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Climate change stressors in the Sahel

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Abstract The Sahel is prone to climate stressors such as droughts, winds and floods. This study employs a systematic review approach to track the frequency with which these stressors are reported in the scientific peer reviewed literature, examining publishing trends to identify which stressors are most reported, documenting the spatial distribution of these stressors from a country and regional perspective, and assessing the role played by climatic and non-climatic drivers in causing the stressors. A total of (n = 388) reports of stressors were documented in (n = 164) peer reviewed articles. From a country perspective, Southern Niger records the highest number of reports on all three stressors (15.97%), followed by Ethiopia (11.85%) and Senegal (10.56%). Regionally, West African Sahel recorded the highest number of reports on all stressors (49.97%) followed by East African Sahel (29.89%) and Central African Sahel (12.11%) respectively. Droughts are observed to be the most frequently reported stressor (n = 219), followed by floods (n = 123) and winds (n = 46). The decade 1975–1985 recorded the highest reports of stressors (n = 207), while the decade 1997–2007 recorded (n = 80) and the decade 1986–1996 recorded (n = 52). While climatic drivers are dominant (52%), there is however an increasing attribution of the drivers of the stressors to non-climatic drivers (47%). The main weakness of this study is that it uses peer reviewed papers dwelling on climate stressors as a proxy for climate stressors in the Sahel and a lot more studies could be hiding in non-peer reviewed studies, underscoring that this work provides a general and baseline overview of the climate stressors in the region.

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Introduction

Climate change cannot be left out of the development and environmental protection debates in Africa because ecosystems respond to climate change and climate change determines the pace of African development (Giannini et al. 2003, 2008; Reynolds et al. 2007). The influence of climate change in Africa south of the Sahara is even more evident, and in the last three and a half decades, the region has witnessed temperatures increasing in the range of 0.2–2.0 °C and declining precipitation (IPCC 2007). However, the decadal projections of temperature increase right up to 2100 cumulatively exceed the 2.0 °C recorded in the last 35 years. This has been substantiated by the fifth assessment report (AR5) of the IPCC which shows that on a decadal basis, mean temperatures are likely to increase by 1.8 °C by 2020, by about 1.9 °C by 2030, by about 1.8 °C by 2040, by about 1.7 °C by 2050 and by about 1.2 °C by 2100 (IPCC 2013). The repercussions of the above variations in temperature and precipitation have been increase vulnerability of agricultural systems, increase poverty and low adaptive capacity and increase in climate stressors (Epule et al. 2014a, b). In spite the importance of climate in the region, non-climatic drivers such as agricultural expansion, deforestation, occasioned by rapid population growth have tilted the debate on which of climatic or non-climatic drivers drives the stressors more into also considering the role of some of these non-climatic drivers in shaping development and environmental protection in Africa (Giannini et al. 2008).

Three main climate stressors (droughts, floods and winds) are dominant across Africa and the Sahel (Agnew and Warren 1996; Agnew and Chappell 1999; Vanmaercke et al. 2010; Epule et al. 2014a, b; Mamadou et al. 2015; Karam et al. 2008; Hastenrath et al. 2009). The Sahel is well known for its droughts and as a result, the region is one of the most susceptible to droughts globally (Prospero and Nees 1976; Sivakumar and Wallace 1991; Tarhule 2005). The causes of these droughts are either human related (human induced climate change) or climatically driven (sea surface temperature, effects of vegetation, CO_2 emissions and land degradation, and dust feed backs) (Epule et al. 2014a, b). Although hydrological droughts are recurrent in the Sahel, there are reports across the region of increasing discharge of major rivers; for example, the Niger River has experienced an increase in discharge of its main tributaries since the 1970s, an unexpected observation that has been referred to as the "Sahel paradox" (Albergel 1987; Lu and Delworth 2005; Mertz et al. 2009; Lopez-I-Gelats et al. 2016; Amogu et al. 2010). In the Sahel, airborne dust is important in impacting the climate system as the uncertainties associated with Sahel airborne dust and climate are no longer tenable (IPCC 2007). The Sahel is also noted as the world's number one source of wind related mineral dust, with satellite sensors documenting that Sahelian dust is not only widespread globally but is also the most persistent and dense on planet earth (Anuforom 2007; Karam et al. 2008). Most of the dust outbreaks recorded around the world are often linked to Sahelian dust and are associated to dust exports from the Sahara during winter due to strong Harmattan winds and the penetration of an upper level trough in the low latitudes (Jankowiak and Tanre 1992; Alpert and Ganor 1993; Tengberg 1995).

