Chapter

Recent Climate Change Adaptation Strategies in the Sahel: A Critical Review

Terence Epule Epule, Abdelghani Chehbouni and Driss Dhiba

Abstract

Climate change adaptation continues to be central on the agenda of most African countries. Current understanding of the state of adaptation is limited in Africa. The Sahel is selected because of persistent declines in precipitation and rising temperatures. Here, we examine the status of adaptation actions across the Sahel by reviewing the primary peer review literature. A total of 70 peer review papers that document 414 discrete adaptations provide a snapshot of adaptations developed between 1975 and 2020. From a country-to-country perspective, Kenya has the highest number of reported adaptation actions (75 or 18.1%). From a regional standpoint, West Africa recorded about 261 or 18.1% of all adaptation actions reported. Income diversification of livelihoods, and water harnessing were reported as the most used adaptation actions in the Sahel. Based on categories, technically based adaptation actions are the most used options. The period 2008–2016 registered 65.2% of all adaptations. 98% of adaptation actions are reported to be driven by climate while non-climatic drivers account for 95% of adaptation actions. The findings presented here are proxies of climate change adaptation; some relevant information might be found in gray literature which not used because gray literature is less standardized because it is not subject to peer review.

Keywords: Climate change, Adaptation, West Africa, Sahel, Income diversification, Technical adaptation

1. Introduction

It is now clear that the world is experiencing climate change and the Sahel of Africa is no exception to this [1–7]. In the past thirty years the Sahel has witnessed temperatures in the range of between 0.2–2.0° C [8]. At the same time, the precipitation gradient has witnessed a decline from the south to the north of the Sahel. The effects of the above precipitation and temperature nexus in the Sahel have been declining crop yield, water resources and degradation of forest species. Specifically, they include: (i) increase mortality and dieback of various tree species in parts of the Sahel such as Mauritania, Chad, Mali, Burkina Faso, Senegal, and Niger, as seen in observations of the last quarter of the 20th century [9]; (ii) enhanced stress on food systems, with about 50% of the 60 million people living in the Sahel believed to be facing food insecurity linked to climate change [10–12], with the region likely projected to potentially experience about 250 million tons of food deficits by 2020 [12–14]; (iii) enhanced

occurrence of malaria and diarrheal diseases, [15–17]; (iv) with more frequent water shortages also documented [18]. These impacts, in turn, are believed to have increased the number of climate refugees in the Sahel [19–22]. Climate change may also present opportunities, including increasing food production through better water management, irrigation, rainwater harvesting [3], and potential increase in crop productivity due to increased aerial fertilization by carbon dioxide [23].

Climate change Adaptation is important as it reduces the damages caused by climate change and takes advantage of new opportunities in-light of the rapid climate change already occurring and expected future impacts [24–31]. Governments, indigenous people, farmers, non-governmental organizations, donor organizations, the African Development Bank, the World Bank, and United Nations Environment Program have been active making suggestions through several policies, programs, and adaptations. For example, actions include those of the United Nations Reductions of Emissions from Deforestation and Forest Degradations (REDD+) which supports reforestation efforts in the Sahel [32, 33], and adaptation funding programs established under the United Nations Framework Convention on Climate Change (UNFCCC) [34] and at the regional level, the African Development Bank (AfDB) is now masterminding the African Climate Change Fund which has as objective to increase access of African countries to international climate finance [35]. Despite the importance of climate change and adaptations in the Sahel, a lot remains unknown with respect to how adaptation actions have occurred over time in various part of the Sahel. This knowledge gap reduces the ability to characterize key gaps in adaptations. Furthermore, this underscore the necessity is create adaptation metrices across Africa that can assist in evaluating progress and monitoring the status of adaptation.

This chapter provides a better understanding of the status of climate change adaptation actions across various Sahel regions and countries, showing how adaptations have changed over time as well as the relative contributions of climatic and non-climatic drivers. This is based on what has been recorded in the scientific peer review literature, underscoring a general and baseline overview of adaptation in the region. This work contributes to an important gap in the literature, with most studies examining the state of adaptation focusing on developed nations e.g., [31, 36, 37], or focused on other regions of Africa e.g., [38, 39]. This chapter is vital because there are currently insufficient studies that adopt the holistic approach fostered by this chapter. Prior to this study, the peer review data on climate change adaptation in the Sahel was found in several scattered publications which evidently did not provide a holistic approach. Furthermore, this chapter is vital because the Sahel remains a territory witnessing persistent shocks that need to be better addressed [40–42] that calls for urgent adaptation actions to enhance resilience. Therefore, a holistic picture on where the peer review literature has so far focused goes a long way in improving our understanding on where the emphasis is and where attention needs to be given.

2. The Sahel: geography, livelihood and overview of climate change

The Sahel is the semiarid strip of land located between the tropical rainforest in the south and the arid north of Africa and covers an area of about 3.053×10^3 km^2 and has about 60 million inhabitants [43]. The Sahel is located between latitude 10° and 20° north and extends from about 5000 km around northern Senegal around the west towards southern Mauritania, central Mali, northern Burkina Faso, south-western Niger, northern Nigeria, central Chad,

