Environmental Research Letters

TOPICAL REVIEW

Environmental change, adaptation strategies and the relevance of migration in Sub-Saharan drylands

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Keywords: environmental change, adaptation, coping, migration, Sub-Saharan Africa

Abstract

Understanding coping and adaptation behaviour of different population groups in the context of global environmental change has become increasingly important, especially in regions with high vulnerability such as Sub-Saharan drylands. In this regard, household strategies tend to be dependent on local and context-specific conditions. However, the strategic development of climate change adaptation measures, as well as natural resource and migration management on national and international level require transferable results and recommendations. In this paper, a first attempt is made to address the lack of meta-knowledge and to create a bigger trans-regional picture on the topic. It provides an exploratory and systematic synthesis of quantitative and qualitative data from 63 studies covering more than 9700 rural households from Sub-Saharan African drylands. Relevant household coping and adaptation strategies under different types of environmental change are assessed with a particular focus on the role and relative significance of migration. The results demonstrate that strategies related to crop, livestock, soil and water management are, by far, the most common. Yet, various forms of migration are reported as strategy by about 23% of the households. Corroborated by qualitative findings, this emphasises the importance of migration for responding to unfavourable environmental conditions at the household level. Based on the synthesised literature, future directions for research needed to support socially and ecologically sustainable coping and adaptation are provided.

Introduction

In light of their extensive global reach and large number of inhabitants, drylands are considered critically important terrestrial environments. They are home to about one third of the world population and cover approximately 45% of the global land area, most of them being prevalent in Asia and Africa (UN 2011, Pravšič 2016). Due to climate change, scholars expect the total dryland area to increase up to 50% of global land surface by 2100 (Huang et al 2015). Often referred to as deserts and semi-deserts, drylands are characterised by scarce and variable rainfall and high potential evapotranspiration (Middleton and Thomas 1997). A wide range of natural hazards occur in dryland environments, with climate hazards such as drought assuming the greatest relative significance in terms of risk (Middleton and Sternberg 2013). Some 10%–20% of drylands worldwide are estimated to be affected by one or more forms of land degradation associated with both climatic and human factors. Existing water scarcity is projected to further increase in drylands as a result of demographic growth, climate and land cover change (Hassan et al 2005, UNCCD 2017).

Rural dryland populations in Sub-Saharan Africa (SSA) are highly vulnerable to climatic fluctuations and environmental change given their strong dependence on rain-fed agriculture or other natural resource-based livelihoods (Juana et al 2013). In addition, their risk level is often aggravated by challenging socio-economic conditions including high poverty, population pressure, food insecurity, political instability and ethnic tensions (Misselhorn 2005, Reynolds et al 2007, FAO 2009, FAO 2018). Future climate projections do not give reason for hope for an alleviation of these pressures as a general increase in aridity and extreme weather events is expected on the African continent.
(Boko et al 2007). Considering the importance of the matter, a comprehensive understanding of coping and adaptation dynamics across these regions is urgently needed. The Intergovernmental Panel on Climate Change (IPCC 2012) defines coping as "[t]he use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term" (p 556), whereas adaptation in human systems is defined as ‘the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities’ (p 558).

Migration is known to be a long-standing livelihood strategy used by different communities in SSA to deal with various types of risks (Morrissey 2013a). Complex and multi-causal by nature, migration can take several forms, ranging from short-distance to international and from temporary to permanent movement1. In the context of environmental change, migration deserves particular attention as an increasing number of scholars emphasise the potential of migration as adaptation strategy (e.g. Foresight 2011, Hunter et al 2015), whereas environment-induced migration is often portrayed as a major problem in political debates and the media (e.g. Tacoli 2009, Bettini et al 2016). At the same time, the number of climate change migrants is expected to increase in the upcoming decades, especially in SSA (Rigaud et al 2018). Consequently, more clarity is needed regarding how migration is to be evaluated in relation to other household responses to environmental change.

A considerable scientific data basis exists on the topic of coping with and adaptation to environmental and climate change in SSA (e.g. Mertz et al 2009, Juana et al 2013). Especially the extensive wealth of information from local case studies (e.g. Hooli 2016, Ng’ang’a et al 2016) is potentially relevant for the strategic development of climate change adaptation measures and natural resource and migration management at the national and international level. However, due to the localised focus and context-specific framework conditions, results from individual case studies are rarely directly applicable to larger regions. This paper aims to address this knowledge gap by providing a systematic synthesis of comprehensive quantitative and qualitative case study data and a descriptive overview of patterns in the literature.

The overarching objectives of this paper are to identify relevant household coping and adaptation strategies and, in particular, to assess the role and relative significance of migration as a strategy in the context of environmental change. Here, environmental change is understood as any process concerning the natural environment including climate that implies an alteration in the socio-ecological system studied. Coping and adaptation are distinguished in reference to the time scale of measures, meaning that coping refers to spontaneous and temporary adjustments while adaptation is used for rather anticipatory and long-term adjustments. The analysis focuses on subsistence livelihoods and rural arid and semi-arid lands in SSA. Based on the results, future directions for research needed to support socially and ecologically sustainable household coping and adaption are indicated.

Data and methods

This paper adopts a systematic synthesis approach including both quantitative and qualitative data from published scientific peer-reviewed literature. A systematic literature search (see appendix B) was conducted in June 2017 using the online search engine ‘Web of Science’. The search term used included all country names of SSA, different processes of environmental change and associated extreme weather events that are known to be relevant in Sub-Saharan drylands and the terms adapt and cope. The final search with the iteratively optimised search term (see appendix B) yielded 2477 papers. These were assessed for eligibility and systematically filtered in a two-step procedure: a screening of papers titles, keywords and abstracts, followed by a more detailed inspection of the full-text articles. Case studies were selected for the analysis if they met all of the predefined eligibility criteria (table 1). The final literature sample comprises 63 studies from 39 full-text articles covering 16 SSA countries (table 2). Individual studies were determined based on the geographical location of study sites and the aggregation level of the results.

The studies included in this review are rather recent; the majority was published after 2009. In terms of applied methods, the studies are relatively homogenous with household surveys (43 studies) and focus group discussions (43 studies) being most common, often complemented by key informant/expert interviews (33 studies), semi-structured household interviews (24 studies), field observations or reviews of secondary data (see table A1). In five studies the authors analysed meteorological data from weather stations. The sample size per study differs considerably across the reviewed studies ranging from 16 to 623 households2. In total, more than 9700 households are covered by this review. Based on the information on the sex ratio of the interviewees (available for 37 of the

1 All of these are covered by the definition of migration proposed in the IOM Glossary on Migration: ‘The movement of a person or a group of persons, either across an international border, or within a State. It is a population movement, encompassing any kind of movement of people, whatever its length, composition and causes; it includes migration of refugees, displaced persons, economic migrants, and persons moving for other purposes, including family reunification’ (IOM 2011, pp 62).

