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## Evaluating the utility of socio-economic indicators to assess the resilience of smallholder agriculture to drought in Africa

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### Abstract

Drought is a recurrent natural hazard that significantly impacts on the livelihoods and sustainability of smallholder agriculture in Africa. A wide range of indicators have been reported in the scientific literature to support assessments of drought at multiple scales (local, regional, national) and from different perspectives, including their physical, environmental, agronomic and socio-economic (SEVI) impacts. In this study, an approach similar to a systematic review was undertaken to evaluate the range of indicators used to assess drought impacts in agriculture, with a specific focus on those that inform SEVI assessments of farmer capacities to build future resilience to drought. Based on an analysis of 355 articles from the scientific and grey literature, the majority (86%) of drought-related indicator articles were published in the last decade, with half (51%) focused on Africa and Asia. In Africa most studies were targeted at South Africa, Ethiopia and Kenya. Regarding the types of indicators used, over a quarter (27%) of studies relied on SEVI indicators with meteorological (20%), composite (19%), hydrological (12%), agricultural (8%), remote sensing (8%) and environmental (4%) indicators also being used. Most (50%) drought impact studies were conducted at the regional level, with a fifth (21%) at national and 15% at local scales, respectively. Within the literature that adopted SEVI assessments of drought, 35 different indicator types were reported. These specifically focused on vulnerability, drought resilience, coping strategies and other aspects involving indigenous knowledge, gender, risk-based and perception-based indicators, as well as various SEVI metrics. The research also identified the challenges associated with using indicators to assess drought resilience, and to support resilience frameworks, and areas for future research to inform policies to support drought risk management and sustainable agricultural development.

## 1. Introduction

Most countries in Africa are heavily dependent on agriculture as the cornerstone of their economy helping to support rural livelihoods and underpinning socio-economic (SEVI) development. Although there has been significant investment and expansion of irrigated croplands following a period of low investment and sustained under performance in irrigation development (Higginbottom *et al* 2023), most production is still rainfed and therefore prone to extreme events including drought. These pose a significant threat to SEVI development at all levels, from individual household's dependent on subsistence agriculture to local NGOs, government agencies, external donors, and international organizations involved in drought risk management and disaster relief provision (Gautam 2006a). Globally, Africa stands out in terms of the frequency of droughts it experiences, with 382 events reported between 1960 and 2006, more than double the number of equivalent incidents in Asia (Gautam 2006a). However, whilst significant progress has been made to mainstream drought preparedness into broader development strategies and policies, new approaches will be needed to improve risk management to cope with the expected

increased frequency and magnitude of droughts under a changing climate. More persistent and debilitating droughts coupled with greater rainfall uncertainty will inevitably increase the vulnerability of those communities whose livelihoods are dependent on rainfed production.

Approximately 60% of sub-Saharan Africa (SSA) is reported to be vulnerable to frequent and severe droughts (Esikuri 2005, Shiferaw *et al* 2014) with many East African countries facing increased aridity due to recurring drought (Haile *et al* 2020). The impacts of drought on agriculture are varied and include direct impacts on crop production, livelihoods, health, assets and infrastructure, and indirect impacts on environmental degradation and human wellbeing (Shiferaw *et al* 2014). For example, in South Africa, Baudoin *et al* (2017) reported that drought led to increased unemployment and debt service costs for farming enterprises through increased pressure on agricultural systems, with indirect impacts on food availability for neighbouring countries which rely on South African imports. Drought is also one of the main causes of famine and malnutrition in the African region. Increasing climate variability and dependence on rainfed agriculture as a main source of livelihood has resulted in major economic losses and increased vulnerability of farmer households (Gautam 2006a, Shiferaw *et al* 2014).

The occurrence of climate related hazards and the magnitude of its effects is significant across the Global South (Dechassa *et al* 2017). This is especially evident in Africa in the form of droughts and floods, and several studies highlight areas or countries across the continent that are at higher risk of and more vulnerable to climate-related impacts. Dechassa *et al* (2017) discussed the devastating impacts in SSA and reported that 350–600 million Africans will be at risk of water stress, extensive floods, drought, famine and endanger to life by the 2050s. Approximately 60% of SSA is vulnerable to frequent and severe droughts (Esikuri 2005, Shiferaw *et al* 2014), and it is estimated that temperatures will rise by +2.1 °C in SSA due to a changing climate (Kassie *et al* 2017). Kilimani (2015) described the impacts of frequent drought occurrences on the human and economic development in the region, claiming 70%–80% of losses for both aspects, whilst Mkonda *et al* (2020) reported that farmers in Tanzania were negatively impacted from climate impacts due to their low adaptive capacity. In addition, many East African countries are facing aridification due to recurring drought (Haile *et al* 2020). Studies also emphasise the impacts from frequent and intense droughts and increasing agricultural risks in southern Africa (Magombeyi *et al* 2008, Meza *et al* 2021, Myeki and Bahta 2021). Past droughts in South Africa have also affected farmers through the loss of crops and employment (Magombeyi *et al* 2008) and impacted on water supply systems (Meza *et al* 2021). For example, the 2014–2016 drought in South Africa affected approximately 40 million people, where a cereal deficit of 9.3 million tons and 640 000 livestock deaths were reported (Myeki and Bahta 2021).

### 1.1. Drought indicators and resilience

In Africa, there are an estimated 33 million smallholder farms which contribute *c.*70% to food supplies. With greater investment in smallholder agriculture, many countries have the potential to increase food production, reduce poverty and increase food security (IFAD 2023). However, when droughts occur the impacts are often severe and do not fall equitably across different sectors due to power inequalities. For example, the economic and political power vested in the commercial horticultural export sector may secure priority over water supplies from smallholders or those involved in agricultural production for domestic markets. Contractual obligations for export produce may also reduce the availability and increase food prices in local markets, and lower skilled workers in the horticultural sector may be laid off when production falls due to drought. Thus, the impacts of drought on marginalized communities and those engaged in smallholder agriculture are often exacerbated. Consequently, development agencies and policy attention are now directing more attention towards ‘building resilience’ and the ‘adaptive capacity’ of smallholders to cope with drought. But what exactly do these terms mean in the context of the utility of drought indicators?