Various stakeholders on Sahel environmental change and protection (governments, indigenous peoples, 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 these climate stressors that affect the Sahel region. Their response has been through policies, programs, and adaptations designed to reduce vulnerability and increase resilience (Tall et al. 2012; Lwasa 2015; Epule et al. 2015). 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 and other stakeholders in the Sahel for planting and preserving trees (Dixon et al. 2010; Drees et al. 1993; Eklundh and Olsson 2003; Mulitza et al. 2010; Epule et al. 2017a, b; Epule et al. 2014a, b; UNREDD+ 2015). The United Nations Framework Convention on Climate Change (UNFCCC) (United Nations 2015) also supports research and the improvement of adaptive capacity in developing countries and at the regional level, the African Development Bank (AFDB) is now masterminding the African Climate Change Fund which has as mandate to increase the access of African countries to international climate finance (African Climate Change Fund 2016) and the Pan African Agency for the "Great Green Wall (GGW)" 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 (O'Connor and Ford 2014).

Despite the abundance of scholarship documenting these stressors and their drivers, a comprehensive understanding of the most reported stressors in the scientific peer reviewed literature, their spatial distribution, location of authors, years of occurrence and the relative contributions of climatic and no-climatic drivers in causing these stressors is lacking. For example, it is unclear which stressors have gained prominence over time in terms of the number of times they have been studied and which parts of the Sahel are more covered? This reduces the ability to identify and characterize key gaps in understanding stressors, examine the relationship between the stressors and adaptations options, and monitor future developments. In this systematic review article, we respond to this gap in understanding, by identifying and characterizing the most reported climate stressors in the Sahel, their spatial distribution from both a country-level and a regional perspective across the West African Sahel (WAS), Central African Sahel (CAS) and East African Sahel (EAS), the location of the authors, the distribution of these stressors between 1975 and 2016, and the most reported causes of these stressors. This study uses reports on climate stressors in the peer reviewed literature as a proxy of the number of times the different stressors have been reported, underscoring that this work provides a general and baseline overview of the climate stressors in the region.

Methodology

The Sahel

The semiarid strip of land that is located between the tropical rainforest in the south and the arid north of Africa is called the Sahel, which is derived from an Arabic word meaning the "edge" or "fringe" or "shore" (Nicholson 1981, 1983, 1985; Lu and Delworth 2005; Anyamba and Tucker 2005). It covers an area of about 3.053×10^3 km^2 with a current population of more than 90 million people. Population projections in the Sahel affirm that by 2020 the region will have a population of about 100 million and a population of about 200 million people by 2050 (IRIN 2017). The Sahel is located between latitude 10° and 20° north and stretches along more than 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). In the Sahel, there is a decrease in precipitation with increasing latitude. Near the southern borders of the Sahel about 450–500 mm of precipitation are recorded annually, with a steady decline in precipitation northwards to about 200 mm annually at the northern fringes of the Sahel (Wang et al. 2005). However, between 1930–1965 and 1966–2000, the Sahel recorded on average about 100 mm of precipitation per year (Maranz 2009). The precipitation pattern in the Sahel is tied to the migration of the Inter-tropical Convergence Zone (ITCZ) (Sinclair and Fryxell 1985). 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.

Systematic stressors tracking approach

The systematic stressors tracking approach developed here is designed to provide a synopsis of the state of knowledge on climate stressors in the Sahel. The approach differs from an ordinary literature review in a number of ways, including a focus on well-defined questions, the specification of inclusion criteria used in selecting the papers to be examined, and documentation of key words used. This is in contrast with traditional literature reviews commonly used in climate change research which typically do not provide details on the review procedure used (e.g. the search engines used, articles included, and excluded and the search terms used) (Ford and Pearce 2010). In the absence of such details, it is difficult to replicate, validate interpretation and assess completeness of a study.

In this study, we focus on data collected from English peer reviewed scientific literature documenting climate stressors in the Sahel between 1975 and 2016, drawing upon the established systematic literature review approaches used in previous environmental change studies (Nicholson 1995, 2001, 2013, 2014; Nicholson et al. 1998; Berrang-Ford et al. 2015). While focusing only on English language peer reviewed literature is limiting as more information may be found in the grey literature, we underscore our work as presenting a

