africa. Building on CAADP, Heads of States committed in the Maputo Accord of 2003 to adopt a policy of allocating, within 5 years, at least 10% of their annual national budgets to agriculture. These initiatives were intended to usher in an era of high levels of agricultural production and productivity. Periodic assessments of progress in the implementation of the accord and outcomes are required to update continental and regional policies.

There is evidence that the achievement of the goals of CAADP and Maputo is under threat from climate change, in terms of impacts on the agroecology, hydrology,

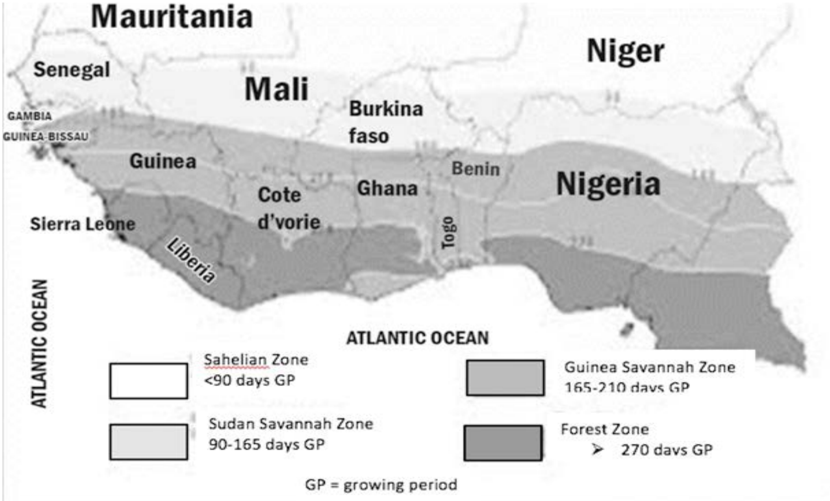

Figure 1 - Location of ECOWAS member states
Source: Adapted from FAO (2016a)

soils, crops, livestock, fisheries, aquaculture and food security if appropriate measures are not put in place (Thornton *et al.*, 2007; Kurukulasuriya and Mendelsohn, 2008; Jones and Thornton, 2009; CGIAR, 2009; Nelson *et al.*, 2009; Adebo and Ayelari, 2011; Lam *et al.*, 2012; Omitoyin and Tosan, 2012; Jalloh *et al.*, 2013; Rhodes *et al.*, 2014; Roudier *et al.*, 2014). Indeed, Maplecroft (2013) reported that the second, third and sixth most vulnerable countries (Guinea Bissau, Sierra Leone and Nigeria respectively) in the world to climate change were in ECOWAS.

The development of appropriate adaptation and mitigation measures to respond to or combat climate change is dependent on knowledge, at various scales, of the nature and trends of the climate change impact chain. The factors that drive the impacts of climate change on food security can be conceptualized in terms of four groups namely: *a*) human (including population, literacy, poverty); *b*) environmental (including temperature, rainfall, hydrology, soils); *c*) biophysical (including land area, land use, production), and *d*) economics (including income, trade, gross domestic product). We propose that the relationship be expressed as ICFS = $f\,(x_1, x_2, x_3, x_{4\,...\,Xn})$, where ICFS is the impact of climate change on food security, f is a non-linear function, and $x_1, x_2, x_3, x_{4 \text{ and } Xn}$ are the factors. This function is complex because the factors in reality interact in various ways and are not mutually exclusive. Examples are that changes in rainfall and temperature affect the hydrology of river basins which are linked to water demand and land use/land cover changes; soil quality influences the hydrology and utility of cultivable land for production; changes in production affect food availability, incomes and trade; and markets drive production beyond subsistence.

Blein *et al.* (2008) reported on agricultural production in West Africa between 1980 and 2005/2006. There is need to build on that study, and assess the status of the climate change impact chain factors, in order to inform research, development and policy agendas in ECOWAS, at the regional and zonal levels. This paper aims to contribute to bridging this gap. The objective of the study is to broadly assess at the regional and zonal levels key human, environmental and biophysical aspects of the climate change impact chain in ECOWAS mainly in 2003 and 2013, that is, within a decade after CAADP and the Maputo Accord.

Method

The assessment consisted of (a) a broad analysis of the findings from several previous studies including those of Windmeijer and Andriesse (1993); Kauffman *et al.* (2000); Blein *et al.* (2008); Jalloh *et al.* (2013) and Niang *et al.* (2014) on climate change and impacts in the agriculture sector, the status of the soils, water resources and agricultural production in ECOWAS and (b) detailed analysis of country-specific data on population, urbanization, literacy, poverty, hydrology, land use, crop and livestock production and yield, fisheries and aquaculture production and food security for 2003 and 2013 that were retrieved mainly from Bot *et al.* (2000); Henry et al. (2009); World Bank (2005a, 2005b, 2006, 2015, 2016); E.I.U. (2016) and FAO (2016b, 2018). The latter analysis involved computation with MICROSOFT EXCEL of sums, means, ranges and percentages for countries in the Sudano-Sahelian Zone, Gulf of Guinea Zone and across ECOWAS as a whole. The time frame was 2003-2013; the limitation of the study was that detailed analysis for each year between 2003 and 2013 was not done because of the wide scope of the study (mapping).

Results and Discussion

Human Factors–Population, Urbanization, Literacy and Poverty

The population of the Gulf of Guinea Zone increased from 203.7 million in 2003 to 260.7 million in 2013; corresponding increases for the Sudano-Sahelian Zone

Table 1 - Population, land area and urbanization in ECOWAS

Zone/ Region	Area (km^2x 1000)	Pop (million)	Pop (million)	Pop density (per km^{-2})	Pop density (per km^{-2})	Ann pop growth rate (%)	Ann pop growth rate (%)	Urban pop (% of total)	Urban pop (% of total)
		2003	2013	2003	2013	2003	2013	2003	2013
				Gulf of Guinea					
Total	2,064	203.7	260.7						
Mean				99	126	2.6	2.5	39.6	45.1
Range	28-911	1.5-136.5	1.7-173.6	32-150	45-191	1.7-5.0	2.2-2.7	28.9-46.7	36-53
				Sudano-Sahelian					
Total	2,968	47.7	66.4						
Mean				16	22	2.9	2.9	36.7	41.5
Range	4-1,267	0.5-12.1	0.5-17.8	9-53	13-180	1.6-3.7	1.3-4.0	17.6-65.7	18-64
				ECOWAS					
Total	5,032	251.4	327.1						
Mean				50	65	2.7	2.7	38.4	43.7

Source: Authors' calculations from Word Bank data (WB 2005a; 2005b; 2015; 2016)

were, respectively, 47.7 million and 66.4 million making a total ECOWAS population of 327.1 million in 2013 (Table 1).

Nigeria accounted for 54% and 53% in 2003 and 2013 respectively of this population. Annual population growth rate was higher in the Sudano-Sahelian Zone compared to the Gulf of Guinea Zone. The average population growth rate (2.7%) of ECOWAS in 2013 was much higher than the 0.72% in 2013 of High-Income Countries of the world (World Bank, 2015). At this high annual growth rate the population of ECOWAS is projected to double by 2039. While this suggests a potentially large common market community, the associated population density measured in persons per square kilometer (per km^{-2}) would significantly increase over and above current levels. Table 1 shows a much higher population density in the Gulf of Guinea Zone (126 per km^{-2}) compared to the Sudano-Sahelian Zone (22 per km^{-2}) in 2013. There were extremes in the Sudano-Sahelian Zone with Gambia having a high population density of 180 per km^{-2}, not very different from Nigeria at 191 per km^{-2} in 2013, and Mali, only 13 per km^{-2} in 2013. Increasing population density would put tremendous pressures on the natural resources including the forests in the Gulf of Guinea Zone. There is evidence of a positive relationship between population density and land degradation in Africa (Bot *et al*., 2000).

Because of migration, for various reasons, from rural areas, a significant proportion of the population, 45% in the Gulf of Guinea Zone and 42% in the Sudano-Sahelian Zone resided in urban areas in 2013. Urbanization in ECOWAS increased between 2003 and 2013 (Table 1) and was already more than half of that of High-Income Countries (World Bank, 2015). Urbanization influences food preferences of non-producers, and levels and types of food imported. The causes of urbanization are many but there is evidence of migration being one of the adaptation strategies to climate change used by farmers in West Africa (Burkina Faso, MECV, 2007; Rhodes *et al*., 2014). The extent to which climate change contributes to rural-urban migration in ECOWAS is yet uncertain (Hochleithner and Exner, 2018).

The United Nations classified eleven of the fifteen countries in ECOWAS as Least Developed Countries (LDC), based on human resources, poverty level and economic vulnerability. The exceptions were Ghana, Nigeria and Cote d'Ivoire in the Gulf of Guinea Zone and Cape Verde in the Sudano-Sahelian Zone (UNCDP, 2016). Unavailable data on literacy for the required years did not allow for the computation of comparable zonal and regional means for 2003 and 2013. Nevertheless, World Bank data for the early 2000's (World Bank, 2006) indicate little or no change in literacy rates for many countries between 2002 and 2005-2013. Table 2 indicates that literacy was lowest for adult females who form the bulk of the farming population and that literacy was higher in the Gulf of Guinea Zone compared to the Sudano-Sahelian Zone in 2005-2013.

However, Cape Verde in the Sudano-Sahelian Zone had a very high literacy rate of 98% for both youth males and females and 90% for adult males and 80% for adult females. An importance of a high level of literacy is that it facilitates communication amongst farmers, researchers, extension agents and service providers, and transition out of subsistence agriculture into intensive but climate smart agriculture.

Countries for which some data on poverty between 2003 and 2013 were available (World Bank, 2016), showed worsening or slight to modest reduction in poverty levels over time. For example, in Sierra Leone, in the Gulf of Guinea Zone, the population living below the national poverty line in 2003 was 66.4% and 52.9% in 2011;

Table 2 - Literacy rates in ECOWAS

	Youth Literacy Rate		Adult Literacy Rate	
	Male	Female	Male	Female
	(% of ages 15-24)		(% of ages 15 and older)	
	2005-13	2005-13	2005-13	2005-13
Gulf of Guinea				
Mean	68	52	59	35
Range	38-88	22-83	37-74	12-65
Sudano-Sahelian				
Mean	61	50	51	35
Range	35-98	15-98	23-90	9-80
ECOWAS	65	51	55	35

Source: Authors' calculations from World Bank (2016)

in Guinea Bissau, it was 64.7% in 2002 and 69.3% in 2010; in Ghana, it was 31.9% in 2005 and 24.2% in 2012. In Senegal, in the Sudano-Sahelian Zone, the population living below the national poverty line was 48.3% in 2005 and 46.7% in 2010; in Mali, it was 47.5% in 2006 and 43.6% in 2009. In both the Gulf of Guinea Zone and Sudano-Sahelian Zone, poverty was much higher in the rural than the urban areas. High rural poverty implies low adaptive capacity of farmers to climate change including limited ability to invest in soil and water conservation technologies that pay off over time. The main challenges regarding the human factors are: *a*) to slow down and stabilize the high population growth rate against the pushback of religious and traditional norms; *b*) to slow down rural-urban migration; c) to ensure access to quality basic education and break the vicious poverty-land degradation cycle.