Resilience refers to the ability of an entity (e.g. agricultural system) to respond to a specific shock or stress, in this case drought (Folke, 2006), with different components of resilience relating to different types of response. Resilience is often referred to in terms of a system ‘capacity’ or ‘ability’ to respond (Manyena *et al* 2019) with Jeans *et al* (2017) defining three dimensions of capacity, including (i) absorption, (ii) adaptation and (iii) transformation. Each describe different extents to which a ‘system’, and its sub-components can respond to change, to retain its original function or integrity, or to change function while maintaining desired system outcomes. Jeans *et al* (2017) defined absorptive capacity as the capacity to bounce back by ensuring stability. In contrast, adaptive capacity refers to ‘the capacity of a system (or part of) to learn, combine experience and knowledge, adjust its responses to changing external drivers and internal processes, and continue developing within the current stability domain’ (Bene *et al* 2014: 600). This implies there would not be a significant system restructuring, though some may adapt

their functioning to some extent to cope with future changes (Walker *et al* 2004). Finally, transformative capacity is defined as ‘the capacity to fundamentally change the interlinked ecological, economic, or social processes and structures that lead to undesirable outcomes, often requiring deep changes in structures and power imbalances that are rooted in culture and expressed through policies, management, and social practices’ (Biggs *et al* 2021: 4). Transformation is therefore different in that it implies system reorganization to maintain desired system outcomes (Walker *et al* 2004) or to move to an alternative, more desirable system outcome (Zurek *et al* 2022).

The term ‘drought indicator’ has a broad definition used to quantify and characterise drought events usually in terms of their duration (onset and termination), intensity and severity (Bachmair *et al* 2016b). There are many such indicators in use which can be categorized according to the type of drought and the intended operational use. For example, precipitation and temperature-based indicators are typically used for tracking meteorological droughts, soil moisture or vegetation stress indicators are used for agricultural droughts, and streamflow, reservoir or groundwater level indicators are most appropriate for assessing hydrological droughts (Zargar *et al* 2011, Bachmair *et al* 2016b). Indicators may also be grouped according to the type of impact (e.g. SEVI) or sector (e.g. agricultural, industrial, public health), whilst others may be grouped according to the stage of the drought (e.g. forecasting drought onset or post-drought impact). Indicators can also be categorized based on their method of calculation, spatial and/or temporal resolution, or data source. Given the complexity of drought and its multifaceted dimensions, the use of combined, multi-variate or composite indicators is also gaining interest (Hao and Singh 2015, Bachmair *et al* 2016).

## 1.2. Indicator knowledge gaps

Whilst numerous indicators exist, Bachmair *et al* (2016) identified key areas that need further development. These included addressing the lack of SEVI indicators—understanding how drought affects the supply and demand of goods, and whilst there is little evidence on ‘thresholds’ and SEVI and ecological impacts there is also a lack of consensus as to which indicators are best suited to understand drought impacts in specific sectors. There is also a need to better understand the different types of indicators used to assess drought risks in agriculture particularly in the African context given its high susceptibility to drought (Haile *et al* 2019). It has been reported that government interventions tend to focus on the consequences of drought, by providing emergency support, and forego addressing the root causes and developing mechanisms to better equip communities and build resilience to drought (Baudoin *et al* 2017). Whilst extensive reviews on drought indicators have been conducted to evaluate their relative strengths and limitations (Zargar *et al* 2011, Bachmair *et al* 2016b) there are still gaps in understanding how indicators can be used to assess SEVI impacts and the capacities of communities to build resilience to drought. As part of a broader study assessing equitable resilience in African agriculture, the aim of this research was to evaluate the utility of SEVI related indicators to reflect the impacts of drought, and the capacities available to build resilience to drought for smallholder farmers engaged in African agriculture.

## 2. Methodology

In this study, an approach similar to a systematic review (CEE 2022) was adopted, in terms of defining an explicit research question, a search strategy (with pre-specified eligibility criteria, search strings and bibliographic databases) and a data extraction strategy. However, our approach also included discursive analysis and critique of the screened literature, which neither a systematic review nor rapid evidence assessment (Varker *et al* 2015) would conventionally include. A brief description of each stage including formulating the key research question, developing, and conducting the search strategy and data synthesis and reporting is provided below.

### 2.1. Research questions

The primary research question was ‘to what extent do the utility of different indicators used globally reflect the impacts of drought, and the capacities of smallholder farmers to build resilience to drought and how relevant are these indicators within the context of African agriculture’. This question was then broken down into three sub-components to accommodate the various types of indicators of relevance. These included (i) what indicators have been successfully used to understand the SEVI impacts of drought in the agricultural sector, (ii) what indicators are relevant to understand the effectiveness of specific strategies to support absorptive, adaptive and transformational capacities to drought risk, and (iii)

how can indicators be usefully integrated into existing resilience frameworks to inform policy responses to reduce impacts and improve drought risk management?

The primary question was unpacked using a conventional population (P), exposure (E), comparator (C) and outcome (O) or PECO framework. The population of interest was smallholder agriculture in Africa, defined as individuals who typically farm on less than 1 hectare of land with a focus on either pastoral, crop, livestock or mixed production systems. The environmental risk to which the population is exposed was 'drought'. The term 'drought' has many different definitions depending on the cause of water deficiency and receptor of impacts. Here we define drought based on its impact as a period of (perceived) reduced water availability (or water stress) to an agricultural sector of interest, due to an imbalance between supply of, and demand for water. The comparator (C) or counterfactual was 'without drought' as the review was interested in comparing outcomes to a situation if a drought had not occurred. This reflects a typical year, or conditions experienced by a neighbouring region that did not experience the drought. The outcomes of interest were the impacts of drought, and the absorptive, adaptive, and transformational capacities of farmers to build resilience to drought. A range search words for each PECO term were defined (table 1) to inform the development of relevant search strings.

## 2.2. Search strategy

Based on the relevant PECO terms (table 1) several search strings were trialled by searching the title, abstract or author-specified keywords in three bibliographic data sources including the peer reviewed and grey literature and institutional websites. Two search strings including 'Drought AND Indicator\*' and 'Drought AND Indicator\* AND Smallholder\* OR Subsistence\*' were ultimately selected. Literature searches were limited to sources published between 2000 and 2022. Geographical terms (such as 'Africa') were not considered as an explicit search term as they may have restricted the search and excluded studies that provided a relevant broader perspective. Only literature published in English was reviewed. Two main sources including bibliographic databases and organizational websites were used (table 2). Academic database sources were sampled first, to avoid duplication later from grey literature and websites. All hits generated from both the search strings were first retrieved from the academic bibliographic databases (Scopus, Web of Science, Science Direct). For other sources (e.g. DOAJ, JSTOR and AGRIS-Land portals) only the first search string was considered. A maximum of 100 hits were considered for review from the organizational websites. For search platforms such as Google, the first 50 hits were considered for review using both search strings. This limit was set based on a preliminary check, which indicated that results beyond these points rarely returned relevant literature. After retrieving all reference sources, all duplicates were removed and a reference list that included all titles and abstracts was produced.