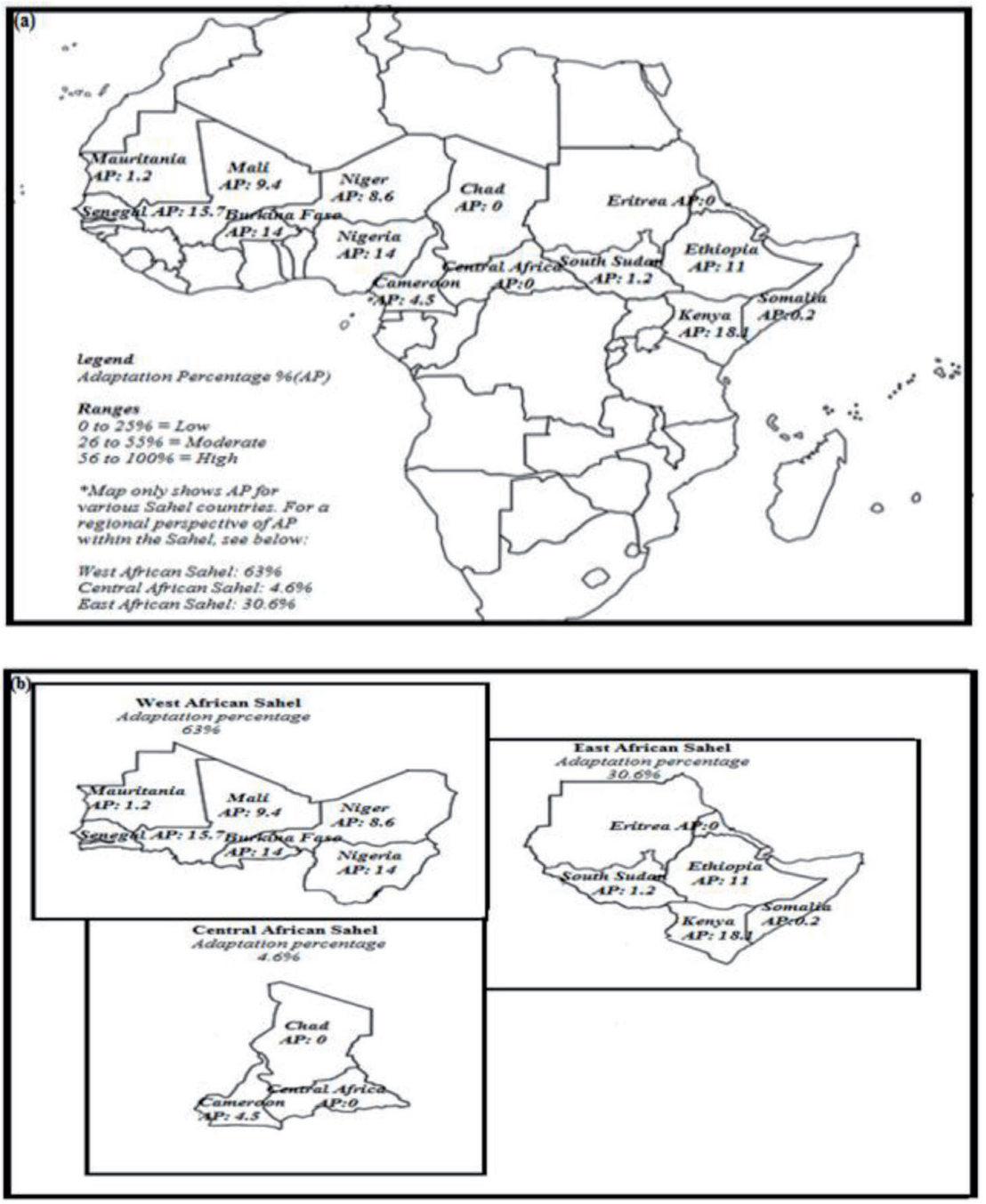

Figure 1.
Location of the various (a) countries and (b) regions of the Sahel.

north of Cameroon, Central African Republic, central Sudan and southern Sudan, northern Eritrea, extreme north of Ethiopia, to Somalia in the east and south east of the Sahel into Kenya (**Figure 1**).

In the Sahel, the vegetal landscape is covered by open Acacia shrubs and grassland. The Sahel represents a transition between the humid savanna in the south and the desert in the north [44, 45]. In terms of rainfall, the Sahel experiences declining rainfall with increasing latitude. At the southern border of the Sahel, about 450–500 mm of rainfall are recorded yearly while towards the higher latitudes less than 200 mm of rainfall are recorded yearly [46, 47]. Between 1930 and 1965 and 1966 and 2000, the Sahel recorded about 100 mm of rainfall per year [48]. The rainfall pattern in the Sahel is tied to the migration of the Inter-tropical Convergence Zone (ITCZ) [44, 46, 47, 49]. In the Sahel, a rainfall gradient of between 250 and

300 mm between the southern and northern spheres of the region is recorded. At 17° latitude north less than 200 mm of rainfall are recorded annually while southwards at about 15° latitude north (southern boundary of the Sahel), more rainfall of about 450–500 mm is recorded annually [44, 46, 47].

3. Countries and regions where adaptations are occurring in the Sahel?

In the Sahel, climate change adaptation actions can be categorized into four main categories (**Figure 2**). These include technically based, economically based, indigenous based and socially based (**Figure 2**). A total of 414 adaptation actions were reported in 70 peer review journal articles. An analysis of the articles illustrates that Kenya had recorded the highest number of adaptation actions of about 75 or 18.1% during the period 1975 and 2015. This was followed by Senegal with 65 or 15.7% of all recorded adaptations (**Figure 3**). Even though these countries recorded the highest rates of adaptation actions, it is worth noting that the overall picture in term of adaptation actions in the Sahel appears to be generally low (**Figure 1**).

Regionally, with a frequency and percentage of about 261 or 63%, West African Sahel witnessed the highest adaptation actions as reported by the peer review literature. East Africa recorded 127 or 30.6% and therefore is the second most adapted region in the Sahel (**Figure 4**). Furthermore, it can be said that when a region has more adaptation actions, the same is said of its adaptive capacity (**Figure 1**).

