Bununu *et al. Sustainable Earth Reviews* (2023) 6:16
https://doi.org/10.1186/s42055-023-00065-4

Sustainable Earth Reviews

REVIEW

Open Access

# Land cover, land use, climate change and food security

Yakubu Aliyu Bununu[1*], Ashiru Bello[1] and Adamu Ahmed[1]

**Abstract**

The article discusses the intricate relationships between land cover and land use change on the one hand and climate on the other. It explores the current state of the climate change debate and submits that evidence abounds that human-induced climate change is indeed happening. It further explains the concepts of land cover and land use and the similarities, differences and relationships between them. The article then goes on to explore the subject of land use and land cover changes and modifications and how these processes can occur as a consequence of climate change and can also be the drivers of climate change. It then discusses how land cover, land use and climate interact to impact food security using secondary data from Nigeria and also outlines other impacts of climate change and their consequences on food security.

**Keywords** Land Cover, Land Use, Climate Change, Food Security, Nigeria

## Introduction

Studies of climate change have shown close association between climate change and land cover and land use modifications. This relationship is both circular and complex. While change in land use can affect the climate, climate change can as well restrict or alter the potential usability of land. 19% of the net total $CO_2$ emissions from anthropogenic activities between 1959 to 2019 were attributable to land use change, and 32% of the total emissions were absorbed by the land [29]. Understanding the interaction between land use, land use change and forests (LULUCF) and climate change have thus demonstrated the potential for providing valuable information in international climate discourse. Incidentally however, compromises have been observed in the way anthropogenic emissions of GHGs were reported to the United Nations Framework Convention on Climate Change (UNFCCC) by countries in a number of sectors including agriculture, forestry and other land uses [62]. Several spill-over effects including drought are associated with changes in land use and forests. In semi-arid and arid regions as well as deprived regions and populations, significant scarcity of water caused by human activities manifests in the form of hostile competition in accessing water, energy and water demand constraints [74]. Effects are equally observable in climate change affected regions which include loss of livelihood, displacements and violent conflicts, etc. In regions faced with such challenges, peasant farmers are constantly facing the possibility of poor harvests that drives them into further poverty, hunger and malnutrition [61, 90]. The paper undertook a review of climate change drivers and impacts and its relationships with land cover, land use and food security. It uses secondary data from Nigeria to demonstrate how climate change can be caused by land cover and land use modifications and vice versa as well as the attendant impacts of this dynamics especially on agricultural systems and food security. The paper reveals that in Nigeria, climate change impacts are causing a reduction in agricultural output, loss of livelihood, violent conflicts, displacement of populations and pushing farmers into abandoning

*Correspondence:
Yakubu Aliyu Bununu
ybaliyu@abu.edu.ng
[1] Center for Spatial Information Science, Department of Urban and Regional Planning, Ahmadu Bello University, Zaria, Nigeria

the farms and resorting to more profitable non-farming activities thus negatively impacting food security [5].

## The climate change debate: Setting the stage for a retrospective review

The debate regarding our changing climate has been a long standing one. Its pattern reflects the human inert tendency of refuting the unknown. In the last century, the quantity of greenhouse gases like methane ($CH_4$) and carbon dioxide ($CO_2$) have been observed to be on the increase [57]. Similarly, average surface temperatures have risen above 2°F during this period [53]. Whether these and other observed changes are responding purely to natural climatic forces or are somehow human-induced has been the foundation of the climate change debate. The other dimension of the argument is whether these observations are significant enough to warrant any serious concerns.

Proponents of the idea that the observations are significant and caused largely by human activities, argue that, severity in the warming of the Earth, melting of sea ice, droughts and increase in sea level rise are directly as a result of human activities like utilization of fossil fuels. Consequently, they contend that international efforts are required to cut down greenhouse gas emissions. The counter argument is that greenhouse gas emissions as a result of human activities are inconsequential to produce a substantial modification of the earth's climate, and the planetary processes will eventually correct any changes. The measurements and climate models used to establish the human-caused global climate change according to this group, are, questionable and misleading.

## International institutions, conventions and agreements for climate change

The Intergovernmental Panel on Climate Change (IPCC) has been leading climate change related reviews globally since its creation in 1988. The IPCC, with 195 member countries as of December 2020 [41] reports that "emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases," resulting in "an additional warming of the Earth's surface" [39]. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) came into being and it paved the way for the 1997 Kyoto Protocol and the 2015 Paris Agreement [41]. The Kyoto protocol and Paris agreement are international treaties aimed at limiting the emission of greenhouse gases and work for the attainment of the objectives of the UNFCCC of ensuring adequate commitment of countries to environmentally sustainable economies.

While efforts to isolate the contribution of nature and that of humans in climate change are still vigorously pursued, a number of studies (such as Anderson [4], Dale [19], Weng and Yang [88], Alberti [2], Beltran et al. [11], Wang et al. [87], Olufemi [66], Maconachie [46] and Bello [8] have demonstrated the attendant effects of different human activities and variations of these effects with the intensity of such activities over space. Changes in the way and manner in which land is used, modifies its character and therefore affects its potential for modifying at least the micro climate of the affected space. Regardless of one's position in the spectrum, the usefulness of understanding earth's climate, its pattern and how humans can get the best out of it cannot be overemphasised. Over the years, the contributions of the scientific community in improving the understanding of the interactions between LULUCF and climate change have been enormous. Actions of the economically strong countries in responding to these conventions, did not show the requisite commitment for a better future in terms of global climate.

## Review of climate change manifestations

Studies in climate science such as [68] and [57] have identified several common manifestations of climate change that are observable locally and at a global scale. They include severe droughts, heatwaves, cold spells, storms and wildfires. Their effects can be disastrous and even lead to the destruction of lives and property.

Cold spells resulting from climate change can occur even in a warming world, with such consequences as disruption to transport system, energy and food supplies. Extreme rainfall events from major unusual storms, hurricane, or intense localised downpours can lead to flash and stream flooding. This is evident particularly in areas with other compounding characteristics such as flat terrain, soils with poor absorption capacity and proximity to streams or floodplains.

Drought as a consequence of a changing climate manifests in many ways. Its effects on human livelihood range from reduced water and food supplies to increasing the risk of wildfires. Regarding wildfires, climate change has been found to have contributed at least 30% in increasing the likelihood of wildfires since 1900 [89]. The Australian wildfire that spanned for 240 days between 2019 and 2020 is a good example. Heatwaves can also occur under severe climate uncertainties and can even lead to deaths in some cases. Severe storms also occur due to a changing climate. They manifest in the form of heavy rain, snow or hail. Storms are commonly characterised by strong winds, thunder and lightning.

## Land cover, land use and the change process

### *The distinction between land cover and land use*

An acceptable definition of land cover is key in any meaningful discussion of its relationship with land use. This is because land cover is often mixed up with land use and the two used interchangeably. Land cover is defined as the observed biophysical cover on the surface of the earth [24]. Strictly speaking, the consideration of land cover should be limited to the explanation of man-made features and vegetation type at any location of interest. As such, the locations where the surface is made up of bare rock or soils are land itself and not land cover. It is also a matter of dispute when it comes to the description of water bodies as the question arises whether or not they are real land cover. Practically speaking however, the scientific community has come to accept and include them as land cover.

Land use on the other hand is described as being characterized by the arrangements, activities and inputs that are undertaken by people over a certain land cover type so as to produce, change or maintain it. Defining land use in this way creates a direct connection between anthropogenic activities and land cover. The definitions given above can be exemplified by the following:

- "grassland" is a cover term, while "rangeland" or "tennis court" refer to the use of a grass cover; and
- "recreation" area" is a land use term that may be applicable to different land cover types: for instance, sandy surfaces, like a beach; a built-up area like a pleasure park; woodlands; etc.

Therefore, while land cover is viewed as mostly the natural state of the earth's surface at a particular point of interest, land use on the other can be said to be a depiction of how landscapes are used by people for purposes that cover development activities, natural conservation or a mixture of a variety of uses [58]. Different land cover types can be managed and put to use in different ways. The determination of land cover types is achievable through the analysis of satellite and aerial imagery. Land use on the other hand cannot be determined from satellite or aerial imagery but through field surveys, ground truthing and production of land use maps. Land cover maps made from satellite images and aerial photos provide managers with data that facilitates their understanding of current landscapes.

Different as they are however, land cover and land use are clearly linked, and that linkage is somewhat a complex one. A single land cover type say grassland is capable of supporting many uses that include livestock farming, fodder production and recreational activities. Whereas a single use, like mixed cropping can produce different types of cover like grassland, cropped and fallow areas. However, despite the fact that there is wide acceptance of the distinction and link between cover and use, the two are also usually mixed or even confused in classification schemes [42] such that the results from land use and cover change analysis becomes difficult to interpret.

#### *The land cover and land use change process*

Land cover change generally consists of changes in the features of the land that include the properties of soil and vegetation while land use change is the modification of the way some parts of the land is being utilized or managed by human beings [67]. This usually involves the transformation of naturally occurring landscape caused by urban development which is now a particularly important issue in developing countries. That is, while land cover change may only occur from natural causes, land use change results largely from human intervention [17].