Environmental Factors–Vegetation, Temperature, Water Resources and Soils

Vegetation, Temperature and Water Resources

The vegetation types within the Gulf of Guinea Zone are mainly secondary forest (over 95% of primary forests have been lost), savannah, and intergrades, while those in the Sudano-Sahelian Zone are mainly savannah, sahelian steppes and intergrades.

Annual air temperatures increase from South to North over ECOWAS countries. Average daily maximum temperatures range from 30^0C to 33^0C along the coast, from 36^0C to 39^0C in the Sahel and from 42^0C to 45^0C on the desert fringe (Jalloh *et al.*, 2013). Assuming an A1B scenario (Nakicenovic *et al.*, 2000), average daily maximum temperatures are projected to increase in 2050 by 0.5^0-3.0^0C and 1.0^0-3.5^0C in the Gulf of Guinea and Sudano-Sahelian countries respectively, compared to a 2000 baseline (Jalloh *et al.*, 2013). A1B is a global GHG emission scenario that assumes fast economic growth, a population that peaks mid-century and the development of new and efficient technologies along with a balanced use of energy sources. These projected increases vary within countries and between General Circulation Models (GCMs). The validity of these assumptions to future socioeconomic scenarios in ECOWAS is untested, but the outlook for increased use of energy-saving technologies is encouraging because ECOWAS and national governments are incorporating clean energy and energy-saving devices into their regional and national development plans (USAID, 2019). In the longer term, West African countries could experience an increase of 3-6 ^{0}C by the end of the 21st century (2081-2100) compared to the late 20th century baseline (Niang *et al.*, 2014). This compares unfavorably with a projected likely increase of global mean surface temperature by the end of the 21st century relative to 1986-2005 (around the end of the 20th century) of 0.3-4.8^{0}C depending on RCP scenarios (IPCC, 2014). Recent research indicates that human activities have caused approximately 1.0 °C of global warming above pre-industrial levels, with a likely range of 0.8 °C to 1.2 °C and that global warming is likely to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate of 0.2^{0}C (likely between 0.1^{0}C and 0.3^{0}C) per decade (IPCC, 2018). This means that the world is heating up faster than predicted and therefore there will be dire consequences for agriculture especially in the Least Developed Countries if appropriate measures are not adopted as soon as possible.

Past long-term data indicate that in the Sahelian Zone typical average rainfall was between 250 mm and 550 mm per annum; it was from 900 to 1,500 mm in the Guinea Savannah Zone and from1, 500 up to over 3,000 mm in the Forest Zone (Windmeijer and Andriesse, 1993; Kauffman, 2000). Annual rainfall increased from North to South. Average annual rainfall depth and volume in 2003-2007; 2008-2012 are shown in Table 3: there was apparently no change between these periods. Long-term average annual rainfall depth was 1,560 mm in the Gulf of Guinea Zone and 489 mm in the Sudano-Sahelian Zone. Variability within the zones was generally wide, but that within the Sudano-Sahelian Zone was very wide. Past and projected rainfall are more inconsistent compared to those for temperature, for which increases are the norm. Niang *et al.* (2014) observed an overall reduction of rainfall in the Sahel in the 20^{th} century but some recovery since 1994. Jalloh *et al.* (2013) projected no change, increases as well as decreases in average annual rainfall in ECOWAS depending on the GCM employed and the area within a country investigated. The direction of projected change has important consequences for farming systems. While reduction in rainfall in unusually wet zones reduces crop production unless adaptive measures are put in place, increases in rainfall in drier zones would adversely affect livestock production adapted to relatively dry conditions but would make conditions more suitable for the cultivation of crop species such as maize that have higher water requirements than crops such as millet. More research (Kurukulasuriya and Mendelsohn, 2008) is indicated on the quantification of the net benefits associated with a zone becoming more suitable for one crop specie compared to another crop specie or becoming more suitable for livestock production than for crop production because of climate change.

The water resources in ECOWAS are huge at 1,057 billion m^3 of total internal renewable water (Table 3).

The major and secondary rivers, which contribute to the mobilization of surface and ground water are shown in Table 4 and Figure 2. Blein *et al.* (2008) estimated that less than 2% of surface water is used annually for agriculture in ECOWAS. This should not be allowed to continue because proper use of surface and ground water can reduce dependence on rain-fed agriculture and consequently vulnerability of farming in ECOWAS to climate change. However, water may be physically available but economically scarce if investments needed to keep up with growing water demand are limited by human, financial and institutional factors (Molden *et al.*, 2007). Water resources (surface and ground) in the Gulf of Guinea Zone as a whole greatly exceeded those in the Sudano-Sahelian Zone, but there was considerable variability within zones. Total Renewable Water resources in some Sudano-Sahelian countries,

Table 3 - Water resources in ECOWAS

	Gulf of Guinea Zone			Sudano-Sahelian Zone			ECOWAS	
Parameter	Total	Mean	Range	Total	Mean	Range	Total	Mean
APD (mm y^{-1}) 2003-7; 2008-12	14,037	1,560	1,039-2,526	2,931	489	151-836	16,968	1,131
APV ($10^9 m^3 y^{-1}$) 2003-7; 2008-12	2,877	320	57.0-435	891	149	0.9-349.7	3,768	251
SWPI ($10^9 m^3 y^{-1}$) 2003-7; 2008-12	926	103	10.0-226	86	14	0.2-50	1,012	67
GWPI ($10^9 m^3 y^{-1}$) 2003-7; 2008-12	281	31	1.8-87	36	6	0.1-20	317	21
TIRW ($10^9 m^3 y^{-1}$) 2003-7; 2008-12	952	106	10.3-226	105	18	0.3-60	1,057	70
TIRW ($m^3 per^{-1} y^{-1}$ 2003-7		4,673	1,183-56,786		2,204	241-4,361		4,205
TIRW ($m^3 per^{-1} y^{-1}$) 2008-12		3,651	1,025-47,733		1,583	199-3,724		3,232
TRW ($10^9 m^3 y^{-1}$) 2003-7;2008-12			14.7-286			0.3-39.0		
TRW ($m^3 per^{-1} y^{-1}$) 2003-7			1,945-65,872			623-8,722		
TRW ($m^3 per^{-1} y^{-1}$) 2008-12			1,701-55,370			599-7,448		

Source: Authors' calculations from FAO (2016b)

Notes:
Long Term Average Precipitation Depth (APD) is average annual endogenous rainfall (produced in countries) expressed in depth; Long Term Average Precipitation Volume (APV) is average annual endogenous rainfall (produced in countries) expressed in volume; Surface Water Produced Internally (SWPI) is an annual volume of surface water generated by direct run-off from the endogenous rainfall and ground water contribution; Ground Water Produced Internally (GWPI) is ground water recharge generated from rainfall within the boundaries of the country; Total Internal Renewable Water (TIRW) is the sum of surface water produced internally and ground water produced internally minus overlap between surface and ground water; Total Renewable Water (TRW) is the sum of internal renewable water resources and external renewable water resources. External Renewable Water (ERW) is that part of a country's average annual renewable water resources not generated in the country. It includes inflows from upstream countries (groundwater and surface water) and part of the water of border lakes and/or rivers.

for example Mali and Senegal, were on a par with or exceeded some countries in the Gulf of Guinea Zone because of the sharing of boundary water resources. The variability of the components of the water resources within zones suggests a need for some country-specific responses to climate change that affects water resources and national water security. This, however, does not detract from the need for regional responses in the management of transboundary waters.

Table 4 - Major catchments of ECOWAS

Basin	Country	Area (km^2)
Chad	Niger, Nigeria	2,381,635
Niger	Benin, Burkina Faso, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria	2,273,946
Senegal	Mali, Senegal, Guinea	483,181
Volta	Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Togo	394,196

Source: FAO (2005)

Renewable Water Resources (m^3 per^{-1} y^{-1}), expressed on a unit, which takes into consideration human population growth, that is the volume of water resources per person per year declined sharply over time as population increased but water resources remained constant or declined. Total Internal Renewable Water (TIRW) resources per capita (m^3 per^{-1} y^{-1}) decreased by 28% in the Gulf of Guinea Zone, 39% in the Sudano-Sahelian Zone and 30% in ECOWAS as a whole between 2003-

07 and 2008-12. Total Internal Renewable Water resources per capita were below the international limit of water requirements (1,700 m^3 per^{-1} y^{-1}) for Benin, Ghana, and Nigeria in the Gulf of Guinea Zone and Burkina Faso, Cape Verde and Niger in the Sudano-Sahelian Zone in 2003-7. In 2008-12 the same countries in the Gulf of Guinea Zone were water insufficient in terms of Total Internal Renewable Water resources per capita and Gambia joined the list in the Sudano-Sahelian Zone. However, when Total Renewable Water (TRW) resources per capita were considered, all countries in the Gulf of Guinea Zone were above the limit in 2003-7 and 2008-12, again underscoring the benefits of accessible regional resources. Burkina Faso and Cape Verde were below this limit in 2003-7 and 2008-12.

Although the FAO source did not indicate decline in long-term water resources (expressed as cubic meters y^{-1}) between 2003-7 and 2008-12, it has been documented that certain water bodies in West Africa have been declining under the impact of climate change and direct exploitation by man. For example, the drastic reduction over time of the size of Lake Chad has been attributed to a combination of climate change and construction of dams in its catchment area to provide electricity (Urama and Ozor, 2010).

