Climate change adaptation in the Sahel

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Abstract

Climate change adaptation now occupies central stage on the agenda of most environmental initiatives in Africa. Our current understanding on the state of adaptation is limited, however, both globally and in Africa in particular. This study examines the status of adaptation in the Sahel by reviewing the primary peer review literature that reports climate change adaptation actions. Based on an analysis of 70 peer review papers that document 414 discrete adaptations, we create a snapshot of adaptations developed between 1975 and 2015. The results show that Kenya has the highest number of reported adaptation actions (75 or 18.1%). The percentages indicate that the adaptive capacity of the entire study area is generally low for all the countries being that the highest country-level percentage is recorded in Kenya (18%). Regionally, West Africa has more adaptation actions (261 or 63%) when compared to other regions of the Sahel. Regional level percentages suggest a higher level of adaptation at the regional level being that the percentage falls within the high scale range. The most commonly used adaptation actions reported are income diversification and water harnessing respectively. When categorized, technically related adaptation actions dominate the adaptation charts. The decade 2008-2016 recorded the highest number of adaptations (65.2 %). Adaptation actions are also reported to be triggered by climatic and non-climatic drivers which both record high frequencies but the climatic drivers (98%) of adaptation are slightly dominant relative to the non-climatic drivers (95%).

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

1. Introduction

The Sahel region of Africa is currently experiencing climate change (Giannini et al. 2003, 2005, 2008; Reynolds et al. 2007; Lu and Delworth 2005; Mertz et al. 2009; Epule et al. 2013a). Over the past three decades temperatures in the Sahel have increased by between 0.2-2.0° C (IPCC 2007) while rainfall has declined from the southern to the northern limits of the Sahel; for example, a rainfall decline gradient of between 250-300 mm is recorded between the southern and northern limits of the Sahel. Precisely, at the 17° latitude north (the northern boundary of the Sahel), less than 200 mm of rainfall is recorded annually while towards the south at the 15° latitude north (southern boundary of the Sahel), more rainfall of about 450-500 mm of rainfall is recorded annually (Nicholson 1995; Wang et al. 2005; Zeng 2003). The impacts of rising temperature and rainfall variations in the Sahel are significant and include: i) increasing tree mortality or dieback, with declines in tree density and species richness across sites in the Sahel such as Mauritania, Chad, Mali, Burkina Faso, Senegal and Niger recorded in the last half of the 20th century (Gonzalez et al. 2012); 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 (Clover 2010, Verpoorten et al. 2013), with the region likely projected to potentially experience about 250 million tons of food deficits by 2020 (Nyariki and Wiggins 1997; Battisti and Naylor 2009; Sissoko et al. 2011); iii) enhanced occurrence of malaria and diarrheal diseases, (UNAID 2002; Costello et al. 2009; Watts et al. 2015); and iv) with more frequent water shortages also documented (Rohr et al. 2011). These impacts, in turn, are believed to have increased the number of environmental refugees in the Sahel (Myers 2001, 2002; Myers and Kent 2001; Epule et al. 2015). Climate change may also present opportunities, including increasing food production through better water management, irrigation, rainwater harvesting (Giannini et al. 2008), and potential increased crop productivity due to increased aerial fertilization by carbon dioxide (Prince et al. 1998).

Adaptation is essential to reduce the damages and take advantage of new opportunities in-light of the rapid climate change already occurring and expected future impacts (Ford et al. 2007; Verchot et al. 2007; Mertz et al. 2009; Ford and Pearce 2010; Pearce et al. 2011; Lesnikowski et al. 2013; Berrang-Ford et al. 2014; Ford et al. 2014; Lesnikowski et al. 2016). Stakeholders on Sahel environment and climate change (governments, indigenous people, farmers, non-governmental organizations, donor organizations, the African Development Bank, the World Bank, and United Nations Environment Program etc.) have not been passive in the face of the climate stresses that affect this region. Their response to the climate stresses has been through several policies, programs, and adaptations. Examples of such actions at the global scale include the United Nations Reductions of Emissions from Deforestation and Forest Degradations (REDD+) which provides financial incentives to farmers in the Sahel for planting trees (Epule et al. 2014; UNREDD+ 2015), and adaptation funding programs established under the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations 2015) 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 (African

Climate Change Fund 2016). In spite of the increasing importance of climate change adaptations and related stresses, it is unclear which shocks and adaptation actions have gained prominence over time and in which parts of the Sahel? This compromises our ability to identify and characterize key gaps in the adaptation response, examine how adaptations taking place compare to the risks posed by climate change, and monitor future developments.

This paper responds to this gap in understanding, and identifies and characterizes the state of climate change adaptation in the Sahel, documenting how adaptation as a response to climate change has evolved over time and explore to role of climatic and non-climatic drivers in triggering adaptation actions. We use reporting on adaptation in the peer reviewed literature as a proxy of adaptation, underscoring that our work provides a general and baseline overview of adaptation in the region. The work contributes to an important gap in the literature, with most studies examining the state of adaptation focusing on developed nations (e.g. Ford et al. 2011; Austin et al 2015; Lesnikowski et al. 2016), or focused on other regions of Africa (e.g. Lwasa, 2015; Tucker et al., 2015). This study is particularly timely because, to our knowledge, no studies focusing on the Sahel develop a holistic baseline on the status of adaptation across all Sahel countries and sub regions, with research primary focusing on particular nations or regions with in nations. Moreover, the Sahel remains a region of recurrent climate change stressors (droughts, floods and winds) (Agnew and Chappell, 1999; Mamadou et al. 2015; Karam et al. 2008) that calls for adaptation actions to enhance resilience, further underpinning the need for studies to document and examine the current state of action on adaptation.

2. The Sahel

The Sahel represents 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 (Anyamba and Tucker 2005). The area is located between latitude 10° and 20° north and stretches some 5000 km from northern Senegal in the west, through southern Mauritania, central Mali, northern Burkina Faso, south-western Niger, northern Nigeria, central Chad, north of Cameroon, Central African Republic, central Sudan and southern Sudan, northern Eritrea, extreme north of Ethiopia, to Somalia in the east and to the south east of the Sahel into Kenya (Fig 1). The extreme south of Algeria that is also part of the northern Sahel is not included in this study because of insufficient data and the fact that it is found out of the west-east gradient used in this study. The vegetation type is dominated by open Acacia shrubs and grassland, with the region representing a transition between the desert and the more humid savannah to the south. The word Sahel is derived from an Arabic word meaning the "edge" or "fringe" or "shore" (Nicholson 1995; Lu and Delworth 2005 2005). In terms of rainfall, the Sahel experiences declines with increase in latitude. At the southern border of the Sahel, about 450-500 mm of rainfall are recorded yearly while towards higher latitudes less than 200 mm of rainfall are recorded yearly (Zeng 2003; Wang et al. 2005). Between 1930 and 1965 and 1966 and 2000, the Sahel recorded about 100 mm of rainfall per year (Maranz 2009). The rainfall pattern in the Sahel is tied to the migration of the Inter-tropical Convergence Zone (ITCZ) (Sinclair and Fryxell 1985; Zeng 2003).

The Sahel was selected for this systematic review because, to our knowledge, no detailed review on the status of climate change adaptation in the Sahel has been carried out before. In addition, the region has a growing population that is exerting pressure on environmental resources such as food and water resources which are increasingly becoming less and less accessible in the Sahel. This is seen as the Sahel ecosystem is one of the most fragile on the African continent facing recurrent droughts, declining precipitation, acute food insecurity, HIV-AIDS inter alia.