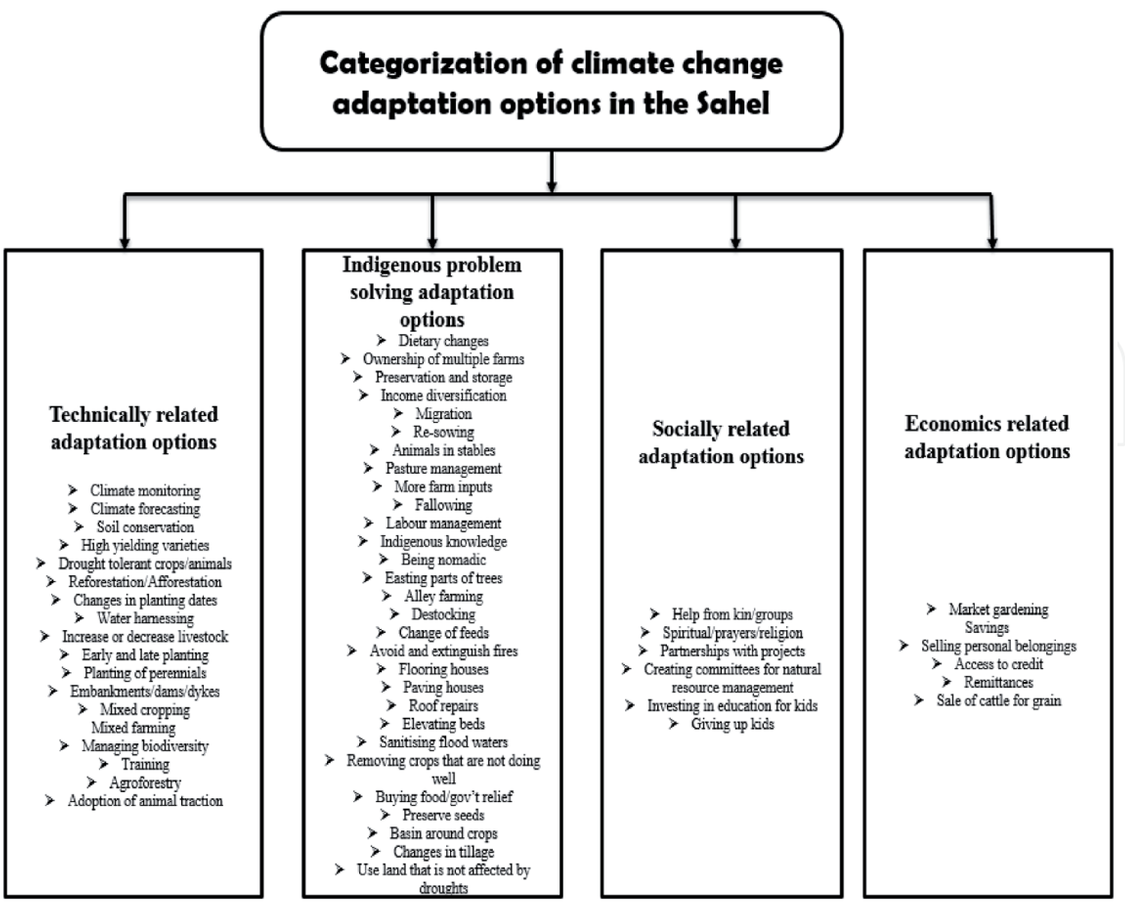

Figure 2.
The four categories of climate change adaptation actions in the Sahel.

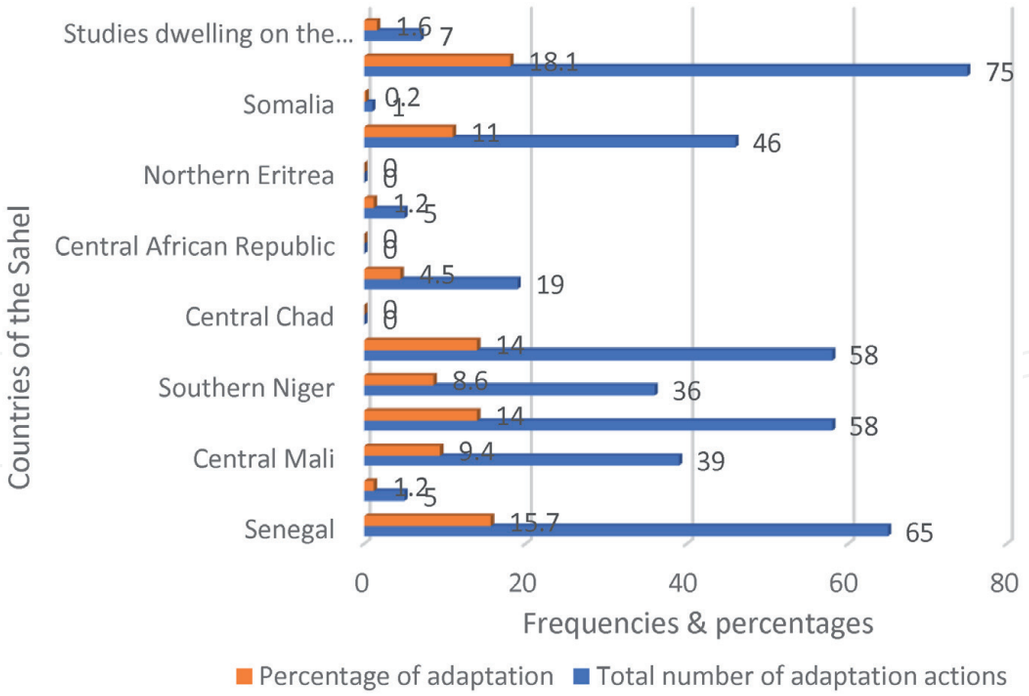

Figure 3.
Number of adaptation options and calculated percentage reported in the peer review literature published between 1975 and 2015 for various Sahel countries.