The literature was screened for relevance using inclusion and exclusion criteria drawing on terms given in table S1. These included reference to relevant subjects, types of exposure/intervention, comparators, methods used and reported outcomes. Relevant subjects included any countries/regions all scales from field/farm to regional and national levels, smallholder agriculture including subsistence farmers, the plantation sector, food crop and livestock production systems and biophysical, agricultural, social, economic, environmental, or meteorological indicators used for assessing drought impacts on agriculture. Subjects excluded were crops grown for biofuels, forestry and literature focused on genetic breeding for markers or traits and use of genetic indicators to improve plant resilience to abiotic (drought) stress.

The inclusion criteria for 'types of exposure or intervention' included studies on the absorptive, adaptive and/or transformational capacities that build resilience and reduce the vulnerability of agricultural systems to drought risks. This included policy or governance interventions to build social resilience and reduce drought risks on agriculture (e.g. crop insurance, disaster risk reduction (DRR) initiatives, micro finance support, climate information services, early warning systems), enabling policies to support stakeholder engagement in drought risk management, training and extension services to help farmers and communities build adaptive capacity, and ecosystem-based interventions to build resilience to drought. The 'comparator' criteria included any reported comparisons of mitigation impacts based on policy or management interventions for 'before' and 'after' specific drought events. Any methods used, including quantitative and qualitative studies or combination methodologies, the use of indicators to understand the effectiveness of specific strategies to support adaptation and capacity building, and sub-regional or sector specific case studies were included. Outcomes included studies that reported on how the application of indicators has built resilience and improved levels of preparedness to cope with the onset of droughts, the application of indicators to demonstrate improved capacity to understand drought impacts and responses and reported application of indicators to understand the effectiveness of specific strategies to support absorptive, adaptive and transformational capacities to drought risk.

**Table 1.** Breaking down the research question (PECO).

|                | Population                   | Exposure                                                 | Outcome                                    |
|----------------|------------------------------|----------------------------------------------------------|--------------------------------------------|
| General        | Agricultur*                  | Climat* change                                           | Innovation                                 |
|                | Agriculture sector           | Weather extremes                                         | Early warning system                       |
|                | Crops and livestock          | Drought                                                  | Drought risks                              |
|                | African agriculture          | Climate risks and hazards                                | Resilience                                 |
|                | Indicator                    | Drought impact                                           | Resilience framework                       |
|                | Socio-ecology                | Drought risk management                                  | Sustainability                             |
|                | Land                         | Capacity building in disaster risk management            | Capacity                                   |
|                | Water                        | Building capacity                                        | Absorptive capacity                        |
|                |                              | Building resilience                                      | Transformational capacity                  |
|                |                              | Adapt*                                                   | Adaptive capacity                          |
|                |                              | Climate smart agriculture                                | Improved water efficiency                  |
|                |                              | Conservation agriculture                                 | Improved crop yields                       |
|                |                              | Animal husbandry                                         | Effectiveness of the strategies            |
|                |                              | Diversification                                          | Policy response                            |
|                |                              | Sustainable intensification                              |                                            |
|                |                              | Increased water availability (RWH, irrigation)           |                                            |
|                |                              | Water and land availability                              |                                            |
|                |                              | Policy                                                   |                                            |
|                |                              | Enabling regulatory and policy frameworks                |                                            |
| Socio economic | Community                    | Advocacy for smallholder support                         | Community-based adaptation                 |
|                | Vulnerable communities       | Participatory stakeholder engagement                     | Improved and diversified rural livelihoods |
|                | Smallholder                  | Training and extension                                   | Improved household wellbeing               |
|                | Subsistence                  | Political willingness to support smallholder agriculture | Collaboration                              |
|                | Gender                       | (Climate-resilient) financial services                   | Local farmers' knowledge                   |
|                | Women versus men             |                                                          | Experiential knowledge                     |
|                | Youth                        |                                                          | Food security                              |
|                | Education class              |                                                          |                                            |
|                | Employment status            |                                                          |                                            |
|                | Income class                 |                                                          |                                            |
| Environmental  | Agroecosystem                | Climate-resilient rural infrastructure                   | Ecosystem conservation                     |
|                | Agroforestry                 | Ecosystem-based adaptation                               | Ecosystem risk                             |
|                | Ecosystem                    | Ecological intensification                               | Ecosystem adapt*                           |
|                | Ecosystem services           | Landscape management/restoration                         | Ecosystem remediation                      |
|                | Natural resources            | NR restoration and enhanced NRM                          | Ecosystem resilien*                        |
| Bio physical   | Institutional infrastructure | Institutional support                                    | Decentralized institutional framework      |
|                | Government                   | Institutional capacity building                          |                                            |
|                | NGOs and private sector      | Improved government support                              |                                            |
|                | Farming systems              |                                                          |                                            |

Filtering using the inclusion and exclusion criteria was initially undertaken based on the article title, and a second filter then applied based on the content in the abstract or technical report summary. The filtering process was undertaken by two researchers working independently. Finally, a comparison between the researchers accepted and rejected references was undertaken to ensure consistency in the application of the inclusion/exclusion criteria.

### 2.3. Data extraction and synthesis

The screened literature was first analysed to produce a set of summary statistics relating to the types and numbers of indicators identified, the publication year, geographical (country) focus, scale of application

**Table 2.** Database sources and organization websites used for the literature searches.

| Bibliographic databases  | Organization                                  | Website                                                                       |
|--------------------------|-----------------------------------------------|-------------------------------------------------------------------------------|
| Web of science           | World bank                                    | <a href="http://www.worldbank.org">www.worldbank.org</a>                      |
| Scopus                   | Food and agriculture organization (FAO)       | <a href="http://www.fao.org">www.fao.org</a>                                  |
| Science direct           | International fund for agricultural           | <a href="http://www.ifad.org">www.ifad.org</a>                                |
| Directory of open Access | Development (IFAD)                            | <a href="http://www.resources.org">www.resources.org</a>                      |
| journals (DOAJ)          | Resources for the future                      | <a href="http://www.cgiar.org">www.cgiar.org</a>                              |
| JSTOR                    | Consultative group on international           | <a href="http://www.afdb.org">www.afdb.org</a>                                |
| AGRIS land portal        | Agricultural research (CGIAR)                 | <a href="http://www.adb.org">www.adb.org</a>                                  |
| googlescholar.com        | African development bank                      | <a href="https://climate.org">https://climate.org</a>                         |
|                          | Asian development bank                        | <a href="http://www.up.ac.za/ceepa">www.up.ac.za/ceepa</a>                    |
|                          | Climate institute                             | <a href="http://www.scidev.net">www.scidev.net</a>                            |
|                          | Centre for environmental economics            | <a href="http://www.ids.ac.uk">www.ids.ac.uk</a>                              |
|                          | and Policy in Africa                          | <a href="http://www.iied.org">www.iied.org</a>                                |
|                          | Science and development network               | <a href="http://www.wur.nl">www.wur.nl</a>                                    |
|                          | Institute for development studies (IDS)       | <a href="http://www.unep.org">www.unep.org</a>                                |
|                          | International institute for environment and   | <a href="http://www.weadapt.org">www.weadapt.org</a>                          |
|                          | development (IIED)                            | <a href="https://futureclimateafrica.org">https://futureclimateafrica.org</a> |
|                          | Wageningen university                         | <a href="http://www.asiapacificadapt.net">www.asiapacificadapt.net</a>        |
|                          | United nations environmental programme        | <a href="http://www.iwmi.org">www.iwmi.org</a>                                |
|                          | (UNEP)                                        | <a href="http://www.google.com">www.google.com</a>                            |
|                          | WeAdapt (global)                              |                                                                               |
|                          | Future climate for Africa                     |                                                                               |
|                          | Asia Pacific adaptation network, Africa Adapt |                                                                               |
|                          | International water management institute      |                                                                               |
|                          | (IWMI)                                        |                                                                               |
|                          | Google                                        |                                                                               |