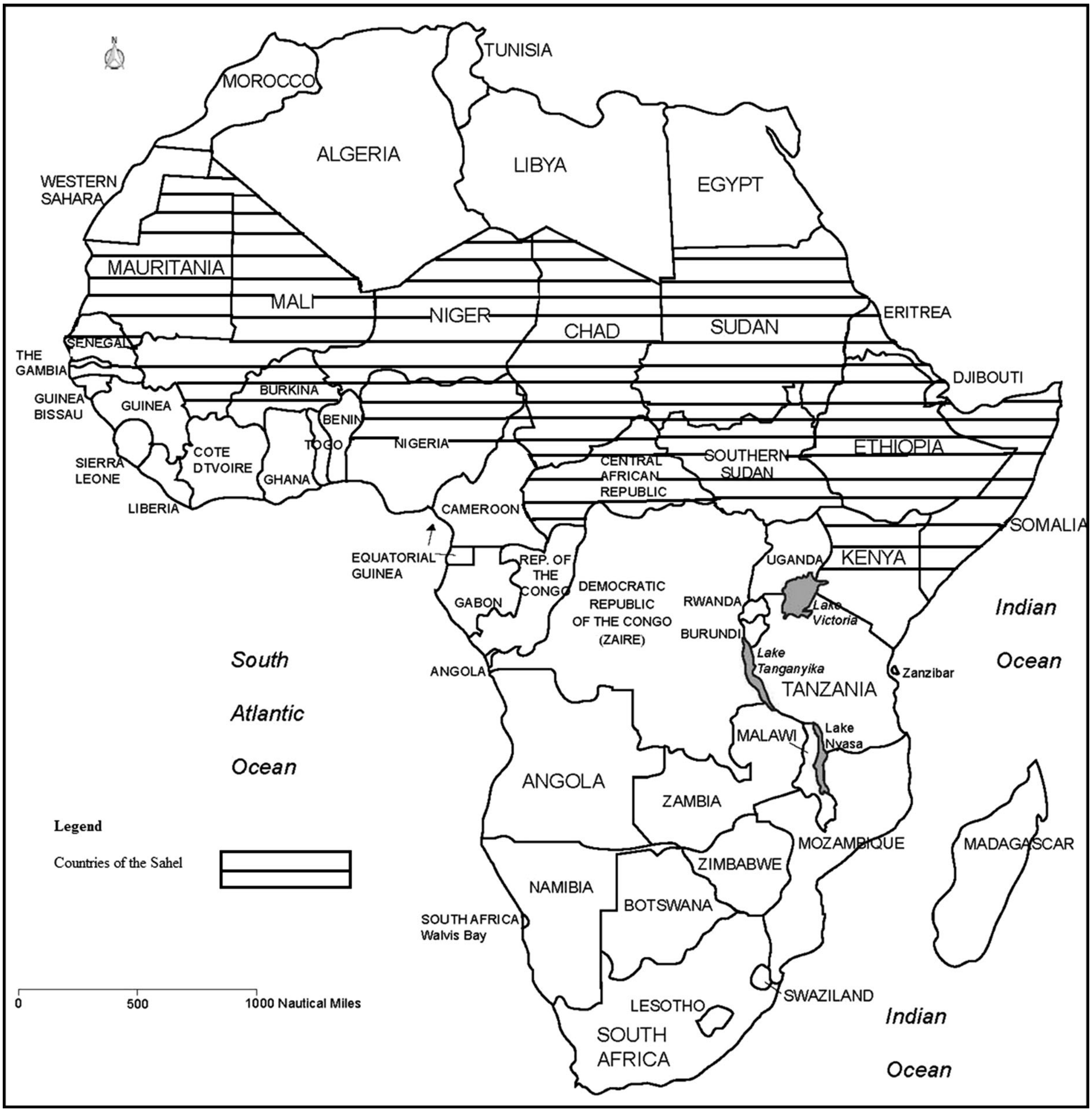

Fig. 1 Countries of the Sahel included in this study

general outline of climate stressors in the Sahel, with a focus on peer reviewed articles introducing an element of quality control, with the search procedures consistent with other work in the field (Tschakert et al. 2010; Ford et al. 2011, 2014; McLeman 2011; McLeman et al. 2014; Berrang-Ford et al. 2015). This study aims at capturing studies that document climate stressors, where stressors include: droughts, floods and winds. In the context of the Sahel, we define droughts as periods of moisture/precipitation deficit below the minimum moisture threshold over a specific duration (Epule et al. 2014a); floods are periods of moisture/precipitation surplus above the maximum moisture/precipitation threshold over a specific duration (Hitchcock and Hussein 1987; Ozga-Zielinska 1989; Rung and Nguimalet 2005; Reynolds et al. 2007); winds are high speed air in motion towards a specific direction that transport huge amounts of dust and are caused by uneven heating of the earth's surface by the sun. The inclusion and exclusion criteria for selecting relevant articles in the peer reviewed literature are listed in Table 1.

The articles documented in this study were obtained through the following search engines: Scientific Citation Index (SCI) database, ISI Web of Science, and Google Scholar. The search terms used to obtain the papers included: *climate change and stressors or shocks, climate change and stressors or shocks in Africa*, *climate change and stressors or shocks in the Sahel and searches based on the specific country names*.

A total of 412 papers were selected from the initial search. When duplicates were removed a total of 214 papers were retained. After a visual inspection of the titles of the remaining articles, more irrelevant articles were removed. This was followed by reading the abstracts of the remaining 202 articles in relation to the inclusion criteria. From this, 192 papers were retained for full review and during the full review process, 28 papers that were found not to meet the inclusion criteria were excluded, with 164 papers retained for full analysis.

To verify the extent to which our study captures the state of scholarship in the fields of climate stressors, we also conducted 'ground truthing' whereby we focused on three Sahel nations and searched for both peer reviewed and important grey literature profiling climate stressors in the Sahel. This enabled us verify if we have missed any relevant studies that might alter our results in major standard deviations. Ground truthing was performed in google scholar, SCI database, and ISI web of science on the following countries: Niger (WAS), Cameroon (CAS) and Ethiopia (EAS). The search terms used included: *climate change stressors/shocks in Niger or Cameroon or Ethiopia*. Ground truthing resulted in no new relevant peer reviewed studies for all the three sites and between 3 and 5 not-peer reviewed grey literature reports.