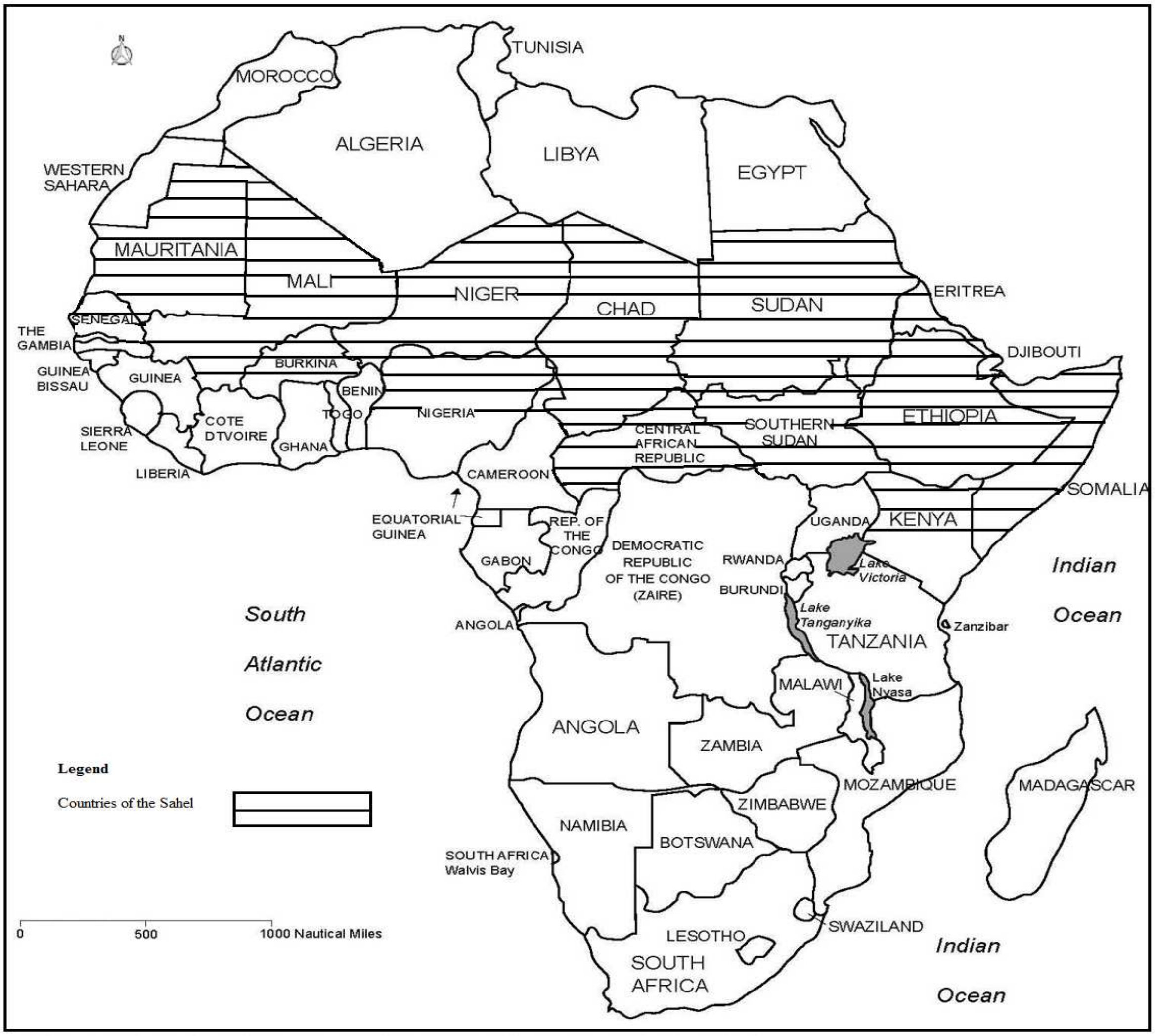

Fig.1. Location of the various countries in the Sahel.

3. Methods

3.1 Systematic adaptation tracking approach

The systematic review approach had long been established in the health sciences but neglected in climate sciences. This approach is a summary and assessment of the state of knowledge on a given topic or research question structured to rigorously summarize existing knowledge. Systematic reviews are different from traditional literature reviews in a number of ways (Ford and Pearce

2010; Berrang-Ford et al., 2015). Firstly, the review is based on clearly formulated questions, secondly, the approach specifies systematic and explicit methods and criteria to select relevant research, furthermore, the approach includes full reporting of search terms and the criteria for inclusion and exclusion of articles. The latter contrast with literature reviews common in climate change research which typically do not provide details on the review procedure used (e.g. the search engines, articles included, and excluded and the search terms used). In the absence of such details, it is difficult to replicate, validate interpretation and assess completeness. Lastly, the systematic approach easily subjects the collected data to the use of qualitative and quantitative analysis of trends, meta-analysis and percentages revealed by the literature.

This current study is based on data collected from English peer review scientific literature documenting climate change adaptation actions between 1975 and 2015, drawing upon established systematic literature review approaches used in environmental change research (Berrang-Ford et al. 2015). While we note the limitations of only using English peer reviewed literature and underscore our work as developing a general outline of adaptation in the region, such literature has nevertheless been used in other adaptation tracking studies and has established quality control mechanisms (Ford et al. 2011; McLeman 2011; Ford et al. 2014; McLeman et al. 2014; Berrang-Ford et al. 2015; Lopez-i-Gelats et al. 2016).

We sought to capture papers that document intentional adaptation actions, where adaptation is defined based on the IPCC’s AR4 definition of planned adaptation as the “result of deliberate policy decisions based on awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve a desired state’’ (IPCC 2007; Araos et al. 2015, 2016). Inclusion and exclusion criteria for selecting relevant articles in the peer reviewed literature are listed in Table 1.

Table 1: Summary of inclusion and exclusion criteria used in the systematic review

Inclusion criteria	Exclusion criteria
1. *Based only on primary peer review literature*	1. *All grey literature*
2. *Papers published between 1975 and 2015*	2. *All papers published before 1975*
3. *Papers published in English*	3. *Papers in all other languages*
4. *Papers dwelling on real or concrete adaptations*	4. *Recommendations, forecasts, theoretical and conceptual*
5. *Dwelling on the Sahel*	5. *Dwelling on other parts of Africa*
6. *Technical, indigenous, & socio-economic adaptations*	6. *Adaptive capacity, sensitivity, exposure and paleo-adaptations*

Articles were acquired through the following search engines: Scientific Citation Index (SCI) database, ISI Web of Science and Google Scholar. These search engines have been used in other studies cataloguing adaptation actions, and captures the main search engines typically used in literature reviews. We used the following search terms: *global climate change adaptation, climate change adaptation in Africa*, *climate change adaptations/coping actions in the Sahel and searches based on the specific country names*.

In the case of climate change adaptation, a total of 317 possibly relevant publications were selected from the initial search. However, duplicates were deleted after importing the articles into EndNote and a total of 250 papers were retained. A visual inspection of the titles of the remaining articles resulted in removal of more irrelevant papers. The abstracts of the remaining 111 papers were read in relation to the inclusion criteria. From this, 81 papers were retained for full review and during the full review process, 11 papers that were found not to meet the inclusion criteria were deleted. Seventy articles were retained for full analysis.

We also conducted 'ground truthing' whereby we focused on three Sahel nations and searched for relevant grey literature profiling adaptation actions, and did a more detailed search of the peer reviewed literature to see if we were missing any relevant studies. Ground truthing was performed in google scholar, SCI database and ISI web of science on the following countries: Mali (West African Sahel), Chad (central African Sahel) and Ethiopia (East African Sahel). The search terms used included: *climate change adaptation/coping in Mali or Chad or Ethiopia*. This process resulted in no new relevant peer reviewed studies for all the three sites and between 3 to 5 not-peer reviewed grey literature reports mostly on blogs per country.

3.2 Data analysis

All the discrete climate change adaptation actions were sub-categorized according to a coding system based on the following adaptation tracking framework sub-categories or questions: What is (are) the: *Name of lead author? Year of publication? Title of publication? Name of journal? Lead author's affiliation (academic, government, NGO, Intergovernmental, civil society and unknown)? Lead author's country of affiliation? Climate change adaptation action(s) presented? Location of the climate change adaptation intervention? Year of occurrence of the climate change adaptation? Decade between 1975 and 2015 with the highest number of adaptation actions? Role of climatic vs non-climatic drivers of adaptation actions?* (See supplementary materials S2). The coding scheme is similar to procedures used by (Labbe et al. 2017; Lesnikowski et al. 2013; Berrang-Ford et al. 2014; Austin et al. 2015; Ford et al. 2015; Araos et al. 2015, 2016). Multiple adaptations from the same publication were also considered, coded and included in this study. It is for this reason that the 70 articles resulted in 414 discrete climate change adaptation actions. The quantitative and qualitative data obtained were aggregated and analyzed to identify general trends. Once these data were obtained, descriptive statistics (frequencies and percentages) were used to establish a pool of studies and their reported adaptation actions that track the status of climate change adaptations in the Sahel between 1975 and 2015 while figures and tables were drawn in excel. All computations were done in SPSS version 22 while Arc Map 10 was used to cartographically represent the study sites. To further process the information obtained from the systematic adaptation tracking process, the percentages were evaluated on an adaptation scale ranging from low to high as follows: 0 to 25 % represents a low; 26 to 55 % represents a moderate; 56 to 100 % represents a high. It is important to note that the 414 adaptation actions recorded are not applicable to the climatic and non-climatic components of this study which were based on multiple responses as several studies reported more than one climatic and non-climatic driver of adaptation.