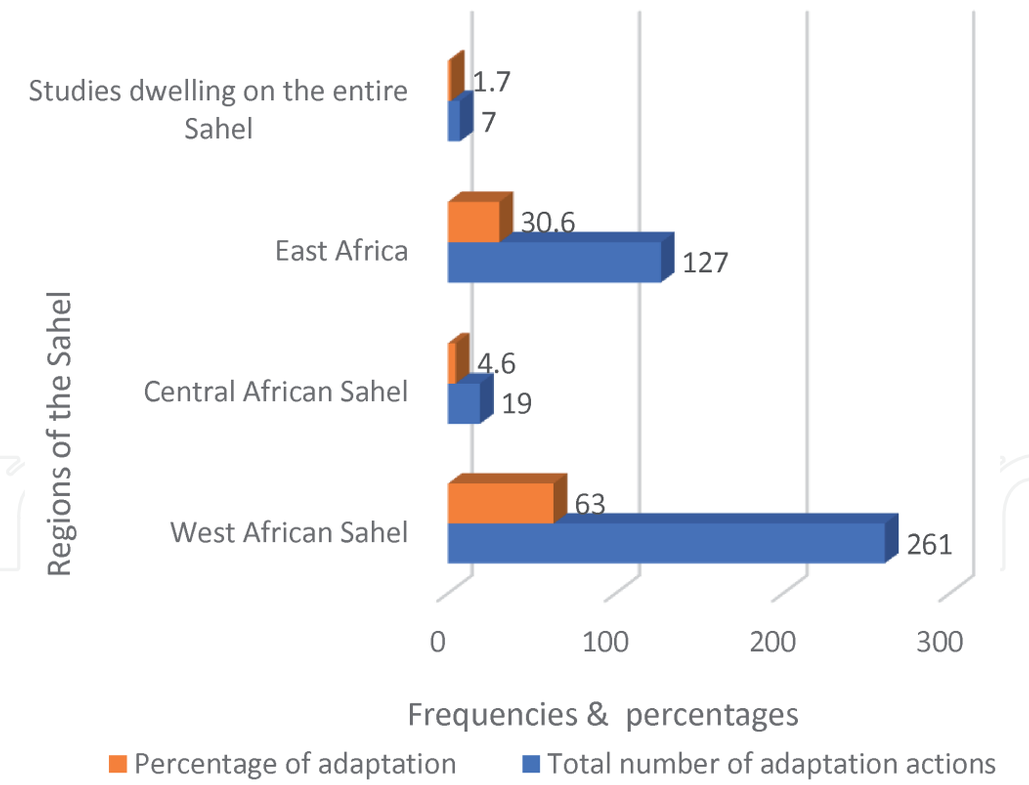

Figure 4.
Number of adaptation options and calculated percentage reported in the peer review literature published between 1975 and 2015 for various regions of the Sahel.

4. Actual adaptation actions in the Sahel

Based on this systematic review, income diversification adaptation actions recorded the highest frequencies in the scientific peer review literature. This

is seen as they stood at a frequency of 53 or 12.8% and tailed closely by water harnessing actions which recorded a frequency of 48 or 11.5%. Adaptation actions like soil conservation, farm inputs, and planting high yielding varieties recorded 6.5%, 6.2% and 5.5% respectively (**Figure 5**, **Table 1**). From these results, we note

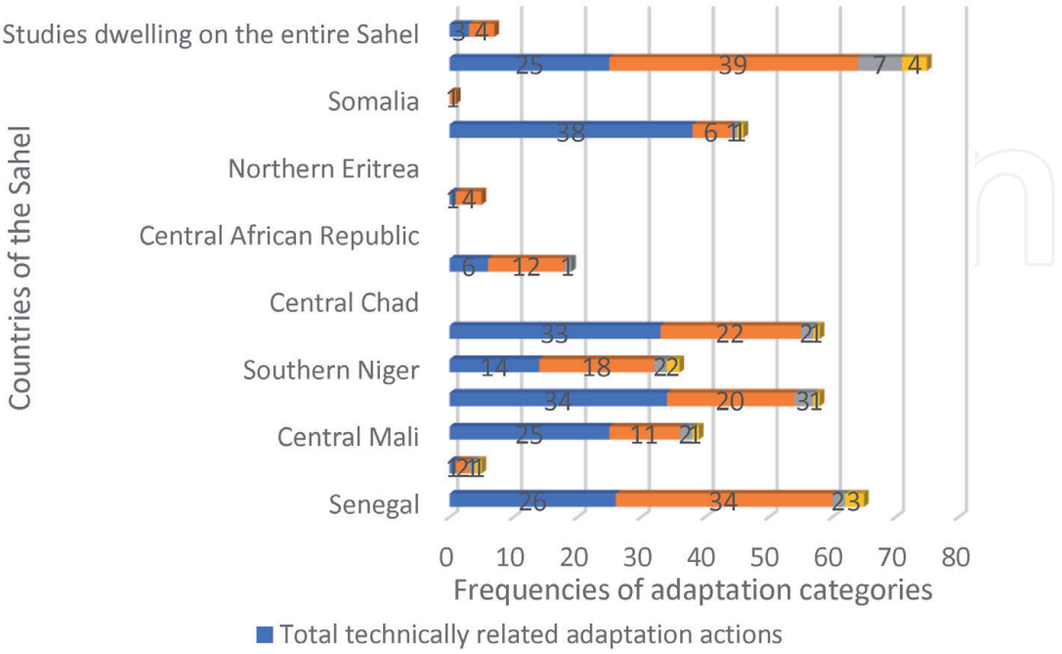

Figure 5.
Composite distribution of categorized number of adaptations options reported in the peer review literature published between 1975 and 2015 for various countries of the Sahel.