Data analysis

We developed a coding system based on some climate stressors tracking framework sub-categories that served as a guide in culling the information from each paper as follows: what is (are) the: *Name of the 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 stressor(s)/shock(s) presented? Location (country) where the climate change stressor(s)/shock(s) occurred? Year of occurrence of the climate change stressor(s)/shock(s)? Decade between 1975 and 2016 with the highest number of climate stressor(s)/shock(s)? Are the stressor(s)/shock(s) caused by climatic or non-climatic variables?* (see supplementary materials 1). This scheme is similar to procedures used by similar studies such as Ozga-Zielinska (1989), Lesnikowski et al. (2013), Berrang-Ford et al. (2014), Austin et al. (2015), Pierre et al. (2015), Ford et al. (2015), Araos et al. (2015, 2016), and Labbe et al. (2017). Studies that reported multiple stressors were coded and included. It is for this reason that the 164 papers resulted in 388 reports of climate stressors. The data obtained were aggregated and analyzed to identify general trends. Once these data were obtained, frequencies and percentages were used to establish a pool of studies and their reported climate stressors that track the status of climate stressors in the Sahel between 1975 and 2016. All computations were done in SPSS version 22 while Arc Map 10 was used to cartographically represent the study sites.

Table 1 Inclusion and exclusion criteria used in the systematic review

Inclusion criteria	Exclusion criteria
1. Peer reviewed literature	1. All grey literature
2. Papers published between 1975 and 2016	2. All papers published before 1975
3. Papers published in English	3. Papers in all other languages
4. Papers focusing on droughts, floods and winds	4. Forecasts and projections, theoretical and conceptual
5. Sahel focused	5. Non-Sahel focus

Results

In what countries and regions are there more reports of climate stressors and where are the authors located?

A total of 388 climate stressors (droughts, floods and winds) were documented in 164 different peer reviewed papers (see supplementary material 1). The results show further that in terms of countries, Southern Niger recorded the highest frequency and percentage of reports (n = 62, 15.97%) between 1975 and 2016. This is followed by Ethiopia (n = 46, 11.85%), Senegal (n = 41, 10.56%) and Kenya (n = 33, 8.5%) (Fig. 2). Regionally, WAS recorded the highest frequency and percentage of climate stressors (n = 193, 49.97%). This is followed by EAS with (n = 116, 29.89%) and CAS with (n = 47, 12.11%). Larger scale studies not focused on any single country but rather on the entire Sahel recorded (n = 32, 8.24%) (Fig. 3).

In terms of authorship, this study has found that of the 164 peer reviewed papers, 55 are affiliated in the USA, 19 in France, 17 in the UK and 10 in Germany. With the exception of the USA, France, the UK Germany are countries that had huge colonial influence across Africa. In terms of authorship from Africa, Nigeria has 9 authors followed by Ethiopia with 6 authors, and Niger and Cameroon with 4 authors. There is therefore increasing evidence that much of the research on climate stressors in the Sahel is carried out mostly by researchers with affiliations out of Africa (supplementary material 2: Fig. S1).

Which are the most frequently reported climate stressors in the Sahel

Three main climate stressors are identified in the literature, these include droughts, floods and winds. Among these stressors, the most commonly reported stressors are droughts with a frequency of (n = 219) (Figs. 4, 5 and Table 2). The second and third are floods (n = 123) (Figs. 3, 5 and supplement 2: Table S1) and winds (n = 46) (Figs. 4, 5 and supplement 2: Table S2). It can be inferred that the Sahel is a zone of climatic extremes with droughts topping the chart during the dry periods and with floods taking over during periods of prolonged precipitation.

In terms of the distribution of these stressors in various countries, of the studies tracked here droughts were most commonly focused on in Kenya (n = 28), followed by Ethiopia (n = 26) and Niger (= 24). In terms of floods, Cameroon records the highest (n = 27), Niger (n = 24), and Ethiopia (n = 20). As concerns winds, Niger record the highest with (n = 14), Senegal with (n = 10) and Mali with (n = 5) (Fig. 4).

From a regional perspective, WAS recorded the highest number of droughts (n = 100). This is followed by EAS (n = 78), studies dwelling on the entire Sahel (n = 24) and CAS (n = 17). In terms of floods, WAS recorded the highest with (n = 56); this