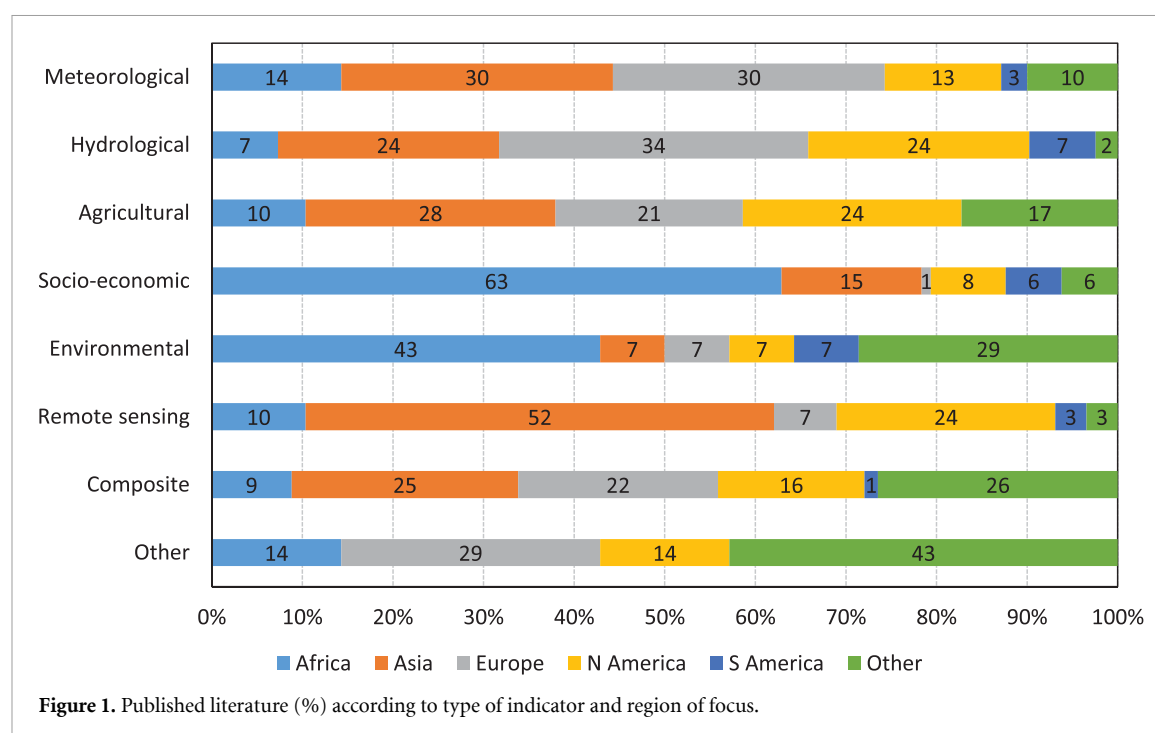
and relevance to specific agricultural sub sectors. A typology of drought indicators was defined including meteorological, agricultural, hydrological, remote sensing, socio economic, environmental, composite and ‘other’ categories. Literature that specifically focussed on the development and application of SEVI indicators was then selected for the narrative synthesis, with evidence extracted and synthesized to address the three sub-research questions defined in section 2.1. These three sub-questions were answered systematically using the filtered indicators derived from those studies that specifically focused on SEVI aspects within the context of African smallholder agriculture.

### 3. Results and discussion

#### 3.1. Statistical summary of drought indicator types, scales and application

A summary of the number of individual sources of evidence identified from various bibliographic databases and search engines (peer and grey literature), and from organizational websites is given in figure S1. In total, 1414 sources were identified with most (92%) attributed to academic and open access published literature. Following the removal of duplicates, then title and abstract screening, 355 sources were selected for data extraction (figure S2). A temporal analysis of the number of drought indicator papers published between 2000–2022 is given in figure S3. From 2000 and 2014 there were a limited number of papers published each year, but then a noticeable uplift occurred from 2015, with most (86%) sources being published between 2015–22. The significant increase in drought indicator related publications in recent years (figure S3) may also be linked to the increased frequency and severity of droughts experienced in Africa. Our analysis noted that most publications on drought indicators were focused on countries in this region, which is not surprising given the increasing incidence of events in Africa (Kassie *et al* 2017) and that >75% of rural communities in Africa are dependent on rainfed agriculture for food and livelihoods (Chisadza *et al* 2013).

In terms of geographical spread, a quarter (26%) of all drought indicator studies were reported in Africa. Nearly a fifth (17%) of studies were focussed on Europe, with 15% in North America, 4% in South America, and 1% each in Central America and Australia. A small proportion (11%) of studies did not specify a geographical region or country. For Africa, the countries where studies were undertaken is summarized in figure S4, with South Africa, Ethiopia and Kenya being the most popular for drought indicator application. A focus on these countries may be due to past drought events and the risks from future droughts. Indeed, several assessments have noted that South Africa is a highly drought