2 This number refers to survey or household interview participants, not to additional focus groups, workshops or expert interviews.
Table 1. Eligibility criteria for study selection.

- Only English-speaking literature including primary data from local case studies
- Study sites located in predominantly rural and arid/semi-arid areas in SSA
- Study populations characterised by subsistence livelihoods or small-scale agriculture
- Data at the household level (given that the coping/adaptation decision-making usually takes place at the household level)
- Information on more than a single coping or adaptation strategy
- Only actually adopted coping or adaptation strategies (not preferred or planned strategies)
- Frequency of adoption of the listed strategies (important indicators of their relative importance)
- Reference to an environmental change process

a The Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database (Trabucco and Zomer 2009) was used to determine the aridity for each study site.

b (Literal interpretation of text-based information, i.e. terms like ‘decrease’, ‘degradation’, ‘drying’ were considered a change, ‘climate variability’ or ‘water scarcity’ not per se).

studies), on average one-fourth of the respondents was female. Three of the studies are located in Central Africa, 20 in East Africa, 29 in West Africa, and 11 studies in Southern Africa. It is worth noting that a high number of studies included in this review focus on relatively few countries such as Ethiopia, Burkina Faso or South Africa whereas several other SSA countries are not included at all (figure 1). Sixteen study sites contain arid lands, 49 semi-arid lands, and five include some dry sub-humid territory.

The information extracted from the studies comprises the conceptual framework, data collection methods, socio-economic household characteristics, reported environmental change processes, other environmental and non-environmental factors shaping the general context of the study, and the coping or adaptation strategies adopted by households. A qualitative content analysis of the selected studies was done in ATLAS.ti to guide the categorisation of collected data and substantiate the interpretation of results. Repeated cross-checking during the data extraction and coding process served to reduce the risk of potential biases.

The livelihoods of the studied households were divided into three overarching groups: farmers (crop, vegetable and livestock farmers that are predominantly sedentary), agro-pastoralists (semi-nomadic groups that engage in crop cultivation in combination with livestock herding) and pastoralists (nomadic livestock herders). Information describing measured or perceived environmental changes in the study areas was grouped into increasing stress related to temperature, rainfall amount, rainfall variability, land degradation, degradation of water bodies, wind, drought and flood events (see footnote 4). In order to assess the relevance of household strategies, three types of information were used: the number of studies in which each of the response strategies was reported (i.e. vote counting); the number of households that adopted each strategy (calculated based on the sample size and frequency of adoption per strategy category and study); and the estimated relevance of each strategy category per study (for each individual study the strategy categories were ranked based on their frequency of adoption by households relative to the other categories). The descriptive statistical analysis of the coded data comprised frequency distribution analyses.

Results and discussion

Rural livelihoods

The livelihood activities of the study populations are essentially agricultural. Farming is by far the dominant livelihood activity across the studied populations covered by 51 of the studies. Sixteen studies included agro-pastoralists and twelve studies pastoralists. Thereby, livelihood activities are not necessarily mutually exclusive as many population groups analysed comprise a mix of different livelihoods. Complementary livelihood activities that are often mentioned include petty trading, informal employment, fishing or artisanal work. Based on the literature reviewed here, it cannot be assessed whether this imbalance between the livelihood groups reflects a general dominance of or trend towards sedentary agriculture in SSA or whether this hints at a gap in the research field.

Scholars seem to disagree on which type of livelihood enables households best to deal with environmental change. McKune and Silva (2013), for instance, argue that drought-induced loss of livestock has a more severe impact on livelihood security than the loss of crops as the subsequent rebuilding of a herd takes much more time. In contrast, some studies point at the major advantage of livestock mobility that allows households to relocate herds to higher grounds, for instance to avoid flood damage (Haile et al 2013), and to use resources more opportunistically (Opiyo et al 2015). Others suggest that a more diversified livelihood portfolio in general is conducive to a higher adaptive capacity due to the spreading of risk (e.g. Motsholaphoko et al 2012).