Furthermore, all the 414 adaptation actions were analyzed and grouped into four broad categories (Fig 7). The categorization process involved a process in which adaptation actions with similar characteristics were grouped into categories. These include: i) the technically related adaptations which are defined as adaptation actions anchored on technology or science. These are often used by communities but often have their origins from the scientific community and external stakeholders. They include inter alia: climate monitoring, climate forecasting, soil conservation, water harnessing, use of high yielding drought tolerant varieties and changes in planting dates (Fig. 2). ii) The indigenous problem solving adaptations which are defined as adaptation actions emanating from the local communities themselves and anchored on indigenous knowledge. Examples here include, preservation and storage, migration, fallowing, destocking and dietary changes (Fig. 2). iii) Socially related adaptation actions are defined as adaptations that have social underpinnings or social safety nets and includes examples such as help from kin, spirituality or prayers, investing in kids' education and giving up kids (Fig. 2). while iv) economically related adaptation actions are adaptation actions anchored on economic and financial safety nets that are used to adapt to climate change. Examples here include remittances, access to credits, savings and sale of cattle for grain (Fig. 2).

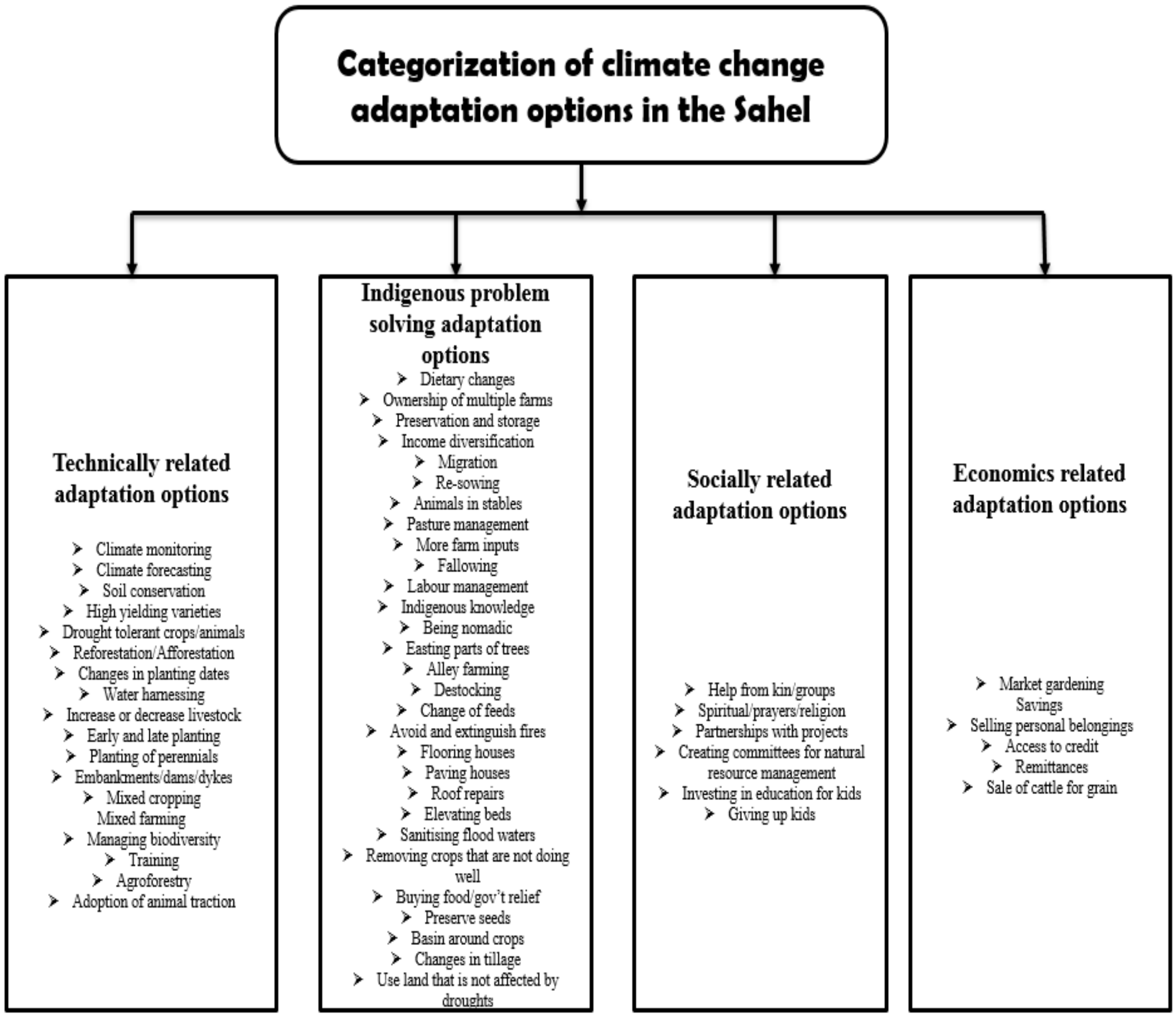

Fig 2. The four categories of climate change adaptation actions in the Sahel.

4. Results

4.1 In what regions and countries are adaptations occurring the most?

A total of 414 adaptation actions were reported in 70 peer review journal articles (See Supplementary Materials 2). An analysis of the articles shows that in the Sahel and based on the available peer review literature, Kenya recorded the highest number of adaptations based on frequency and percentage (n = 75, 18.1%) between 1975 and 2015, followed closely by Senegal (n = 65, 15.7%) (Fig 3). While these countries dominate the region in terms of frequencies and percentages, they however, have percentages belonging to the low range scale. Overall it can be said the level of adaptation is low as judged from the frequencies and percentages.

From a regional perspective, West African Sahel recorded the highest frequency and percentage (n = 261 or 63%). The second is East Africa with a total of (n =127 or 30.6%) frequency and percentage respectively (Fig 4). Again, it can be said that when the adaptation actions are high, the adaptive capacity is also higher. As such, West Africa has a higher adaptive capacity than the other regions and its percentage of 63% falls within the 56 to 100 scale range which represents a high level of adaptation within the Sahel. East Africa had a percentage of 30.6% which falls within the 26 to 55 scale range which also means the region is moderately adapted to climate change.