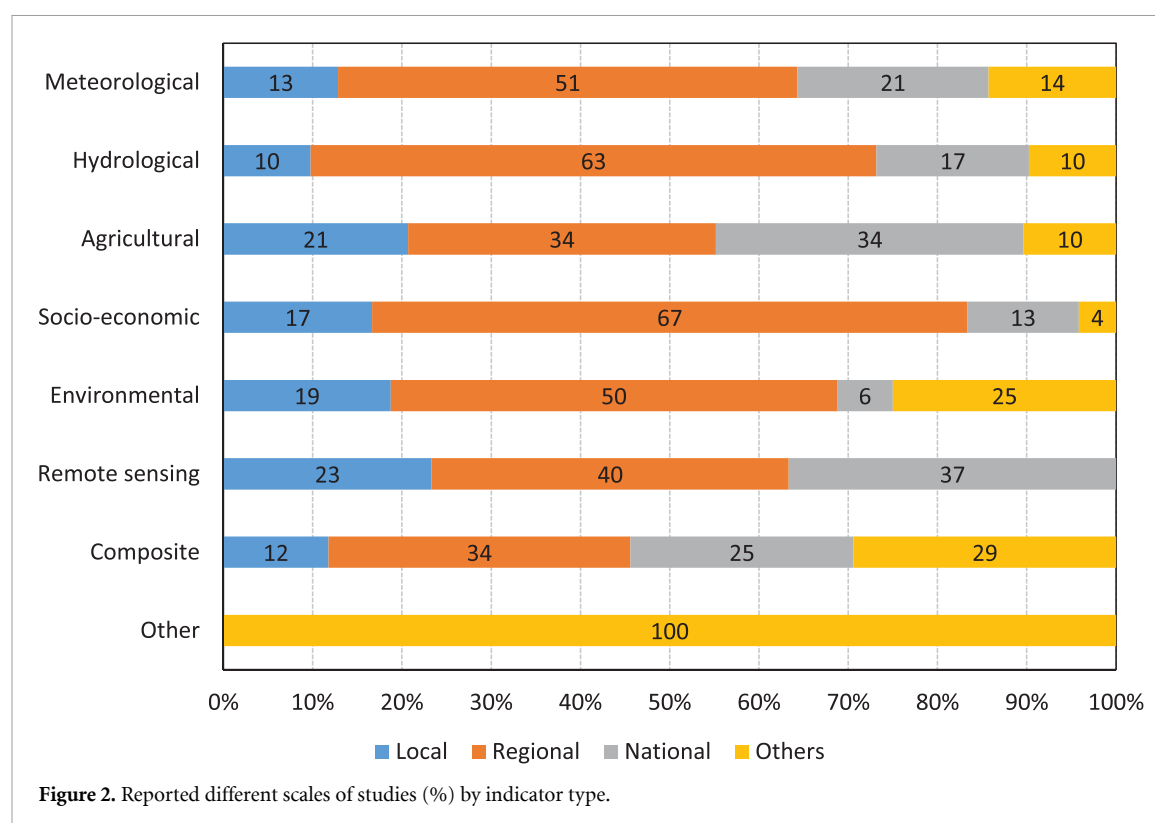
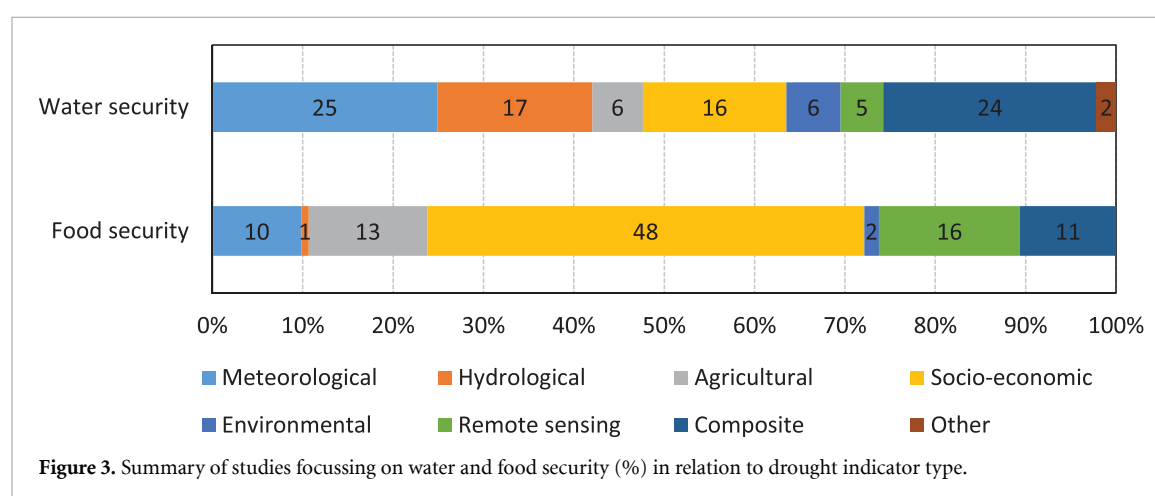


prone country with a high risk of impacts of drought on agriculture (Carrao *et al* 2016, Baudoin *et al* 2017, Meza *et al* 2021).

Based on the 355 studies, a typology of drought indicators was then defined including meteorological, hydrological, agricultural, SEVI, environmental, remote sensing, composite and 'other' and analysed by geographical region (figure 1). For Africa, 14% of studies focused on the development and application of meteorological indicators, 7% on hydrological indicators, 10% on agricultural and remote sensing indicators, 63% on SEVI indicators, 43% on environmental indicators and 9% used composite indicators. For the 93 Africa (only) studies, the proportional split was slightly different, with 11% focused on meteorological indicators, 3% each on agricultural, hydrological and remote sensing indicators, 66% focused on SEVI indicators, and 6% each for composite and environmental indicators. Only 1% of studies did not report any specific indicator type.

The literature was then assessed for its scale of application ranging from local (household, farm, town/city), to regional (district, province, landscape) and national (country) level (figure 2). For Africa, nearly a fifth (18%) of studies were at local scale, 63% at regional and 17% at national scale. Most studies (67%) that focussed on SEVI indicators were at the regional scale, with 17% at the local and 13% at national scale. Similarly, for other drought indicator typologies, most applications were at the regional scale. Meza *et al* (2021) assessed drought literature in South Africa and found that there was significant information on drought impacts at the regional level but found only one national assessment of drought risk on agricultural systems and a very few studies at the local level. This signifies a multi-scalar lack of understanding of drought risk from local to national scales, despite the importance of comprehensive assessments being important to assess the impacts and risks at community, region, system and/or sector levels, to develop effective adaptation strategies (Meza *et al* 2021). Mdungela *et al* (2017) also highlighted the need for social and environmental (drought) vulnerability indicators at the local community level to understand drought risks links to outputs and food security.

Finally, the literature was assessed for its sector focus, and whether the studies were predominantly water or food security focussed (figure 3). The main types of indicators used to assess water security were meteorological, composite, and hydrological. SEVI indicators were predominantly used to assess food security which includes food cropping, livestock and mixed farming systems. For Africa, 39% of the drought indicator literature was water security related compared to 58% for food security, with SEVI indicators being the dominant approach for both studies focussing on water (47%) and food security (76%). Bacon *et al* (2022) noted that in recent years the focus on water security had broadened to also include political aspects. The 355 studies were then further filtered to provide deeper insights into how SEVI indicators were being used to understand the resilience of smallholders to drought. The key findings are briefly summarized below.