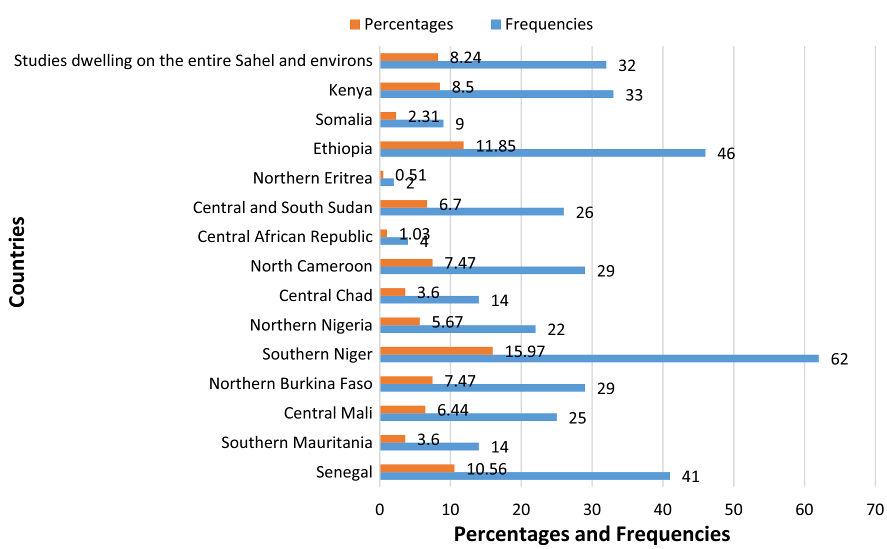

Fig. 2 Percentages and frequencies per country of reported/tracked climate stressors in the Sahel from 1975 to 2016

Fig. 3 Percentages and frequencies of reported/tracked climate stressors in various regions of the Sahel from 1975 to 2016

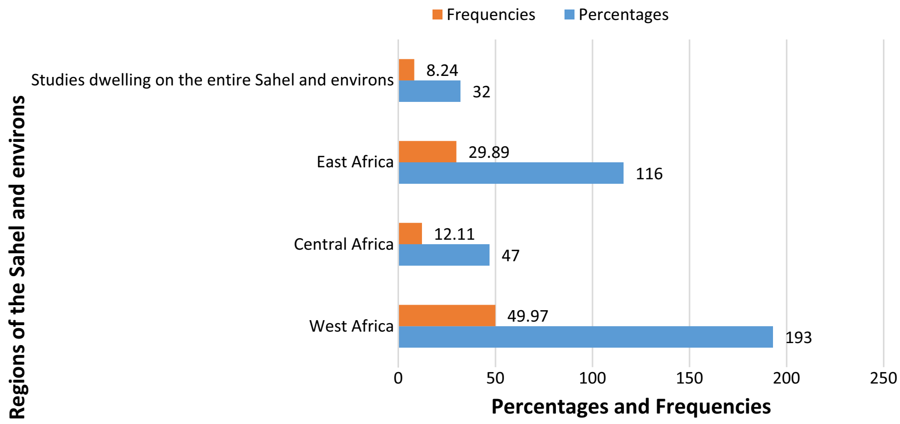

Fig. 4 Composite frequencies per country of reported/tracked climate stressors in the Sahel from 1975 to 2016

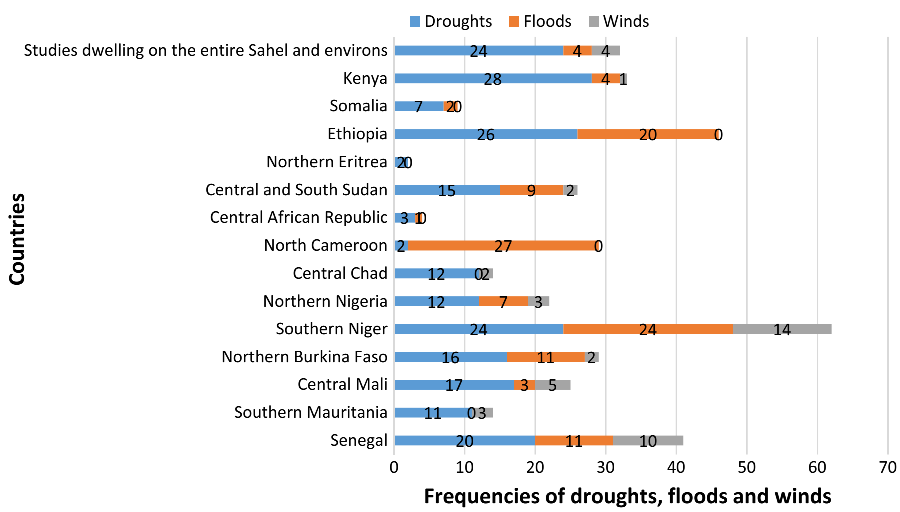

Fig. 5 Composite frequencies per region of reported/tracked climate stressors in the Sahel from 1975 to 2016