The meaning of land use change however is not always quite clear in trying to understand the links between land and biodiversity. Does it basically mean gross changes where a complete replacement of one cover type or use by another occurs, or is it about the more qualitative change in the physical attributes of the land? The latter class of change is what Lambin [45] described as "land cover modifications" where it is suggested that they happen with more regularity and are more common than wholesale conversion from one cover type to another. These change types are subtle and difficult to characterise, but have as important a consequence as that of a complete transformation for the characteristics of biodiversity of the land. It has been suggested by Turner et al. [83] that of the many challenges facing land change science, a most important one is the need to develop new and better methods of land characterization. Even though this suggestion was prompted by a more general consideration of issues, it is particularly true when considering biodiversity especially within the context of the current economic, social and environmental arguments for the conservation, protection and restoration of ecological systems. Lately, research in the area of land use and cover change have emerged as interdisciplinary endeavours [70] with characterization of ecosystem services as the best example of this new approach (Fig. 1).

Worthy of interest is the fact that land cover and land use change are responsible for some local and global effects which include loss of biodiversity and attendant effects on the health of humans and the disappearance of natural habitat of some species and the consequential loss of ecosystem services.

## Climate change determinants: from anthropogenic to land use change drivers

### Anthropogenic drivers

Global climate has been changing even without humans. The extent to which the change is exacerbated when humans are thrown into the equation is the concern in

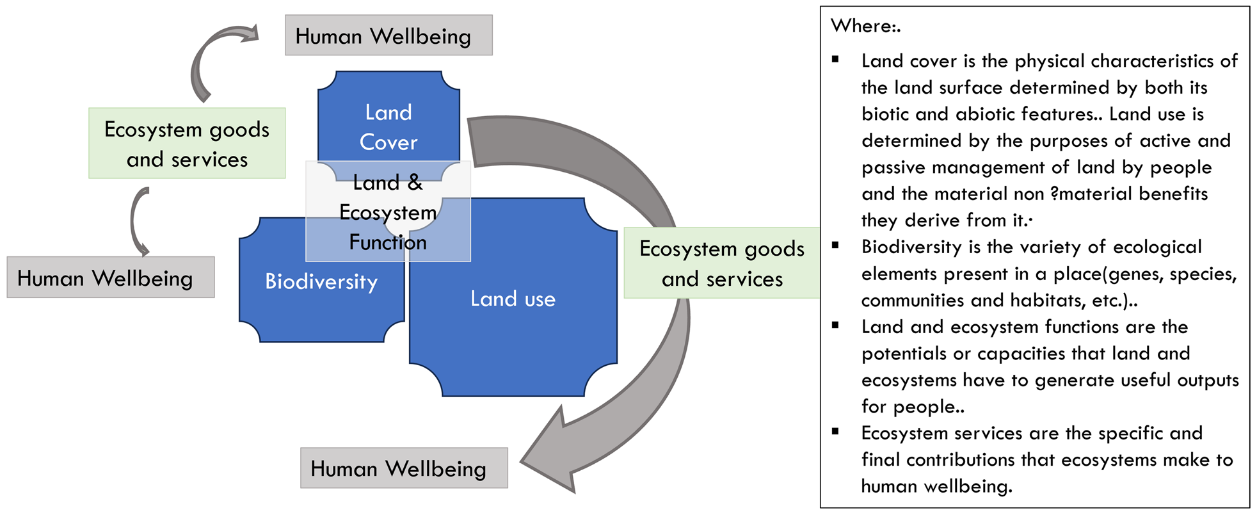


**Fig. 1** Land Use, Land Cover and Biodiversity Dynamics (after [85])

this section. Typically, climate change can be in the form of considerable increase or decrease in temperature for example. The present-day climate change is largely in the form of global warming and not cooling. In Fig. 2, we can see that earth's temperature is generally on the increase. The sun's energy output on the other hand, remained fairly stable since 1978.

While the 2013 NIPCC report held a position that global warming since 1860 is natural resulting from solar variation or ocean–atmosphere oscillations [59], other

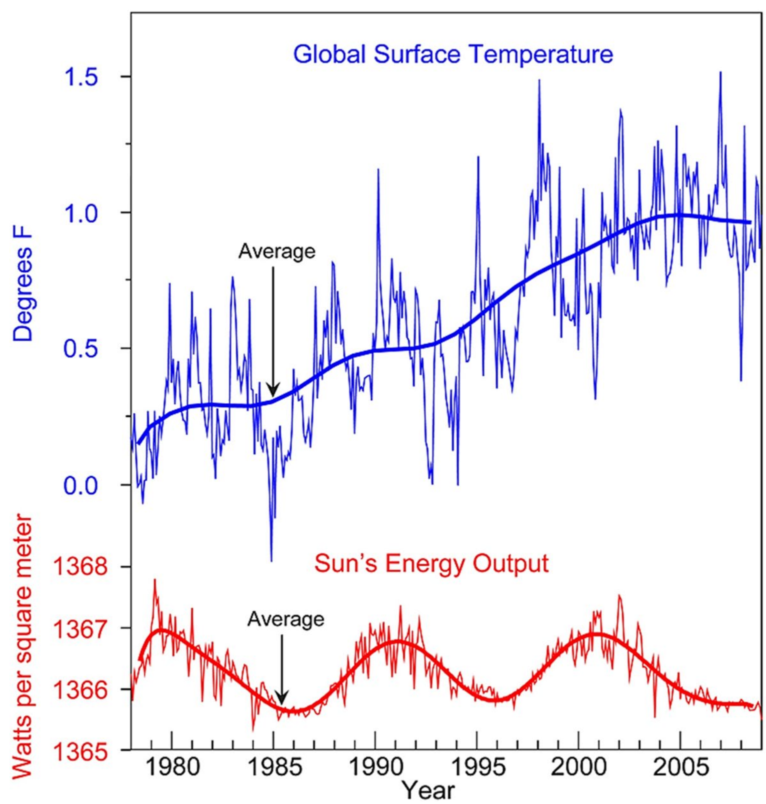


**Fig. 2** Changes in Sun's Energy Output and Global Surface Temperature 1980—2005. Source: NOAA [57]

climate change reports indicate the contrary. Both the IPCC and the 2014 National Climate Assessment report produced by the US Global Change Research Program [37, 84] emphasized a considerable contribution to global warming from human activities.

According to Berbesi et al. [12], the present-day warming trend is attributable to an annual increase in the atmospheric methane concentration and carbon dioxide. Concentration of these greenhouse gasses is exacerbated by humans because of dependence on fossil fuels for our energy needs. In their study of western Canada sedimentary basin, Berbesi et al. [12] estimated a maximum thermogenic methane leakage rate as a result of petrol systems in the order of $10^{-2}$ – $10^{-3}$ and maximum biogenic methane generation rates of $10^{-2}$Tg/yr. With these results, the authors concluded that the sudden release of surface methane over geological time scales as a result of petroleum systems can influence the climate.

According to Dale [19], carbon dioxide ($CO_2$) release had been the key anthropogenic driver of climate change since the beginning of the industrial revolution and the intensification of fossil fuels use (see Fig. 3). As at 1997, 61% of the anthropogenic greenhouse forcing is attributable to $CO_2$ releases [78]. Presently, it accounts for up to 64% and 40% higher in concentration than when industrialization began [57]. Between 1850 and 1980, fossil fuels accounted for the release of 150 – 190 PgC [72]. According to Houghton and Skole [35], forest clearing and urban development has made the greatest contribution prior to 1910. Figure 2 shows the contribution of biota, soils and fossil fuels to atmospheric $CO_2$ concentrations between 1850 and 1990).

The increasing influence of anthropogenic activities on the earth's climate contributes in its warming through combustion of carbon-based fuels, land use change (usually in the form of land transformation), farming practices and livestock production, which increases the amount of greenhouse gases in the atmosphere. These gases include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and fluorinated gases (HFCs, PFCs, $SF_6$ and $NF_3$).

Between 1880 and 2018, the relationship between global temperature and $CO_2$ concentration has been a direct positive one. From 1980 upwards, the slope gets steeper regarding both the temperature increase and $CO_2$ concentration. This is shown in Fig. 4.

#### Land use change as driver

As indicated earlier, the key concern of climate change is the increased amount of greenhouse gasses in the atmosphere which has led to global warming. It is obvious that large scale forest clearing for agriculture or urban development induces an eco-system modification that can alter at least the micro climate. Field studies in this regard have largely focused on the extent to which land use or land cover change can produce a regional effect on the climate or even its contribution to global warming.

Dale [19] asserts that, changes in the patterns of landcover can impact energy and mass fluxes through the clearing of vast areas of forests which subsequently reduces transpiration thereby decreasing cloud formation, rainfall, and increases drying. Earlier in Dickinson [20], simulation models of the deforestation of Amazonia show that evapotranspiration and forests would be replaced by desert or grassland. At this scale, the density of vegetation can be seen to affect the regional climatic character.