Adaptation options	References
Income diversification actions	
Off farm employment	Fleuret [50]; Mertz et al. [6]; Elmqvist and Olsson [51]; Morand et al. [52]
Working for development projects	Nielsen and Reenberg [53]; Moretimore [54]
Small-scale commerce	Nielsen and Reenberg [53]
Non-farm income	Mertz et al. [55]; Reardon et al. [56]; Burnham and Ma [57]
Selling of personal belongings	Schaer [58]; Brockhaus et al. [59]; Opondo [60]
Supplemental occupation	Epule et al. [61]; Opiyo et al. [62]
Hunting	Mosberg and Eriksen [63]
Water Harnessing	
Rainwater harvesting	Bryan et al. [64]; Zampaligré et al. [65]; Barbier et al. [66]
Irrigation	Bryan et al. [64]; Deressa et al. [67]; Fleuret [50]
Water management	Rockström [68]; Douxchamps et al. [69]; Burnham and Ma [57]
Boreholes	Mbow et al. [70]
Construction of dams and drainage systems	Magistro and Medou [71]
Use of water pumps	Schaer [58]
Use of green and blue water	Recha et al. [72]

Adaptation options	References
Soil conservation	
Mulching	Burnham and Ma [57]
Change in tillage and rotation	Bryan et al. [64]
Half-moon and stone dykes	Zampaligré et al. [65]
Planting shade trees	Burnham and Ma [57]; Deressa et al. [67]; Bryant et al. [61]
Fallowing	Gebrehiwot and Van der Veen [73]; Nyong et al. [74]
Soil erosion control/stabilization dunes	Okoye [75]; Brockhaus et al. [59]; Burnham and Ma [57]
Farm inputs	
Manure	Mertz et al. [6]; Marenya and Barrett [76]; Wood et al. [77]
Fertilizers	Mertz et al. [6]; Mertz et al. [55]; Croppenstedt et al. [78]
Inorganic fertilizers	Marenya and Barrett [76]; Wubeneh and Sander [79]
Adoption of compost	Somda et al. [80]
Organic fertilizers	Epule et al. [61]
High yielding crops and animals	
High yielding crop varieties	Bryan et al. [64]; Deressa et al. [67]; Fleuret [50]
Improved varieties of potatoes	Thuo et al. [81]; Burnham and Ma [57]; Abebe et al. [82]
Improved varieties of sorghum	Adesina and Baidu-Forson [83]
Improved varieties of maize	De Groote et al. [84]
High biomass variety of maize	De Groote et al. [84]
Improved animal husbandry	Zander et al. [85]

Table 1.
Adaptation actions in the Sahel in order of importance.

that emphasis is placed on employment diversification actions or on providing water harnessing options. While Kenya and Senegal recorded the highest cumulate amounts of adaptation actions with income diversification actions appearing to record the highest frequencies.

5. Categorization of actual adaptation actions in the Sahel

In terms of broad adaptation categories, four key categories of broad adaptation actions were identified. All other actions fall within any of these four categories, these include: (i) technically based actions; (ii) indigenous problem-solving based; actions; (iii) socially based actions and (iv) economics-based actions (**Figure 5**).

Technically based adaptation actions recorded the highest number of adaptation actions with a frequency of 206 or 49%. The other broad-based categories in order of importance are: Indigenous problem-solving based options with a frequency of 173 or 41.7% (**Table 2**), socially related based actions with a frequency of 21 or 5% and economics-based actions with frequencies of 14 or 3.3%. Though the technically based actions are leading, Kenya has the highest number

Adaptation options	References
Technically related adaptation options	
Water Harnessing	Zampaligré et al. [65]; Barbier et al. [66]; Recha et al. [72]
Soil conservation	Burnham and Ma [57]; Deressa et al. [67]; Bryan et al. [64]
Climate monitoring	Boyd et al. [86]; Huq et al. [87]; Reenberg [88]
Early harvesting	Tambo and Abdoulaye [89]; Burnham and Ma [57]; Deressa et al. [67]
Mixed farming	Moretimore [54]
Indigenous problem-solving adaptation options	
Income diversification	Schaer [58]; Brockhaus et al. [59]; Opondo [60]
Migration/relocation	Zampaligré et al. [65]; Scheffran et al. [90]; Burnham and Ma [57]
Farm inputs	Marenya and Barrett [76]; Wubeneh and Sanders [79]
Pasture management	Brockhaus et al. [59]; Burnham and Ma [57]; Mertz et al. [6]
Buying food/gov't relief	Epule et al. [61]; Oluoko-Odingo [91]
Socially related problem-solving options	
Help from kin/social organizations	Mortimore [54]; Epule et al. [61]; Oluoko-Odingo [91]; Fleuret [50]
Spiritual/prayers/religion	Fleuret [50]; Mertz et al. [6]; Burnham and Ma [57]
Partnership between local people and development project	Nielsen et al. [92]
Creating local committees for natural resources management	Brockhaus et al. [59]
Investing in education of kids	Opondo [60]
Economics related adaptation options	
Market gardening	Mertz et al. [55]; Mertz et al. [6]; Nielsen et al. [92] and Reenberg [88]
Savings	Schaer [58]
Selling of personal belongings	Schaer [58]
Access to credits	Ebi et al. [93]
Remittances	Fleuret [50]

Table 2.
Four categories of adaptation actions in the Sahel.

of total adaptation actions. The indigenous problem-solving based actions recorded 39 or 9.4%. Similarly, in Senegal, indigenous problem-solving adaptation recorded a frequency of 34 or 8.2%. When all the categories are put together, the frequencies for the latter category, does not outbid the former (**Figure 5**). Regionally, the West African Sahel recorded the highest number of adaptation actions and tallied highest in the context of technically based adaptation actions with a frequency of 133 or 32.1%. In terms of other regions, East Africa records the second highest frequency as technically based adaptation actions recorded 64 or 15.4% (**Figure 6**).