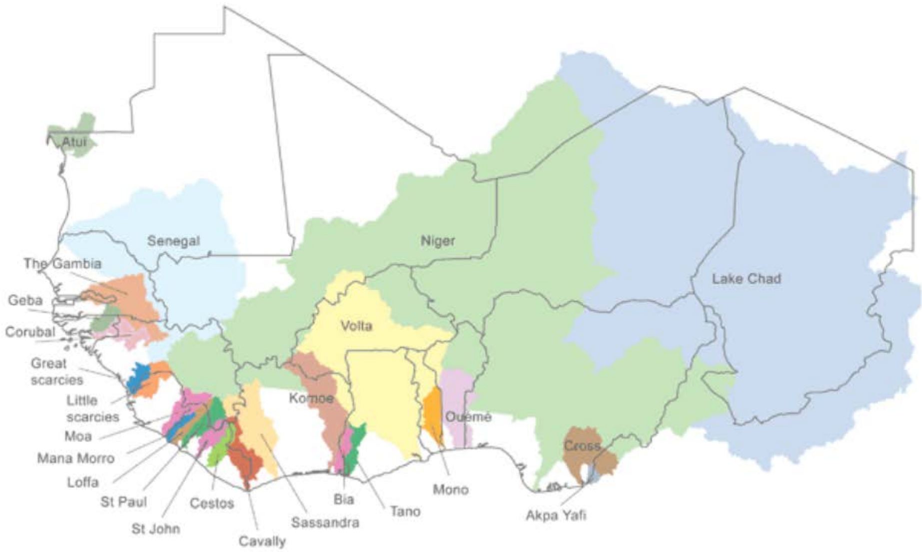

Figure 2 - River Basins of West Africa
Source: West Africa Gateway of Club du Sahel (2011)

There are relationships between evaporation, surface and ground water and position on the topography that have implications for the water balance and water management in the agriculture sector of West Africa (Windmeijer and Andriesse, 1993). They reported that in the Sahel Savannah Zone there is no upland ground water replenishment, rainfall is lost through evaporation and surface run-off, stream discharges occur during the rainy season but are very irregular and there is no effective extension of the growing period because of seepage in the lower slopes of valleys. Also, although water accumulates in valley bottoms, the soils are not saturated for long periods. In the Sudan Savannah Zone, rainfall is not completely lost by evaporation and surface runoff during the rainy season and there is some amount of replenishment of ground water in uplands, and ground water flow may occur in flat to rolling land. Stream discharge increases as one moves into wetter zones. In the Guinea Savannah and Forest Zones, water tables in uplands and valley bottoms rise substantially during the rainy season, ground water flow is important and growing periods in the valleys considerably extended. Soils in the valleys may be saturated throughout the year especially in the Forest Zone. These water regimes impact upon the agrarian species and duration of crops that can be successfully cultivated, the extent of dry/wet season cropping and the associated soil and water management practices.

With temperatures already high and projected to increase, the fundamental challenge is to avoid degradation of forests, and to cope with the high temperatures and low rainfall in the Sahelian Zone and the high temperature and variable rainfall in the Forest Zone. The inconsistency between downscaled GCM projections of temperature and rainfall changes aggravates the challenge. In the line of mitigation of GHG emissions, the initial challenge was for ECOWAS to contribute to keeping the rise in average global temperature to below 2^{0}C as agreed in the 21^{st} Conference of Parties of the United Nations Framework Convention on Climate Change (COP 21) in Paris in 2015, through the implementation of the Intended Nationally Determined Contributions (INDC) (FAO, 2016 c), many of which promote good management of soils and livestock.

For the water resources, the major challenge is to optimize their use and protect them against degradation. This includes collaborative management of international water basins, better use of rainfall in the context of changing rainfall patterns, increasing the efficiency and extent of irrigated agriculture and extending the period of cropping into the dry season. Quantifying accurately and monitoring the water resources in the various agro-ecological zones (AEZs) are also important challenges. The opportunities include the substantial water resources for irrigated agriculture and the availability of AEZs where there is substantial stored water in the soil at the end of the rainy season and the availability of water harvesting technologies especially for the Sahelian and Savannah ecologies.

Soils and Carbon Storage

The soils as related to agro-ecology (Windmeijer and Andriesse, 1993; FAO, 2001; Bationo *et al.*, 2006; Jalloh *et al.*, 2011) have been described and classified in the FAO-UNESCO system mainly as Arenosols and Lixisols in the semi-arid (Sudan Savannah Zone); mainly as Ferralsols and Lixisols in the sub-humid Guinea Savannah Zone with some occurrence of Arenosols, Acrisols, and Nitosols; and mainly as Ferralsols and Acrisols in the humid Forest Zone, with Nitosols, Lixisols and Arenosols occurring to a lesser extent. Other soils in ECOWAS are Planosols, Plinthosols, Leptosols, Cambisols, Vertisols (cracking clays), Fluvisols and Gleysols in bottom lands, and salt-affected soils (in coastal areas liable to sea water intrusion or resulting from poor irrigation management). The classification of the soils of ECOWAS would not have changed between 2003 and 2013 but quality could have in terms of physical, chemical and biological properties. Comprehensive data were, however, not available to assess changes in soil quality. The properties and limitations of the soils for agriculture have been described by FAO (2001). -

Organic matter (carbon) content is a key factor in determining soil quality. Organic carbon contents vary by agro-ecology, soil types and management, and usually ranges from about 0.2% in the sandy soils of the Sudan Savannah Zone to 4% in the finer textured soils of the Forest Zone; these values are much lower than the highly fertile Mollisols (Chernozems) of the temperate zone.

Carbon stored in soils, globally, has a very important role in mitigating and responding to climate change, as acknowledged at the UNFCCC-COP 21, in terms of aiming for a global soil organic carbon storage rate of 0.4% per annum (Lal et al., 2015). Even though ECOWAS countries are poorly industrialized, the important role of their ecosystems in the global carbon cycle is recognized (Ciais *et al.*, 2011). Table 5 shows that total amounts of carbon stored in soils of ECOWAS are substantial at 13,338 million t at the 0-30 cm depth, and 23,502 million t at the 0-100 cm depth.

Table 5 - Carbon stocks in soils of ECOWAS

Geographical and Agro-ecological Zones	Carbon Stocks (Tg or million t)		Mean Carbon Contents (Kg m^{-2})[1]
Depth	0-30 cm	0-100 cm	0-30 cm
Gulf of Guinea			
Total	7,344	13,215	
Mean	816	1,468	3.9
Range	134-2,873	247-5,108	1.8-7.6
Sudano-Sahelian			
Total	5,994	10,287	
Mean	999	1,715	2.0
Range	22-2,634	34-4,489	0.9-3.1
ECOWAS			
Total	13,338	23,502	
Mean	889	1,567	2.3

Note: [1] Soil carbon expressed on an area basis
Source: Authors' calculations from Henry et al. (2009)

Total carbon stock was greater in the Gulf of Guinea Zone than in the Sudano-Sahelian Zone. The variation of soil carbon stocks with agro-ecology/vegetation at local levels has also been reported. In the Forest Zone of Nigeria, Anikwe (2010) found that carbon stocks at the 0-30 cm depth were 9.51 x 10^{-9} Tg C m^{-2} and 8.98 x 10^{-9} Tg C m^{-2} for natural forest and planted forest sites respectively. Tondoh et al. (2016) reported that soil organic carbon stocks in semi-arid landscapes (Sudan Savannah Zone) of Ghana, Burkina Faso and Mali potentially ranged from 1.1 x 10^{-1} Tg C and 2.5 x 10^{-1} Tg C in a study area consisting of 3 sites each of 100 km^2 size. They also estimated accumulation rates of soil organic carbon in cultivated lands (not under optimal management) in the Sudan-Savannah Zone ranging from 4 x 10^{-8} to 1.8 x 10^{-7} Tg C ha^{-1} y^{-1} and depletion rates of - 4 x 10^{-9} to - 7.3 x 10^{-7} Tg C ha^{-1} y^{-1} suggesting a potential for improved carbon storage under good soil management. The total amounts of carbon stored and potentials are substantial because of the extensive land area of ECOWAS.

The key challenge is in the management of soils for high and sustainable crop and forage yields, through control of one or more of the soil problems limiting crop growth and yields in specific situations. Overcoming this challenge would involve: soil cover, water harvesting especially in drier areas for dry season cropping, avoidance of soil nutrient mining in a situation of low usage of mineral fertilizers and insufficient cattle manure in the Forest Zone, management to improve carbon storage in soils as a mitigation of GHG emission and adoption by farmers of integrated soil fertility management.

Biophysical Factors- Land Resources, Land Use, Land Degradation, Farming Systems and Production

Land Resources, Land Use and Land Degradation

The total surface area of ECOWAS is 504 million hectares made up of 207 million hectares in the Gulf of Guinea Zone and 297 million hectares in the Sudano-Sahelian Zone (Table 1). Inland valley swamps accounting for approximately 2 to 5% of land in West Africa (Blein et al., 2008) were still not fully utilized. Total cultivable land area for the 15 ECOWAS countries are 196 million hectares out of which 130 million hectares were in the Gulf of Guinea Zone and 66 million hectares in the Sudano-Sahelian Zone (FAO, 2005). The acreages of arable crop land and permanent crop land in 2003 and 2013 are shown in Table 6.

Arable land increased to a much greater extent in the Sudano-Sahelian Zone compared to the Gulf of Guinea Zone as a whole. Nigeria was the only country in the Gulf of Guinea Zone that reported a decline in arable land (-2.9%). Overall, arable land in ECOWAS increased by 7.3%. Area under permanent crops increased more in the Sudano-Sahelian Zone than in the Gulf of Guinea Zone, with an average increase of 10.5% for ECOWAS. Arable plus permanent croplands were 32% of total land in 2003, and 33% in 2013 in the Gulf of Guinea Zone; in the Sudano-Sahelian Zone, it was 9.7% in 2003, and 11.3% in 2013; for ECOWAS as a whole it was 18.7% in 2003 and 20.2% in 2013.