### 3.2. Indicators to understand the SEVI impacts of drought

Based on the screened literature, 35 SEVI focused studies were identified in which 23 indicators had been used to understand the SEVI impacts of drought on agriculture. The results are summarized in table 3. In general, three broad categories were identified including (i) drought vulnerability related indices, (ii) drought resilience/coping indicators and (iii) ‘other’ indicators focussing on a range of aspects including indigenous knowledge, gender, perception and disaster risk management. SEVI impact indicators included LPCIEA which is a multi-criteria index used to assess the social resilience of villagers, particularly in the context of drought. It evaluates resilience based on six factors, namely land use, population, crops, irrigation level, education, and the age of village residents (Ebrahimi 2022). Other SEVI indicators included metrics on agricultural land holdings (<2 ha), family incomes and secondary sources of income, business equity, operating profit (per unit area), returns on capital, and debt to income ratios. Hagenlocher *et al* (2019) reported that most SEVI studies (62%) relied on vulnerability indices (Vis) to assess the social dimensions of drought risk.

Evidence from each of these studies (table 3) were then used to understand smallholder strategies to build capacity to drought risks, and how selected indicators could then support the development of resilience frameworks to inform policy responses to drought risks.

**Table 3.** Summary of the different types of socio-economic indicator used and their application.

| Indicator                                   | Application                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | References                       |
|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| IPCC-drought vulnerability index (IPCC-DVI) | Assessed the smallholder farmers vulnerability to climate change based on the socio economic and biophysical characteristics of Chiredzi district                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Jiri <i>et al</i> (2017)         |
|                                             | Analysed smallholder's livelihood vulnerability to drought at a household level in Awash, Ethiopia using DVI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Maru <i>et al</i> (2021)         |
|                                             | Evaluated different components of VI among the communities that includes biophysical, social and economic indicators depicting the three components of drought vulnerability: exposure (temperature, rainfall, population, drought frequency, vegetation cover), sensitivity (% irrigated land and agric. Dependent and landless people) and adaptive capacity (ownership, diversity crops, income, literacy, insecticide, herbicides, fertilizer, changing of crop varieties and planting dates, insurance, market and finance)                                                                                                                                                                                                                                                                                                                           | Mohammed <i>et al</i> (2018)     |
|                                             | Developed a framework for smallholder's vulnerability assessment with a focus on household planting structure and family related indicators in arid and semi-arid rainfed agricultural areas                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Guo <i>et al</i> (2022)          |
| Livelihood vulnerability index (LVI)        | Analysed overall socioeconomic vulnerability of North Darfur households using biophysical, social and economic indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Mohammed <i>et al</i> (2018a)    |
|                                             | Analysed the effects of climate change on rice farmers' livelihoods using LVI based on seven components including health (H), food (F), water (W), socio-demographic profile (SDP), livelihood strategies (LS), social network (SN), and natural disasters and climate variability (NDCV) in an agro-ecological region                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Ho <i>et al</i> (2022)           |
|                                             | Constructed LVI using three components of vulnerability including exposure (change in temperature and precipitation, occurrence of extreme events), sensitivity to ecosystem (land use/cover change, land suitability, land management, irrigation potential), sensitivity to agriculture (changes in productivity, diversity of crop species), adaptive capacity to wealth (farm size, number of livestock, loans, non-agricultural income), adaptive capacity to technology (insecticide and fertilizer supply, seed supply, irrigation potential), adaptive capacity to infrastructure (access to roads, schools, vet services, markets, saving and credit facilities, electricity and phones) and adaptive capacity to community (sex of household heads, education level, health services, radio ownership, availability of extension skill/training) | Dechassa <i>et al</i> (2017)     |
|                                             | Constructed LVI with identified econometric and integrated indicator approaches including biophysical and socio-economic attributes and their role in exposure, sensitivity and adaptive capacity differences among smallholder farmers in different agroecology's and different type of cropping seasons using principal component analysis                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Asfaw <i>et al</i> (2021)        |
|                                             | Evaluated the vulnerability of smallholder's livelihoods to climate change using a composite index as LVI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Abeje <i>et al</i> (2019)        |
|                                             | Assessed gender vulnerability to climate induced shocks using LVI. LVI was estimated quantitatively as a function of adaptive capacity (AC), exposure (E) and sensitivity (S) of households to climate shocks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Mekuyie (2021)                   |
| Drought vulnerability indicators (DVI)      | Evaluated economic components of DVIs including insuring crops, land ownership type, access to loan among wheat farmers in Mashhad, Iran                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Khoshnodifar <i>et al</i> (2012) |
|                                             | Classified DVIs based on exposure to drought, sensitivity and selected vulnerability factors including basin reaches, land use pattern, soil type, monthly rainfall departure, surface, and ground water availability                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Kar <i>et al</i> (2018)          |

(Continued.)

**Table 3.** (Continued.)

| Indicator                                                               | Application                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | References                                          |
|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| Social vulnerability index (SVI)                                        | Assessed social vulnerability to climate change of smallholding farmers in Zambia using SVI indicator that integrated demographic factors (household size and literacy), economic factors (diversified sources of income, and household income level), and social factors (ownership of media (TV, radio), and access to climate change information)                                                                                                                                                                                                                                                                                                                                                      | Dumenu and Takam Tiamgne (2020)                     |
| Economic vulnerability index (EVI)                                      | Identified indicators including lack of access to resources; unemployment; price sensitivity of products; on-farm diversification; level of debt; market access; financial safety nets/ alternative source of income; off-farm diversification as economic vulnerability to drought in South Africa                                                                                                                                                                                                                                                                                                                                                                                                       | Mdungela <i>et al</i> (2017)                        |
| Composite drought index of socio-economic vulnerability                 | Assessed vulnerability of communities to drought using quantitative (multicriteria vulnerability assessment approach that resulted a composite drought index of socio-economic vulnerability) and qualitative (database analysis and development) analysis                                                                                                                                                                                                                                                                                                                                                                                                                                                | Dumitraşcu <i>et al</i> (2018)                      |
| Vulnerability capital index (VCI)                                       | Summarized the benefits of VCI and their inclusion in climate adaptation models to provide insights for policy design and measures designed for vulnerable farmers during drought                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Muthelo <i>et al</i> (2019)                         |
| Ecological vulnerability index (EVI)                                    | Constructed EVI with selected ecological variables including over grazing, soil erosion, land degradation, surface and ground water supply and land use management to reduce drought vulnerability                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Bahta <i>et al</i> (2019)                           |
| Agricultural drought resilience index (ADRI)                            | Constructed ADRI with selected factors affecting livestock farmers agricultural drought resilience to food insecurity that included assets, adaptive capacity, social safety nets and climate change<br>Used ADRI to determine the effects of drought resilience on the welfare of farming households                                                                                                                                                                                                                                                                                                                                                                                                     | Myeki and Bahta (2021)<br>Banda <i>et al</i> (2016) |
| Drought coping strategy index (DCSI) and drought resilience index (DRI) | Used DCSI to incorporate both income and consumption smoothing strategies and measures to which households cope with drought impacts. In addition, DRI was used to measure household resilience to drought                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Murendo <i>et al</i> (2011)                         |
| Drought Exceedance Probability Index (DEPI)                             | Used DEPI based on cumulative monthly rainfall anomalies and evapotranspiration to assess hydrology for dam construction                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Bahta and Myeki (2022)                              |
| Composite drought hazard indicator (CDHI)                               | Calculated CDHI for irrigated and rainfed crop systems separately using drought indices based on historical climate, derived drought exposed areas as irrigated and non-irrigated crops by local municipality. Vulnerability to drought was assessed through this approach that includes social susceptibility indicators (unemployment, medical assistance, sanitation, dependency ratio, alternative sources of income, violence and crime rates, gender inequality, food security), environmental susceptibility (farmland ratio, land degradation index, fertilizer application rate), coping capacity (total dam storage, borrowed money, social grants, road density, area equipped for irrigation) | Meza <i>et al</i> (2021)                            |