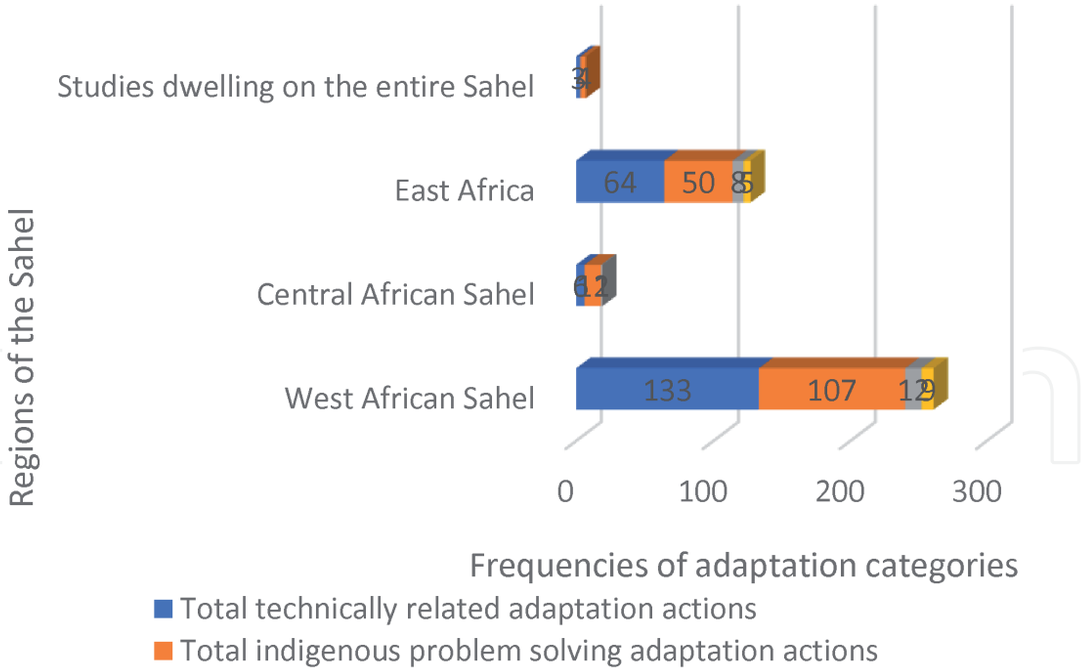

Figure 6.
Composite distribution of categorized number of adaptations options reported in the peer review literature published between 1975 and 2015 for various regions of the Sahel.

6. Temporal variations in adaptation actions and drivers of adaptation in the Sahel

The decade 2008–2016 recorded a total of 270 or 65.2% adaptation actions which represent the highest number of adaptation actions in the Sahel. The subsequent decades witnessed adaptation actions as follows: 1997–2007: (n = 58, 14%); 1986–1996: (n = 29, 7%); 1975–1985: (n = 57, 13.7%). In summary, we end up having a total of 414 adaptation actions which is like the total number of adaptation actions (**Figure 7a**). It can be observed that there has been an increase in the number of adaptation actions over the decades. A review of the drivers shows that most of the adaptation actions are anchored on climatic factors. The climatic drivers recorded 406, or 98% while the non-climatic drivers recorded 395 or 95% (**Figure 7b**). Though the climatic drivers are dominant, an interesting observation is the increase prominence of non-climatic drivers. Some potential climatic drivers include increase precipitation, decreasing precipitation, temperature increase, temperature decline, sea surface temperature changes, trade winds, El Niño, increase solar radiation, atmospheric circulation, and the prevalence of winds/sandstorms like the equatorial westerlies. Non-climatic drivers of adaptation cited in the literature encompass agriculture, population growth, settlements, poor urban planning, pastoralism, and cattle rearing, over exploitation of resources, grazing of animals, deforestation and land degradation, wildfires, insects, economic fluctuations and socio-political.

In the Sahel, some adaptation actions have gained prominence over time. Income diversification which is the highest used adaptation action recorded a frequency of 21 during the decade 1985–1996. Th decade 2008–2016; also recorded 18 adaptation actions. Here also, water harnessing actions were dominant during the decade 1985–1996 in which they recorded a frequency of 27. The decade 2008–2016, witnessed 15 adaptation actions. On the other hand, soil conservation related actions recorded their highest frequency during the decade 1985–1996. Migration had a frequency of