Environmental change processes

Increasing environmental stress is predominantly reported in terms of temperature increase, declining precipitation and more variable, unpredictable or
| References                          | Country         | No. of studies extracted | Rural livelihoods characterised by | Environmental change related to |
|------------------------------------|-----------------|--------------------------|-----------------------------------|---------------------------------|
| Padonou et al (2014)               | Benin           | 1                        | Farming                           | Land degradation                |
| Oyerinde et al (2015)              | Benin           | 1                        | Farming                           | Rainfall, flood, land degradation |
| Dah-gbeto and Villamor (2016)      | Benin           | 1                        | Farming                           | Rainfall                        |
| Motsholapheko et al (2011)         | Botswana        | 1                        | Farming                           | Rainfall, flood                 |
| Motsholapheko et al (2012)         | Botswana        | 1                        | Farming                           | Degradation of water bodies     |
| Barbier et al (2009)               | Burkina Faso    | 1                        | Farming, Agro-Pastoralist         | Rainfall, land degradation       |
| Zampaligre et al (2014)            | Burkina Faso    | 2                        | Farming, Agro-pastoralist, and Pastoralist | Rainfall, land degradation, degradation of water bodies |
| Okpara et al (2016)                | Chad            | 3                        | Farming, Agro-pastoralist and Pastoralist | Degradation of water bodies     |
| Gebrehiwot and van der Veen (2013)| Ethiopia        | 1                        | Farming                           | Rainfall, drought, flood         |
| Haile et al (2013)                 | Ethiopia        | 1                        | Farming, Agro-pastoralist         | Flood                           |
| Ariti et al (2015)                 | Ethiopia        | 1                        | Farming                           | Rainfall, drought, land degradation, degradation of water bodies |
| Berhanu and Beyene (2015)          | Ethiopia        | 1                        | Pastoralist                       | Drought, rainfall, land degradation |
| Feleke et al (2016)                | Ethiopia        | 3                        | Farming                           | Temperature, rainfall           |
| Mersha and Laerhoven (2016)        | Ethiopia        | 1                        | Farming                           | Drought, land degradation, rainfall |
| Ng‘anging‘a et al (2016)           | Ethiopia        | 1                        | Agro-pastoralist                  | Drought, rainfall               |
| Tesfaye and Seifu (2016)           | Ethiopia        | 3                        | Farming                           | Temperature, rainfall, flood, land degradation |
| Yaffa (2013)                       | Gambia          | 1                        | Farming                           | Rainfall, drought, land degradation |
| Antwi-Agriey et al (2014)          | Ghana           | 1                        | Farming                           | Temperature, rainfall           |
| Dumenu and Obeng (2016)            | Ghana           | 1                        | Farming, Agro-pastoralist         | Temperature, rainfall, degradation of water bodies |
| Limantol et al (2016)              | Ghana           | 1                        | Farming                           | Temperature, rainfall           |
| Tambo (2016)                       | Ghana           | 3                        | Farming                           | Temperature, rainfall           |
| Smucher and Wisner (2008)          | Kenya           | 2                        | Agro-pastoralist                  | Rainfall, land degradation       |
| Silvestri et al (2012)             | Kenya           | 1                        | Farming, Agro-pastoralist, and Pastoralist | Temperature, rainfall           |
| Opiyo et al (2015)                 | Kenya           | 1                        | Agro-pastoralist, Pastoralist     | Drought, land degradation, degradation of water bodies |
| Sanogo et al (2017)                | Mali            | 1                        | Farming, Agro-pastoralist         | Temperature, rainfall, wind, drought |
| Hooli (2016)                       | Namibia         | 1                        | Farming                           | Flood, land degradation         |
| McKune and Silva (2013)            | Niger           | 4                        | Agro-pastoralist, Pastoralist     | Rainfall                        |
| Snorek et al (2014)                | Niger           | 3                        | Farming, Agro-pastoralist, and Pastoralist | Rainfall, land degradation       |
| Chiana et al (2004)                | Nigeria         | 1                        | Farming                           | Rainfall, land degradation       |
| Tambo and Abdoulaye (2013)         | Nigeria         | 2                        | Farming                           | Temperature, rainfall           |
| Yila and Resurreccion (2014)       | Nigeria         | 1                        | Farming                           | Rainfall, drought, wind, land degradation, degradation of water bodies |
| Mertz et al (2009)                 | Senegal         | 1                        | Farming                           | Temperature, rainfall, wind, land degradation, degradation of water bodies |
| Ghetibouo et al (2016)             | South Africa    | 4                        | Farming                           | Temperature, rainfall           |
| Osbahar et al (2016)               | South Africa    | 3                        | Farming                           | Wind, drought, flood, land degradation |
| Rankoana (2016)                    | South Africa    | 1                        | Farming                           | Land degradation, degradation of water bodies, rainfall |
| Pauline et al (2017)               | Tanzania        | 2                        | Farming                           | Drought, rainfall               |
| Bola et al (2014)                  | Zimbabwe        | 1                        | Farming                           | Rainfall, drought, flood        |
| Jiri et al (2017)                  | Zimbabwe        | 1                        | Farming                           | Temperature                     |
| Mertz et al (2012)                 | Multi-country study (Burkina Faso, Mali, Niger, Nigeria, Senegal) | 3 | Farming, Pastoralist | Rainfall, temperature, wind, land degradation, degradation of water bodies |
erratic rainfall. An increase in stress related to drought and flood events is mostly reported in terms of increasing frequency, magnitude or severity in the reviewed studies. Increasing stress related to wind especially refers to increasing wind speed or dust storms. Examples of increasing stress related to the degradation of land and water bodies include soil erosion, bosalization6, lake drying and the desiccation of floodplains. As shown in figure 2, slow-onset changes relating to temperature, rainfall and soils are more commonly reported in the studies than changes relating to fast-onset extreme weather events. In general, there is a strong emphasis on the context of climate change and variability in the majority of studies. Land degradation—although mentioned in half of the studies—is rarely the focus of the reviewed literature, but often mentioned more as a side note.

Human perceptions of environmental change play a decisive role in the process of coping and adaptation. Local views on environmental changes are shaped by a number of factors, including farming experience, contact with extension services, or the media, and may not always fully correspond to real changes (e.g. Mertz et al 2012, Silvestri et al 2012, Kosmowski et al 2016). Yet, perception is a prerequisite for coping and adaptation as households are unlikely to take action and change their practices unless they perceive a change and adverse effects in the first place (e.g. Tambo and Abdoulaye 2013). Nevertheless, instead of reporting local views, meteorological data or secondary sources are often used in the academic literature to underline changing local or regional environmental conditions. However, a solid understanding of household behaviour in this context calls for the consideration of local perceptions, whether (and if, why) they contradict climate data and how they translate into concrete action. Here, perceptual data can act as a valuable complement to climate data as they might reveal important underlying drivers or processes which specific environmental parameters fail to detect (e.g. Mertz et al 2009).

Contextual factors and barriers
A diverse range of environmental and non-environmental factors that shape the broader contexts in which household coping and adaptation take place are cited in the reviewed studies. Some are based on the perceptions of the local population, whereas others are

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6 (A form of land degradation that entails the lateral expansion of ferricrete horizons.)
determined by the authors or retrieved from secondary sources. These factors include characteristics of the study area and population (e.g. infertile soils, land tenure issues, weak infrastructure, illiteracy problems, resource conflicts, ethnic diversity, gender inequalities), causes and impacts of environmental change processes (e.g. land use changes, overexploitation, crop failure, livestock deaths, health issues, food insecurity) and adaptation barriers (e.g. lack of financial capital, farm inputs and information, inaccessibility of markets). However, the reviewed studies partly remain ambiguous about which of these are to be interpreted as factors enabling or constraining coping and adaptation. Moreover, many factors act at different scales and are strongly intertwined which hampers a clear-cut categorisation.

It is important to bear in mind that, even if an environmental change is perceived, households may not be able to adopt adequate measures due to certain constraints (e.g. Silvestri et al 2012, Tambo and Abdoulaye 2013, Ariti et al 2015, Oyerinde et al 2015). Gebrehiwot and van der Veen (2013) for example show that, despite a high local awareness of climate change, almost half of the Ethiopian study population was unable to adopt any adaptive measure due to lack of information and finance. Gbetibouo et al (2010) report similar findings from the Southern African Limpopo Basin, where the lack of credit and water access plays a major role for hindering farmers’ adaptation. In the case of people wanting to emigrate due to environmental risks but not being able to do so, researchers often refer to so-called ‘trapped populations’ (e.g. Black et al 2011, Murphy 2015). In general, barriers to adaptation are often not clearly defined in the academic literature, highly context-dependent, interconnected and have a differentiated effect on different actors, such as male- and female-headed households (Biesbroek et al 2013, Yila and Resurreccion 2014, Mersha and Laerhoven 2016). Moreover, scientific knowledge on how adaptation barriers impact specific adaptation choices, such as migration, is still limited. For a detailed review of climate change adaptation barriers faced by natural-resource dependent communities in SSA see Shackleton et al (2015).

Coping versus adaptation

In the majority of studies household strategies are framed as ‘adaptation’, whereas only in about one third the framing of ‘coping’ is used, either instead of or in addition to ‘adaptation’. In about one out of three studies these terms are used without any definition provided; some authors seem to use both terms synonymously. This observation has also been addressed by other scholars, e.g. Murtinho and Hayes (2012) who advocate greater conceptual and methodological clarity in adaptation field research. Other concepts that were used in the analysed literature include adaptive and buffer capacity, resilience (e.g. climate resilience) and vulnerability (e.g. social or gender-differentiated vulnerability).