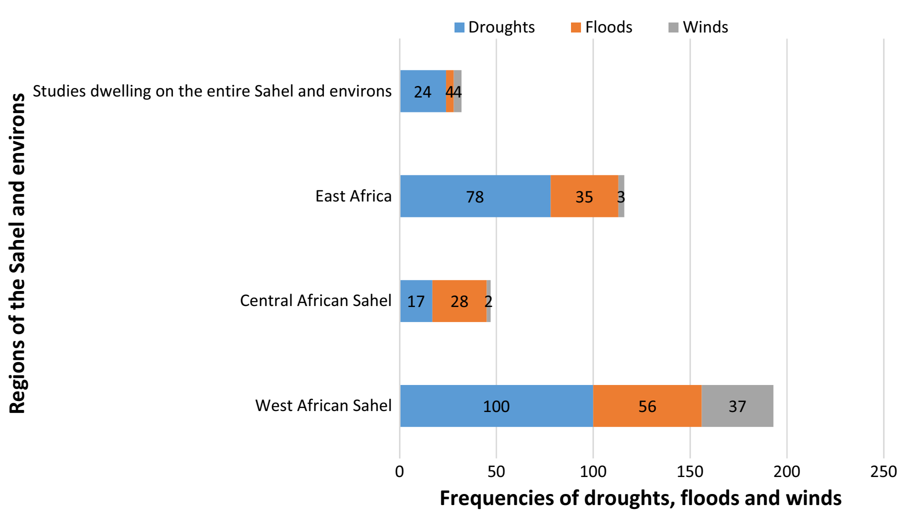

Table 2 Examples of Sahel countries with drought studies

Stressors	Examples of studies
Droughts: WAS	
Senegal	Faure and Gac (1985), Agnew and Warren (1996)
Niger	Boyd et al. (2013), Reenberg (1994)
Mali	Nicholson (1981), Nicholson et al. (1998), Hiernaux et al. (2009)
Burkina Faso	Nicholson (1985), Prospero and Nees (1976)
Mauritania	Le Houerou (1996), Nicholson (2013)
Northern Nigeria	Adefolalu (1986), Derrick (1977)
Droughts: EAS	
Somalia	Boyd et al. (2013), Hitchcock and Hussein (1987)
Ethiopia	Deressa et al. (2009), Turton and Turton (1984)
Kenya	Epule et al. (2014a, b), Nicholson (2014)
Eritrea	Huho et al. (2011), Keller (1992)
Sudan	Agnew and Warren (1996), Epule et al. (2015)
Droughts: CAS	
Central African Republique	Nicholson (1983), Epule et al. (2015)
Northern Cameroon	Nicholson (1983, 1985)
Chad	Nicholson (2013), Ozer et al. (2003)

WAS West African Sahel, *EAS* East African Sahel, *CAS* Central African Sahel

is followed by EAS with (n = 35) and CAS with (n = 28). In the case of winds, WAS recorded the most reports with a frequency of (n = 370), the entire Sahel with (n = 4) and East and CAS with (n = 3 and n = 2) respectively (Fig. 5).

Which decade records the highest number of studies on stressors and what are the main drivers of the stressors in the Sahel?

From a decadal perspective, the decade 1975–1985 recorded the highest number of reports of stressors with a frequency of (n = 207). This is followed by the decade 1997–2007 with (n = 80), the decade 1986–1996 with (n = 52) and the decade 2008–2016 with (n = 49) (Fig. 6a, b). The decade 1975–1985 recorded the highest number of droughts with a frequency of (n = 182). The highest number of floods and winds were recorded during the 1997–2007 decade with (n = 50 and n = 23) respectively (Fig. 6a, b). The overwhelming observation here is that there is a decrease in the number of papers that report on climate stressors over time. This is further substantiated by the frequency of drought reports which has reduced from 182 during the 1975–1985 decade to 9 during the 2008–2016 decade. Floods reports have increase from 12 in 1975–1985 to 39 during the 2008–2016 decade while winds are still irregular in terms of publications. So, we can say that studies on droughts have reduced over time while studies on floods have increase over time as revealed by the data; a type of inverse relationship between studies on droughts and studies on floods is observed (Fig. 6 and supplementary material 2: Fig. S2).

In terms of drivers, most of the studies tilted towards climatic drivers as the fundamental triggers behind the stressors; this category recorded (n = 341, 52%) while non-climatic drivers recorded (n = 314, 47%). These frequencies when combined (n = 655) are more than (n = 388) which is the total number of stressors reported because some studies reported both climatic and non-climatic adaptations (Fig. 7). The climatic drivers contribute to (n = 200) droughts, (n = 111) floods and (n = 30) winds while the non-climatic drivers contribute to (n = 176) droughts, (n = 102) floods and (n = 36) winds. It can be observed that climatic drivers contribute more to the occurrence of droughts and floods than non-climatic drivers with the exception of winds which are driven more by non-climatic drivers. Even though the

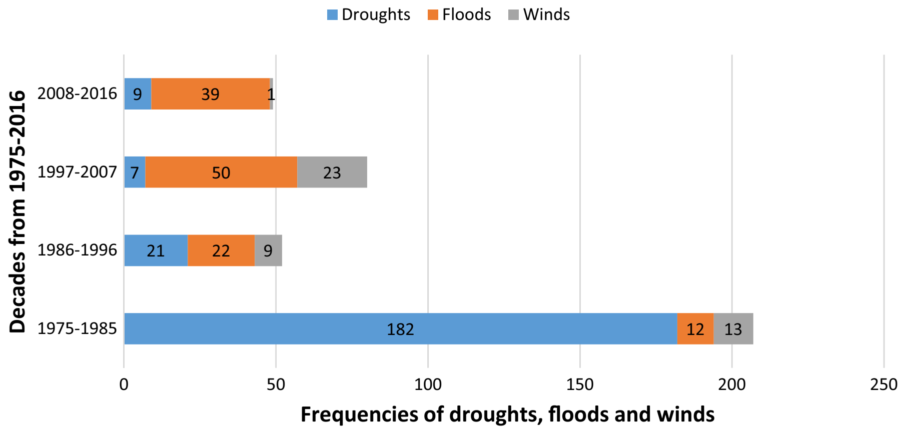

Fig. 6 Composite distribution of stressors per decade from 1975 to 2016 in the Sahel