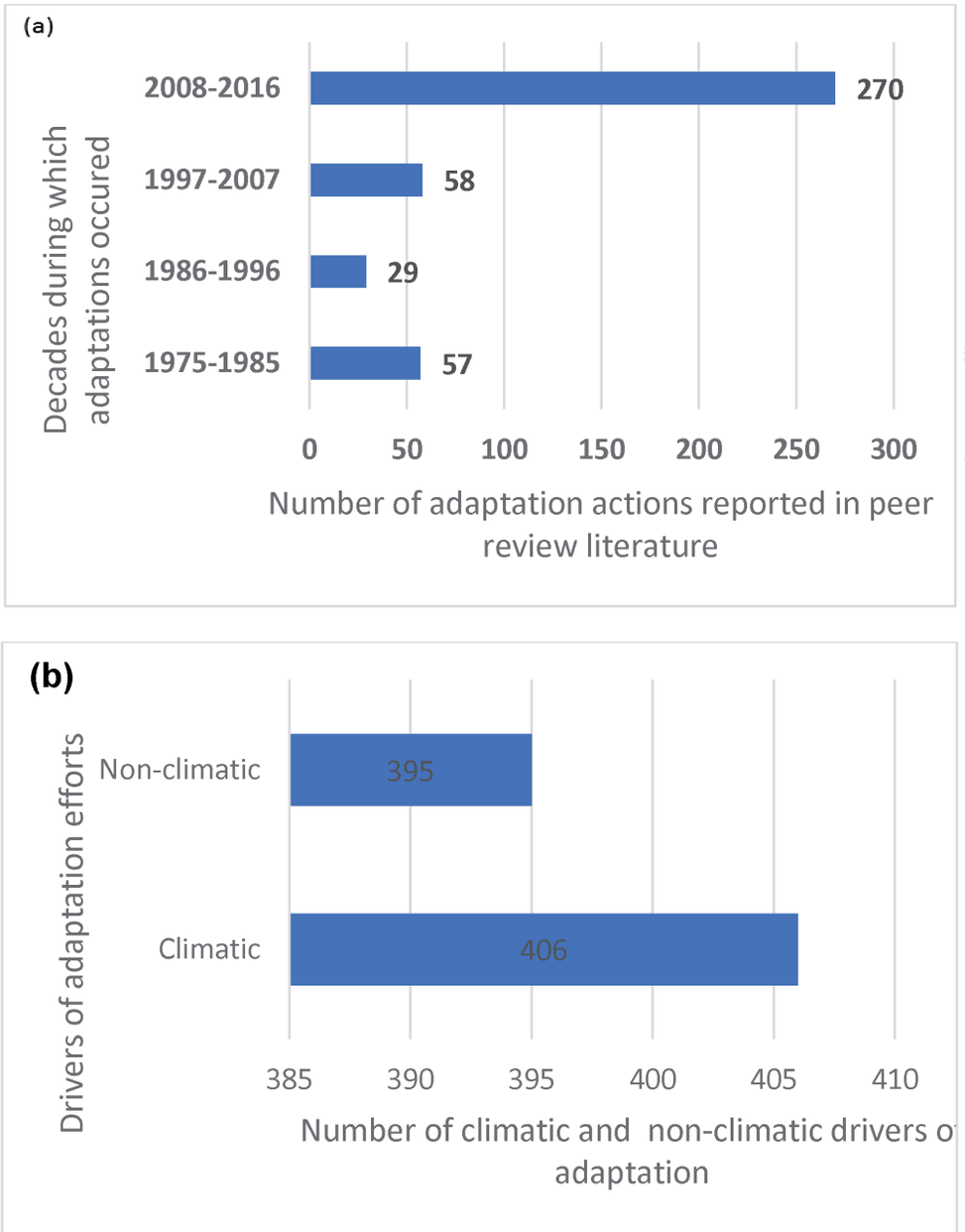

Figure 7.
(a) Variations in adaptation action in various decades in the Sahel. (b) Climatic and non-climatic drivers of adaptation actions in the Sahel.

8 and this was during the decade 2008–2016. High yielding varieties also recorded a frequency of 13 adaptation actions during the decade 2008–2016. Generally, during the decade1975–1985, two adaptation actions were most frequently used. These included *income diversification* and *migrations*. Help from *kin* and *network* such as friends and family options were second (**Figure 8**). The decade 1985–1996 also had as the most important adaptation option *water harnessing* related options with a frequency of 27; soil conservation recorded the second with a frequency of 19 while income diversification was third with a frequency of 18 (**Figure 8**). During the decade 1997–2007, *income diversification* led with the highest frequency of 8 while more *farm inputs* came second with a frequency of 6 and migration recorded a frequency of 3 (**Figure 8**). During the decade 2008–2016, *income diversification* was still the most used adaptation option with a frequency of 21; water harnessing came second with a frequency of 15 while high yielding varieties were third with a frequency of 13 (**Figure 8**).

Figure 8.
Composite distribution of variations in different adaptation options reported in the peer review literature published over time for various countries of the Sahel.

7. Discussion

Climate change adaptation is currently receiving a lot of global attention as governments, NGOs, International organizations, civil society groups inter alia are now placing climate change adaptation as a priority on their political and environmental agenda [94, 95]. Even though we have agreed that climate change adaptation is vital in establishing resilience in the Sahel, stakeholders are still in disagreement with

respect to what approach climate change adaptation actions represent [96, 97]. This chapter attempts at improving our understanding of the regional and country level adaptation actions in the Sahel as well as their drivers and evolution through several decades. The approach used in this study is similar to those used by Ford et al. [30, 98]. Systematic reviews enhance the ability to compare how adaptation is taking place across the Sahel [30, 98, 99]. The results from this study should therefore be considered as proxies for the level of adaptation in the Sahel as they are based on what exist in the scientific literature and therefore provide a baseline.