It is noteworthy that—despite the ‘adaptation’ framing in most studies—many authors claim the reported strategies to be reactive and short-term rather than preventative and anticipatory, often due to various barriers (e.g. Tambo and Abdoulaye 2013, Opiyo et al 2015, Dumenu and Obeng 2016, Hooli 2016). Okpara et al (2016), for instance, indicate that many adaptive measures to environmental changes require the use, combination or substitution of assets in different ways. Consequently, the low asset profile of parts of the study population at Small Lake Chad has restricted them to actions that are largely reactive (ibid.). According to Pauline et al (2017), many coping strategies could be transformed into longer term adaptation strategies but are limited by non-climatic factors. Whereas coping strategies tend to depend on locally available resources, such as labour, many longer term adaptation methods in the farming sector require financial capital or government support, which are often unavailable to smallholder farmers (ibid.). This generally supports findings from other studies, such as Berrang-Ford et al (2011) who point at the reactive adaptation profile of low income countries.

Figure 2. Environmental change processes reported in the reviewed studies.
Other activities
Religious activities
Prayers, turn to faith and church groups, go to the mosque, ritual ceremonies

Consult extension officers, send children to school, join information group, access weather forecast information, early warning systems

Erosion control, terracing, drainage ditches, ridges, micro-catchments, ploughing, stone bunds, mulching, digging of boreholes and wells, construction of small dams, water storage, drinking water treatment

Off-farm employment, local wage labour, petty trading, hunting, charcoal selling, tourism/wildlife-related income, sell bush products, fishing, pottery

Reduce food consumption, change diet, seek food aid, eat wild fruits, work for food, sell assets to buy food, store food, purchase fish, use savings to obtain food, harvest to obtain food, plant food trees

Rely on support from relatives/friends, borrow money from neighbours, send out children, receive remittances, collaboration

International migration, labour migration, rural-urban migration, temporary relocation to government camps

Rely on/ask for humanitarian aid provided by the government, NGOs or religious organisations

Income diversification
Food provision
Social networks
Migration
Humanitarian aid
Information
Religious activities
Other activities* 
No coping/adaptation

Table 3. Categorisation of household strategies adopted to deal with environmental change.

| Strategy type                  | Examples of specific strategies from the studies                                                                 |
|-------------------------------|------------------------------------------------------------------------------------------------------------------|
| **Crop management**           | Crop diversification, intercropping, monocropping, crop rotation, increase of farm size, use of organic/chemical fertiliser, drought-tolerant/early maturing varieties, change timing of land preparation/planting, crop irrigation, grain storage, sharecropping |
| **Livestock management**      | Livestock sale, fodder storage, transhumance, herd diversification, drought-tolerant species, culling of sick animals, provision of shade, bull fattening, veterinary care, purchase of hay, home feeding |
| **Soil and water management** | Erosion control, terracing, drainage ditches, ridges, micro-catchments, ploughing, stone bunds, mulching, digging of boreholes and wells, construction of small dams, water storage, drinking water treatment |
| **Income diversification**    | Off-farm employment, local wage labour, petty trading, hunting, charcoal selling, tourism/wildlife-related income, sell bush products, fishing, pottery |
| **Food provision**            | Reduce food consumption, change diet, seek food aid, eat wild fruits, work for food, sell assets to buy food, store food, purchase fish, use savings to obtain food, harvest to obtain food, plant food trees |
| **Social networks**           | Rely on support from relatives/friends, borrow money from neighbours, send out children, receive remittances, collaboration |
| **Migration**                 | International migration, labour migration, rural-urban migration, temporary relocation to government camps |
| **Humanitarian aid**          | Rely on/ask for humanitarian aid provided by the government, NGOs or religious organisations |
| **Information**               | Consult extension officers, send children to school, join information group, access weather forecast information, early warning systems |
| **Religious activities**      | Prayers, turn to faith and church groups, go to the mosque, ritual ceremonies |
| **Other activities**          | Sale of property, insurance scheme, sedentarisation, household splitting, get loan or credit, reduce expenses after drought, measures to prevent inundation of houses, reduction of gifts to the poor |

* ‘Others’ also include strategies that were somewhat ambiguous and could not be assigned clearly to any of the other categories, and strategies that entail activities from various categories and could not be disaggregated further.

Relevant household strategies

The reported household strategies from each study were aggregated into twelve overarching categories, acknowledging that a clear-cut distinction is difficult due to real-world overlap: crop management, livestock management, soil and water management, income diversification, food provision, social networks, migration, humanitarian aid, religious activities, information, other activities, and no coping/adaptation (table 3). Although migration is commonly viewed as a form of income diversification, it is treated as a separate category here to allow for a closer examination. It needs to be added that some strategies are likely to be underreported in the literature under study, either because they are illegal in some countries, such as grazing in protected areas, local beer brewing or cutting wood for charcoal production, or because they are socially stigmatised, e.g. the consumption of wild plants (e.g. Antwi-Agyei et al 2014, Smucher and Wisner 2008, Goldman and Riessman 2013).

The results reveal that agricultural strategies, including the management of crops, livestock, soil and water, are by far the most commonly adopted in rural Sub-Saharan drylands (figure 3). This is most notable in the case of crop management that is reported in more than three quarters of the reviewed studies and soil and water management reported in about two thirds. Here, the number of studies in which a strategy was reported is contrasted with the number of households who adopted a strategy (figure 4) in order to account for the differences in sample sizes but also the varying shares of study populations that adopted a certain strategy. The household numbers reveal an even more clear-cut picture as the gap between agricultural and resource management and other strategy types increases notably. In sum, this reflects the predominantly agricultural character of the rural livelihoods as well as the harsh conditions in Sub-Saharan drylands shaped by severe soil erosion and water scarcity. The fact that approx. 17% of the interviewed households claimed to not have adopted any response measure underlines the need to consider locals’ perceptions of environmental change (i.e. do they perceive the need to take any action?) and factors constraining coping and adaptation (i.e. are they actually able to adopt response measures?).

Given the discrepancy between the number of studies and the number of households presented here, a ranking approach was chosen to combine both types of information and estimate the strategy relevance. The results are compared between the three livelihood groups in order to provide a more nuanced picture (figure 5). Not surprisingly, strategies related to crop cultivation are dominating for farming households, which corresponds to findings by other researchers such as Juana et al (2013). Livestock management, in turn, is the most common strategy type in the sample of pastoralist households. Agro-pastoralist households figure somewhere in between the other two groups, reflecting the combination of cultivation and herding that is characteristic for agro-pastoralist livelihoods.