In a conceptual model proposed by Vitousek et al. [86], land transformations in the form of clearing and

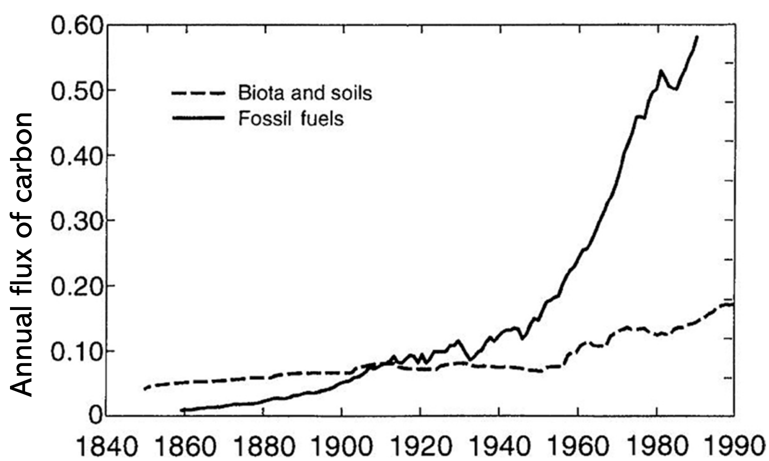


**Fig. 3** Contributions of Greenhouse Gases to Atmospheric $CO_2$ Concentrations since the Industrial Revolution (Marland et al. [48] and Houghton [34], in [19] Pp.755)

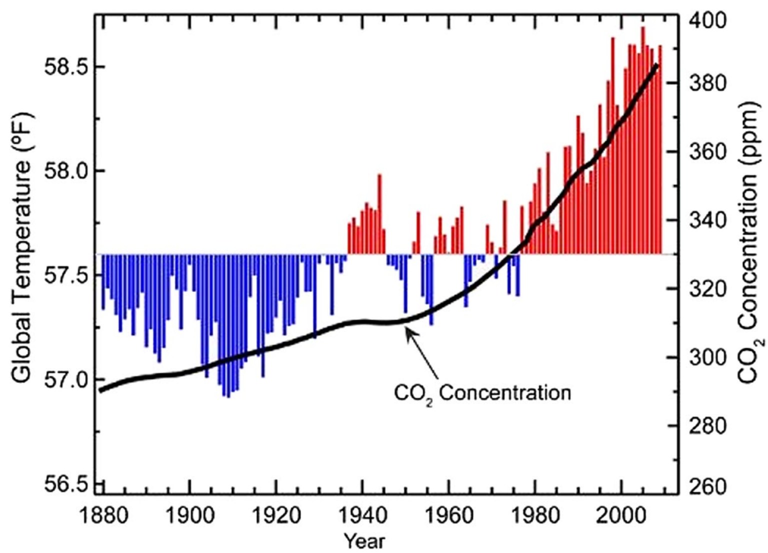


**Fig. 4** Correlation Between Rising CO2 levels and Higher Global Surface Temperatures. Source: National Oceanic and Atmospheric Administration NOAA [54]

grazing appeared to be among the fore front drivers of climate change through its association with extinction of species and populations as well as loss of ecosystems (see Fig. 5). This concurred with Pielke et al.'s [69] assertion that, on a scale of tens of kilometers, spatial alternation of vegetation with dry soil can influence atmospheric circulation and cloud formation. The reason for this, according to Pielke et al., is because of the potential for inducing convection and enhancement of clouds and precipitation by contrasting character of adjacent land cover types.

The land use change and climate change relationship is circular as well as complex. While change in land use affects the climate, climate change can as well restrict or alter the potential usability of land. This is demonstrated by Dale [19] in Fig. 6.

The complexity in the relationship is in two ways. First and foremost, land cover – usually determined by land

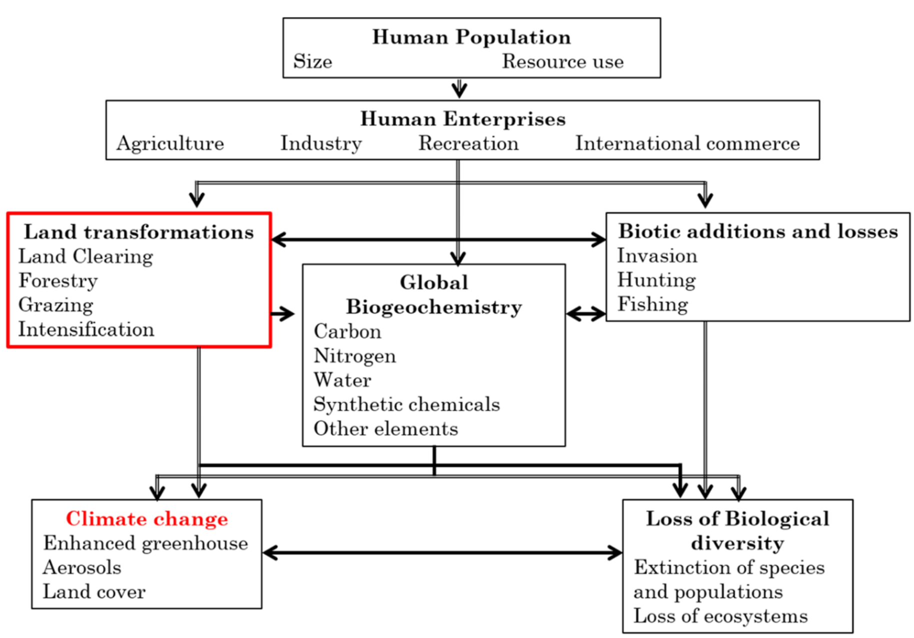


**Fig. 5** Direct and Indirect Effects of Anthropogenic Activities on the Earth System. Source: Vitousek et al. [86]

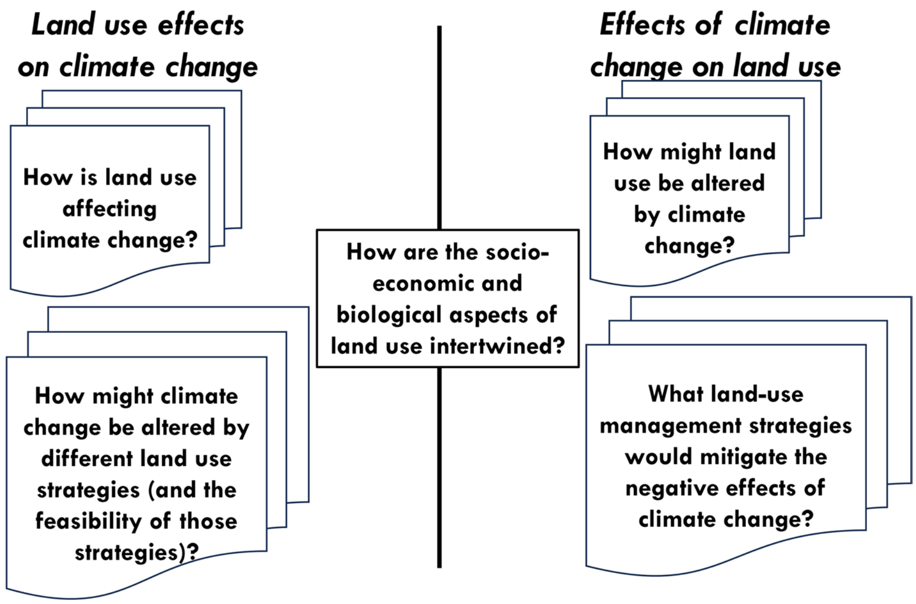


**Fig. 6** Land Use Change and Climate Change Relationship. Source: Dale [19] Pp. 754

use practices – impacts atmospheric levels of greenhouse gasses (GHGs). Secondly, while climate change is driven by land use change among other factors, climate change also leads to changes in land use and land cover. For instance, farmers may change their traditional crops to those that are more profitable under changing climatic conditions [10, 36].

It is also generally perceived that climatic variability and increased climate change will have an effect on land use to the extent that economic activities such as food production, urban development, biodiversity and water resources systems will be modified [40]. For example, climate change impacts local agriculture and hydrological conditions directly and as a consequence also influences the potential for economic development. Thus, climate change has a modifying effect on the demand for land as well as its supply and the general sustainability of space and how it is utilized [6]. The assessment of these processes can be achieved using land use simulation models [14, 15] which integrate sector-specific demands such as agriculture and housing as well as the suitability of land for certain uses and provide a prediction of the future use at a specified location given varying climatic conditions [44]. Climate change is a modifying force on the dynamics of demand and supply interplay and the boundary conditions and scenarios within which it occurs. The key processes by which climate change and socio-economic developments impact the interactions between the demand for land and its supply are:

- The alteration of the appropriateness of some areas for certain specified uses of the land;
- The change in the productive capacity of economic sectors like agriculture;
- Modifications of the primary roles of economy and society that leads to different sets of policies that end up determining economic development and its different variants (free market versus government driven) and;
- The demand for additional space consequent upon different adaptation strategies implemented in various sectors [44] pp. 6).

## Climate change impacts induced by land use/land cover modifications

We have seen earlier that the climate and land use changes relationship is reciprocal. Either modifications in climate changes the way land is used or modifications in the way land is used changes the climate. In any case however, a number of spill-over effects are associated with these changes. Drought is one of these effects. In semi-arid and arid regions as well as deprived areas and populations, significant water scarcity caused by human activities manifests in the form of hostile competition in water use, energy and water demand constraints. As a consequence, drought and other effects are equally observable in climate change impacted regions which include loss of livelihood, displacements and violent conflicts, etc. [74].

### Loss of livelihood

Climate change affects livelihood in several ways. The effects register in reduced production owing to extreme weather conditions or the complete destruction of livelihood means. Among the worst affected regions of the world, a number of studies [16] have shown that the Sahel and Semi-arid drylands of Africa are emblems of climate change vulnerability that has severe impact on livelihood. The regions in which the Lake Chad is located for instance, have faced such challenges as livestock and crop losses as well as traditional livelihood systems. The Lake Chad as a transregional water resource serves as a food producing cluster for at least 3 countries. Nigeria, Cameroun and Chad are all served by this strategic water body. The Lake was at one time considered to be the sixth largest lake in the world, but has shrunk by 90% between 1963 and 2013.