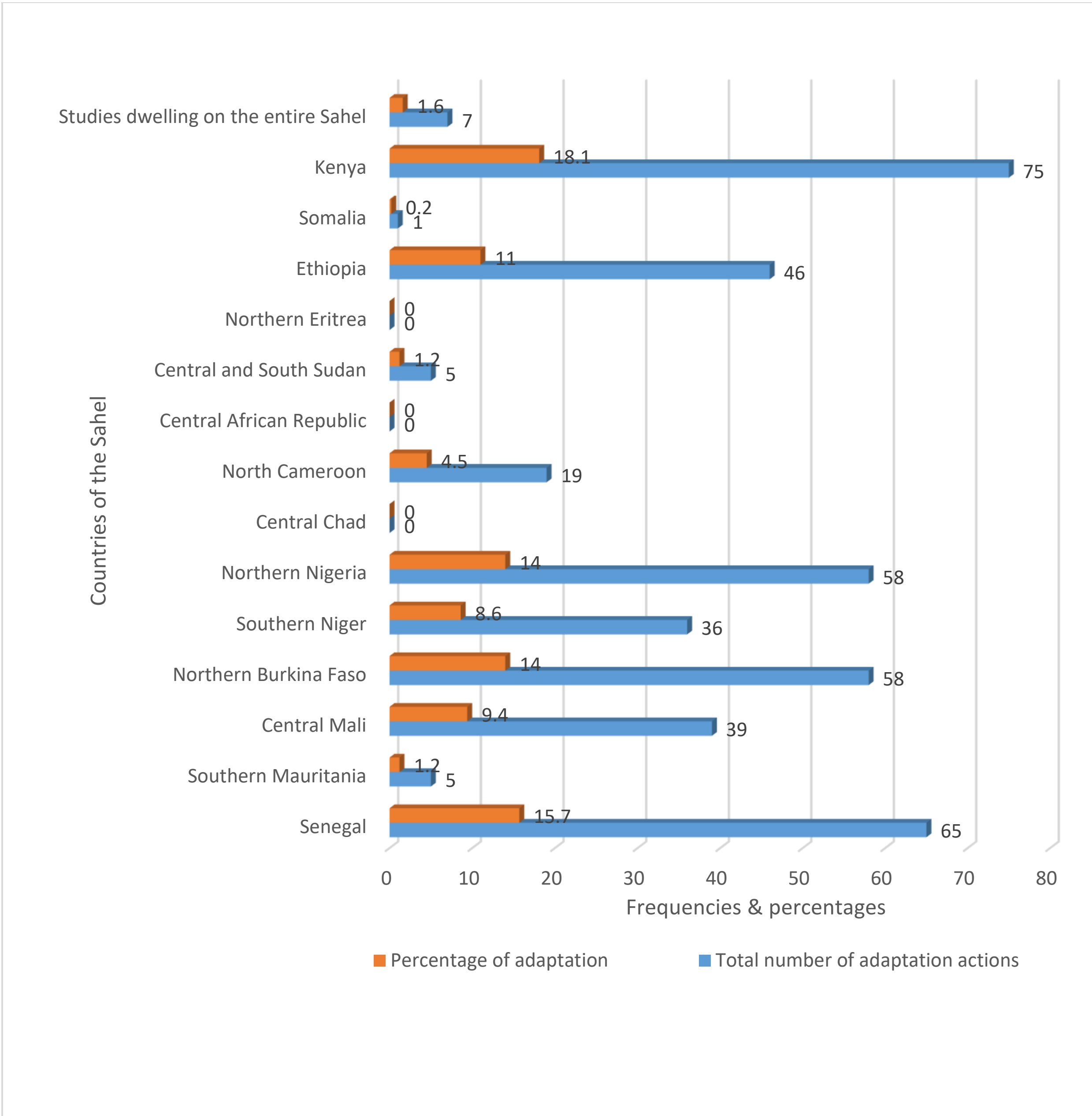

Fig 3. Number of adaptation options and calculated percentage reported in the peer review literature published between 1975 and 2015 for various Sahel countries.

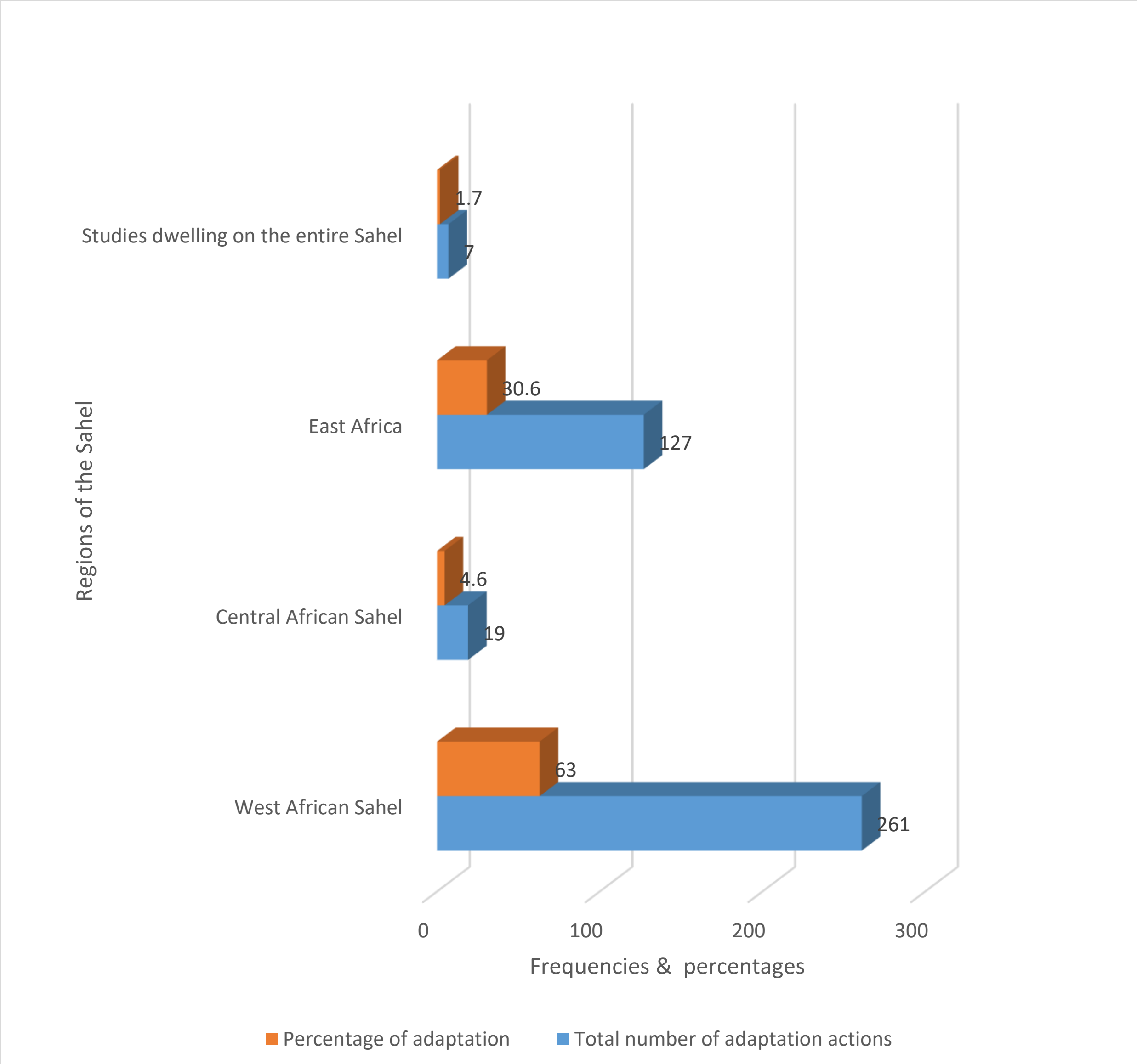

Fig 4. Number of adaptation options and calculated percentage reported in the peer review literature published between 1975 and 2015 for various regions of the Sahel.

4.2 Which are the most commonly used specific adaptations actions in the Sahel

Income diversification related adaptation actions were most frequently documented (n = 53, 12.8%), followed by water harnessing (n = 48, 11.5%), soil conservation (n = 27, 6.5%), farm inputs (n = 26, 6.2%) and planting high yielding varieties (n = 23, 5.5%) (Fig 5, Table 2 & Table S1). It can be gathered that emphasis is placed on alternative employment actions or on providing water management options that can counter the effects of recurrent water shortages in the Sahel. It is observed that Kenya and Senegal have the highest frequencies in terms of cumulative number of adaptation actions (Appendix 1), however, when you consider what obtains in all the Sahelian countries running up from Kenya in the bottom to Senegal in the top, income diversification stands out as the most frequently used adaptation action.