(Continued.)

**Table 3.** (Continued.)

| Indicator                                                                                                    | Application                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | References                                                           |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Blended drought index (BDI)                                                                                  | Presented a blended drought index (BDI) as a composite indicator for estimating the impact of drought as a drought hazard map. BDI constructed using a copula function to combine meteorological (SPI and SPEI) and agricultural (SSI and SVI) drought characteristics that impair the population's ability to ensure food and water scarcity                                                                                                                                                                                                                                                                                            | Luetkemeier <i>et al</i> (2017)                                      |
| Risk index (RI)                                                                                              | Evaluated RI to drought based on indicators of hazard (number of drought damage evaluations and drought incidence), exposure (the percentage of population living in households without access to piped water), and vulnerability (poverty and educational level at the municipal level)                                                                                                                                                                                                                                                                                                                                                 | Sena <i>et al</i> (2017)                                             |
| Indigenous knowledge system (IKS) indicators                                                                 | Assessed agricultural seasons and the risk of drought and other climatic impacts<br>Evaluated different IKS indicators for rangeland management to understand rangeland degradation, landscape grazing suitability and potential, livestock production performances<br>Compared selected IKS indicators including animal species, cloud formations, temperature, plant characteristics with science-based predictors such as temperature, rainfall, windspeed and direction, sunshine duration and cloud cover to assess reliability of indigenous knowledge predictors to predict climate—rainfall times, seasons, and rainfall amounts | Jiri <i>et al</i> (2018)<br>Oba (2012)<br>Ankrah <i>et al</i> (2022) |
| Gender parity index (GPI)                                                                                    | Used GPI to indicate different levels of inequality in a household in terms of five domains of empowerment including production, resources, income, leadership and time                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Maltitz and Bahta (2021)                                             |
| Gender analysis indicator                                                                                    | Used gender analysis as an indicator to understand drought impacts in smallholder agricultural households and their adaptive capacity to drought                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Kiumbuku <i>et al</i> (2020)                                         |
| Perception index (PI)                                                                                        | Utilized PI and primary data from 207 smallholder livestock farmers based on a structured questionnaire survey and multistage sampling procedures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Bahta (2021)                                                         |
| Standardized precipitation and evapotranspiration index (SPEI)                                               | Addressed the association between drought exposure in early life and childhood under nutrition in Ethiopia                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Dimitrova (2021)                                                     |
| Sustainable development indicator (SDI)                                                                      | Used a Delphi based approach that reflects the opinion of experts for selection of SDIs from socioeconomic activities that had a cause-and-effect relationship with desertification                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Hai <i>et al</i> (2016)                                              |
| LPCIEA indicator—land use, population, crop level, education, irrigation level, and age of village residents | Used the LPCIEA indicator to identify drought resilient and liveable villages to assess the areas of change including water supply and their trend to drought severity in southwest Iran, Dorodzan Dam, Fars Province                                                                                                                                                                                                                                                                                                                                                                                                                    | Ebrahimi (2022)                                                      |
| Economic indicators                                                                                          | Used economic indicators including business equity, operating profit per ha, return on capital, and debt to income ratio to assess the impact of farm economic performance to drought                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Lawes and Kingwell (2012)                                            |
| Socioeconomic indicators                                                                                     | Identified selected socioeconomic indicators that includes family's monthly income, agricultural land holding of < 2 ha and non-availability of secondary sources of income for understanding the vulnerability of households to drought                                                                                                                                                                                                                                                                                                                                                                                                 | Saha <i>et al</i> (2012)                                             |

### 3.3. Indicators to understand smallholder strategies to build capacities to drought risk

Among the dominant indicators identified to understand smallholder's strategies to build capacities to drought risks included vulnerability, composite and drought resilience indicators (DRIs) (12 of 23). The VIs included metrics that were linked to either social, livelihoods, economics, capital or ecology. Composite indices included both VIs and biophysical drought indicators that could be useful to understand strategies to support absorptive, adaptive and transformational capacities. DRIs were constructed using variables including production and consumption as major factors. Other factors used to construct DRIs included assets, social safety nets (cash, training, food support, water rights, equipment, sanitary latrines, farm input), and adaptive capacity.

Within the literature, the VIs including the IPCC-drought vulnerability index (IPCC-DVI) and the livelihood vulnerability index (LVI), were the dominant ones used, with each representing 5 studies from the sample of 35. For example, Jiri *et al* (2017) proposed using the IPCC-DVI to map local area vulnerability as a basis to recommend coping and adaptation strategies to counter the impacts of climate change hazards. They reported that severe economic vulnerability was linked to areas where a large proportion of the population depends on agriculture with limited alternative employment. Economic vulnerabilities can be reduced by modifying the exposure and sensitivity of communities to climate risk and increasing their adaptive capacity, including the adoption of crop varieties that can tolerate increased levels of soil moisture stress, the timely supply of pesticides and insecticides, interventions including weather indexed crop and livestock insurance, expansion of rural technologies, and creating awareness to engage in livelihood diversification strategies such as trading of agricultural products during off farm periods (Maru *et al* 2021). Studies that used the IPCC-DVIs also included several aspects of adaptive capacity (ownership, diversification of crops, income, literacy, insecticide, herbicides, fertilizer, changing of crop varieties and planting dates, insurance, market, and finance). However, Mohammed *et al* (2018) identified sites that had a greater diversity of crops that were assumed to be more resilient, but data on the sites resilience was lacking. This study produced a drought exposure map comprised of landless and dependent populations, livestock ownership and vegetation changes over the years. In another study, Guo *et al* (2022) used the IPCC-DVI as a reference for reducing the drought risk of smallholders and promoting the harmonious co-existence of local communities with their environment. It was also reported that effective irrigation area and slope can contribute up to 20% of the spatial variation in drought vulnerability in Xinghe province, China. Mohammed *et al* (2018a) assessed drought risk and SEVI vulnerability by analysing the spatio-temporal characteristics of the drought based on a mix of biophysical and meteorological indicators including the combined drought indicator, vulnerability capital index (VCI), standardized climate index and standardized precipitation index (SPI). According to the above study, vulnerability to drought and climatic variability is characteristically shaped by social and economic structures alongside patterns of regional development.