These findings can be weakened by the fact that several adaptation actions in the Sahel might be beyond the scope covered by this current study. For example, this work does not consider the gray literature and studies beyond 2020. However, the fact that this study covers a time frame that goes beyond 40 years makes these results valid. The decade 1975–1985 recorded the highest number of adaptation actions while the decade 1985–1996 recorded fewer adaptation actions. The surge in adaptation actions recorded during the decade 1975–1985 can be attributed to the surge in climate change shocks in the form of droughts that dominated this decade [43, 48]. These shocks triggered a lot of actions from governments, international and non-governmental organizations to enhance adaptations [7, 46]. From 1985, the droughts that affected the Sahel had reduced and so did the number of adaptation actions due to 'adaptation fatigue' of the previous decade. The adaptation actions of the 1970s and 1980s have already produced positive results in the Sahel. Recent studies show that the Sahel has become greener with a parallel increase in precipitation. Normalized difference vegetation index (NDVI) and precipitation across the Sahel show a strong correlation between NDVI and greening [3, 53, 100, 101]. Prince et al. [23] has argued that the increase precipitation and greening recorded in the Sahel can be attributed to rising aerial fertilization effect of carbon dioxide. The decades 1997–2007 and 2008–2016 recorded 14% and 65.2% adaptations, respectively. These decades are consistent with an increase in the number of adaptation initiatives over time. It is difficult to argue that the climate change adaptations reported in this study are mainly driven by the adaptation initiatives presented in the peer review literature. In addition, with a total of 414 discrete adaptation actions reported in this study, it remains clear that the level of adaptation is still relatively low in the Sahel. Regionally, West African Sahel dominates in terms of adaptation actions. However, in term of countries, Kenya in East Africa records the highest frequency of 18.1%. According to Ford et al. [95], during the period 2006–2012, Kenya recorded a total of 34 adaptation actions and thus was the highest in terms of adaptation actions from a set of African and Asian countries. The fact that West African Sahel has a higher adaptation rate from a regional perspective can be linked to the "Great Green Wall of the Sahara and the Sahel initiative" (GGWSSI) [102].

The finding that income diversification is the most used adaptation action in the Sahel is consistent with other previous studies that report that to better reduce the effects of climate shocks in the Sahel, it is important to resort to a diversification of livelihoods [103, 104]. Water management actions on the other hand which are second in terms of use are vital as the regions keeps facing recurrent droughts and therefore there is an urgent need for adaptation actions to remedy the situation. With respect to the broad categories of adaptation, technically based adaptations are dominant. This in other words shows that adaptation actions anchored on science and technology are those that are mostly reported in the scientific literature. This is without doubts as the response of technical field experts in the Sahel is often in the form of technically based solutions at the expense of indigenous knowledge, economic based and socially based actions. Examples of these technically based actions are drought resistant species, rainwater harvesting and high yielding varieties.

In terms of policy, it has become evident that income diversification and water harnessing actions have gained prominence over time. This provides an opportunity to further leverage these actions and to investigate how other actions can be further enhanced to improve adaptations. The fact that technically based adaptation actions are more frequently reported shows that policies that enhance both technically based adaptations and others that are less cited should be leveraged in other to enhance the level of adaptation actions in the Sahel. It is important to emphasize the fact that no single adaptation action can single handedly revamp the adaptation landscape in the Sahel because several actions indeed work together better. Those that have been ignored this far need to be researched into to verify what the indigenous people think about them before concrete suggestions are made.

Most of the studies presented here showed that most of the adaptations are driven by climatic variables. However, we also observe an increase attribution of the drivers to non-climatic drivers. Non-climatic drivers are becoming increasingly vital as there are many cases when adaptations are not just taken to adapt to climate change but also in response to other issues such as health, poverty, literacy, and socio-cultural disparities that affect adaptive capacities [95, 96]. The evidence across Africa and the Sahel shows that the problems that Africa and the Sahel are facing ranging from food crisis, deforestation, water scarcity, pandemics and epidemics are mainly caused by non-climatic variables such as deforestation, population movements, wars, and land degradation inter alia with climate change only playing a reinforcing role [1, 3–5].

These results tend to be similar and different from some previous studies based on results and methodology. A study by Ford et al. [95] researched into the status of climate change adaptation in Africa and Asia based on a systematic approach and showed that Kenya had the highest number of adaptation actions. When compared with other vulnerable regions, as the Arctic, there are more reports of adaptation actions in the Sahel. Also, another study by, Ford et al. [30], reported about 157 adaptation actions between 2003 and 2013 while this current study reports 414 adaptation actions for the Sahel for the period 1975–2020. The major areas of differences are that the Ford et al. [95] study focused on both peer review and gray literature while this chapter is based on peer review literature. The Ford et al. study is based on Africa and Asia and covers studies published from 2006 while this current study is based on the Sahel and covers studies from 1975 to 2020. Also, Berrang-Ford et al. [97] used the systematic approach and focused on the peer review literature only, an approach like that adopted by this current study. The results from the latter are also consistent with this in that they report that considerable research has been done with a greater focus on intentions than groundwork. Also, non-climatic drivers are increasingly being presented as the drivers of climate change adaptation [38].

8. Conclusions

In this chapter, we investigated the state of climate change adaptation in the Sahel. The findings show that Kenya recorded the most adaptation actions while regionally, West Africa reported the highest. The approach used in this study provides a proxy-based perspective and baseline from which climate change can be monitored and tracked over time. It is important that various stakeholders come together using this information to further enhance climate change adaptation in the Sahel. This is important as the results from this study show that at country level adaptations to climate change are still at infancy judged by the low frequencies and percentages recorded at the country level.

Due to the existence of a lot that is unknown about climate change adaptation across the Sahel, it becomes important that moving forward attention is given to evidence-based research. It is suggested that more systematic reviews that cover most other regions of Africa be considered. Additionally, gray literature and a wider time scale should be considered. Advancing more research into other regions will go a long way in providing a bigger picture of the status of climate change adaptation across the continent of Africa. Looking at the gray literature will help in brining to the lamplight other potential options not found in the peer review literature. Finally, it is also important to better understand the climatic and non-climatic shocks that are driving adaptation actions in the Sahel and Africa in general. This will enhance the policy process aimed at triggering better adaptation options based on the actual drivers of change.

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Conflict of interest

The authors declare no conflict of interest.

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