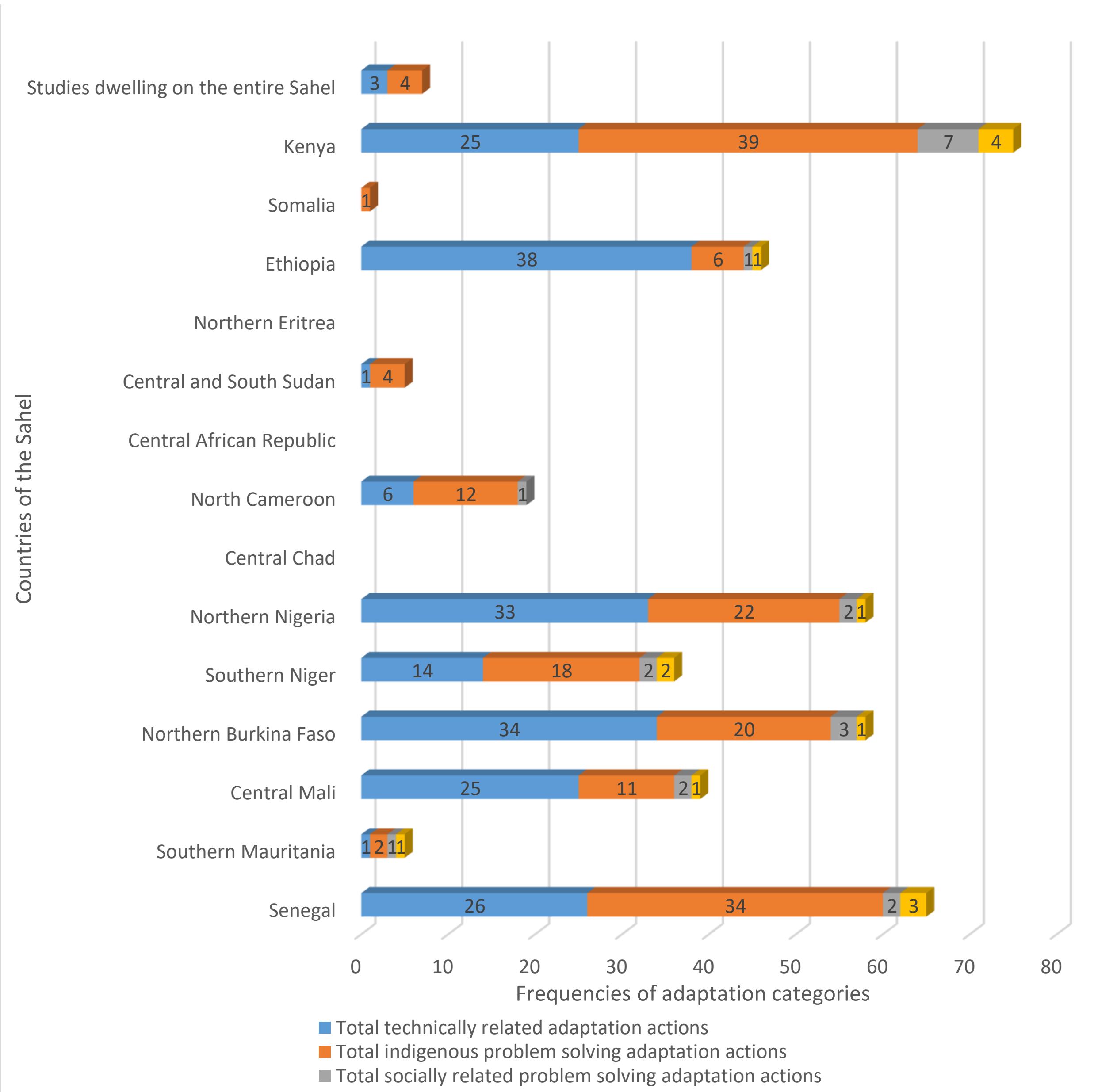

Fig 5. Composite distribution of categorised number of adaptations options reported in the peer review literature published between 1975 and 2015 for various countries of the Sahel.

Table 2: Examples of five most used adaptation actions in the Sahel

Adaptation options	References
Income diversification actions	
Off farm employment	*Fleuret 1986; Mertz et al. 2009; Elmqvist and Olsson 2006; Morand et al. 2012*
Working for development projects	*Nielsen and Reenberg 2010; Moretime 2010*
Small-scale commerce	*Nielsen and Reenberg 2010*
Non-farm income	*Mertz et al. 2011; Readon et al. 1988; Burham and Ma 2016*
Selling of personal belongings	*Schaer 2014; Brockhaus et al. 2013; Opondo 2013*
Supplemental occupation	*Epule et al. 2016; Opiyo et al. 2015*
Hunting	*Mosberg and Eriksen 2015*
Water Harnessing	
Rain water harvesting	*Bryan et al. 2009; Zampaligre et al. 2014; Barbier et al. 2009*
Irrigation	*Bryan et al. 2009; Deressa et al. 2009; Fleuret 1986*
Water management	*Rockstrom 2003; Douxchamps et al. 2016; Burham and Ma 2016*
Boreholes	*Mbow et al. 2008*
Construction of dams and drainage systems	*Magistro and Lo 2001*
Use of water pumps	*Schaer 2014*
Use of green and blue water	*Recha et al. 2016*
Soil conservation	
Mulching	*Burham and Ma 2016*
Change in tillage and rotation	*Bryan et al. 2009*
Half-moon and stone dykes	*Zampaligre et al. 2014*
Planting shade trees	*Burham and Ma 2016; Deressa et al. 2009; Bryan et al. 2009*
Fallowing	*Gebrehiwot and Van der Veen 2013; Nyong et al. 2007*
Soil erosion control/stabilization dunes	*Okoye 1998; Brockhaus et al. 2013; Burham and Ma 2016*
Farm inputs	
Manure	*Mertz et al. 2009; Marenya and Barrett 2007; Wood et al. 2014*
Fertilizers	*Mertz et al. 2009; Mertz et al. 2011; Croppenstedt et al.2003*
Inorganic fertilizers	*Marenya and Barrett 2007; Wubeneh and Sander 2006*
Adoption of compost	*Somda et al. 2002*
Organic fertilizers	*Epule et al. 2016*

High yielding crops and animals	
High yielding crop varieties	*Bryan et al. 2009; Deressa et al. 2009; Fleuret 1986*
Improved varieties of potatoes	*Thuo et al. 2011;Burham and Ma 2016; Abebe et al. 2013*
Improved varieties of sorghum	*Adesina and Baidu-Forson 1995*
Improved varieties of maize	*De Grootr et al. 2013*
High biomass variety of maize	*De Grootr et al. 2013*
Improved animal husbandry	*Zander et al. 2013*

4.3 Which are the most commonly used broad adaptation categories in the Sahel?

To verify the general direction of adaptation actions within the Sahel, broad categories of adaptation actions were categorized. In this study, four key categories were identified and all the adaptation actions fall into one of these categories. The first category is captioned: i) technically related adaptation actions; the next is captioned: ii) indigenous problem solving adaptation actions. We also carved out: iii) socially related adaptation actions and iv) economics related adaptation actions (Fig 5).

In terms of frequencies, the technically related adaptation actions recorded the highest of (n = 206 or 49%) (Table 3 & Table S2) while the others in order of importance and their frequencies were as follows: Indigenous problem solving adaptations (n = 173, 41.7%) (Table 3 & Table S3), socially related adaptation actions (n = 21, 5%) (Table 3 & Table S4) and economics related adaptation actions (n = 14, 3.3%) (Table 3 & Table S5). To further support these, it can be observed that though the technically related adaptation actions have the highest rates of usage, a country like Kenya which has the highest number of total adaptations tilts away from the general direction as the indigenous problem solving adaptation actions had a higher frequency of (n = 39, 9.4%); the same applies to Senegal in which indigenous problem solving adaptation actions had a frequency of (n = 34, 8.2%). However, when we add up all the frequencies for the latter category, it still does not outbid the former (Fig 5). From a regional perspective, the West African Sahel does not only have a higher number of adaptation actions but also records the highest tallies for all the categories with technically based adaptation actions at the fore (n = 133, 32.1%). East Africa is next with technically based adaptation actions at the fore (n = 64, 15.4%) as well. It can therefore be argued that, as said before, just as most of the adaptation actions have been recorded in West Africa, categorized technically based adaptation actions are also consistent with this conclusion as they seem to be highest in West African Sahel (Fig 6).