From Fig. 7, it can be seen that, the Nigerian portion of the Lake Chad which in the 70s had the largest water volume is completely dry by 2018. The livelihood support being provided by the lake in terms of water supply, fisheries and irrigation agriculture will certainly be affected.

### Population displacements

The typology of climate change events, spatial and temporal contexts, as well as the degree of vulnerability, and availability of alternative responses determines to a reasonable degree its effect on population displacement [1]. Displacements are often some of the response mechanisms to loss of livelihoods. Although rising sea level has been identified by [1] as the most certain climate change impact leading to displacement and resettlement, changes in rainfall, availability of water and arable land also lead to disruption of livelihoods and general weakening of peoples' living conditions. That can equally necessitate displacement. It is estimated that droughts and other climate change events would trigger the displacement of up to 50 million people by 2050 [51]. Sea level rise as the principal impact according to Myers [51, 52], will be responsible for the displacement of up to 162 million people also by 2050.

### Violent conflicts

Literally, climate change may not be seen to cause conflicts. By implication however, climate change has been described as "a threat to global security, a threat multiplier, a driver of conflict, and an accelerator of fragility" [80] p. 7. This means that although it is difficult to directly accuse climate change as being responsible for some conflicts, a number of empirical studies suggest some association [43, 7975 ]. According to Skah and Lyammouri [80], the link between environmental degradation and conflicts has been well established by academic literature historically. The pending issue according to Skah and Lyammouri is in isolating the role of environmental factors and its extent in promoting conflicts. Hauge and Ellingsen [33] similarly showed that deforestation, soil degradation, and lack of freshwater access leads to an increase in the occurrence of political violence. According to Robin & Norton [71], the risk of armed conflicts can be aggravated by adverse climate change (see Fig. 8).

### Effects on food security

Food security according to FAO [28] connotes a situation where the majority of a community of people can be able to source the food they require to give them a healthy life, and where there are social safety nets that ensure that those who can't still get enough to eat do so. It is clear from this definition that several factors can affect the ability of people to obtain the requisite food by themselves and also the ability of those who lack resources to still get enough to eat. Changing climate that can potentially undermine livelihood support systems including agriculture, exacerbates communal conflicts

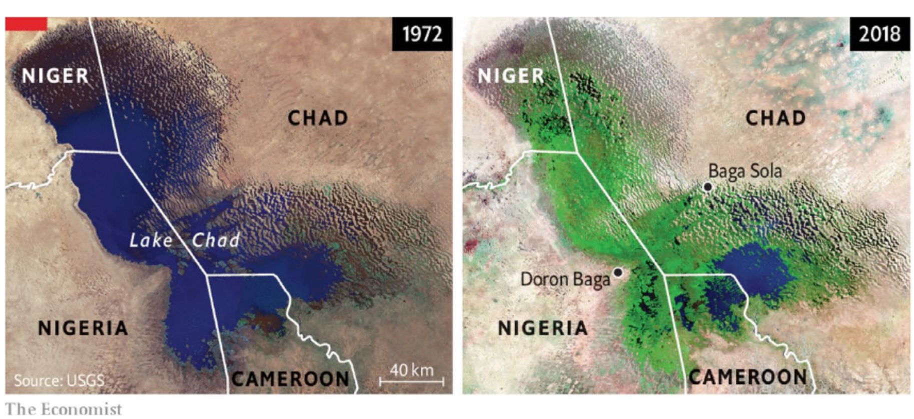


**Fig. 7** Shrinking of the Lake Chad. Source : The Economist, May 23, 2019. in, Skah & Lyammouri [80]

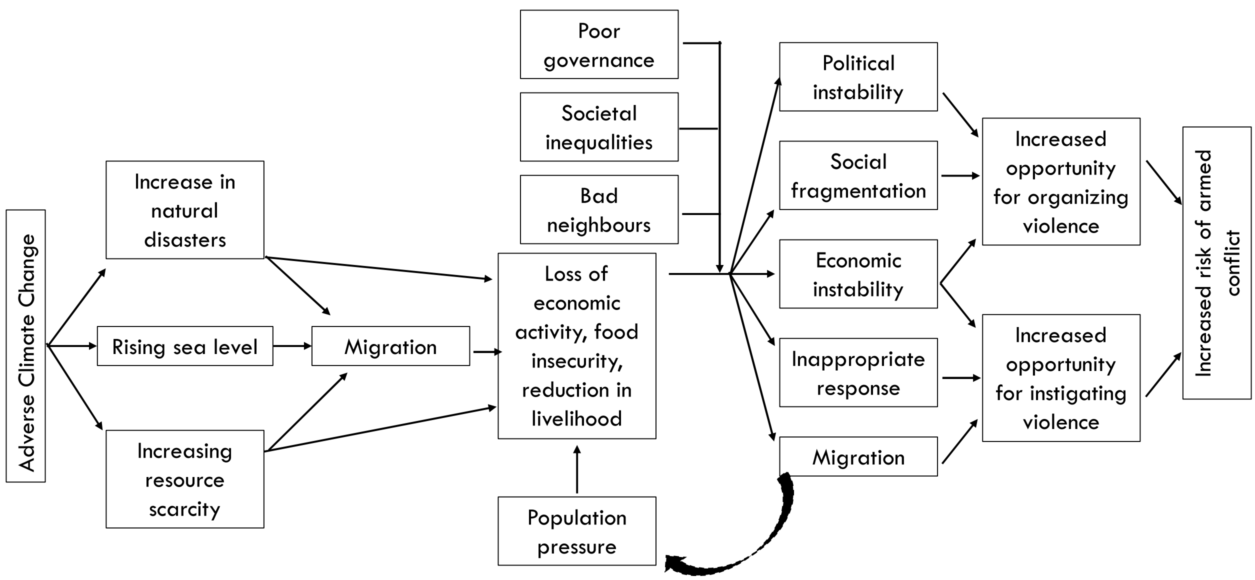


**Fig. 8** Climate change and conflicts. Source : Robin & Norton [71]

and displacements, and will directly or indirectly affect these abilities. Studies on this subject are focused largely on establishing the link between climate change and food security, and also presenting future projections of food supplies as climate changes or specifically in relation to the availability of arable land.

Over the last decades, there has been a rapid decline in the share of agriculture in total GDP in many developing countries [76] (see Fig. 9). In addition to droughts, some of the spillover effects of climate change such as fluctuations in harvests coupled with higher risks of the occurrence of landslides and other natural disasters, can negatively impact food supplies and thus, food security. With differing development paths therefore, food insecurity is possible as a result of higher food prices in societies where income levels are low and household expenditures on food are high. This is particularly the case with decreasing importance of agriculture in national economies in the past decades.

Fluctuations in local food supplies have been documented by Neven & Reardon [55] for a supermarket in

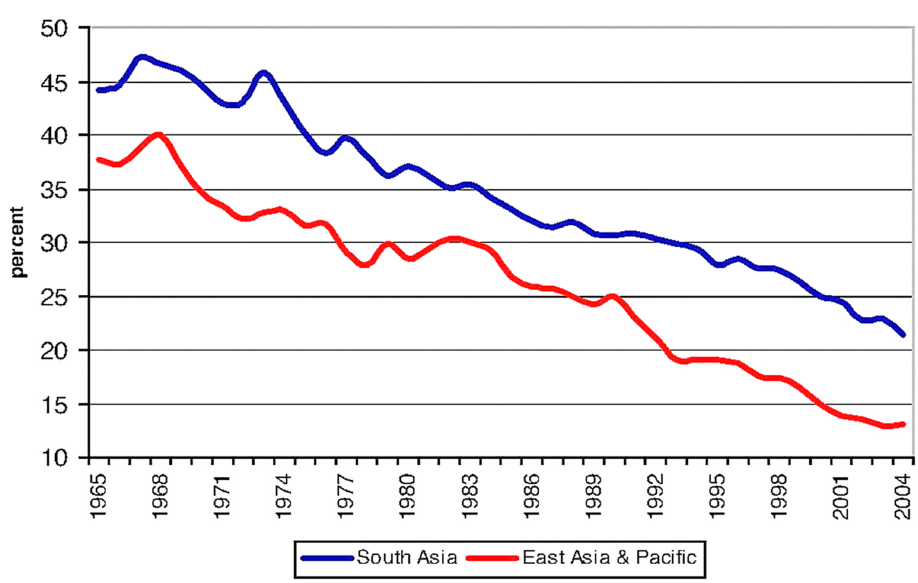


**Fig. 9** Agriculture share of total GDP in South Asia, Asia and the Pacific Regions. Source : Schmidhuber & Tubiello [76]

Kenya. The percentage contribution to the total supply from different types of suppliers is presented in Table 1.

The seven most frequently cited drivers of food insecurity at the household level in about 49 studies in southern Africa have been compiled by Scholes & Biggs [77], cited in Gregory, Ingram, & Brklacich [30]. Although climate and environment are ranked 12th, they were among the factors noted as being chronic and acted primarily via reductions in food production (see Fig. 10).

**Effects on biodiversity and ecosystem balance**

One of the most pressing global challenges today resulting from climate change induced by land cover and land use modifications is biodiversity loss and the attendant pressure it exerts on ecosystem services. The loss of biodiversity at a global scale is so intense that it has come to be described as "biological annihilation" [7, 44]. Generally, land use and land cover changes occur slowly but are closely linked to declines in the population and diversity of species and usually have pronounced impacts on ecosystems [38, 67].