These findings suggest an apparent high proportion of land reserves for agricultural production. The apparent large proportion of cultivable land not under annual crops in the forest areas of the Gulf of Guinea Zone gives the impression of

Table 6 - Land use: areas under arable and permanent crops in ECOWAS

	Arable Land (ha x 1000)	Permanent Crops Land (ha x 1000)	Arable+ Permanent Land (% of total land)	Arable Land (hax1000)	Permanent Crops Land (ha x 1000)	Arable+ Permanent Land (% of total land)
Year	2003	2003	2003	2013	2013	2013
Zone/Region						
Gulf of Guinea						
Total	51,367	14,257	31.8	52,434	15,685	33.0
Range	270-35,000	130-6,450	6.4-45.9	300-34,000	165-6,500	7.3-52.2
Sudano-Sahelian						
Total	28,371	322	9.67	33,106	427	11.30
Range	47-14,050	2-145	5.0-30.5	55-16,800	4-150	5.4-44.5
ECOWAS	79,738	14,579	18.74	85,540	16,112	20.2

Source: Authors' calculations from World Bank (2016); World Bank (2016)
Note: Arable and permanent croplands are defined by FAO (2005) as follows:
Arable land is land under temporary crops (double cropped areas are counted only once) + temporary meadows for mowing or pasture + land under market and kitchen gardens + land temporarily fallow (less than five years).
Permanent croplands are lands cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber.

large tracts of land lying idle and has sometimes been used to justify land grabbing for commercial tree crop/biofuel plantations. Estimates of land reserves in the Forest Zone should, however, be used with caution because the bush fallow rotation system of land use requires that land under bush fallow must be far greater than land under cropping for soil fertility to be restored. In other words, the apparently idle land under fallow is part of a rotation system and is not regarded by smallholder farmers as idle. We argue that it would have been more useful to express arable plus permanent croplands as a percentage of cultivable land, but the definition of cultivable land lacks clarity. According to FAO (2005) "Cultivable area is an area of land potentially fit for cultivation. This term may or may not include part or all of the forests and rangeland. Assumptions made in assessing cultivable land vary from country to country. National figures have been used whenever available, despite possible large discrepancies in computation methods." It is necessary to reliably estimate cultivable land in the context of land reserves of ECOWAS available for future cropping in the face of climate change

Area under forests declined in both zones: -9.8% in the Gulf of Guinea Zone and -8.5% in the Sudano- Sahelian Zone. Nigeria reported a very high decline of -34.4%, followed by Mali (13.9%). Overall, there was a -9.4% of decline in area under forests in ECOWAS over 10 years (Table 7). The decline in the Sudano-Sahelian Zone may, however, not be the same across the zone because Le *et al.* (2014) reported that conversion of biomass into forest has taken place in the Sahelian Zone. The increase in arable area and the decrease in forest area in ECOWAS associated with the release of carbon to the atmosphere would be expected to result in soil degradation if adequate soil management practices including integrated soil fertility management are not adopted by farmers.

Carbon stocks in forests of ECOWAS (Table 7) were substantial (6,708 million t in 2003 and 6,034 million t in 2013): several folds greater in the Gulf of Guinea Zone, where forests predominate, compared to the Sudano-Sahelian Zone.

Table 7 - Land use: areas under forests and carbon stock in forests of ECOWAS

	Forests (ha x1000)	Forests (% total land)	Forests (ha x1000)	Forests (% total land)	Carbon Stock in Forests (million t)	
	2003	2003	2013	2013	2003	2013
Zone/Region						
Gulf of Guinea						
Total	52,903	25.6	47,717	23.1	5,874	5,264
Range		7.9-74.7		4.2-71.1	38-1,841	20-1,839
Sudano-Sahelian						
Total	22,336	7.5	20,436	6.9	834	770
Range		1.0-45.4		0.9-43.3	3.7-352	3.9-336
ECOWAS	75,239	15.0	68,153	13.5	6,708	6,034

Source: Authors' calculations from World Bank (2005b; 2015)

Tables 5 and 7 show that the carbon stock in forest biomass of ECOWAS (6,708 Tg C) was much less than in soil (23,502 Tg C) at the 0-100 cm depth. The influence of ecosystems on carbon stocks was underscored by Woomer *et al.* (1994) who reported that for some tropical ecosystems only primary rainforests stored more carbon than soil, and Kauffman and Bhomia (2017) who showed that for mangrove ecosystems roots and soil accounted for about 86% of the total ecosystem carbon stocks (4.63 x 10^{-4} Tg C ha^{-1} and 1.38 x 10^{-3} Tg C ha^{-1} in the low mangroves of semi-arid Senegal and in the tall mangroves of humid Liberia respectively).

ECOWAS countries have experienced and continue to experience significant land degradation (Bot *et al.*, 2000; Nkonya *et al.*, 2016). Human induced severely plus very severely degraded lands were estimated at 0% and 57.4% of total lands for Guinea Bissau and Togo respectively, in the Gulf of Guinea Zone, and 0% and 56.9% for Gambia and Burkina Faso respectively, in the Sudano-Sahelian Zone (Bot *et al.*, 2000). Based on both land area data of World Bank (2005) and area of degraded land by Bot *et al.* (2000), we estimate that up to 644,000 km^2 of lands in the Gulf of Guinea Zone (31%), 1,124,000 km^2 of lands in the Sudano-Sahelian Zone (38%), and 1,768,000 km^2 of lands in ECOWAS (35%) were severely to very severely degraded by 2000. More recent assessments, by Land Use Cover Change Analysis (LUCC), still indicate that Western Africa including ECOWAS has undergone serious land degradation (Le *et al.*, 2014; Nkonya *et al.*, 2016). LUCC analysis showed that, excluding deserts, 19% of lands in Niger in the Sudano-Sahelian Zone experienced land degradation (Moussa *et al.*, 2016). The primary causes of land degradation in ECOWAS are deforestation, agriculture, conversion of grasslands to croplands and overgrazing (Bot *et al.*, 2000; Nkonya *et al.*, 2016). Deforestation in ECOWAS is not only associated with slash and burn agriculture but with fuelwood, charcoal and timber production. Deforestation and loss of soil cover promote soil erosion and loss of soil nutrients in eroded soil and run-off water.

Farming Systems

As the Length of Growing Period (LGP) increases from North to South (Figure 1), the farming system changes from pastoral to agro-sylvi-culture through agro-pastoral and agro-sylvo-pastoral systems. The FAO data on agricultural production is available on the basis of country and not on farming systems or agro-ecological zones (AEZ), but relevant information is available from previous studies to provide context to the status of and changes in agricultural production between 2003 and 2013. Windmeijer and Andriesse (1993), Kauffman *et al.* (2000) and Blein *et al.* (2008) outlined the farming systems in major agro-ecologies of West Africa and estimated their production potentials as follows:- in the Sahelian Zone, the farming system is based on a semi-nomadic rangeland, where cattle are raised in the North and includes extensive rain-fed millet cultivation in the southern parts. Rice is cultivated in lowlands and irrigation is practiced in parts of the Niger, Senegal and Volta basins. They estimated crop production potential as modest. Data on crop yields and production in ECOWAS are presented in section 3.

In the Sudan and Guinea Savannah Zones, the bush fallow system is being replaced by semi-intensive systems. The major food crops in the Sudan Savannah Zone are millet (*Panicum spp.*), sorghum (*Sorghum spp.*) and bambara nut (*Vigna subterranea*). Because of land availability, climate change and availability of new adapted varieties, some of the major crops of the humid areas such as cassava (*Manihot esculenta*), yam (*Dioscorea spp.*) and maize (*Zea mays*) are increasingly being cultivated in the Sudan Savannah Zone. Similarly, the production of millet (*Panicum spp.*) and certain legumes and livestock hitherto considered as belonging to the Sahelian zone are spreading South. The main cash crops are cotton (*Gossypium spp.*), cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogeae*). The cultivation of maize (*Zea mays*) increases at the expense of sorghum (*Sorghum spp.*), as one moves into the Guinea Savannah Zone. Cassava (*Manihot esculenta*) and yam (*Dioscorea spp.)* cultivation takes place in the southern wetter parts. Rice (*Oryza sativa*) is cultivated under irrigation and in valley bottoms as happens in the Sahelian Zone. The crop production potential in the Sudan Savannah Zone was deemed moderate. Livestock-raising is a very important enterprise. With inputs, properly used, the agricultural production potential in the Guinea Savannah Zone was estimated as moderate to good.

In the Forest Zone, the traditional bush fallow system (long tree fallows, short cropping period) involving slashing and burning of vegetation (deforestation) although giving way to semi-intensive systems still operates. Extensive systems of farming lead to destruction of forests, which are the main repository of biodiversity and are carbon sinks. The major food crops are rice (*Oryza sativa*), maize (*Zea mays*), cassava (*Manihot esculenta*), yam (*Dioscorea spp.*), sweet potato (*Ipomea batatas*), groundnut (*Arachis hypogeae*) and beans (*Phaseolus and Vicia spp.*). Rice (*Oryza sativa*) is cultivated in rain-fed uplands and in undeveloped, underdeveloped and developed swamps. They have good potential for intensive and sustainable rice production when developed, and water control is practiced that involves alternate wetting and drying cycles to minimize GHG emissions. The key perennial cash crops are cocoa (*Theobroma cacao*), coffee (*Coffea spp.*), oil palm (*Elaeis guineensis*) and rubber (*Hevea braziliensis*). The overall crop production potential was considered to be moderate to good. Because of inadequate grazing lands, high humidity and pest and disease incidence, cattle production is much less important than in the Sahelian and Savannah Zones. The typical systems outlined above are changing in response to the effects of climate change (for example dry areas becoming drier, hitherto wet areas becoming drier and dry areas becoming wetter). Crop and livestock production in ECOWAS are mainly under smallholders, non-intensive conditions involving manual labour and low use of mineral fertilizers. Cattle manure is mostly available in the Sahelian and Savannah Zones. Key challenges concerning land use and degradation are to get smallholders and large scale operators to minimize deforestation both from slash and burn agriculture, and logging for timber, and to seriously implement reforestation programmes.

Agricultural Production

Crop Production

Production and its components (acreage harvested and yield) of major food and cash crops- rice (*Oryza sativa*), maize (*Zea mays*), millet (*Panicum spp.*) and sorghum (*Sorghum spp.*) grains, cassava (*Manihot esculenta*) and yam (*Dioscorea spp.*) tubers, groundnut (*Arachis hypogeae*) (unshelled), cotton (*Gossypium spp.*) lint, coffee (*Coffea spp.*)-green berries, cocoa (*Theobroma cacao*) beans (*Phaseolus and Vicia spp.*) and palm (*Elaeis guineensis*) oil for the Gulf of Guinea and the Sudano-Sahelian Zones are shown in Tables 8, 9 and 10.