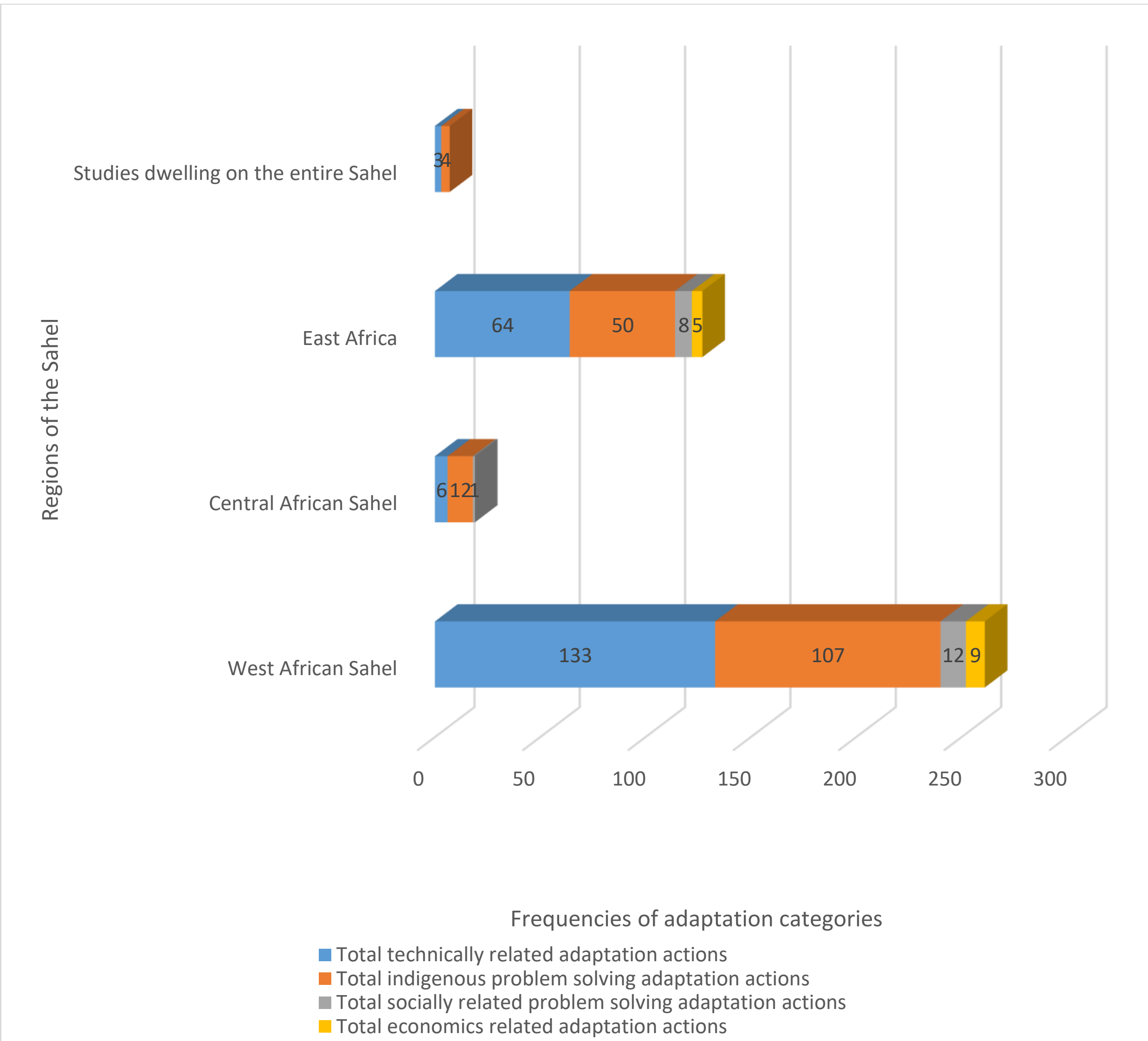

Fig 6. Composite distribution of categorised number of adaptations options reported in the peer review literature published between 1975 and 2015 for various regions of the Sahel.

Table 3: Examples of the four categories of adaptation actions

Adaptation categories	References
Technically related adaptation options	
Water Harnessing	*Zampaligre et al. 2014; Barbier et al. 2009; Recha et al. 2016*
Soil conservation	*Burham and Ma 2016; Deressa et al. 2009; Bryan et al. 2009*
Climate monitoring	*Boyd et al. 2013; Huq et al. 2004; Reenberg 1994*
Early harvesting	*Tambo and Abdoulaye 2013; Burham and Ma 2016; Deressa et al. 2009*
Mixed farming	*Moretimore and Adams 2001*
Indigenous problem solving adaptation options	
Income diversification	*Schaer 2014; Brockhaus et al. 2013; Opondo 2013*
Migration/relocation	*Zampaligre et al. 2014; Scheffran et al. 2012; Burham and Ma 2016*
Farm inputs	*Marenya and Barrett 2007; Wubeneh and Sander 2006*
Pasture management	*Brockhaus et al. 2013; Burham and Ma 2016; Mertz et al. 2009*
Buying food/gov't relief	*Epule et al. 2016; Oluoko-Odingo 2011*
Socially related problem solving options	
Help from kin/social organizations	*Mortimore 2010; Epule et al. 2016; Oluoko-Odingo 2011; Fleuret 1986*
Spiritual/prayers/religion	*Fleuret 1986; Mertz et al. 2011; Burham and Ma 2016*
Partnership between local people and development project	*Nielsen et al. 2012*
Creating local committees for natural resources management	*Brockhaus et al. 2013*
Investing in education of kids	*Opondo 2013*
Economics related adaptation options	
Market gardening	*Mertz et al. 2011; Mertz et al. 2009; Nielsen and Reenberg 2010*
Savings	*Schaer 2014*
Selling of personal belongings	*Schaer 2014*
Access to credits	*Ebi et al. 2011*
Remittances	*Fleuret 1986*

4.4 Which decade records the highest number of adaptation actions and what are the main drivers of adaptation in the Sahel?

During the decade 2008-2016 the highest number of adaptation actions of (n = 270, 65.2%) were recorded in the primary peer review literature in the Sahel. The other decades recorded adaptation actions as follows: 1997- 2007: (n = 58, 14%); 1986-1996: (n = 29, 7%); 1975-1985: (n = 57, 13.7%). If we add up these frequencies, we obtain 414 which is consistent with the total number of adaptations reported in this study (Fig 7a). The overwhelming observation here is that there has been a systematic increase in the number of adaptation actions reported over time. In terms of drivers, most of the studies tilted towards climatic drivers as the fundamental triggers behind adaptations; this category recorded (n = 406, 98%) while non-climatic drivers recorded (n = 395, 95%). These frequencies when combined are more than 414 because some studies reported both climatic and non-climatic adaptations (Fig 7b). Even though the climatic drivers seem to dominate, there is an increasing attribution of the problem to non-climatic drivers as in an increase in the number of studies that attribute the response efforts to non-climate drivers. Examples of climatic drivers of adaptation cited are: rainfall decline, rainfall increase, temperature increase, temperature decline, sea surface temperature increase, trade winds, El Niño, increase solar radiation, atmospheric circulation and the prevalence of winds like the equatorial westerlies. Some examples of non-climatic drivers of adaptation cited include: land use change, agriculture, population growth, settlements, poor urban planning, pastoralism and cattle rearing, over exploitation of resources, grazing of animals, deforestation and land degradation, wild fires, insects, economic fluctuations and socio-political.