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| **Soil and water management** | Erosion control, terracing, drainage ditches, ridges, micro-catchments, ploughing, stone bunds, mulching, digging of boreholes and wells, construction of small dams, water storage, drinking water treatment |
| **Income diversification**    | Off-farm employment, local wage labour, petty trading, hunting, charcoal selling, tourism/wildlife-related income, sell bush products, fishing, pottery |
| **Food provision**            | Reduce food consumption, change diet, seek food aid, eat wild fruits, work for food, sell assets to buy food, store food, purchase fish, use savings to obtain food, harvest to obtain food, plant food trees |
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Relevant household strategies

The reported household strategies from each study were aggregated into twelve overarching categories, acknowledging that a clear-cut distinction is difficult due to real-world overlap: crop management, livestock management, soil and water management, income diversification, food provision, social networks, migration, humanitarian aid, religious activities, information, other activities, and no coping/adaptation (table 3). Although migration is commonly viewed as a form of income diversification, it is treated as a separate category here to allow for a closer examination. It needs to be added that some strategies are likely to be underreported in the literature under study, either because they are illegal in some countries, such as grazing in protected areas, local beer brewing or cutting wood for charcoal production, or because they are socially stigmatised, e.g. the consumption of wild plants (e.g. Antwi-Agyei et al 2014, Smucher and Wisner 2008, Goldman and Riessman 2013).

The results reveal that agricultural strategies, including the management of crops, livestock, soil and water, are by far the most commonly adopted in rural Sub-Saharan drylands (figure 3). This is most notable in the case of crop management that is reported in more than three quarters of the reviewed studies and soil and water management reported in about two thirds. Here, the number of studies in which a strategy was reported is contrasted with the number of households who adopted a strategy (figure 4) in order to account for the differences in sample sizes but also the varying shares of study populations that adopted a certain strategy. The household numbers reveal an even more clear-cut picture as the gap between agricultural and resource management and other strategy types increases notably. In sum, this reflects the predominantly agricultural character of the rural livelihoods as well as the harsh conditions in Sub-Saharan drylands shaped by severe soil erosion and water scarcity. The fact that approx. 17% of the interviewed households claimed to not have adopted any response measure underlines the need to consider locals’ perceptions of environmental change (i.e. do they perceive the need to take any action?) and factors constraining coping and adaptation (i.e. are they actually able to adopt response measures?).

Given the discrepancy between the number of studies and the number of households presented here, a ranking approach was chosen to combine both types of information and estimate the strategy relevance. The results are compared between the three livelihood groups in order to provide a more nuanced picture (figure 5). Not surprisingly, strategies related to crop cultivation are dominating for farming households, which corresponds to findings by other researchers such as Juana et al (2013). Livestock management, in turn, is the most common strategy type in the sample of pastoralist households. Agro-pastoralist households figure somewhere in between the other two groups, reflecting the combination of cultivation and herding that is characteristic for agro-pastoralist livelihoods.
Here, it is noteworthy that in the sample of agro-pastoralists migration is reported in more studies than all other strategy types. In the sample of pastoralist households migration is more common than other income diversification strategies. Nevertheless, as illustrated in figure 5, in the studies in which migration is reported, it is usually not the strategy that the majority of households adopted.

**Migration as strategy to deal with environmental change**

A diverse range of migration types are reported as response to environmental change in almost half of the reviewed studies. About 23% of the interviewed households claim to have been involved in some type of migration. Thus, together with food-related strategies other forms of income diversification, migration constitutes one of the most relevant strategies after agricultural and resource management. The types of migration include, amongst others, temporary/short-term migration (e.g. Osbahr et al 2010), permanent migration (Zampaligre et al 2014), migration *en exode* (McKune and Silva 2013), economic/labour migration (e.g. Snorek et al 2014, Opiyo et al 2015), rural-urban migration (e.g. Dumenu and Obeng 2016) and international migration (e.g. Mersha and Laerhoven 2016) (table 4). Information about the duration or migration distance is often not provided, which makes a more detailed comparison infeasible. Temporary migration and economic/labour migration (which are often overlapping) are the most common types in the sample of studies. Moreover, even if migration is not explicitly framed as ‘economic’, it is often mentioned in association with job search or remittances and, thus,
hints at economic purposes. Antwi-Agyei et al (2014), for instance, conclude that temporal migration is still one of the dominant strategies among vulnerable farming communities in northern Ghana, mostly undertaken by younger people to engage in wage labour in southern Ghana.

An interesting observation from the qualitative analysis is that in several studies out-migration is described as common phenomenon or household strategy in the study area without explicitly considering it as either coping or adaptation strategies (e.g. Eriksen et al 2005, Silvestri et al 2012, Dah-gbeti and Villamor 2016, Tambo 2016). For instance, in a case of Ethiopian smallholder farmers the vast majority of respondents perceive that migration has ‘aggravated’ as a result of climate change. However, the reported frequency of migration as climate change adaptation strategy is almost negligible (Tsefaye and Seifu 2016). Similarly, Mertz et al (2009) recognise migration as both a climate change impact and a household adaptation strategy in

Figure 5. Estimated relevance of strategies as reported by different livelihood groups: farmers, agro-pastoralists and pastoralists (based on the frequency of adoption aggregated per strategy category and assessed in relation to other categories per study; the darker the grayscale, the more common the strategy category in the individual study).
their cross-country study. But the provided quantitative information only includes migration as a perceived impact of climate-related parameters, whereas more work done by old people in all seasons is named as associated adaptation measure (ibid.).

These examples hint at the fundamental conceptual and methodological challenges of grasping the links between the environment and human migration. As illustrated in the framework presented in the influential Foresight Report (2011), the migration decision by households or individuals involves a complex set of interlinked factors in which environmental change also acts as indirect driver influencing other migration drivers. This indirect, and perhaps less obvious influence partly explains why local people are more likely to associate migration with more apparent socio-economic factors, such as the search of labour, than environmental change—although the latter significantly shapes local framework conditions (see e.g. Morrissey 2013b). This corresponds to Neumann and Hermans (2015) who show that economic and social motivations account for 80% of the migration drivers reported in 53 studies from the Sahel. In other words, even though migration forms part of household coping or adaptation, it may not always be perceived as such and is, thus, likely to be underreported as strategy in the literature under study.

Strategy dynamics

Despite existing evidence that households usually adopt various coping or adaptation strategies simultaneously (see e.g. Silvestri et al 2012, Mogotsi et al 2013, Hooli 2016, Tesfaye and Seifu 2016), only four of the reviewed studies explicitly investigate the interconnectedness and dynamic interactions of individual strategies, i.e. how they complement, substitute, reinforce or undermine each other (e.g. Tesfaye and Seifu 2016). Examples from the analysed literature include Tambo (2016) who used the correlation between different adaptation measures as an indicator and concluded that most of the measures analysed are complementary rather than substitutes. Beyond that, Eriksen et al (2005) underline the tendency of households to engage in one principal coping strategy complemented by various less favoured activities during drought periods. Interestingly, Ng’ang’a et al (2016) found that migration is associated with the enhanced adoption of measures for self-protection against weather shocks, especially in cases of high investment costs, suggesting that remittances flows constitute a key mechanism supporting local agricultural innovation. A more nuanced understanding of these strategy dynamics in general could make a substantial contribution to making adaptation planning more effective.