The variety of life at the genetic, species and ecosystem levels is what is known as biodiversity. It represents the range and variety of our planet's animals and micro-organisms and is critical to food security [16]. Food production is dependent on the crops, livestock, other plants, animals and fungi that nature provides which we eat directly – food production is also dependent on a variety of other species and the ecosystem in which they exist [25]. For instance, majority of the most important crop species around the world are dependent on insect pollinators and sometimes bats or birds. Multitudes of invertebrates and micro-organisms are an important component of soil fertility that supports crop, livestock and forest production. There are also a variety of species that aid pest and parasite control that would otherwise adversely affect food producing animals and plants. Identifiable ecosystems such as inland wetlands, grasslands, forests as well as coastal and marine ecosystems like mangroves, coral reefs and seagrass beds offer a range of services to agriculture and food production [7]. These services include the regulation of water flow, improvement of ambient air quality, carbon binding, provision of habitats for species that aid food production and mitigation of extreme weather events like floods and storms.

A good understanding of the interdependencies between land use and biodiversity is critical to increased awareness of how people and their environment are interwoven. While land use management and transformations are major drivers of biodiversity change at the local, national and global scales, the biodiversity of an area of land or a specific site often place

**Table 1** Fluctuations in fresh fruit and vegetables supply to a supermarket chain in Kenya by supplier type 1997–2008

| Type of supplier | Vegetables | | | Fruits | | |
|---|---|---|---|---|---|---|
| 1997 | 2003 | 2008 | 1997 | 2003 | 2008 | 1997 |
| Small farms | 13 | 10 | 15 | 5 | 10 | 10 |
| Medium farms | 10 | 25 | 30 | 10 | 10 | 10 |
| Large farms and plantations | 5 | 15 | 35 | 0 | 15 | 35 |
| Traditional brokers/wholesalers | 70 | 45 | 10 | 70 | 40 | 10 |
| Imports | 2 | 5 | 10 | 15 | 25 | 35 |

*Source*: Neven & Reardon [55]

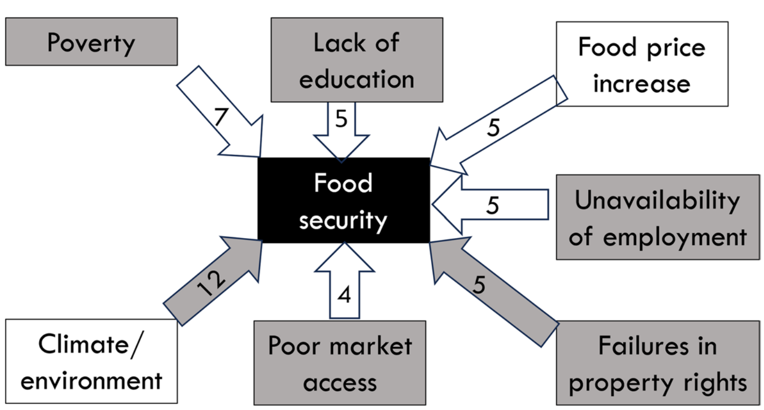


**Fig. 10** Drivers of household-level food insecurity in southern Africa. Source : Gregory, Ingram, & Brklacich [30]

constraints on the choices about how it is used given the need for the sustainability of ecosystems and the services as well as benefits derived from them. The study of the relationship between land use and biodiversity is so important a topic to the extent that Turner et al. [83] have argued that the study of land use change is now a part of mainstream efforts on the subject of environmental sustainability. It is envisaged that by 2100, the impacts of land use change on biodiversity will be more significant than that of climate change, nitrogen deposition, species introduction and changes in atmospheric concentrations of CO2 [73].

Biodiversity generally has relationship to food security in four dimensions namely availability, access, utilization and stability [23, 26, 38, 81]. Food availability is dependent on the production of good quality food as well as its distribution in adequate quantities so as to meet the nutritional needs of people everywhere. This is dependent on a variety of components of biodiversity that are wild as well as domesticated. Improvements in genetic engineering in the last couple of decades has enabled global food production systems to keep pace with an exploding population. However, intensive selection and emphasis on a few species and varieties has also led to the loss of genetic diversity which has the potential of reducing the capacity of global food systems to respond to future challenges and risks.

Food Utilization refers to the ways by which food products are processed and combined in order to produce healthy diets. The nutritional content and value of foods vary across different species of plants and animals as well as across varieties and breeds within same species. Additionally, safe and nutritionally standard diets are dependent not only on the food products but also on the other ecosystem services. As an example, many communities rely on local ecosystems for water purification and fuelwood. In other communities, livestock dung is an important source of fuel for cooking. Micro-organisms also play a hugely important role in food processing like bread and cheese making and food preservation through processes such as fermentation.

Access to food is dependent on ensuring that food is available and affordable locally through an efficient distribution mechanism. Constraints to food acquisition that may be physical, social as well as economic need to be surmounted in order to ensure that all—including the poor, marginalized and vulnerable – are able to have access when they need it. In addition to providing many with the wherewithal to cultivate, collect or hunt the food they need, biodiversity also provides income which can then be used to purchase food or reinvested in the cultivation, storage or processing of food and this further enhances access to food and food security.

Food stability is the continuous availability, convenient access and utilization of food over time. Food stability is impacted by biodiversity in a variety of ways. Different kinds of food are provided by different plants and animals at different times of the year or seasons based on different weather and climatic conditions. Some plant and animal species have evolved to adapt to extreme weather or climatic conditions and are also resistant to pests and diseases. In some situations, biodiversity in the wild provide an alternative source of food when the domesticated food production systems fail. Ecosystems make huge contributions to the stability of the food production system through the mitigation of natural disasters like hurricanes and associated floods and by providing the natural abodes for wild pollinators and other species thereby lessening risk and uncertainty in natural food production processes like pollination as well as other ecosystem services.

## Climate change and food security in Nigeria: a review of the relationships with land use change processes

### Evidence of climate change in Nigeria

Nigeria is a vast country with a total area of approximately 923,768km$^2$ that spans across different vegetation and climatic zones [10], as depicted in Fig. 11. Observable climate change is impacting these different climatic and vegetation zones in different ways. In the northern region, the key environmental challenges that are closely linked to climate change are desert encroachment and droughts. The rate at which the desert is encroaching inwards and to the south of the Sahara is said to have accelerated over the last fifty years and droughts are occurring more frequently and more severely [27, 60]. This is leading to a rapid depletion of surface water, flora and fauna and causing people to exploit previously untouched land which leads to further deforestation and the increase in desert encroachment evidenced by the emergence of more sand dunes/aeolian deposits in north western and north eastern parts of Nigeria [10]. In the southern parts of Nigeria, the coastal areas are vulnerable to and constantly threatened by incessant flooding, destruction of the mangrove swamps, surface water contamination and attendant transmission of water borne diseases that leads to the displacement of people and communal crisis over competition for space [63]. In northern Nigeria, the Sahara Desert is rapidly extending southward at approximately 0.6 km per annum, and in the south, the rainforest ecosystem which accounted for about 10% of the country's land mass as at 1934 has been reduced to a mere 5% today.