Annual Crops-Cereals

Area harvested, production and yield of rice in the Gulf of Guinea Zone increased by 70%, 99% and 17% respectively. For the Sudano-Sahelian Zone the corresponding values were 72%, 113% and 24%. Area harvested and production of maize in the Gulf of Guinea Zone rose by 59% and 53% respectively but yield declined by 4%. Area harvested, production and yield of millet in the Gulf of Guinea Zone declined by 60%, 78% and 45% respectively. In the Sudano-Sahelian Zone area harvested

Table 8 - Cereal production in ECOWAS

	Area harvested (x 1000 ha)		Production (x1000 t)		Yield (t ha^{-1})	
	2003	2013	2003	2013	2003	2013
Rice (paddy)						
Gulf of Guinea	4,004	6,795	5,912	11,739	1.48	1.73
Range	23.4-2,210	92.2-2,931	54.2-3,116	209.7-4,823	0.83-2.31	1.25-3.30
Sudano-Sahelian	572	985	1,344	2,863	2.35	2.91
Range	11.6-405.6	11.7-659	20.5-938.2	69.7-1,978	1.77-3.10	1.05-6.28
ECOWAS	4,576	7,780	7,256	14,602	1.59	1.88
Maize						
Gulf of Guinea	5,929	9,421	8,878	13,577	1.50	1.44
Range	15-3,469	15-5,763	16-5,203	7.3-8,423	1.00-2.24	0.49-2.15
Sudano-Sahelian	985	1,780	1,569	3,504	1.59	1.97
Range	4.4-435.4	14.5-913.6	2.2-665.5	5.8-1,636	0.38-2.28	0.18-2.59
ECOWAS	6,914	11,201	10,447	17,081	1.51	1.52
Millet						
Gulf of Guinea	5,126	2,047	6,765	1,474	1.32	0.72
Range	10-4,536	14.0-1,485	10-6,260	18.1-910	0.65-1.38	0.61-1.29
Sudano-Sahelian	10,034	11,237	5,938	6,464	0.59	0.58
Range	109.9-5,771	105.8-7,083	120.3-2,745	93.8-2,922	0.48-1.09	0.41-0.94
ECOWAS	15,160	13,284	12,703	7,938	0.84	0.60
Sorghum						
Gulf of Guinea	7,758	6,223	8,768	6,079	1.13	0.98
Range	15-6,935	28.5-5,449	10-8,016	26.9-5,300	0.55-1.16	0.67-1.35
Sudano-Sahelian	4,806	6,838	3,115	4,792	0.65	0.70

Source: Authors' calculations from FAO (2018)

and production increased by 12% and 9% respectively but yield declined by 3%. For sorghum, area harvested, production and yield in the Gulf of Guinea Zone decreased by 20%, 31%, and 14% respectively. Contrary to this, area harvested, production and yield increased by 42%, 54% and 8% respectively in the Sudano-Sahelian Zone.

Annual Crops-Roots and Tubers and Groundnut

Area harvested and production of cassava in the Gulf of Guinea Zone increased by 68% and 37% respectively, but yield declined by 19% (Table 9). In the Sudano-Sahelian Zone, area harvested declined by 21% but production and yield increased by 12% and 42% respectively; this was an uncommon, but desirable, case of higher production being associated mainly with higher yield. Area harvested and production of yam in the Gulf of Guinea Zone increased by 70% and 27%, but yield decreased by 25%. Similarly, area harvested, and production in the Sudano-Sahelian Zone increased by 262% and 157% respectively, but yield declined by 29%. The large increase in yam production in the Sudano-Sahelian Zone may indicate evolving farming systems because yam was traditionally a major crop in the humid areas of ECOWAS. Area harvested of groundnut in the Gulf of Guinea increased by 25% but production and yield declined by 10% and 28% respectively, suggesting that production was more associated with yield than the area harvested. In the Sudano-Sahelian Zone, area harvested, production and yield increased by 49%, 50% and 1% respectively. Thus for both cereals and roots & tubers acreage harvested rather than yield was the major determinant of the level of crop production.

Overall Zonal Effects on Production and Yield

Production of most (rice, maize, sorghum, cassava, yam and groundnut) of the crop species studied was higher in the Gulf of Guinea Zone compared to the Sudano-Sahelian Zone. Nigeria in the Gulf of Guinea Zone was the highest producer in ECOWAS of rice, maize, sorghum, cassava, yam and groundnut in both 2003 and 2013. Blein *et al.* (2008) reported higher crop production in the humid and sub-humid AEZs compared to the semi-arid zone and concluded that the humid and sub-humid zones are the “bread basket” of ECOWAS. The greater proportion of the humid and sub-humid zones falls within the Gulf of Guinea Zone and this may explain in part why production of the major crops was higher in this zone. On the other hand, the average yields of rice, maize and yam in the Sudano-Sahelian Zone

Table 9 - Cassava, yam and groundnut production in ECOWAS

	Area harvested (x 1000 ha)		Production (x 1000 t)		Yield (t ha^{-1})	
Cassava	2003	2013	2003	2013	2003	2013
Gulf of Guinea	5,415	9,108	55,647	76,215	10.28	8.37
Range	2.5-3,490	2.4-6,741	38-36,304	23-47,407	5.86-15.2	3.52-18.27
Sudano-Sahelian	50	39	344	384	6.86	9.75
Range	0.28-36.1	0.52-20.9	3.4-181.7	4.1-156.1	2.17-17.90	1.36-19.97
ECOWAS	5,465	9,147	55,991	76,599	10.25	8.37
Yam						
Gulf of Guinea	3,926	6,669	41,017	52,197	10.45	7.83
Range	2.0-2,828	2.5-5,088	20.5-29,697	21.5-35,618	8.67-12.11	6.61-16.78
Sudano-Sahelian	5	20	67	171	12.36	8.77
Range	2.4-2.9	3.8-15.6	31-35	79.2-91.6	12.01-12.80	5.86-20.63
ECOWAS	3,931	6,689	41,084	52,368	10.45	7.83
Groundnut						
Gulf of Guinea	3,029	3,785	4,056	3,664	1.34	0.97
Range	7-1,985	8-2,733	4.3-3,037	6.5-2,475	0.60-1.53	0.64-1.24
Sudano-Sahelian	1,712	2,546	1,316	1,979	0.77	0.78
Range	107.9-524.8	0.40-916.8	92.9-440.7	0.28-677.5	049-0.89	0.49-1.38
ECOWAS	4,741	6,331	5,372	5,643	1.13	0.89

Source: Authors' calculations from FAO (2018)

were higher than the average yields of these crops in the Gulf of Guinea Zone in both 2003 and 2013. Indeed, the highest yield of rice in 2003 and 2013 was reported for Niger; in 2003, the highest yield of maize was for Senegal and in 2013 it was for Mali. In both 2003 and 2013, the highest yield of cassava was reported for Niger and the highest yield of yam in these two years was for Mali. More investigations are needed to confirm and explain this pattern and how climate change may impact production and productivity differently under smallholder farming conditions in ECOWAS and how this knowledge can be exploited for improved food security. Such studies could involve a year by year trend analysis from 2003 to 2013 and/or comparisons of 2-3 years averages around 2003, with around 2013 in well-defined agro-ecologies so as to capture more precisely variability between years due to weather or climate change and/or pest infestation.

Overall Changes in Production and Yield Over Time

For ECOWAS as a whole, the production of rice, maize, cassava, yam and groundnut increased between 2003 and 2013, but that of millet and sorghum decreased. Blein *et al.* (2008) reported increases in the production of annuals in ECOWAS between 1980 and 2006. In contrast to this positive trend in production, yields of millet, sorghum, cassava, yam and groundnut decreased and even though those of rice and maize increased slightly in ECOWAS as a whole, yields were low and well below their potentials. The increases in production were most often more related to the area harvested than to yield per unit area. Lipton (2012) reported yields of 1.01 t ha^{-1} for rice, 0.78 t ha^{-1} for maize, 0.56 t ha^{-1} for millet, 0.76 t ha^{-1} for sorghum and 7.63 t ha^{-1} for cassava in Western Africa for 1961-1963. These levels, compared to those shown in Tables 8 and 9, indicate only modest increases over a span of 40-50 years from a very low baseline. Thus, the indications are that while the area of land harvested and crop production increased, the boosting of crop yields, a major concern of CAADP and the Maputo Accord did not materialize at national and zonal levels, at least in the short to medium term. The impacts of climate change on agriculture have reinforced the need for achievement and maintenance of high crop yields as an adaptation measure. This situation should be a major concern, challenge and opportunity given that the CGIAR centers in collaboration with the National Agricultural Research and Extension Systems (NARES) have developed and released high-yielding crop varieties, for example the New Rice Varieties for Africa (NERICAs), Drought Tolerant Maize for Africa (DMTA), Cassava variety IITA-TMS-1982132 with vitamin A containing yellow tubers and Sorghum variety 12KN1CSV-188 (IITA, 2013; ICRISAT, 2016; Tadele *et al*., 2017) with associated improved crop and soil management practices, over the past three to four decades. Increase in on-farm and national agricultural yields is recognized as a major step towards poverty reduction and food security (Lipton, 2012).

Perennial and Cash Crops

Data for coffee, cocoa and palm oil (from oil palm) were available almost only for the Gulf of Guinea Zone where the climate is most suitable for their cultivation. For coffee, the area harvested in the Gulf of Guinea Zone increased by 62%, but production and yield decreased by 10% and 45% respectively. Area harvested and production of cocoa increased by 23% and 19% respectively while yield decreased by 3%. Cote d'Ivoire in 2003 and 2013 was the highest producer in ECOWAS of coffee-green berries and cocoa beans. Like for the annual crops, yields of cocoa and coffee were well below their potentials and improving the status is a challenge. Production of palm oil increased by 7% in the Gulf of Guinea Zone and 96% in the Sudano-Sahelian Zone (data only for Gambia and Senegal). Production of cotton lint in the Gulf of Guinea Zone and Sudano-Sahelian Zone decreased by 36% and 6% respectively. This contrasts with the 7.3% per annum increase in cotton production in West Africa between 1980 and 2006 as reported by Blein *et al*., (2008). Mali in 2003 and Burkina Faso in 2013 were the highest producers of cotton lint in ECOWAS. Data were not available on the area harvested and yield of oil palm and cotton.

Livestock, Fisheries and Aquaculture Production

Livestock

Cattle production (number of heads) and yield of meat in the Gulf of Guinea Zone increased by 35% and 5% respectively and in the Sudano-Sahelian Zone by 37% and 2% respectively (Table 11). Goat production and yield of meat in the Gulf of Guinea Zone increased by 52% and 2% and in the Sudano-Sahelian Zone by 49% and 19% respectively. Sheep production increased by 37% but yield decreased by 1% in the Gulf of Guinea Zone; in the Sudano-Sahelian Zone, production increased by 41% but yield decreased by 10%. Pig production in the Gulf of Guinea Zone increased by

Table 10 - Perennial and cash crop production in ECOWAS

	Area harvested (x1000 ha)		Production (x 1000 t)		Yield (t ha^{-1})	
Coffee green	2003	2013	2003	2013	2003	2013
Gulf of Guinea	512.9	831.9	192.3	172.6	0.37	0.21
Range	0.3-410.5	0.36-737.4	0.06-140.0	0.07-103.7	0.2-1.7	0.14-2.48
Sudano-Sahelian		0.3		0.062		0.21
ECOWAS	512.9	832.2	192.3	172.7		0.76
Cocoa beans						
Gulf of Guinea	4,585	5,643	2,263	2,696	0.49	0.48
Range	15-2,000	17.4-2,670	0.1-1,352	0.12-1,449	0.17-0.68	0.14-0.86
ECOWAS	4,585	5,643	2,263	2,696	0.49	0.48
Cotton lint						
Gulf of Guinea			573	368		
Range			1.8-172	1.4-133.5		
Sudano-Sahelian			447	422		
Range			0.18-259.7	0.19-280		
ECOWAS			1,020	790		
Palm oil						
Gulf of Guinea			1,528	1,638		
Range			4.9-1,022	6-880		
Sudano-Sahelian			9	17		
Range			2.5-6	3-13.7		
ECOWAS			1,537	1,655		