An even more pressing issue in this context concerns the impact of strategies on the households themselves and the socio-ecological system in general. The literature indicates that—despite short-term gains—certain coping or adaptation strategies might not be sustainable in the long run and undermine the viability of local livelihoods (e.g. Yaffa 2013). This includes activities that erode the natural resource base (Chianu et al 2004, Opiyo et al 2015), reduce the adaptive or buffer capacity of local agents (Silvestri et al 2012, Goldman and Riosmena 2013, Haile et al 2013, Bola et al 2014) and generate negative externalities for other population groups (Osbahr et al 2010, McKune and Silva 2013). A well-known example of the latter is the expansion of farmland that reduces pastoral space and therewith limits pastoral adaptation (Snorek et al 2014). These processes are captured by terms such as ‘maladaptation’, ‘erosive coping’ or ‘divergent adaptation’. Whereas the benefits of remittances are often emphasised in the literature (e.g. Dumenu and Obeng 2016), several scholars mention risks and negative effects of emigration on the remaining communities, such as weakened local labour force (Mertz et al 2009), increased divorce rates and loss of solidarity (McKune and Silva 2013), and the migrants themselves (e.g. Yaffa 2013, Mersha and Laerhoven 2016). A holistic and systemic policy approach that supports both ecologically and socially sustainable adaptation demands prior consideration of potential repercussions.

A remaining question is whether there have been significant changes in coping and adaptation strategies and whether the overall mobility of certain groups has increased or decreased in the course of evolving environmental stressors. Some indications exist in the analysed literature of pastoralist groups becoming more sedentary (e.g. McKune and Silva 2013, Snorek et al 2014), whereas some farming and fishing groups are said to become more mobile in search of fertile lands and fish-abundant areas (e.g. Dah-gbeto and Villamor 2016). Furthermore, it remains questionable to what extent there is a general trend of traditional agricultural livelihoods being increasingly abandoned in favour of more diversified livelihoods and off-farm income-generating activities (e.g. Eriksen et al 2005, Antwi-Agyei et al 2014, Rankoana 2016). Based on surveys conducted in Kenya in 1977 and 1996, Campbell (1999) concludes that more coping strategies have become available over time. Interestingly, Smucker and Wisner (2008) argue that, within the same country, the range of coping strategies has declined between 1971 and 2001. Either way, more longitudinal studies of this kind are needed to draw meaningful and generalisable conclusions on this issue.

Methodological challenges and limitations

In this paper, a first attempt has been made to systematically generate and quantify knowledge on
household behaviour under environmental change on a macro scale. Obviously, there are certain limitations to this study that shall be addressed briefly. First and foremost, as this study is confined to published English-speaking scientific literature, the risk of publication bias exists. However, even leaving aside grey literature and articles in other languages, the scientific data basis on this research topic is already quite extensive. Besides, the fact that only studies from peer-reviewed journals were included ensures a certain quality standard and formal uniformity of the publications under analysis. Nevertheless, it is important to acknowledge that the uneven country coverage in the reviewed literature puts a clear limitation on the scope of this paper’s findings. Beyond this, given that this synthesis is literature-based, the results presented here are completely dependent on the information provided in the selected papers and were not verified using external data.

Despite the narrowly defined criteria for the selection of studies, the type of information and richness of detail provided in the studies differ considerably, leading to what is known as the ‘lowest common denominator problem’. This proved especially problematic regarding the environmental conditions at the study areas and the socio-economic characteristics of the study populations which are viewed as important determinants of household coping and adaptation behaviour (e.g. Gbetibouo et al 2010, Gebrehiwot and van der Veen 2013, Juana et al 2013, Zampaligre et al 2014, Berhanu and Beyene 2015, Feleke et al 2016, Ng’ang’a et al 2016, Tambo 2016, Tesfaye and Seifu 2016). Limited comparable information on these has reduced the leeway for systematic comparison of the studies and interpretation. In addition, lacking definitions of used terminology, including coping and adaptation, agro-pastoralism, different types of migration and environmental change processes, has been a major challenge, as well as often inexplicit descriptions of how information about the household strategies was elicited (e.g. what was the formulation of the interview questions?).

Synthesising the vast and diverse range of strategies reported in the studies requires aggregating the strategies into strategy groups. When it comes to the frequency of adoption, the aggregation proved problematic because usually no information was provided by the individual studies regarding how many households were adopting two or more of the listed strategies simultaneously (i.e. the overlap of percentages). Consequently, the relative importance of broad strategy groups such as crop, livestock, soil and water management are likely to be overestimated as multiple answers (and therewith higher household numbers) are more likely than in the case of more narrowly defined strategy groups, such as religious practices, humanitarian aid or information.

For a discussion on why climate change research in Africa is biased towards certain countries see Hendrix (2017).

Conclusion

This paper constitutes a first step towards addressing the lack of meta-knowledge on rural household behaviour in the context of environmental change in drylands. Comprehensive quantitative and qualitative data from 63 systematically selected studies covering more than 9700 households and 16 Sub-Saharan African countries were integrated and synthesised to create a bigger trans-regional picture. Within the sample of analysed studies, we identified an information gap regarding certain dryland areas such as in Sudan or Somalia, and pastoralist and female-headed households, which are considered two of the most vulnerable population groups. The results demonstrate that the vast majority of reported environmental change processes are related to slow-onset hazards and the context of climate change and variability. In terms of response strategies, agricultural and resource management are most commonly adopted by rural households, followed by various forms of migration, other income diversification strategies and measures for food provision. About 23% of the households claim to have been involved in some form of migration. Yet, it is hypothesised that migration plays a bigger role in the process of adaptation than the quantitative data synthesised here suggest. This is likely explained by methodological and conceptual challenges of grasping the complex and dynamic environment-migration-nexus in which environmental change acts as both a direct and indirect driver. Other less frequently adopted strategies are related to social networks, religious practices, humanitarian aid and information.

From a synthesis perspective, the following information is considered important to enhance the comparability of local case study results and to draw meaningful and generalisable conclusions:

- Clear definition of used terminology (e.g. adaptation and coping concepts, migration, agro-pastoralism and pastoralism), especially regarding environmental change and stress (to allow for a better distinction between actual change processes and typical site-specific phenomena or natural variability).
- Reliable indication of the case study site (e.g. coordinates of study site and month/year of field data collection) so that complementary external data (e.g. climate or census data) may be integrated if necessary.
- Basic socio-economic characteristics of the study population (age mean/range and sex ratio of the interviewees, ethnic background, economic status of households, e.g. farm size or number of livestock, and number of household members) as these are known to be important factors influencing the coping and adaptation behaviour of households.
The analysed studies consistently indicate that significant obstacles to long-term adaptation by rural households remain and that enhanced support from governments and organisations is needed to overcome these effectively. Furthermore, more nuanced and substantial knowledge of strategy dynamics (i.e. their interlinkages, impacts on people’s livelihoods and the socio-ecological system in general, and potential changes over time) is crucial for increasing households’ capacity to deal with environmental change and for reducing the risk of maladaptation, resource degradation and conflict. Such an improved understanding is essential for advancing the development of appropriate adaptation policy instruments and interventions at all levels.