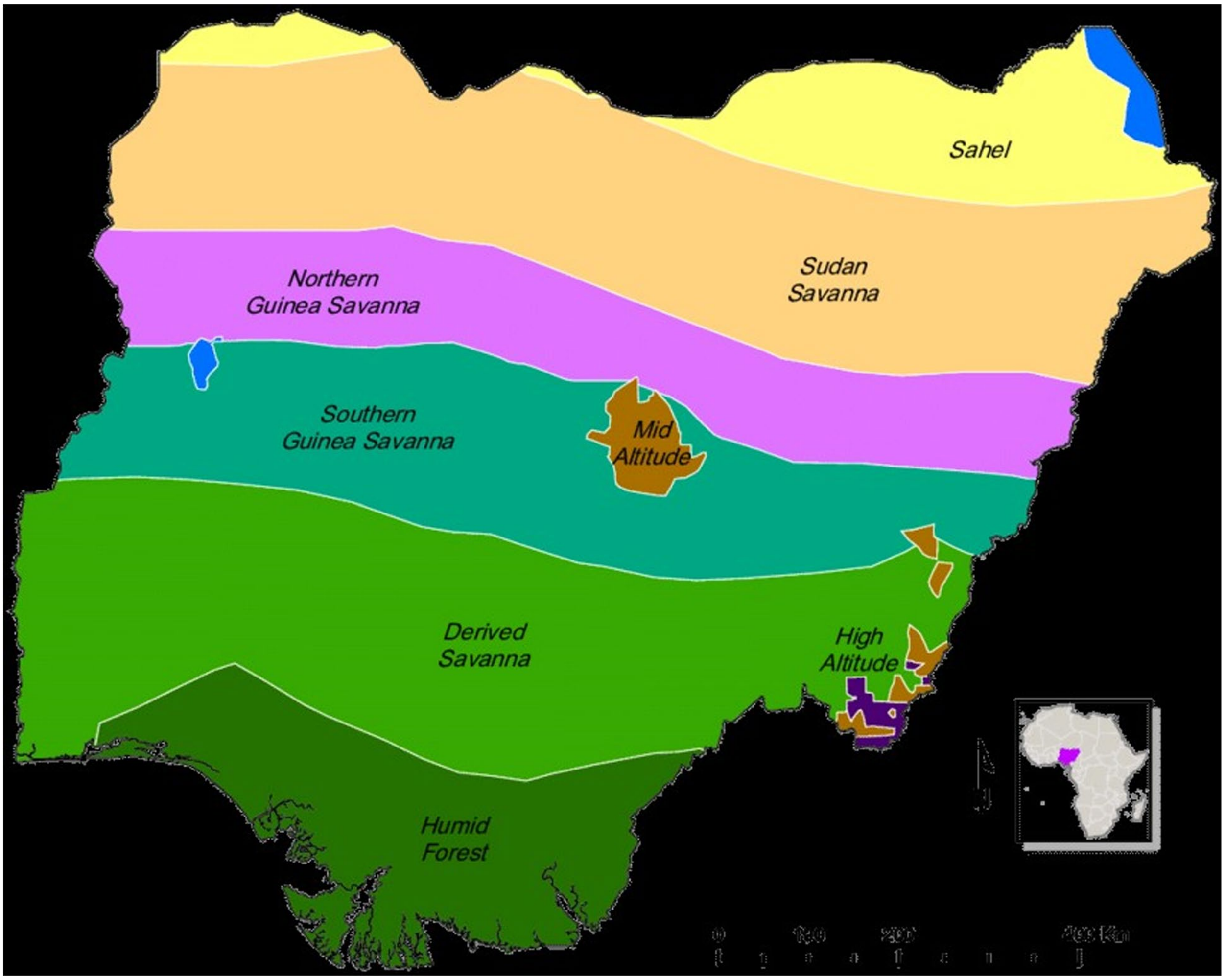


**Fig. 11** Nigeria's agroclimatological zones. Source: ODNRI

### Impacts on food security

Climate change impact on food security has been an issue of concern for academics, policy makers and global institutions such as the United Nations Organization in the last several decades [16, 23, 25, 26, 32]. In Nigeria, a number of studies focused on how climate change is impacting agricultural production and by extension food security have been carried out and have mostly returned an unfavourable verdict that shows that climate change is in a lot of ways responsible for the low agricultural productivity that has been recorded in Nigeria in the last several decades [10, 36, 61]. The agricultural sector is one of Nigeria's top employers as approximately 70% of the population is estimated as being engaged in some sort of commercial or subsistence farming [36]. In the decades immediately after the discovery of oil in commercial quantity, agriculture in Nigeria suffered serious neglect and lost its place as the country's top foreign exchange earner. That situation is gradually being reversed now as the current national government has embarked on a programme of massive funding and expansion of the sector towards self-sufficiency in food production and the achievement of food security nationally.

However, farmers in Nigeria are poor and have limited access to capital which makes them heavily reliant on natural systems and resources that are extremely sensitive to changes in climatic conditions [36]. The small land holder farming practices and techniques, which is the most prevalent agricultural practice in Nigeria also impacts these natural systems adversely and by so doing compound the problem even more. Consequently, there occurs shrinkage of fertile arable lands, decline in productivity, high produce prices as well as food insecurity. The nexus of climate change which is characterized by extreme dryness or drought in Nigeria's north and excessive rainfall that leads to flood and coastal erosion in the south, and food production is not an issue under any doubt in Africa, generally speaking and particularly in Nigeria [61]. A good example that demonstrates this connection is the drought experienced between 1972 and 1973 in Nigeria's Savannah zone which caused the death of approximately 300,000 livestock and led to a 60% drop in farm output [36]. This suggests that droughts adversely affect food production and can impact food security especially in regions that rely on rain-fed agriculture. Droughts have also been known to have caused serious crop failures and consequently food shortages in Africa. In Eritrea, the failure of the seasonal rains in the aftermath of the war with Ethiopia led to food shortages and starvation that affected a quarter of the 3.7 million people of Eritrea. The International Institute of Tropical Agriculture (IITA) estimated that approximately 300 million people in sub-Saharan Africa (SSA) suffered from malnutrition in 2010 and current estimates suggest that 690 million people globally are undernourished and 250 million of that live in Africa [31]. The indicators examined by past studies suggest that food production in Nigeria, particularly in the Savannah vegetation zone that accounts for the largest share of agricultural production has not grown appreciably in the last two decades [36].

As indicated in Sect. 1.0, unsustainable farming practices can cause and also exacerbate climate change. Deforestation results in 55.7% loss of Nigeria's primary forest between 1990 and 2010 [64]. Extensive land clearing for cultivation is also common. This is in addition to fuelwood exploitation for energy on which more than 70% of the country's population depend upon [49]. The recent shift to liquified petroleum gas (which would have served as some mitigation measure) has equally been hampered by a continuous hike in its price [9]. With these realities, the potentials of the forest to serve as carbon sink can be reduced significantly thereby increasing the magnitude and effect of climate change.

Climate change impact on local agriculture is further compounded by violent conflicts among sedentary communities as well as between sedentary farmers and nomadic pastoralists. This is a consequence of population pressure which leads to a scramble for arable land as well as water and fodder [3, 18, 21, 47, 65]. The growing aridity as well as the encroaching desert from the far north of Nigeria is causing a displacement of population southwards and into the central areas that is predominantly Guinea Savannah [3]. The areas in the middle belt that usually act as buffers for the pressure of the migrating human and livestock population from the far north or Sahel savannah belt already have approximately 10–15% of their land being threatened by desert encroachment [61]. The combination of desert encroachment and migration affect this buffer zone in an adverse manner to the extent of the intensive utilization of marginal and fragile areas that result in the progressive degradation of the environment even in the years of stable rainfall [27]. Furthermore, the pasture resources are put under additional pressure by livestock and their herders from other Sahelian countries particularly Chad, Niger and Cameroon. This happens when livestock from these countries are attracted to Nigeria's Guinea savannah belt from the North east axis due to available fodder around the patches of wetlands in the Lake Chad area and beyond leading to competition and even conflicts over grazing land, livestock and water points between the Nigerian and Cameroonian communities and among the Nigerian communities also at the border areas [21]. As there occurs conflict over grazing land and cattle amongst pastoralist, so does it over cultivable land amongst peasant farmers within the same communities and also between different communities [61] pp. 114). These sorts of conflicts have persisted over the last several decades and have for some reason become more regular and pervasive in the last ten to fifteen years in Nigeria [18, 47]. These types of conflicts as witnessed in Nigeria are similar to those occurring in other parts of Africa like the ones between the Karamajong of Uganda and Pokot of Kenya over grazing land that has been going on for over thirty years [13]. Other instances of conflicts amongst pastoralists are found in other parts of Africa among which are the ones attributable to Somalis, *Oromos, Karamojong, Pokot* and *Masai* among others ([61] pp. 114).

## Responding to the impacts of climate change in Nigeria

The response to the dramatic and somewhat alarming situation in Nigeria as described above has been multifaceted. In responding to the challenges of drought and desertification, the federal government has launched or rejuvenated a number of interventions that include agricultural extension services and awareness campaigns that promote the use of drought resistant seeds. Other initiatives include measures aimed at slowing down desertification such as awareness campaigns that aim to educate local populations on the adverse effects of indiscriminate felling of trees and the promotion of planting of local tree and shrub species that have economic value [22, 64]. This has culminated into a community based regional initiative of extensive tree planting in the desertification frontline states of Nigeria and the neighbouring countries of Niger and Chad known as the Great Green Wall (GGW) project in 2007 [50]. The GGW project is supported by the African Union and other multinational development organisations. The GGW project promotes agroforestry among farming communities while creating awareness on the benefits of sustainable farming practices at local, national and regional levels. Additionally, the Nigerian Meteorological Agency (NIMET) also releases rainfall forecasts several weeks before the commencement of the planting season as an advisory about when to expect the onset as well as cessation of the rains in different parts of the country and by extension suggesting to farmers when to begin land preparation and subsequently, planting. This is aimed at avoiding planting either too early or too late which may lead to poor harvests. Lastly, in response to the violent conflicts between farmers and cattle herders that have festered for decades now, the federal government of Nigeria introduced the RUGA (Rural Grazing Area) project in 2019 that aimed to recreate the colonial grazing reservations across the country. This generated a lot of controversy and has actually been rejected by several states in the central and southern parts of the country [56]. These states have even gone ahead to enact laws that have made nomadic pastoralism illegal in their domain. In response, the federal government replaced the RUGA concept with the Livestock Intervention Programme (LIP) which will establish large cattle herders' settlements in six pilot states, namely Adamawa, Kwara, Niger, Bauchi, Kaduna and Gombe. However, the LIP is yet to take off fully about two years after its official launch.

## Conclusion

The concentration of GHGs in the atmosphere is being increased by emissions from human activities which consequently adds to the warming of the surface of the Earth. While efforts to isolate the contribution of nature and that of humans in climate change are still vigorously pursued, numerous studies have demonstrated the attendant effects of different human activities and variations of these effects with the intensity of such activities over space. Changes in the way and manner in which land is used, modifies its character and therefore affects its potential for modifying at least the micro climate of the affected space. The climate and land use change relationship has been shown to be circular. While change in land use can affect the climate, climate change can as well restrict or alter the potential usability of land. Land use modification can be a necessary response to changing climate. The climate in turn responds to the way and manner in which the land is put to use.

Manifestations of climate change are observable locally and at global scale which include severe droughts, heatwaves, cold spells, storms and wildfires. Such manifestations can be disastrous and even lead to destructions. In addition to the socioeconomic issues surrounding the Lake Chad for example, climate change is also at the moment being experienced in the form of severe droughts in some parts of Europe and Asia. This has seriously affected energy supply and food security.