Source: authors' calculations from FAO (2018)

Table 11 - Livestock production in ECOWAS

	Number of Live Animals (x1000)		Yield of Meat (Hg animal^{-1})	
	2003	2013	2003	2013
Cattle				
Gulf of Guinea	23,963	32,299	1,201	1,258
Range	36-15,164	42-19,374	950-1,596	1,030-1,935
Sudano-Sahelian	24,299	33,256	1,272	1,293
Range	21.8-7,312	22.8-10,733	1,100-1,435	892-1,635
ECOWAS	48,262	65,554	1,230	1,272
Goat				
Gulf of Guinea	57,045	86,590	103	104
Range	220-47,552	345-70,699	90-132	90-151
Sudano-Sahelian	35,661	51,671	107	127
Range	112-10,857	190-18,216	81-140	80-238
ECOWAS	92,706	138,261	104	114
Sheep				
Gulf of Guinea	38,785	53,050	117	116
Range	189-30,086	275-40,319	100-155	85-155
Sudano-Sahelian	27,758	39,024	128	115
Range	9.2-8,581	11.6-13,081	90-160	69-149
ECOWAS	66,543	92,074	121	116
Pig				
Gulf of Guinea	7,592	9,530	407	383
Range	11.8-5,678	62.3-6,795	300-580	268-580
Sudano-Sahelian	2,514	2,940	414	417
Range	16-1,887	4.9-2,345	300-500	300-500
ECOWAS	10,106	12,470	410	397

Source: Authors' calculations from FAO (2016c; 2018)

26% but yield decreased by 6%; in the Sudano-Sahelian Zone, production and yield increased by 17% and 1% respectively. Chicken numbers increased by 36%, egg production by 43% and yield of meat by 10% in the Gulf of Guinea Zone. In the Sudano-Sahelian Zone, chicken numbers increased by 51%, egg production by 25% and yield of meat by 16% (Table 12). Under extensive systems of livestock management in ECOWAS increase in production was more closely related to increase in numbers of livestock than yield.

Overall Zonal Effects on Production and Yield and Changes Over Time

Cattle production (number of heads) was higher in the Sudano-Sahelian Zone in both 2003 and 2013, but the production of sheep, goats, pigs and chicken was higher in the Gulf of Guinea Zone in both years. Nigeria had the highest numbers in ECOWAS of each livestock species in 2003 and 2013. For ECOWAS as a whole, the production of each livestock species increased between 2003 and 2013. However, there were very small increases or decreases in yield of meat for cattle, sheep, goats and pigs and only for chicken meat did the increase rise up to 10% in the Sudano-Sahelian Zone, to 16% in the Gulf of Guinea Zone and 13% in ECOWAS between 2003 and 2013 (Table 12). Extensive systems of livestock husbandry, associated with low productivity, is common in all zones of ECOWAS. A move to more intensive systems is considered as an adaptation option to and mitigation of climate change (Harvey *et al.*, 2013) because of the associated efficient use of inputs and better recycling of animal wastes.

Fisheries and Aquaculture

Fisheries capture takes place from marine and inland sources. Marine capture is from the Economic Exclusive Zone (EEZ) of ECOWAS countries, which have shorelines with the Atlantic Ocean. These are Cape Verde, Gambia and Senegal (Sudano-Sahelian Zone) and all 9 countries in the Gulf of Guinea Zone namely Cote d'Ivoire, Benin, Guinea Bissau, Guinea, Ghana, Liberia, Nigeria, Sierra Leone and Togo (Figure 1). Not surprising therefore, the amount of fish captured in the Gulf of Guinea Zone far exceeded that captured in the Sudano-Sahelian Zone (Table 13). Fish capture increased by 25% in the Gulf of Guinea Zone, although Ghana and Togo reported declines of 23% and 27% respectively. There was a smaller increase of 5% in

Table 12 - Chicken production in ECOWAS

	Number of Live Chicken (x1000)		Number of Eggs (x1000)		Yield of Meat (0.1g animal^{-1})	
	2003	2013	2003	2013	2003	2013
Gulf of Guinea	255,626	347,526	12,318,380	17,626,195	8,773	9,684
Range	1,500-137,680	1,900-134,839	22,560-10,222,200	29,200-14,444,000	7,199-10,000	6,834-20,326
Sudano-Sahelian	91,934	138,532	2,009,427	2,520,847	8,489	9,868
Range	417-29,000	1,117-48,796	14,620-927,650	19,140-1,304,000	6,636-10,298	8,000-13,624
ECOWAS	347,560	486,058	14,327,807	20,147,042	8,659	9,758

Source: Authors' calculations from FAO (2016c; 2018)

the Sudano-Sahelian Zone with Niger reporting a decline of 19%. Capture increased by 18% in ECOWAS between 2003 and 2013.

Aquaculture production was several folds higher in the Gulf of Guinea Zone than in the Sudano-Sahelian Zone. It was most important in Nigeria and Ghana among the Gulf of Guinea countries and Mali among the Sudano-Sahelian countries. Recognized as an adaptation option to climate change, it increased tremendously between 2003 and 2013; by 870% in the Gulf of Guinea Zone, 200% in the Sudano-Sahelian Zone, and overall by 847% in ECOWAS (Table 13). However, it could not be ascertained from this study whether response to climate change was the main reason responsible for the dramatic change in production. Data on the productivity of aquaculture was not available, but with some fish farmers still using unimproved breeds and practices it should be expected that there is room for improvement of productivity.

The overarching challenge concerning land use and agricultural production is to improve crop and livestock productivity while protecting the land resources against further damage. This would involve the following strategies: matching land use to the land resources under increasing population and competing needs; rehabilitation of degraded lands and reforestation; efficient utilization of water resources in situations of shortened growing seasons and insufficiency of soil moisture especially in the Sahelian Zone; raising yields at the farm level through the adoption by farmers

Table 13 - Fisheries and aquaculture production in ECOWAS

	Fisheries		Aquaculture	
	2003	2013	2003	2013
	(t)			
Gulf of Guinea	1,238,450	1,542,551	32,564	315,984
Range	6,153-475,162	6,707-721,355	2-30,677	23-278,706
Sudano-Sahelian	679,646	716,035	1,156	3,465
Range	8,136-469,284	20,500-471,472	5-1,008	33-2,205
ECOWAS	1,918,096	2,258,586	33,720	319,449

Source: Authors' calculations from FAO (2016b)

of improved but adapted varieties and breeds in all AEZs; moving away from the slash and burn agriculture in the uplands of the Forest Zone and annual burning of Savannah vegetation to sustainable intensification; crop-livestock integration and investment in soil conservation and integrated soil fertility management (ISFM).

The major challenges for the fisheries sector are to quantify the marine resources, prevent their overexploitation by the industrial fishing fleet and poaching by the foreign fleet and meet the quality standards of the European Union and other buyers and improve local processing for example traditional drying (smoking) with firewood. Concerning aquaculture, increased use of improved and adapted species and management practices is required for the improvement of productivity and food security. An extremely important challenge, which cuts across all the agriculture-related subsectors is to curtail activities which lead to unreported data and make accessible good quality data on the basis of which rigorous analysis and policy decisions can be made. In the absence of empirical data collected at country level, some of the data in international databases have to be estimates.

There are opportunities in the agriculture sector for adapting to and mitigating climate change and improving production and productivity. These include the availability of water especially in the Guinea Savannah and Forests Zones and cultivable land; availability of crop species and varieties with different degrees of tolerance to drought and flooding; availability of technology for artificially inseminating local breeds of livestock; and the regional capacity in climate change research, conventional plant and fish (aquaculture) breeding and biotechnology of the international and national agricultural research institutes.

Food Security, Policies and Institutions

There were cases where crop production declined but more often than not crop production increased. In general, the increase of agricultural production suggests that the availability and accessibility (through income earned) aspects of food security in ECOWAS could have improved between 2003 and 2013. Taking into consideration that the population also grew within this period by 28% in Gulf of Guinea Zone and 39% in Sudano-Sahelian Zone, did the increase in production result in improved food security? Data aggregated from a worldwide food security score is shown in Table 14. Except for quality and safety, all indicators of food security are higher in the Gulf of Guinea Zone. Furthermore, food security was poor across ECOWAS almost 10 years after CAADP and the Maputo Accord. An assessment done after 2012 (E.I.U, 2016) continued to show food insecurity in the region. There is need for in-depth studies to unravel and get a good understanding of the interactions between the climate change impact chain factors on food security in ECOWAS.

The Maputo Accord of 2003 required ECOWAS member states to adopt a policy of increasing the annual allocation of funds from national budgets to agriculture to at least 10% within 5 years. Based on Benin and Yu (2012) and the Statistics of Public Expenditure for Economic Development (SPEED, 2013) data set of IFPRI cited in Kreuger (2015), Burkina Faso, Mali, Niger and Senegal in the Sudano-Sahelian Zone and Guinea and Ghana in the Gulf of Guinea Zone, met the 10% commitment by 2012. This raises a research question; why was compliance clearly better in the Sudano-Sahelian Zone? The major regional policy which stems from CAADP (the aims of which were outlined earlier) and the Maputo Accord is ECOWAP, the ECOWAS Regional Agricultural Policy (ECOWAS, 2005). It identifies improving the productivity and competitiveness of West African Agriculture, improved management of shared resources (sustainable fisheries resource management) organized transhumance and rangeland management as priorities. ECOWAP therefore targets, in broad terms, key challenges outlined in this study.

There are other plans, agreements and declarations that complement ECOWAP. For example, ministers of governments agreed on Biotechnology and Safety Action Plan (ECOWAS, 2006) and the ECOWAS Environmental Policy (ECOWAS, 2008).

Table 14- Food security indicators in 2012 in ECOWAS

	Affordability	Availability	Quality and Safety	Overall
		Score/100		
Gulf of Guinea				
Mean	29	42	34	36
Range	21.4-36.2	35.6-49.3	21.3-48.5	30-43.9
Sudano-Sahelian				
Mean	23	39	37	33
Range	18.3-30.1	35.3-46.2	33.9-39.6	29-37.3
ECOWAS	27	41	35	34

Source: Authors' calculations from EIU (2016)

Member states also signed up to the Abuja Declaration on Fertilizers in 2006 in which Heads of States declared "fertilizer" from both organic and inorganic sources a strategic commodity without borders. They agreed to increase fertilizer use from the extremely low continental level of 8 kg ha^{-1} (compared to Asia, Europe and America) to 50 kg ha^{-1} (IFDC, 2006).