Acknowledgments

We gratefully thank Katharine A Tyndall for valuable support of the data collection and coding process and Ralf Seppelt for fruitful discussions. CW and KH acknowledge funding from the German Federal Ministry of Education and Research (BMBF) within the Junior Research Group MigSoKo (01UU1606). The research reported in this paper contributes to the Programme on Ecosystem Change and Society (http://www.pecs-science.org/).

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

The data that support the findings of this study are available from the corresponding author on reasonable request.

Appendix A.

| References          | Focus of the study                                                                 | Conceptual framework                  | Empirical data collection                                      |
|---------------------|------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------------------------------|
| Padonou et al (2014)| Perceived causes and consequences of bowalization and coping strategies            | —                                     | Semi-structured household interviews (random sampling)        |
| Oyerinde et al (2015)| Adaptation mechanisms to CC, consistency of perceived and observed hydro-climatic trends | —                                     | Household survey (random sampling)                            |
| Dah-gbeto and Villamor (2016)| Gender-specific coping/adaptation strategies and perceptions of CV | Anticipatory learning                  | Household survey (stratified random sampling) and experimental gaming exercise |
| Motsholapheko et al (2011)| Household access to capital; impacts of extreme flooding on livelihoods, coping and long-term adaptive strategies | Sustainable livelihood framework, socio-ecological | Household survey (random sampling), key informant/expert interviews, FGD |
| Motsholapheko et al (2012)| Impacts of desiccation on livelihoods, adaptation strategies, influence of institutional changes on households’ adaptive capacity | Sustainable livelihood framework, socio-ecological | Household survey (random sampling), key informant interviews, FGD |
| Barbier et al (2009)| Farmers’ vulnerability to CV and adaptation strategies                           | Vulnerability                          | Household survey (random sampling), FGD                      |
| Zampaligre et al (2014)| Perceptions of CCV and coping and adaptation strategies                          | —                                     | Semi-structured household interviews, FGD (random sampling), incl. other PRA tools, key informant interviews, climate data |
| Okpara et al (2016)| Lake drying and livelihood dynamics (incl. response strategies)                   | Livelihoods and household well-being  | Household survey and semi-structured household interviews (combination of different sampling types), FGD, expert interviews |
| Gebrehiwot and van der Veen (2013)| Perceptions of CC, adaptation strategies, determinants of strategy choice, adaptation barriers | —                                     | Household survey (multi-stage and random sampling), climate data |
| Haile et al (2013)| Flood impacts, flood coping and adaptation strategies and their effectiveness for avoiding loss and damage | —                                     | Household survey (random sampling), key informant interviews, focus groups |
| Ariti et al (2015)| Perceived and observed LULC changes, their drivers and impacts, adaptation strategies, factors affecting adaptation | —                                     | Semi-structured household interviews, expert interviews, field observation, remote sensing data |
| References                         | Focus of the study                                                                 | Conceptual framework                  | Empirical data collection                                      |
|-----------------------------------|------------------------------------------------------------------------------------|---------------------------------------|----------------------------------------------------------------|
| Berhanu and Beyene (2015)          | CC adaptation strategies, their determinants and implied economic impacts           | —                                     | Household survey (random sampling), key informant interviews, FGD, participant observation |
| Feleke et al (2016)                | CC adaptation strategies, determinants of strategy choice                            | —                                     | Semi-structured household interviews (purposive and random sampling), expert interviews, FGD |
| Mersha and Laerhooven (2016)       | Gender-specific CC and drought adaptation strategies and barriers                    | Sustainable livelihood approach       | Semi-structured household interviews (snowball sampling), FGD, expert interviews, participant observation, informal discussions, non-structured interviews |
| Ng’ang’a et al (2016)              | CC adaptation strategies, links between migration and adoption of other strategies   | —                                     | Household survey (random sampling), FGD                         |
| Tesfaye and Seifu (2016)           | Perceived CC and its effects and adaptation strategies, factors influencing strategy choice | —                                     | Semi-structured household interviews (multi-stage sampling)      |
| Yaffa (2013)                       | Drought impacts and coping strategies, effectiveness of strategies for avoiding loss and damage | —                                     | Household survey (random sampling), FGD, expert interviews       |
| Antwi-Agyei et al (2014)           | CV adaptation strategies                                                              | —                                     | Household survey (stratified random sampling), key informant interviews, FGD, other participatory tools |
| Dumenu and Obeng (2016)            | Social vulnerability to CC, CC impacts, adaptation strategies                        | Social vulnerability to CC             | Household survey (stratified random sampling), semi-structured household interviews, FGD |
| Limantol et al (2016)              | Perceived and observed CCV, adaptation strategies                                     | —                                     | Household survey, climate data                                  |
| Tambo (2016)                       | Climate resilience, CCV adaptation strategies, determinants of strategy choice        | Climate resilience                    | Household survey (stratified random sampling)                    |
| Smucker and Wisner (2008)          | Drought coping strategies and livelihood change (longitudinal study)                 | —                                     | Household survey (random stratified sampling), expert interviews, FGD, participant observations, participatory workshops |
| Silvestri et al (2012)             | Perceptions of CC, CC adaptation strategies, adaptation barriers                     | —                                     | Semi-structured household interviews                            |
| Opiyo et al (2015)                 | Drought characteristics, drought adaptation and coping strategies, constraints to adaptations | —                                     | Semi-structured household interviews (systematic and purposive sampling), key informant interviews, FGD, informal interviews, rainfall data |
| Sanogo et al (2017)                | Perceptions of CC, its drivers and impacts on ES delivery of parklands, factors explaining perception, CC adaptation/coping strategies | —                                     | Household survey (stratified random sampling)                    |
| Hooli (2016)                       | Flood coping strategies, role of IK in resilience building                             | Socio-ecological resilience, indigenous knowledge (IK) | Household survey (random sampling), expert interviews, FGD |
| McKune and Silva (2013)            | Interactions between and consequences of environmental and economic stressors, coping strategies | Double exposure framework             | Household survey (random sampling), expert interviews, FGD, participant observation |
| Snorek et al (2014)                | Adaptation strategies, divergent adaptation of different resource users              | Divergent adaptation                  | Semi-structured household interviews (random sampling), expert interviews, FGD, PRA tools |
| Chiana et al (2004)                | Farmers’ agricultural performance and resource pressures, coping strategies, evaluation of strategies | —                                     | Household survey (two-stage random sampling)                      |
| Tambo and Abdoulaye (2013)         | Perceptions of CC and adaptation strategies                                           | —                                     | Household survey, FGD                                           |
| Yila and Resurrection (2014)       | Drought adaptation strategies, factors influencing farmers’ vulnerability and adaptive capacity | Gender-differentiated vulnerability, drought vulnerability | Household survey (purpose and random sampling), key informant interviews, FGD |
Appendix B. Systematic literature search

PRISMA Statement (adapted from: Moher, D, Liberati, A, Tetzlaff, J, Altman, D G, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097).