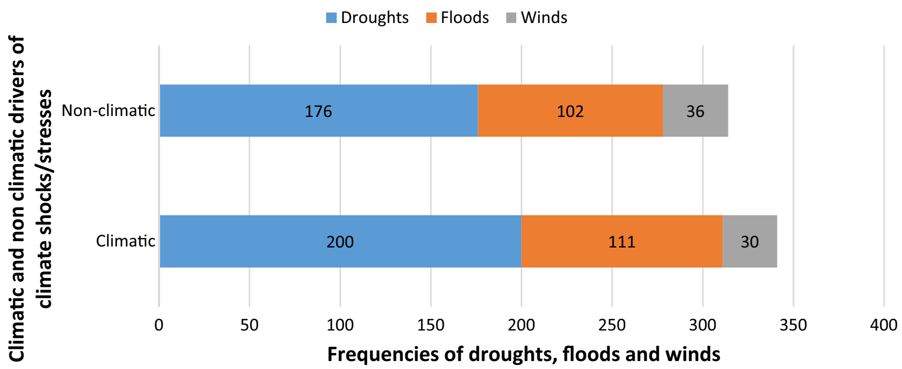

Fig. 7 Composite frequencies of reported/tracked climate stressor/shocks and their relationships with climatic and non-climatic variables

climatic drivers seem to dominate, there is an increasing attribution of the problem to non-climatic drivers as seen in an increase in the number of studies that attribute the response efforts to non-climate drivers.

Discussion and policy implications

This study examines from the peer reviewed literature the frequency with which climate stressors are reported, the decades with the most reported stressors and the role of climatic and non-climatic drivers in causing these stressors. The analysis on where the peer reviewed literature has been focused (1975–2016) in the context of climate stressors in the Sahel is important as this information provides policy experts with an understanding of the stressors that have dominated scientific research as well as the countries and regions which have been more frequent in the scientific literature over time. Such information is vital in land use planning and adaptation elaboration.

An understanding of what stressors researchers are focusing on, where these stressors have been prominent over time also provides a unique opportunity to design adaptations and land use policies to cope with the stressors based on more focused information on the specifications of a given region. For example, based on the results from this study, adaptations or land use policies to climate stressors in the Sahel have to prioritize droughts which are the most frequently reported stressors in the Sahel. This could be followed by flooding and winds respectively. Floods should be considered with care because over time the frequency with which they appear in reports has increased. So we can say that current adaptations and land use policies should also reinforce resilience to floods. However, from a cumulative stand point, droughts still remain the most frequently reported stressors during the time scale covered by this study. This type of information helps to set the right priorities and at the right time. The idea of basing land use policies or adaptations/coping options on the drivers of the problem which is similar to the approach proposed by this paper is also consistent to what is described as the systematic approach initially proposed by Muller et al. (2013) and Epule et al. (2014a, b) in which they identify the drivers of forest area loss in Bolivia and Cameroon respectively and use the identified drivers to propose land use policy options. Basing actions on the actual drivers provides room for accuracy and sustainability; this is a departure from the approach that is based on generalizations and the use of land use policies that have been used elsewhere and not focusing on the drivers of the problem. This current study therefore provides a snap-shot of the frequency with which climate stressors are reported, the location of the authors, where and when they occurred and the contributions of climatic and non-climatic drivers in causing the stressors. Such specific information can assist in making adaptation to be more focused and context specific.

Also, this study has found that Southern Niger and West African Sahel (WAS), are the country and region with the highest reports on climate stressors in general. However, Kenya records the highest number of reported droughts, Cameroon the highest number of reported floods and Niger the highest number of reported winds. This information enables researchers, decision makers and adaptation stakeholders to prioritize and focus their solutions on more specific problems and regions. We observe that most of the peer reviewed papers tracked in this study argue that both climatic and non-climatic drivers are responsible for the stressors. The climatic drivers are slightly dominant; in the past, much of the literature argued that most environmental problems were caused by climate change but this current study shows that the influence of non-climatic drivers is gaining prominence. There is concrete evidence in the scientific literature across Africa and the Sahel that shows that most of the problems that Africa and the Sahel are facing ranging from environmental degradation, loss in forests, food insecurity, pandemics and epidemics and poverty are mainly caused by non-climatic variables such as deforestation, population growth, wars and unsustainable methods of land tenure such as shifting cultivation and slash and burn cultivation inter alia with climate change only playing a reinforcing role (Adefolalu 1986; Birkett et al. 1999; Giannini et al. 2003, 2005, 2008; Mahé et al. 2011; Samimi et al. 2012; Lu and Delworth 2005; Reynolds et al. 2007; Billi et al. 2015; Kaly et al. 2015).