The institutions dealing with the human factors that cut across countries are the United Nations Specialized Agencies mainly UNESCO, UNICEF and UNFPA which provide support to government ministries in their quests to improve standards in education and health. The USAID RFPP and Marie Stoppes have promoted and continue to promote family planning, but they are challenged by shifts in funding policies of High-Income Industrialized Countries (donor countries) on family planning and religious norms of recipient countries.

Concerning the environmental and biophysical factors, there is a wide range of institutions involved in climate change issues related to agriculture, food security and agricultural research and development in the region. They include WASCAL, AGRHYMET and ACMAD. Water Basin Authorities (FAO, 2005, Niang, 2007, WARNER Consultants, 2007) regulate the management of shared water resources. USAID/West Africa works with ECOWAS and their energy institutions, involving the

ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) and the West Africa Power Pool (WAPP) to leverage investment in clean energy generation and enable cross border trade of energy and develop regional public-private partnership (USAID, 2019). The agriculture sector would be modernized from clean energy and energy-saving technologies but the project is in its early stages and not all member states are as of now participating. With regards to agricultural research and development, specifically, the Consultative Group on International Agricultural Research Centers (IFPRI, IITA, IWMI, ICRISAT, World Fish, ICRAF, ILRI, Africa Rice Centre), and others including FAO, World Bank, IFAD, IFDC, UNIRA, AGRA, CORAF/WECARD and FARA collaborate with the National Agricultural Research and Extension Services (NARES) on technical matters and assist in drawing out policy implications of their research and/or conducting policy research. Research and development on tree (cash) crops is mainly in the hands of NARES. Inadequate funding is a major problem for the NARES to effectively carry out their mandates. NGO's also play important roles in environmental protection and agricultural extension activities of government ministries and agencies. The African Development Bank (ADB, 2017) is bringing CGIAR centers, regional organizations and NARES together on a Technology for African Agricultural Transformation (TAAT), the outcome of which will be a technological delivery infrastructure with focus on agro-ecological zones and their priority commodities to reach 40-50% of African farmers (including those of ECOWAS) with the most relevant food production technologies by 2025. This is an important initiative that will significantly contribute to the achievement of the vision of CAADP.

Summary and Conclusions

The impacts of climate change in ECOWAS are felt through a chain of human, environmental, biophysical and economics factors, including population growth, urbanization, water resources and demand, soil quality, land resources, crop, livestock and fisheries production and productivity. Knowledge of the status and interactions of these factors informs policy formulation and research and extension agendas on adaptation to and mitigation of climate change in the agriculture sector.

There were differences between the Gulf of Guinea Zone and Sudano-Sahelian Zone in literacy rates, population density, and population growth rates in 2003 and 2013. Urbanization is high across ECOWAS. Increases in these demographic factors will put further pressure on the natural land and water resources and influence food imports into ECOWAS. A serious challenge would be in matching the exploitation of natural resources to population growth and catering for the food needs of urbanized communities.

Daily temperatures are high throughout ECOWAS but more so in the Sudano-Sahelian Zone. Clear evidence exists of increasing temperature between the late 20th century and the end of the 21st century in West Africa; the projected increase being higher than the global average. The implication is that climate change manifested as global warming will have very serious consequences for ECOWAS where the vulnerability to climate change has been determined to be amongst the highest in the world. Even though the downscaled GCM models, in general, project increase in temperature over time, they do not indicate the same increases. Unlike for temperature, downscaled GCM models on annual rainfall do not in general project increases; they rather project both increases and decreases for West Africa. This has serious implications for agricultural research and development and production because agriculture in ECOWAS is predominantly rainfed, and changes in rainfall patterns, result in changes in agro-ecological zones and their suitability for crop species and livestock breeds. The challenges is to adequately guide policy makers on the allocation of financial resources to adaptation and mitigation initiatives.

Surface and ground water resources in the Gulf of Guinea Zone exceeded those in the Sudano-Sahelian Zone, but Total Renewable Water resources in some countries in the Sudano-Sahelian Zone were greater than those in some countries of the Gulf of Guinea Zone because of shared boundary water basins. Total Internal Renewable Water resources per capita were below international limits in some countries in both the Gulf of Guinea Zone and the Sudano-Sahelian Zone in 2003 and 2013. However, when Total Renewable Water resources were considered, each country in the Gulf of Guinea Zone was above the critical limit. The implication is that there is need for good regional collaboration on the sustainable management of shared water resources in ECOWAS. The challenges are to optimize the efficient use of water resources and strengthen the capacity of the regional Water Basin Authorities in the face of climate change.

The soils of ECOWAS are diverse in properties but are in general low activity- clay soils and of low fertility especially the sandy soils occurring frequently in the Sudano-Sahelian Zone. Carbon stored in soils was substantial and much greater in the Gulf of Guinea Zone compared to the Sudano-Sahelian Zone indicating a good contribution to mitigation of global GHG emissions and need for soil carbon management systems adapted to the different agro-ecologies.

Land is abundant in ECOWAS but there is strong zonal effects in terms of the proportion of arable plus permanent croplands with respect to total land. The amount of land perceived to be reserved for agricultural production (potentially cultivable) is not accurately known and may be overestimated. This information is important in planning responses to climate change in the agriculture sector. The area under forests (reservoirs of agro-biodiversity) declined substantially between 2003 and 2013. Carbon stored in forests were about four folds less than that stored in soils. The challenges are to halt slash and burn agriculture, reverse land degradation, and improve carbon storage in soils and forests bearing in mind the commitments in the INDCs of COP 21.

The production levels of the major crops were higher in the Gulf of Guinea Zone but yields of some crops were higher in the Sudano-Sahelian Zone, indicating good productivity potential within certain areas of the Sudano-Sahelian Zone (presumably the Guinea Savannah), under appropriate management. Among the livestock species, cattle production was more important in the Sudano-Sahelian Zone. Increase in crop production and livestock numbers were more closely related to increases in acreage harvested and livestock numbers than yield increases which is not a desirable situation because extensive cultivation is not environmentally sound. Although production of the major crops, livestock and aquaculture increased between 2003 and 2013, food security remained unsatisfactory. The boost in production and productivity (yield) and by extension improvement of food security envisioned by CAADP and Maputo Accord, did not happen between 2003 and 2013. Adoption by farmers of the improved high-yielding crop varieties with tolerance or resistance to the major pests and diseases released by the research institutions should be a path towards meeting the goals of CAADP and the Maputo Accord.

Existing internationally funded institutions are well capacitated to conduct agricultural research and development on the climate change impact chain factors, but national institutions are funded primarily by governments with little or no supplementation from the local private sectors. Financing levels beyond the capacity of national governments are therefore required from the global climate change funds if adaptation and mitigation projects, based on a good understanding of the climate change impact chain factors can be implemented and proven improved practices upscaled. This would enable ECOWAS to realize its potential of making significant contributions to global food security and the mitigation of global climate change. This study has shown that information is available to aid the formulation and/ or reform of policies and the elaboration of research and development agendas on climate smart agriculture, taking into consideration the similarities and differences between geographical/ agro-ecological zones.

References

ADB 2017. Technologies for African Agricultural Transformation: Framework Programme in Support of Feed Africa. Abidjan: African Development Bank.

Adebo G.M. & Ayelari T.A., 2011. Climate change and vulnerability of fish farmers in Southwestern Nigeria. African Journal of Agricultural Research, 6 (18), 4230-4238.

Anikwe M.A.N., 2010. Carbon storage in soils of Southeastern Nigeria under different management practices. Carbon Balance and Management 2010, 5:5. Retrieved from http://www.cbmjournal.com/content/5/1/5 on 22 August, 2018.

Bationo A., Hartemink A., Lungu O., Naimi M., Okoth P., Smaling E. & Thiombiano L., 2006. African soils: their productivity and profitability of fertilizer use. Background paper prepared for the African Fertilizer Summit Abuja, June 9-13, 2006. Muscle Shoals, Alabama: International Fertilizer Development Center.

Blein R., Soule B.G., Dupraigre B.F. & Yerima B., 2008. Agricultural potential of West Africa (ECOWAS). Presles : Fondation pour l'agriculture et la ruralité dans le monde.

Bot A.J., Nachtergale F.O. & Young A., 2000. Land resource potential and constraints at regional and country levels. World Soil Resources Report 90. Rome: Food and Agriculture Organization of the United Nations.

Burkina Faso, MECV., 2007. Programme d'action nationale d'adaptation (PANA) a la variabilite et aux changement climatiques. Ouagadougou : Ministere de l'Environnement et du Cadre de Vie.

CGIAR, 2009. Identifying livestock based management options to reduce vulnerability to drought in agropastoral and pastoral systems in East and West Africa. Final Report, CGIAR System-Wide Livestock Programme. Nairobi: International Livestock Research Institute.

Ciais P., Bombelli A., Williams M., Piao S.L., Chave J., Ryan C.M., Henry, M., Brender

P. & Valentini R., 2011. The carbon balance of Africa: Synthesis of recent research studies. Phil. Trans. R. Soc. A (2011) 369, 2038–2057. doi:10.1098/rsta.2010.0328.

E.I.U., 2016. Global food security index 2016. New York: Economist Intelligence Unit, Dupont.

ECOWAS, 2005. Regional agricultural policy for West Africa (ECOWAP). Abuja, Nigeria: Economic Community of West African States Commission.

ECOWAS, 2006. Action plan for the development of biotechnology and biosafety in the ECOWAS sub-region, 2006-2010. Abuja: Economic Community of West African States Commission.

ECOWAS, 2008. ECOWAS environmental policy. Abuja: Economic Community of West African States Commission.

FAO, 2001. Lecture notes on the major soils of the World. Rome: Food and Agriculture Organization of the United Nations.

FAO, 2005. Irrigation in Africa: AQUASTAT survey. Rome: Food and Agriculture Organization of the United Nations. Retrieved from www.fao.org on 20 September, 2016.

FAO, 2016a. Agroecological map of West Africa Retrieved from www.fao.org/docrep/006/y4751e/y4751e0p.htm on 17 October, 2016.

FAO, 2016b. AQUASTAT Main Database. Food and Agriculture Organization of the United Nations. Retrieved from www.fao.org on 5 August, 2018.

FAO, 2016c. The agricultural sectors in the Intended Nationally Determined Contributions: Analysis. Rome: Food and Agriculture Organization of the United Nations.

FAO, 2018. Agricultural production data. Retrieved from www.fao.org/statistics/en on 15 September, 2018.

Harvey C.A., Chacon M, Donatti C.I. *et al.*, 2013. Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical landscapes. Conservation Letters 00 (2013), 1-14. Wiley Periodicals.