(1) The search term used in Web of Science to identify topic-related papers included all country and
population names of SSA, the terms ‘adapt’ and ‘cope’, and a range of environmental change processes and associated weather events known to be relevant in SSA drylands (see complete search term below). The use of wildcards in the search term provided for the inclusion of all possible endings. Additionally, Web of Science categories were used to exclude irrelevant papers from unrelated disciplines. A full list of records identified through the data base search can be obtained from the lead author upon request.

(2) Publication titles, keywords and abstracts were screened to filter potentially relevant papers. For a study to be considered relevant it has to be published in English and contain primary household-level data from local case studies located in predominantly rural and arid or semi-arid lands in SSA were considered. The study population has to be characterised by subsistence livelihoods or small-scale agriculture. Information has to be provided on various coping or adaptation strategies that are being or have been adopted by households, including quantitative information on the adoption rate. Some type of environmental change process has to be specified in the paper (literal interpretation of text-based information). 2230 records were excluded at this stage because they did not meet one or several of these eligibility criteria (see also ‘Data and Methods’ section).

(3) At this stage, the remaining selection of publications was assessed in more detail (i.e. full text) for eligibility. A full list of records considered at this stage can be obtained from the lead author upon request. 208 records were excluded as they did not meet one or several of the eligibility criteria.

(4) Studies were included in the quantitative synthesis and analysed in depth if they met all of the eligibility criteria.

**Database search term:**

(((((((((TS=((Sub-Saharan Africa OR ‘Sub-Saharan Africa’ OR Angola’ OR Benin’ OR Botswana’ OR Mozambique OR Burkina’ OR Burundi’ OR Cameroon’ OR ‘Cape Verdi’ OR ‘Cabo Verdi’’ OR ‘Central African Republic’ OR Chad’ OR Comor’ OR Congo’ OR ‘Cote d’Ivoire’ OR ‘Ivory Coast’ OR Ivoirian’ OR ‘Democratic Republic of the Congo’ OR Djibouti’ OR ‘Equatorial Guinea’’ OR ‘Equatoguinean’ OR Eritrea’ OR Ethiopia’ OR Gabon’ OR Gambia’ OR Ghana’ OR Guinea’ OR Guinea-Bissau’ OR Kenya’ OR Lesotho OR Mozambique OR Botswana’ OR Mauritania’ OR Maurit’ OR Liberia’ OR Madagascar OR Malagasy OR Malawi’ OR Mali’ OR Mozambique’ OR Namibia’ OR Niger’ OR Nigeria’ OR Rwanda’ OR Sao Tome’ and Principe OR Senegal’ OR Seychell’ OR ‘Sierra Leone’ OR Somali’ OR ‘South Africa’ OR Sudan’ OR Swazi’ OR Tanzania’ OR Togo’ OR Uganda’ OR Zambia’ OR Zimbabwe’)) AND (‘environment’ chang’’ OR ‘climat’ chang’’ OR ‘ecological chang’’ OR ‘land degrad’’ OR ‘soil degrad’’ OR ‘soil erosion’ OR resource’ degrad’’ OR ‘environment’ degrad’’ OR ‘rainfall variab’’ OR ‘climat’ variab’’ OR ‘precipitation chang’’ OR ‘temperature’ chang’’ OR ‘drought’’ OR ‘desertification’ OR ‘flood’’ OR ‘environmental stress’’)) AND (adapt’ OR cop’) NOT (‘biotic OR cell’ OR molecular’ OR photovoltaic OR photosynthet’ OR pothergon’ OR AMF OR geno-type’ OR ‘plant invasion’’ OR ‘reef coral’’ OR ‘coral reef’ OR bioapatite OR cichlid’ OR ‘bird migration’ OR ‘carbon sequestration’ OR hydrogeochemical OR Pliocene OR ‘marine ecosystem’’ OR ‘tree recruitment’ OR levallois OR ‘fynbos biome’ OR ‘Afro-montane taxa’ OR ‘invasive alien tree’’ OR Paleolithic OR Pleistocene OR ‘urban metabolism’ OR lepidoptera)))(((())))))) AND **LANGUAGE**: (English) AND **DOCUMENT TYPES**: (Article)

Refined by: [excluding] WEB OF SCIENCE CATEGORIES:

- (ENGINEERING CHEMICAL
- OR GENETICS HEREDITY
- OR PHARMACOLOGY PHARMACY
- OR MEDICINE GENERAL INTERNAL
- OR ORNITHOLOGY
- OR ENDOCRINOLOGY METABOLISM
- OR BIOTECHNOLOGY APPLIED

**MICROBIOLOGY**
- OR TOXICOLOGY
- OR PSYCHOLOGY CLINICAL
- OR NEUROSCIENCES
- OR PARASITOLOGY
- OR CHEMISTRY APPLIED
- OR CHEMISTRY ANALYTICAL
- OR MARINE FRESHWATER BIOLOGY
- OR ENTOMOLOGY
- OR BIOCHEMICAL RESEARCH METHODS
- OR LIMNOLOGY
- OR BIOCHEMISTRY MOLECULAR BIOLOGY
- OR TROPICAL MEDICINE
- OR PSYCHIATRY
- OR PHYSIOLOGY
- OR NUCLEAR SCIENCE TECHNOLOGY
- OR EVOLUTIONARY BIOLOGY
- OR OCEANOGRAPHY
- OR MICROBIOLOGY
- OR INFECTIOUS DISEASES
- OR CELL BIOLOGY
- OR PALEONTOLOGY

**Timespan**: All years. **Indexes**: SCI-EXPANDED, SSCI

**Appendix C. Types of information extracted from the reviewed studies.**

- Empirical data collection methods (grouped into: structured household survey/semi-structured household interviews/focus groups discussions/
expert or key informant interviews/participant observations/others

- Sample size and sampling method
- Study area, coordinates and aridity of the study area (arid/semi-arid/dry sub-humid)
- Annual rainfall and temperature means/ranges
- Ethnic background, age mean and sex ratio of respondents

Main livelihood activities of the study population (grouped into: farmers/agro-pastoralists/pastoralists)

- Environmental change processes reported (grouped into: increasing stress related to temperature/rainfall amount/rainfall variability/droughts/floods/wind/land degradation/deterioration of water bodies)
- Conceptual framework and framing of the household response strategies (coping/adaptation)
- Coping and adaptation strategies (grouped into: crop management/livestock management/soil and water management/income diversification/food provision/social networks/migration/humanitarian aid/information/religious activities/other activities/no coping/adaptation)
- Other drivers and barriers reported

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