The finding that the decade 1975–1985 recorded the highest frequency in terms of the number of times peer reviewed papers focused on climate stressors seems to be consistent with most of the scientific literature. It has been argued that the relatively higher climate stressors recorded during the 1975–1985 decade are connected to the fact that this period witnessed what has been described as the most ravaging droughts in the Sahel (Keller 1992; Turton and Turton 1984; Anyamba and Tucker 2005; Maranz 2009). By 1985, the droughts that severely affected the Sahel had reduced because of wide scale adaptation efforts of the 1970s and early 1980s (water management, irrigation, planting of trees) which were already yielding fruits as there are increasing reports of increase rainfall and greening in the Sahel as illustrated by normalized difference vegetation index (NDVI) (Anyamba and Eastman 1996; Eklundh and Olsson 2003; Giannini et al. 2008; Deressa et al. 2009; Reenberg 1994; Nielsen and Reenberg 2010; Boyd et al. 2013; Nielsen et al. 2012). As such, it can be said that while the frequency of reports on droughts have reduced from 1975 to 2016, the frequency of reports on floods has rather increase during the same period. This inverse relationship is driven by increase adaptations during the 1970s and 1980s aimed at subverting droughts and a consequent reduction in droughts and a surge in other stressors; in this case floods (Nka et al. 2015).

This study is the first to use the systematic tracking approach to track the climate stressors in the Sahel. However, the systematic tracking approach has previously been used in tracking adaptations around the world and examples of studies that have done this include (Faure and Gac 1985; Le Houerou 1996; Ozer et al. 2003; Giannini et al. 2003, 2005, 2008; Ologunorisa and Adeyemo 2005; Moreno et al. 2006; Ford and Pearce 2010; Ford et al. 2011, 2014, 2015; McLeman 2011; Berrang-Ford et al. 2015; Nielsen and Reenberg 2010; Ochola et al. 2010; Nielsen et al. 2012; Noble and Huq 2014; Lwasa 2015; Fernandez et al. 2016). This current study therefore gives us an understanding of the areas where researchers have focused with respect to stressors over time. However, these should be considered as proxies since many stressors are often under-represented by the peer reviewed literature. As such, this work is a baseline and the results are simply reflections of the general patterns. In addition, many stressors might have occurred outside the time line covered by this study

(1975–2016). However, the close to 40 years over which peer reviewed papers were reviewed offers a time frame that is long enough to make these results to be of considerable importance to land use policy stakeholders.

This analysis constitutes a proxy based reflection of the country level and regional distribution of climate stressors in the Sahel. The study has been able to highlight which amongst droughts, floods and winds are more frequently reported in the peer reviewed literature and how they have evolved over time. It is observed that Southern Niger has the highest number of stressors from a country perspective while WAS has the highest number of droughts from a regional perspective followed by EAS. Also, among the three stressors, droughts record the highest number of records followed by floods and the decade 1975–1985 recorded the highest number of stressors. However, there is an inverse relationship between droughts and floods, as droughts reduce with time while floods increase. Even though climatic drivers are reported as dominant, non-climatic stressors are increasingly becoming important in the Sahel as shown by this review. The stressors reporting approach used in this paper offers a proxy or indicator approach against which the status of climate change stressors in the Sahel can be inventoried.

Being that this study is a first attempt at providing a systematic tracking snap-shot of the stressors that affect the Sahel, much attention has to be given to: (1) Performing similar reviews at wider scales to capture the stressors that affect the entire African continent. (2) A review of how the peer reviewed and the grey literature report these stressors should also be carried out. (3) Snap-shots of which research institutions and countries have been more involved in performing climate stressors research across Africa will be valid and will go a long way in providing the much required financial leverage needed by African based researchers; this will have enormous implications for land use planning. This is very important because the African based researchers have unique understandings of these stressors due to the fact that they are based within the epicenter of these stressors; this knowledge is invaluable in advancing our understanding of climate stressors and adaptation/land use policy in Africa. Though these findings simply serve as a proxy of the stressors and provide a baseline, the ability of this study to provide a snap-shot of these stressors might be of help to land use policy experts or adaptation experts to understand the regions, countries and stressors that require urgent attention. This is valid as ground truthing was unable to provide more relevant studies. Understanding that the Sahel is more prone to droughts than floods for example could help land use policy experts, land use planners and adaptation professionals to tailor and leverage funding and actions towards the dominant stressors. However, the situation may vary from a country to country perspective. The understanding here is that when researchers focus more on a particular stressor there is an indication that the stressor is a major concern; this is the kind of snap-shot that this study provides and it may help stakeholders to understand where the emphasis has been and to direct adaptations in the same order of priorities. The uniqueness of this study therefore lies in its ability to reflect what before now was only found in several publications which could not provide a holistic understanding; a snap-shot that cannot be culled from a single study.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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