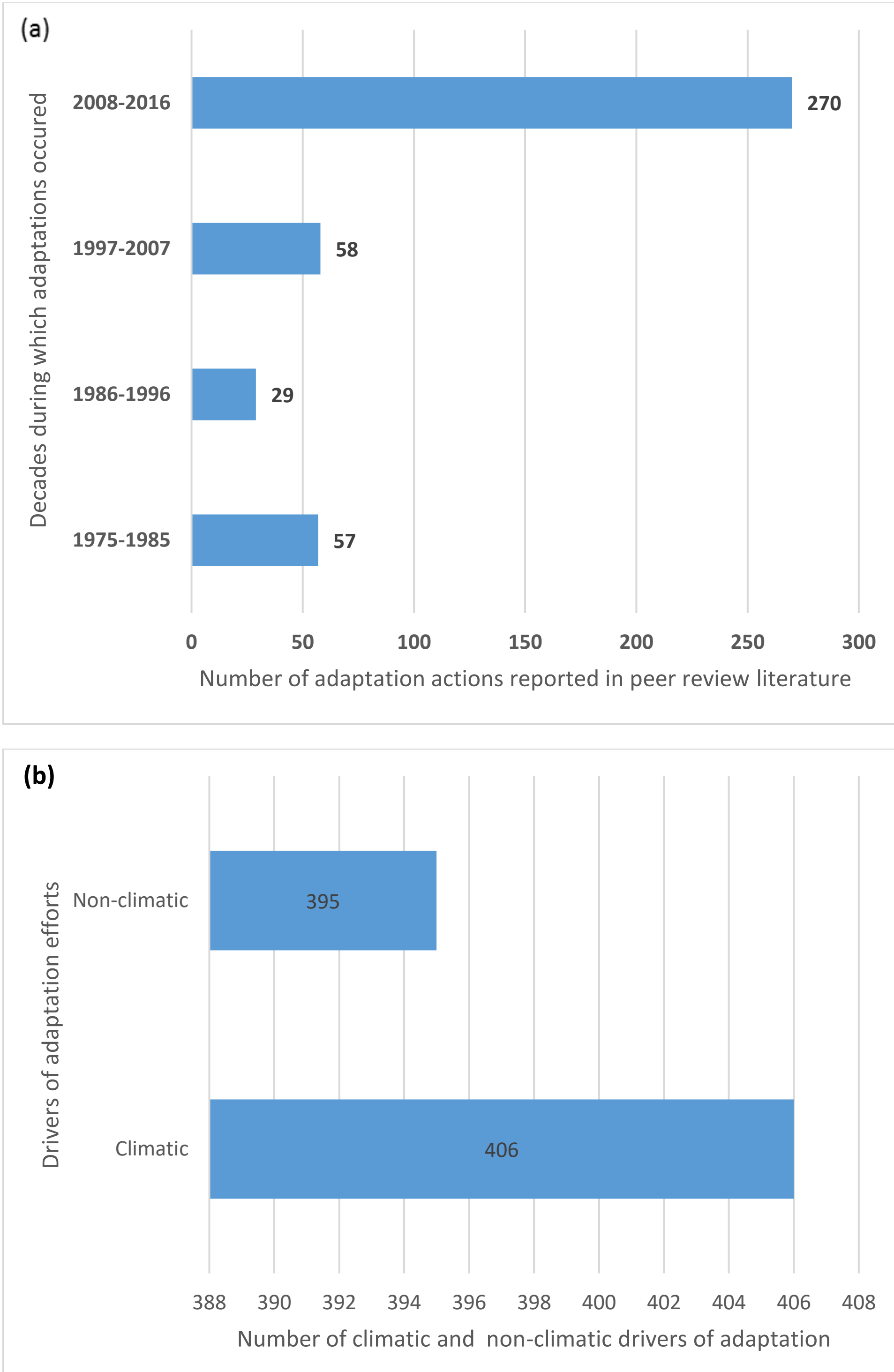

Fig 7. (a): Number of adaptation options reported in the peer review literature published between 1975 and 2016 in the Sahel. (b): Number of climatic and non-climatic drivers of adaptation efforts in the Sahel. Total frequencies more than 414 because some publications report more both climatic and non-climatic drivers.

Some adaptation actions have gained importance over time. Income diversification which is the most used discrete adaptation option recorded its highest usage of 21 during the decade 2008-2016; it also recorded 18 during the decade 1985-1996. Water harnessing related options were most important during the decade 1985-1996 during which they recorded a frequency of 27; during the decade 2008-2016, it recorded 15. Soil conservation related options recorded their highest usage during the decade 1985-1996 while migration had 8 during the 2008-2016 decade. High yielding varieties recorded a frequency of 13 uses during the 2008-2016 decade. Generally, during the 1975-1985 decade, there were two most used adaptation actions with usage frequencies of 6 each, these are, *income diversification* and *migrations* while help from kin and network related options were second (Fig. 8). During the decade 1985-1996 the most used adaptation actions was *water harnessing* related options which recorded a frequency of 27; soil conservation was second with a frequency of 19 while income diversification was third with a frequency of 18 (Fig. 8). During the decade 1997-2007, *income diversification* was highest with a frequency of 8 while more farm inputs came second with a frequency of 6, migration recorded a frequency of 3 (Fig. 8). During the decade 2008-2016, *income diversification* was 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 (Fig. 8).

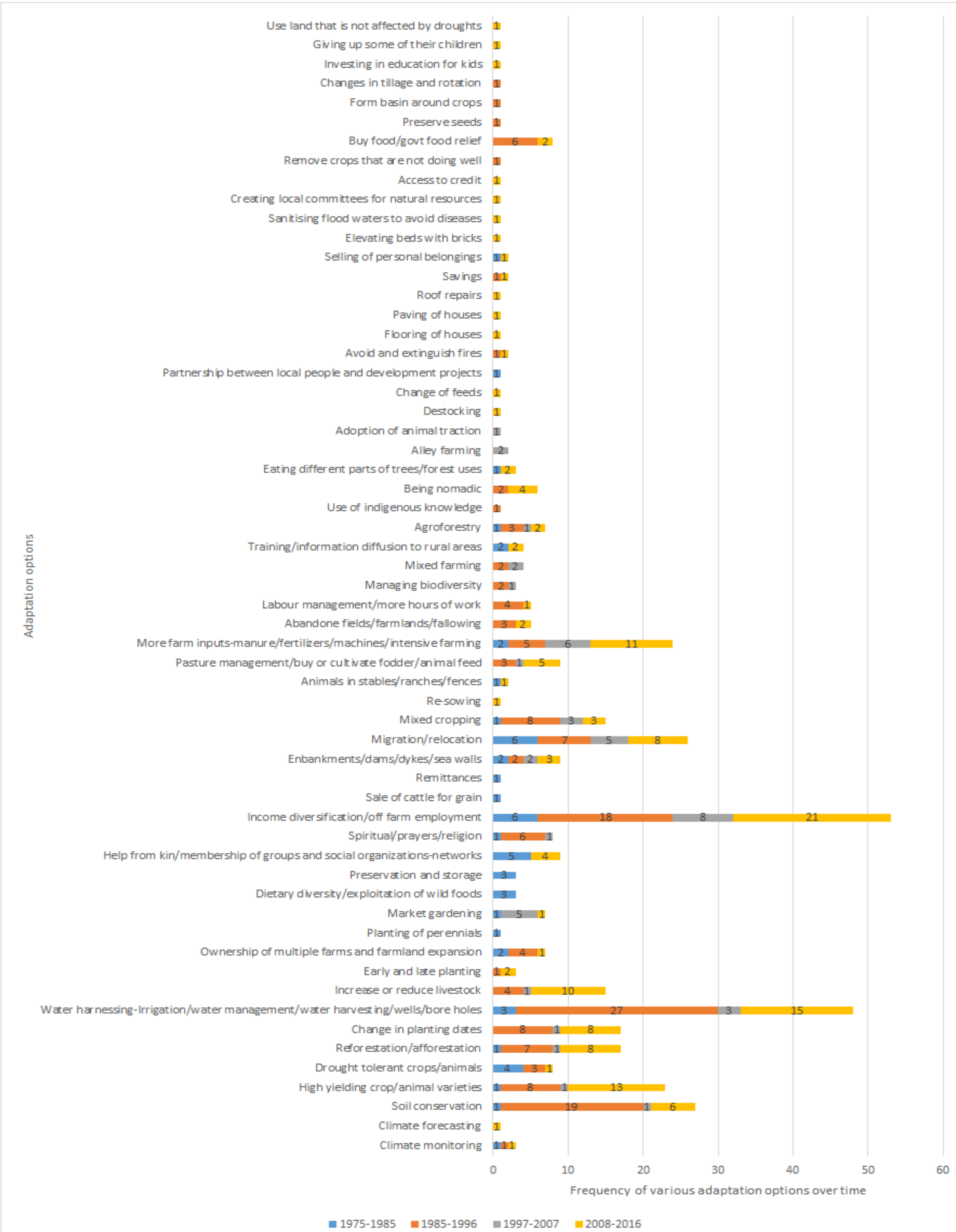

Fig 8. Composite distribution of variations in different adaptation options reported in the peer review literature published over time for various countries of the Sahel.

5. 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 (Noble and Huq 2014; Ford et al. 2015). In spite of the agreement that climate change adaptation is of great importance in responding to climate change, a lot of divergence still exist among stakeholders with reference to what really constitutes climate change adaptation (Dupuis and Biesbroek 2013; Berrang-Ford 2014). This study develops an understanding of the spatial variations and properties of climate change adaptation in the Sahel. This approach used is similar to the action based approach used by Ford et al. (2013, 2014) in reporting real climate change adaptation actions in the arctic. The systematic review approach employed in this study enables comparison between regions and enhances the identification of general patterns of change in climate change adaptation over time (Mannke 2011; Ford et al. 2013, 2014). It is however, important to note that the patterns reported by this study should be considered as proxies because many adaptation actions are under-represented by the peer review literature; our work should thus be considered baseline. These results are therefore simply indications of general patterns and policy formulation should be based on more detailed and specific country level information. Additionally, several adaptation actions in the Sahel might have taken place outside the range presented by this study (1975-2015). As a result of this limitation, we consider this study as a proxy of adaptations that are currently in effect in the Sahel. However, the 40 years covered by the timeframe used still goes a long way in making these results valid as it provides enough time to track and consider the changes in climate.