Henry M., Valentini R., & Bernoux M., 2009. Soil carbon stocks in ecoregions of Africa. Biogeosciences Discuss. 6, 797-823. Retrieved from www.biogeosciencees-discuss.net/61797/2009 on 24 February, 2019.

Hochleithner S. & Exner A., 2018. Outmigration, development and global environmental change: A review and discussion of case studies from the West African Sahel. Working Paper 15. Visby: Swedish International Centre for

Local Democracy.

ICRISAT, 2016. Sorghum in Africa. Retrieved from www.icrisat.org/sorghum-in-eastern-and-southern-africa on 24 February, 2019.

IFDC, 2006. Africa fertilizer summit proceedings. June 9-13, 2006. Abuja, Nigeria. Muscle Shoals, Alabama: International Fertilizer Development Center.

IITA, 2013. Nigeria releases improved cassava varieties to boost cassava productivity. Retrieved from https://www.iita.org/news-item/nigeria-releases-improved-cassava-varieties-boost-productivity on 24 February, 2019.

IPCC, 2014. Climate change2014: Synthesis report summary for policy makers. Geneva: Intergovernmental Panel on Climate Change.

IPCC, 2018. Global warming of 1.5 °C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty: Summary for Policymakers. Geneva: Intergovernmental Panel on Climate Change.

Jalloh A., Nelson G.C., Thomas T.S., Zougmore R. & Roy-Macauley H. (Eds), 2013. West african agriculture and climate change. Washington: International Food Policy Research Institute.

Jalloh A., Rhodes E.R., Koll I., Roy Macauley H. & Sereme P., 2011. Nature and management of the soils in West and Central Africa: A review to inform farming systems research and development in the region. (Monograph). Dakar: Council for Agricultural Research and Development in West and Central Africa.

Jones P. & Thornton P.K., 2009. Croppers to livestock keepers: Livelihoods transitions to 2050 in Africa due to climate change. Environment Science and Policy 12, 427-437.

Kauffman J.B. & Bhomia R.K., 2017. Ecosystem carbon stocks of mangroves across broad environmental gradients in West-Central Africa: Global and regional comparisons. PLoS ONE1 2 (11): e0187749. Retrieved from https://doi.org/10.1371/journal.pone.0187749 on 22 August, 2018.

Kauffman S., Koning N. & Heerink N., 2000. Integrated soil management and agricultural development in West Africa 1: Potentials and constraints. The Land. Retrieved from www.isric.org/isric/webdocs/paper%201%kauffman.pdf on 15 September, 2016.

Kreuger L.J., 2015. Has the Maputo Declaration Made a Difference? Looking at the past ten years of Sub-Saharan Agriculture within the CAADP. Bachelor Thesis Lund University, Development Economics. Retrieved from http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8045580&fileOId=8045604. on 7 November, 2018.

Kurukulasuriya P. & Mendelsohn R., 2008. How will climate change shift agroecological zones and impact African agriculture? Policy Research Working Paper4717. Washington: World Bank.

Lal R., Negassa W. & Lorenz K., 2015. Carbon sequestration in soil. Current Opinion in Environmental Sustainability 15, 79-86.

Lam V.W.Y., Cheung W.W.L., Swartz, W. & Sumaila U.R., 2012. Climate change impacts on fisheries in West Africa: Implications for economic, food and nutritional security. African Journal of Marine Science 34 (1), 103-117.

Le Q.B., Nkonya, E. & Mirzabaev A., 2014. Biomass productivity-based mapping of global level degradation hotspots. ZEF Discussion Papers on Development Policy No 193. Bonn: University of Bonn.

Lipton M., 2012. Learning from others: Increasing agricultural productivity for human development. Working Paper WP 2012-007. Washington, USA: United Nations Development Programme.

Maplecroft, 2013. Climate change vulnerability index 2014. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/Climate_Change_Vulnerability_Index_%202014_Map_0.pdf on 12 December, 2016.

Molden D., Frenken K., Barker R., de Fraiture C., Mati B., Svendsen M., Sadoff C. & Findlayson M., 2007. Trends in water and agricultural development. Chapter 2. In D. Molden (Ed.), Water for food, water for life: A comprehensive assessment of water management in agriculture (pp.57-89). Colombo: Earthscan & International Water Management Institute.

Moussa B., Nkonya E., Meyer S., Kato S., Johnso, T. & Hawking J., 2016. Economics of land degradation in Niger p499-539. In E.Nkonya et al. (Eds), Economics of land degradation and improvement: A global assessment for sustainable development (pp.499-539). Washington, & Bonn: International Food Policy Research Institute & Center for Development Research (ZEF). University of Bonn.

Nakicenovic N., 2000. Special report on emissions scenarios: A special report of working group 3 of the International Panel on Climate Change. Cambridge

University, Cambridge

Nelson G. C., Rosegrant M.W., Koo J., Robertson R., Sulser T., Zhu T., Ringler C., Msangi S., Palazzo A., Batka M., Magalhaes M., Valmonte-Santos R., Ewing, M. & Lee D., 2009. Climate Change: Impact on agriculture and costs of adaptation. Washington: International Food Policy Research Institute.

Niang I., 2007. Institutional framework in relation to climate change in West and Central Africa. Consultancy Report. Climate change adaptation in Africa Programme. Dakar: Universite Cheik Anta Diop.

Niang I., Ruppel O.C., Abdrabo M.A., Essel A., Lennard C., Padgham J. & Urquhart P., 2014. Africa. In Climate Change 2014: Impacts, adaptation, and vulnerability. Part B; Regional Aspects. Contribution of Working Group 2 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Nkonya E., Johnson T., Kwon H.Y. & Kato E., 2016. Economics of land degradation in sub-Saharan Africa. In E. Nkonya *et al.* (Eds.), Economics of land degradation and improvement-a global assessment for sustainable development (pp. 215-259). Washington & Bonn: International Food Policy Research Institute & Center for Development Research (ZEF), University of Bonn.

Omitoyin S.A. & Tosan F.B., 2012. Potential impacts of climate change on livelihood and food security of artisanal fisheries in Lago State. Nigeria Journal of Agricultural Science 4 (9), 20-30.

Rhodes E.R., Jalloh A. & Diouf A., 2014. Review of research and policies for climate change adaptation in the agriculture sector in West Africa. Working Paper 090. AfricaInteract, Institute of Development Studies, Brighton: Future Agriculture Consortium.

Roudier P., Ducharne A. & Feyen L., 2014. Climate change impacts on run off in West Africa: A review. Hydrol. Earth Syst. Sci 18, 2789-2801. Retrieved from www.hydrol-earth-syst-sci-net/18/2789/2014 on 16 August, 2018.

Thornton P., Herrero M., Freeman A., Mwai O., Rege E., Jone, P. & McDermott J., 2007. Vulnerability, climate change and livestock: Research opportunities and challenges for poverty alleviation. Journal of Semi-Arid Tropical Agricultural Research 4 (1), 1-23.

Tadele Z., 2017. Raising crop productivity in Africa through intensification. Agronomy 7, 22; doi:10.3390/agronomy 70100022. Retrieved from www.mdpi.com/jounal/agronomy on 24 February, 2019.

Tondoh J.E., Ouedrago I., Bayala J., Tamene L., Sila A., Vagen T. & Kalinganire A., 2016. Soil organic carbon stocks in semi-arid West African drylands: Implications for climate change adaptation and mitigation. SOIL DISCUSSION doc: 10.5194/soil-2016-45, 2016. Retrieved from https://www.soil-discuss.net/soil-2016-45/soil-2016-45.pdf on 15 August, 2018.

UNCDP, 2016. List of Least Developed Countries. New York: United Nations Committee for Development Policy.

Urama K.C. & Ozor N., 2010. Impacts of climate change on water resources in Africa: The role of adaptation. Nairobi: African Technology Policy Studies Network.

Warner Consultants, 2007. Sourcebook on Africa's River Basins Organizations. Retrieved from http://www.cesa.co.za/sites/default/files/GAMA2017_G1_Sine%20Aly%20Badara%20Coulibaly%20PLEAH_River%20Basins%20integreted%20water%20resources%20management%20and%20sustainable%20development%20in%20 West%20Africa.pdf on 18 July, 2018.

West Africa Gateway of Club du Sahel, 2011. West Africa Gateway. Retrieved from www.westafricagateway.org.

USAID, 2019. Clean and efficient energy. Retrieved from https://www.usaid.gov/west-africa-regional/clean-and-efficient-energy on 24 February, 2019.

Windmeijer P.N. & Andriesse W., 1993. Inland valleys in West Africa: An agro-ecological characterization of rice growing environments. Wageningen: International Institute for Land Reclamation and Improvement.

Woomer P.L, Martin A., Albrecht A., Resck D. V.S. & Scharpenseel H.W., 1994. The importance and management of soil organic matter in the tropics. In P.L. Woomer & M.J. Swift (Eds.), The biological management of tropical soil fertility (pp. 47-80). New York: John Wiley & Sons.

World Bank, 2005a. Africa development indicators. Washington: International Bank for Reconstruction and Development.

World Bank, 2005b. World development indicators. Washington: International Bank for Reconstruction and Development.

World Bank, 2006. World development indicators. Washington: International Bank for Reconstruction and Development.

World Bank, 2015. World development indicators. Washington: International Bank for Reconstruction and Development.

World Bank, 2016. World development indicators. Washington: International Bank for Reconstruction and Development.

World Bank, 2017. World development indicators. Washington: International Bank for Reconstruction and Development.

Abbreviations

ACMAD	African Centre of Meteorological Application for Development
AGRA	Alliance for a Green Revolution in Africa
AGRHYMET	Agro-Hydro-Meteorology
AU-NEPAD	African Union New Partnership for Africa's Development
CAADP	Comprehensive Africa Agricultural Development Programme
CGIAR	Consultative Group for International Agricultural Research
CILSS	Permanent Inter State Committee Against Drought in the Sahel
COP	Conference of Parties
CORAF/WECARD	Council for Agricultural Research and Development in West and Central Africa
ECOWAP	Regional Agricultural Policy for West Africa
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Regional Centre for Renewable Energy and Energy Efficiency
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
GCM	General Circulation Model
GHG	Green House Gas
ICRISAT	International Crop Research Institute for the Semi Arid Tropics

IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Center
INDC	Intended Nationally Determined Contributions
IWMI	International Water Management Institute
LGP	Length of Growing Period
NARES	National Agricultural Research and Extension Services
RCP	Representative Concentration Pathway
RFPP	Regional Family Planning Project
TAAT	Technology for African Agricultural Transformation
UNCDP	United Nations Committee for Development Policy
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
UNU-INRA	United Nations University Institute for Natural Resources in Africa
USAID	United States Agency for International Development
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
WAPP	West Africa Power Pool