As at 2020, half of the global land cover developed is dedicated to agriculture and urban development [82]. The physical attributes of land cover are dependent on and influenced by the use to which it is put as well as its characteristics in relation to biodiversity. Likewise, the uses to which a piece of land can be put to is constrained by and produces the resulting land cover and its ecological status. This means that land use modification affects biodiversity. Consequently, biodiversity affects availability, access, utilization and stability of food security. In Nigeria, climate change impact, which is characterized by extreme dryness or drought in the northern parts of Nigeria and excessive rainfall that leads to flood and coastal erosion in the south is quite clear. Also, there occurs shrinkage of fertile arable lands, decline in productivity, high produce prices and food insecurity. Because the relationship between land use modification and climate change is complex as shown, a transdisciplinary approach is required to climate change studies for improved appreciation of future roles of land cover and land use change patterns.

**Acknowledgements**
Not applicable.

**Authors' contributions**
All authors read and approved the final manuscript.

**Funding**
No funding was received to enable the preparation of this article.

**Availability of data and materials**
Not Applicable.

## Declarations

**Ethics approval and consent to participate**
Not Applicable.

**Consent for publication**
Not Applicable.

**Competing interests**
The authors declare that they have no competing interests.

Received: 30 August 2023 Accepted: 6 November 2023
Published online: 06 December 2023

**References**

1. Adamo SB. Slow-onset hazards and population displacement in the context of climate change. Center for International Human Rights, John Jay College of Criminal Justice, CUNY, New York Liaison Office, UNHCR April. 2011;27:2011.
2. Alberti M. The effects of urban patterns on ecosystem function. Int Reg Sci Rev. 2005;28(2):168–92.
3. Amusan L, Abegunde O, Akinyemi TE. Climate change, pastoral migration, resource governance and security: the Grazing Bill solution to farmer-herder conflict in Nigeria. Environ Econ. 2017;8(3):35–45.
4. Anderson DG. Effects of urban development on floods in northern Virginia. Washington, DC, USA: US Government Printing Office; 1970.
5. Apata TG, Ogunyinka A, Sanusi RA, Ogunwande S. Effects of global climate change on Nigerian agriculture: an empirical analysis. Edinburgh,

Scotland: Paper presented at the 84th annual conference of Agricultural Economics Society; 2010. p. 345–51.

6. Beinat E, Nijkamp P. Land Use Planning and Sustainable Development. Amsterdam: Vrije Universiteit; 1997.
7. Bélanger J, Pilling D. The state of the world's biodiversity for food and agriculture. Food and Agriculture Organization of the United Nations (FAO); 2019.
8. Bello A. Heat Island. In: Egunjobi L, editor. Contemporary concepts in physical planning. Ibadan: Department of Urban & Regional Planning, University of Ibadan; 2018. p. 257–70 4.
9. Bello A, Bello-Yusuf S, Ahmed A. Climate change mitigation paradox: poverty and greenhouse gas reduction in a global South City. Centre Hum Settlements Urban Dev J (CHSUDJ). 2023;9(1):21–9.
10. Bello OB, Ganiyu OT, Wahab MKA, Afolabi MS, Oluleye F, Ig SA, Abdulmaliq SY. Evidence of climate change impacts on agriculture and food security in Nigeria. Int J Agri Forestry. 2012;2(2):49–55.
11. Beltrán-Przekurat A, Pielke RA Sr, Eastman JL, Coughenour MB. Modeling the effects of land-use/land-cover changes on the near-surface atmosphere in southern South America. Int J Climatol. 2012;32:1206–25. https://doi.org/10.1002/joc.2346.
12. Berbesi LA, di Primio R, Anka Z, Horsfield B, Wilkes H. Methane leakage from evolving petroleum systems: masses, rates and inferences for climate feedback. Earth Planet Sci Lett. 2014;387(1):219–28.
13. Bujra A. African conflicts: their causes and their political and social environment. In: Paper presented at the Ad Hoc experts group meeting on the economics of civil conflicts in Africa. Addis Ababa: UNECA; 2000. April 7 to 8 2000.
14. Bununu YA. Connecting urban form and travel behaviour towards sustainable development in Kaduna, Nigeria. Johor Bahru, Malaysia: PhD Thesis, Universiti Teknologi Malyasia; 2016.
15. Bununu YA. Integration of Markov chain analysis and similarity-weighted instance-based machine learning algorithm (SimWeight) to simulate urban expansion. Int J Urban Sci. 2017;21(2):217–37.
16. CBD, FAO, World Bank, UNEP, UNDP**. (**2016). Biodiversity and the 2030 Agenda for Sustainable Development. Technical Note (available at https://www.cbd.int/development/doc/biodiversity-2030-agenda-technical-note-en.pdf), and Policy Brief (available at https://www.cbd.int/development/doc/biodiversity-2030-agenda-policy-brief-en.pdf).
17. Chakraborty A, Sachdeva K, Joshi PK. Mapping long-term land use and land cover change in the central Himalayan region using a tree-based ensemble classification approach. Appl Geogr. 2016;74:136–50.
18. Chukwuma KH. Constructing the herder–farmer conflict as (in) security in Nigeria. Afr Sec. 2020;13(1):54–76.
19. Dale VH. The relationship between land-use change and climate change. Ecol Appl. 1997;7(3):753–69 The Ecological Society of America.
20. Dickinson RE. Global change and terrestrial hydrology—a review. Tellus A: Dynamic Meteorol Oceanogr. 1991;43(4):176–81.
21. Egbuta U. Understanding the herder-farmer conflict in Nigeria. Conflict Trends. 2018;2018(3):40–8.
22. Emodi EE. Drought and dsertification as they affect Nigerian environment. J Environ Manage Saf. 2013;4(1):45–54.
23. FAO (2020b). How the world's food security depends on biodiversity. food and agricultural organization of the United Nations. Rome, Italy. Available at http://www.fao.org/3/cb0416en/CB0416EN.pdf
24. FAO (Food and Agricultural Organization) (2020a). Land cover classification systems. http://www.fao.org/3/y7220e/y7220e06.htm
25. FAO (Food and Agriculture Organization of the United Nations). 2014. The State of Food and Agriculture 2014. Innovation in Family Farming. Rome. (available at http://www.fao.org/3/a-i4040e.pdf).
26. FAO, IFAD, UNICEF, WFP & WHO**.** 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. (Available at https://doi.org/10.4060/ca9692en).
27. Federal Ministry of Environment (2004). Expert report on combating desertification and mitigating the effects of drought in Nigeria; a revised national report on the implementation of United Nations convention to combat desertification in those countries experiencing drought and desertification particularly in Africa. Abuja: Federal ministry of environment. Abuja. Available at www.nigeria.com.ngcichng.org/ccinfo.php
28. Food and Agricultural Organization (FAO). *Climate change and food security: a framework document*. Rome, FAO, UN: FAO Interdepartmental Working Group on Climate Change; 2008.
29. Friedlingstein P, O'Sullivan M, Jones MW, Andrew RM, Hauck J, Olsen A, Peters GP, Peters W, Pongratz J, Sitch S, et al. Global carbon budget 2020. Earth Syst Sci Data. 2020;12:3269–340. https://doi.org/10.5194/essd-12-3269-2020.
30. Gregory PJ, Ingram JS, Brklacich M. Climate change and food security. Philos Transact Royal Soc B: Biol Sci. 2005;360(1463):2139–48.
31. Gustafson S, (2020). 2020 State of food security and nutrition report. Food security portal. https://ssa.foodsecurityportal.org/blog/2020-state-food-security-and-nutrition-report.
32. Hamza IA, Iyela A. Land use pattern, climate change and its implication for food security in Ethiopia: a review. Ethiopian J Environ Stud Manage. 2012;5(1):26–31. https://doi.org/10.4314/ejesm.v5i1.4.
33. Hauge W, Ellingsen T. Beyond environmental scarcity: causal pathways to conflict. J Peace Res. 1998;35(3):299–317.
34. Houghton RA. The worldwide extent of land-use change. BioScience. 1994;44(5):305–13.
35. Houghton RA, Skole D. Changes in the global carbon cycle between 1700 and 1985. In: Turner BL, editor. The earth transformed by human action. New York, New York, USA: Cambridge University Press; 1990. p. 393–408.
36. Idumah FO, Mangodo C, Ighodaro UB, Owombo PT. Climate change and food production in Nigeria: implication for food security in Nigeria. J Agric Sci. 2016;8(2):74–83.
37. Intergovernmental Panel on Climate Change (IPCC) (2013). "Headline Statements from the Summary for Policy Makers," ipcc.ch, Sep. 27, 2013. Accessed on 19th December 2020
38. IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673
39. IPCC (1990). Intergovernmental Panel on Climate Change, "IPCC First Assessment Report," ipcc.ch, 1990
40. IPCC. Impacts, adaptation & vulnerability. Contribution of working group II to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC). UK: Cambridge University Press; 2001.
41. IPCC (2020). The Intergovernmental Panel on Climate Change. https://www.ipcc.ch/, accessed on 13th December 2020
42. Jansen LJM, Di Gregorio A. Parametric land cover and land-use classification as tools for environmental change detection. Agr Ecosyst Environ. 2002;91:89–100.
43. Khoday, K. & Ekdahl, O. (2017). Confronting Climate Change as an Accelerator of Crisis, United Nations Development Program. Available online @ https://www.undp.org/content/undp/en/home/blog/2017/confronting-climate-change-as-an-accelerator-of-crisis.html Accessed on March 24, 2021.
44. Koomen E, de Moel H, Steingröver EG, van Rooij SA, van Eupen M. Land use and climate change. Programme Office Climate changes Spatial Planning; 2012.
45. Lambin EF. Monitoring forest degradation in tropical regions by remote sensing: some methodological issues. Glob Ecol Biogeogr. 1999;8:191–8.
46. Maconachie R. Urban growth and land degradation in developing cities: change and challenges in Kano Nigeria. Routledge; 2016.
47. Madu IA, Nwankwo CF. Spatial pattern of climate change and farmer–herder conflict vulnerabilities in Nigeria. GeoJournal. 2021;86(6):2691–707.
48. Marland G, Boden TA, Griffin RC, Huang SF, Kanciruk P, Nelson TR. Estimates of $CO_2$ emissions from fossil fuel burning and cement manufacturing, based on the United Nations energy statistics and the US Bureau of Mines cement manufacturing data. Oak Ridge, TN (United States): Oak Ridge National Lab (ORNL); 1989.
49. Mohammed D, Akpan AE, Aliyu HS. Role of community participation in combating desertification in the Arid Zone of Nigeria: an overview. J Environ Manage Saf. 2013;4(3):49–58.
50. Mohammed, M. (2023, 3 September). The success story of Nigeria's Great Green Wall Project. *Vanguard*, https://www.vanguardngr.com/2023/09/the-success-story-of-nigerias-great-green-wall-project/.
51. Myers N. Environmental refugees: a growing phenomenon of the 21st century. *Philosophical transactions of the Royal Society of London*. Ser B, Biol Sci. 2002;357(1420):609–13. https://doi.org/10.1098/rstb.2001.0953.