The decade 1975-1985 recorded a total of (n = 57, 13.7%) of adaptation initiatives. While the 1985-1996 decade recorded far lesser adaptation initiatives (n = 29, 7%), it can be argued that the relatively higher adaptation initiatives recorded during the 1975-1985 decade are linked to the fact that this period witnessed what has been described as the most ravaging droughts in the history of the Sahel (Anyamba and Tucker 2005; Maranz 2009). As such, governments and other stakeholders made a lot of efforts to enhance adaptations (Zeng, 2003; Epule et al. 2013a). By 1985, the droughts that ravaged the Sahel had reduced and so too did the number of adaptation initiatives reduce due to ‘adaptation fatigue’ of the previous decade. The adaptation efforts of the 1970s and early 1980s (water management, irrigation, planting of trees) are already yielding fruits as there are increasing reports of increase rainfall and greening in the Sahel as shown by normalized difference vegetation index (NDVI) (Anyamba and Eastman 1996; Eklundh and Olsson 2003; Giannini et al. 2008, Nielson and Reenberg 2010; Nielson et al. 2012). However, Prince et al. (1998) argue that the increase greening could be as a result of the increase aerial fertilization effect of carbon dioxide. In general, the subsequent decades witnessed an increase in the number of adaptation initiatives over time from (n = 58, 14%) during the decade 1997-2007 to (n = 270, 65.2%) during the decade 2008-2016. It may be a difficult task trying to argue that the state of climate change adaptation in the Sahel can be mainly assessed from the adaptation initiatives reported in the peer review literature, still, the fact that the 70 peer review papers have reported only 414 adaptation initiatives supports the argument that the Sahel remains highly vulnerable as adaptive capacities remain low and much more reporting through scientific research needs to be carried out. This is supported by the low percentages for most of the countries of the Sahel which generally are found within the low range scale of between 0-25 percent.

From a regional perspective, there is a variation across the Sahel as West African Sahel seems to dominate the tallies in terms of recorded adaptation initiatives. However, when we consider individual countries, Kenya in East African Sahel records the highest number of adaptation initiatives of (n = 75, 18.1%). In a related study carried out by Ford et al. (2015), covering the period 2006-2012, Kenya (n = 34) was equally reported to be at the top of countries reporting the highest adaptation actions from a group of African and Asian countries. However, the fact that from a regional perspective West African Sahel recorded the highest number of adaptation initiatives could be linked to the fact that the region is closer to the desertification belt of the Sahel and the “Great Green Wall of the Sahara and the Sahel initiative” (GGWSSI). The Pan African Agency for the GGWSSI is overseeing the planting of a broad band of trees from Senegal in West Africa to Djibouti in east Africa. The GGW of Africa was initially proposed in the 1980s and aims at reducing desertification and droughts through the planting of trees with promising results already being obtained in countries like Senegal (O’Connor and Ford, 2014).

Also, the result that the most commonly used adaptation option in the entire Sahel as reported in the peer review literature is income diversification (n = 53, 12.8%) seems to be consistent with previous studies that argues that to absorb the shocks of climate change and environmental protection, many communities in Africa resort to income diversification (Le et al. 2012; Epule et al. 2013b). The second most reported option is water harnessing related options (n = 48, 11.5%); this is also important as the Sahel is a zone facing recurrent droughts and water stress all year round and its populations tend to work towards adaptations that can absorb the water deficit shocks through water management and harnessing. However, when we categorize the adaptation actions, the technically related adaptation actions turn to be dominant (n = 206, 49%). This heralds the argument that technically based adaptation actions that require a scientific backing are more reported in the Sahel than other options. This could further be linked to the increasing importance of climate stressors which have attracted many stakeholders and increased the interest of these stakeholders in the region. Response from high level stakeholders from the research community to technical field experts is often in the form of technically based adaptation actions such as drought resistant species, rainwater harvesting and high yielding varieties. This does not, however, mean that other non-technical adaptations are of little importance. For example, adaptation actions grounded in indigenous knowledge or skills that communities have acquired over time as a result of extensive experience still remains valid though currently given little consideration in the adaptation scholarship.

From a policy perspective, it can be said that though this study is more of a proxy of the state of adaptation, the policy formulation process is enhanced as all stakeholders might become aware of the fact that diversification of livelihood and water harnessing actions are more rampant in the study sites. This provides opportunities to further enhance these dominant options and to leverage those that are not frequently reported. The result that technically based adaptation actions are more frequently cited shows further that policies that enhance both technically based actions and other less cited actions should be put in place. The overall policy implication here is that a single adaptation action cannot enhance resilience completely, several actions need to be used and maybe, the 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.

Furthermore, the overwhelming majority of the studies reviewed here have shown that a majority of the adaptations are driven by climate change (n = 406, 98%) while non-climatic drivers contribute (n = 395, 95%). The approach of verifying the shocks to which people are reported to be adapting to goes a long way to provide further information with respect to whether climate or non-climatic variables tend to trigger adaptations. As such, non-climatic drivers are getting increasingly important because there are often many cases when adaptations are not just taken to adapt to climate change but also in response to other issues such as poverty, health, literacy, financial disparities and socio-cultural disparities which can either enhance or reduce adaptive capacity (Dupuis and Biesbroek 2013; Ford et al. 2015). There is currently evidence across Africa and the Sahel that shows that most of the problems that Africa and the Sahel are facing ranging from food insecurity, pandemics and epidemics and poverty 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 (Giannini et al. 2003, 2005, 2008; Reynolds et al. 2007; Lu and Delworth 2005). With this, policy makers and all stakeholders will increasingly have to leverage resources towards non-climatic drivers which for a long time have been ignored in favor of climatic drivers.

The results presented in this study are consistent and also vary with some other similar studies in terms of results and methodological perspectives. Firstly the study by Ford et al. (2015) verified the status of climate change adaptation in Africa and Asia. This study is consistent with our study in that it used the systematic review approach, its results show that there is an increase in the number of reported adaptation actions across Africa and Ethiopia is presented as the country with the highest number of adaptation initiatives. When the Sahel is compared with other vulnerable regions such as the Arctic, there are more reports of adaptation actions in the Sahel. For example, Ford et al. (2014), reported about 157 adaptation actions between 2003 and 2013 while this current study reports 414 adaptation actions for the Sahel for the period 1975-2015. However, this should be interpreted with caution as the reference period for the Sahel is longer. However, the major areas of differences are that, the Ford et al. (2015) study is based on both peer review and grey literature while this current study 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 2015. Another paper by Berrang-Ford et al. (2011)

comes close to this study because it used the systematic approach and focused on the peer review literature only. The results from the latter are also consistent to ours in that they report that considerable research has been done with a greater focus on intentions than ground work and that non-climatic drivers are increasingly being presented as the motivations for climate change adaptation. However, the latter study departs from this current study as it reviewed papers submitted between 2008 and 2012 and it is more of a global perspective to climate change adaptation. Lwasa (2015) also looks at climate change adaptations policy and practice across Africa and Asia and in the context of deltas, based on both grey literature and peer review papers published from 2006. From these papers, this current study is unique because it uses mainly peer review papers published between 1975 and 2015 and dwells on the Sahel.

6. Conclusion

This study verifies the status of climate change adaptation in the Sahel based on peer review literature. The results show that in the Sahel, Kenya is the country with the most reported cases of adaptations. Regionally, West Africa cumulatively dominates the adaptation chart as it has a higher frequency and percentage. The country level percentages are within the range scale called low indicating that the Sahel still has much to be done in terms of climate change adaptation. The adaptation reporting approach used in this paper offers a proxy or indicator approach against which the status of climate change adaptations in the Sahel can be inventoried. This therefore provides a baseline from which changes can be monitored over time and space. With this, various stakeholders need to verify and characterize strategies and measures to reduce the effects of climate change and thus provide means for assessing the effectiveness of adaptation actions. This is particularly urgent as the results from this study show that at country level adaptations to climate change are still at infancy as most of the countries have percentages that are described as low, though regional disparities exist.

Being that there is still much that is unknown about climate change adaptation in Africa, moving forward, there are areas of research that need to be given attention. The first is a systematic review study on the entire African continent using both peer review and grey literature covering the 1970s to present. This will help provide a regional picture of the state of climatic change adaptations across Africa from both a country by country and a regional perspective. An understanding of where most of the adaptation actions are being reported should also be perfected (whether it is in the peer review or grey literature?). Secondly, a lot of attention is being focused on climate change adaptation across Africa using the systematic review; the climate shocks such as winds, droughts and floods that are driving adaptations need to be given attention and verified. It is still unclear how these shocks are spatially and temporally distributed in the Sahel and across Africa, a major knowledge gap to be filled. Furthermore, more studies that cover both actions and groundwork in the context of adaptations reported in the peer review and grey literature need to be carried out. This will help throw more light on the disparities between adaptation plans in the context of ground work and real or concrete actions.

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