52. Myers N. Environmental refugees: an emergent security issue. 13th Economic Forum of the Organization for Security and Co-operation in Europe. Prague; 2005.
53. NASA. Analyses Reveal 2019 Second Warmest Year on Record, Press Release, NASA; 2020.
54. National Oceanic and Atmospheric Administration (NOAA) (2020), "Global Climate Change Indicators," www.ncdc.noaa.gov Accessed on 17th December 2020
55. Neven D, Reardon T. The rise of Kenyan supermarkets and the evolution of their horticulture product procurement systems. Dev Pol Rev. 2004;22(6):669–99.
56. Nnodim O, Alagbe J. (2021, July 24). FG Replaces Controversial RUGA With New Scheme, Begins Camps in Six States. Punch, https://punchng.com/fg-replaces-controversial-ruga-with-new-scheme-begins-camps-in-six-states/.
57. NOAA (2020). Earth System Research Laboratory, "Trends in Atmospheric Carbon Dioxide," www.esrl.noaa.gov/gmd/ccgg/trends/ (accessed Dec. 13, 2020)
58. NOAA. What is the difference between land cover and land use? National Ocean Service website, https://oceanservice.noaa.gov/facts/lclu.html, 11/05/20.
59. Nongovernmental International Panel on Climate Change (NIPCC) (2013). "Climate Change Reconsidered II: Physical Science," https://www.heartland.org/_template-assets/documents/publications/10-17-2013_ccr-ii_entire_book.pdf. accessed on 19th December 2020
60. Obioha E. Climate Change, population drift and violent conflict over land resources in North Eastern Nigeria. J Hum Ecol. 2008;23(4):311–24.
61. Obioha EE. Climate variability, environment change and food security nexus in Nigeria. J Hum Ecol. 2009;26(2):107–21.
62. Ochiai, O., Poulter, B., Seifert, F. M., Ward, S., Jarvis, I., Whitcraft, A., ... & Rosenqvist, A. (2023). Towards a roadmap for space-based observations of the land sector for the UNFCCC global stocktake. Iscience. https://www.cell.com/iscience/pdf/S2589-0042(23)00566-7.pdf
63. Odjugo PAO. General overview of climate change impacts in Nigeria. J Hum Ecol. 2010;29(1):47–55.
64. Olagunju TE. Drought, desertification and the Nigerian environment: a review. J Ecol Nat Environ. 2015;7(7):196–209.
65. Oli NP, Ibekwe CC, Nwankwo IU. Prevalence of herdsmen and farmers conflict in Nigeria. Int J Innovative Stud Sociol Humanit. 2018;3(1):30–9.
66. Olufemi OJ. The effects of electricity consumption on industrial growth in Nigeria. J Econ Sustain Dev. 2015;6(13):54–9.
67. Patel SK, Verma P, Singh GS. Agricultural growth and land use land cover change in peri-urban India. Environ Monit Assess. 2019;191(9):600.
68. Pielke RA, Beven K, Brasseur G, Calvert J, Chahine M, Dickerson RR, Krajewski W. (2009) Climate change: the need to consider human forcings besides greenhouse gases. Eos, Transact Am Geophys Union. 2009;90(45):413–413.
69. Pielke RA, Schimel DS, Lee TJ, Kittel TGF, Zeng X. Atmosphere-terrestrial ecosystem interactions: implications for coupled modelling. Ecol Model. 1993;67(1):5–18.
70. Rindfuss RR, Walsh SJ, Turner BL, Fox J, Mishra V, (2008). Developing a science of land change: challenges and methodological issues. PNAS 101(39);13976–13981, online: www.pnas.org/cgi/doi/https://doi.org/10.1073/pnas.0401545101.
71. Robin M, Norton A. Social Dimensions of Climate Change Equity and Vulnerability in a Warming World, New Frontiers of Social Policy. Washington, DC: The World Bank; 2010.
72. Rotty RM. Estimates of seasonal variation in fossil fuel $CO_2$ emissions. Tellus. 1987;39(2):184–202.
73. Sala OE, Chapin FS III, Armesto JJ, et al. Global biodiversity scenarios for the year 2100. Science. 2000;287:1770–4.
74. Satterthwaite D, Huq S, Reid H, Pelling M, Lankao PR. Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low-and Middle-Income Nations. Human Settlements Discussion Paper Series. Routledge; 2012. pp. 3–47.
75. Scheffran J, Link M, Schilling J. Climate and conflict in Africa. In: Claussen M, editor. *Oxford research encyclopaedia of Climate Science*. USA: Oxford University Press, New York online only; 2019.
76. Schmidhuber J, Tubiello FN. Global food security under climate change. Proc Natl Acad Sci. 2007;104(50):19703–8.
77. Scholes RJ, Biggs RA. Ecosystem services in Southern Africa a regional assessment. Annual Report of the Council for Scientific and Industrial Research (CSIR) No. 33355 Caja (533). 2004.
78. Shine KP, Derwent RG, Wuebbles DJ, Morcrette JJ. Radiative forcing of climate. In: Houghton JT, Jenkins GJ, Ephraums JJ, editors. Climate change: the IPCC scientific assessment. New York, New York, USA: Cambridge University Press; 1990. p. 40–68.
79. Shuval HI. Are the conflicts between Israel and her neighbors over the waters of the Jordan River Basin an obstacle to peace? Israel- Syria as a case study. Water Air Soil Pollut. 2000;123(1):605–30.
80. Skah, M. & Lyammouri, R. (2020). The Climate Change-Security Nexus: Case study of the Lake Chad Basin. Policy Centre for the New South. Available online @ https://media.africaportal.org/documents/the_climate_change_security_nexus.pdf Accessed on March 29th 2021.
81. Thapa RB. Field research report on food and nutrition security of the forest dependent households from the forests of Nepal. Bhaktapur: Nepal, Renaissance Society Nepal (RSN); 2013.
82. Tobias S, Price B. How effective is spatial planning for cropland protection? An assessment based on land-use scenarios. Land. 2020;9(2):43.
83. Turner WR, Brandon K, Brooks TM, Costanza R, Da Fonseca GA, Portela R. Global conservation of biodiversity and ecosystem services. BioScience. 2007;57(10):868–73.
84. US Global Change Research Program (UGCRP). US National Climate Assessment. 2014. https://nca2014.globalchange.gov/. Accessed 18 Dec 2020.
85. Vandewalle M, Sykes MT, Harrison PA, Luck GW, Berry P, Bugter R, Dawson TP, Feld CK, Harrington R, Haslett JR, Hering D, Jones KB, Jongman R, Lavorel S, Martins da Silva P, Moora M, Paterson J, Rounsevell MDA, Sandin L, Settele J, Sousa JP, Zobel M, (2008). Review paper on concepts of dynamic ecosystems and their services. http://www.rubicode.net/rubicode/RUBICODE Review on Ecosystem Services.pdf (accessed November 6, 2008).
86. Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. Human domination of earth's ecosystems. Science. 1997;277(5325):494–9.
87. Wang S, Fang C, Wang Y, Huang Y, Ma H. Quantifying the relationship between urban development intensity and carbon dioxide emissions using a panel data analysis. Ecol Ind. 2015;49(1):121–31.
88. Weng Q, Yang S. Managing the adverse thermal effects of urban development in a densely populated Chinese city. J Environ Manage. 2004;70(2):145–56.
89. World Weather Attribution (WWA). Attribution of the Australian Bushfire Risk to Anthropogenic Climate Change. 2020. worldweatherattribution.org. Accessed 20 Dec 2020.
90. Zoellick S and Robert BA. Climate Smart Future. The Nation Newspapers. Lagos, Nigeria: Vintage Press Limited; 2009. pp 18.

## Publisher's Note