In addition to the IPCC-DVI, composite indices such as LVI have been developed, given their capacity to capture multidimensionality of vulnerability by integrating both socio economic and biophysical attributes. Asfaw *et al* (2021) for example, used the LVI to measure vulnerability to extreme events as a means of identifying the drivers of vulnerability and prioritizing suitable adaptation strategies. Their study emphasized the importance of feasible and resilience building interventions to enhance the adaptive capacity of subsistence smallholder farmers to withstand climate related risks. Recommended measures included expansion of small-scale irrigation, improving access to microfinance services, providing timely early warning information, strengthening extension support, promoting non-farm income sources, training and skill development, and the expansion of rural infrastructure. In another study, Abeje *et al* (2019) used LVI to differentiate the relative livelihood vulnerability difference among agroecologically different watersheds as a function of exposure, sensitivity and adaptive capacity. Among the strategies followed in different catchments, communities that followed more diversified strategies were less vulnerable to climate extremes. Mekuyie (2021) used the LVI to assess the vulnerability of households to climate-related risks, and suggested vulnerability could be reduced by enhancing access to credit, markets, climate information, health services, diversification of farmer incomes, soil water conservation and afforestation of hilly areas. Jordaan *et al* (2019) proposed a multidisciplinary approach including LVI for the management of natural resources to support a livelihoods program by incorporating the natural environment (soil and water supply), human capital (enhance farmer's skill, through training and disseminating information), social capital (e.g. networks), financial capital (access to funding), and cultural and political capitals (access to public sources).

Other vulnerability related indices that were linked to either social (DVI, SVI), SEVI, economic (EVI), capital (VCI), ecology and composite drought hazard indicators (CDHI), blended drought index (BDI) were reported in a limited number of studies. Naumann *et al* (2014a) proposed the use of DVIs

as drought early warning systems in Africa and found a good association between DVI and individuals affected by droughts. Dumitraşcu *et al* (2018) calculated the SEVI from three indices that included demographic and social, economic and infrastructure vulnerabilities, which identified land quality and crop production as the first components to be affected by extreme climate, resulting in increased vulnerability of rural communities. Meza *et al* (2021) used a mixed method approach that included CDHI and a vulnerability component to generate integrated risk maps for both rainfed and irrigated agriculture, by local municipality. The vulnerability component was then assessed using expert judgement; this involved experts weighting each indicator including social susceptibility (including unemployment, medical assistance, sanitation, dependency ratio, alternative sources of income, violence and crime rates, gender inequality, and food security), environmental susceptibility (farmland ratio, land degradation index, fertilizer application rate) and coping capacity (total dam storage, borrowed money, social grants, road density, area equipped for irrigation). Luetkemeier *et al* (2017) applied the BDI as a composite indicator using a copula function to combine meteorological (SPI and SPEI) and agricultural indices including the standardized soil moisture index (SSI) and standardized vegetation index (SVI) to map drought hazards and assess impacts to food and water security. The BDI was then fed into a comprehensive drought risk assessment at a household level HDRI to provide a better decision basis for government and non-governmental stakeholders.

In addition to the vulnerability indicators described above, other dominant indices reported in SEVI studies included the agricultural DRI (ADRI), and drought coping strategy index (DCSI). Myeki and Bahta (2021) constructed an ADRI dataset for South Africa using asset, social safety net, adaptive capacity and climate change indicators and structural equation modelling—this showed that climate change indicators had a significant impact on household resilience to food insecurity compared to the other indicators. This study also suggested that greater government assistance and stakeholder support would improve smallholder resilience to food insecurity. Banda *et al* (2016) used the Drought Reconnaissance Index (DRI) to determine the effect of drought resilience on farm household welfare, with a positive DRI value for a household indicating that they were more likely to have improved welfare compared to their counterparts with a negative DRI. It was also observed that DRI correlated with farm level output. To support building capacities for farmer welfare development, various actions were identified that included increasing funding/aid for new irrigation technologies, encouraging farmers to adopt off-farm livelihood activities, and involving NGOs to provide relief items to the targeted areas. Murendo *et al* (2011) used DCSI in Ethiopia to understand *ex-ante* adaptation strategies including storage of fodder for livestock, rearing drought tolerant livestock, implementing mixed cropping, growing short duration cultivars and the adoption of soil and water conservation practices for minimising drought risks.

The ‘other’ category identified from the evidence synthesis included indigenous knowledge system (IKS) and gender-based indicators, the perception index (PI), SEVI and purely economic indicators. By integrating IKS indicators with scientific based seasonal climate forecasts (SCF) at the local level, Jiri and Mafongoya (2018), proposed that communities could enhance their resilience to a changing climate. They classified local coping and adaptation responses into five categories including (i) mobility, (ii) storage, (iii) diversification, (iv) communal pooling, and (v) market exchange to support building adaptive capacity to climate and drought risks. A few studies have also identified an association between gender and the uptake of adaptation strategies that include accumulation of livestock, changing livestock breeds, crop diversification, use of resistant crop varieties, tree planting and employment (Kiumbuku *et al* 2020). Using the gender parity index (GPI), Maltitz and Bahta (2021) assessed levels of inequality between men and women in households and their vulnerability to drought in terms of five domains of empowerment level including production, access to resources, income, leadership and time. The perception index (PI) was also reported in a few studies as a composite indicator. For example, Bahta (2021) used PI to assess the perception of smallholder livestock farmers to agricultural drought resilience. The study reported that a negative PI implied the role of social networks and government’s role in enhancing farmers resilience towards agricultural drought was insufficient. However, the perception of smallholder livestock farmers to the role of social networks was lower than that of the government. Respondents on this study indicated that support from the government was often not on time and not good enough to enhance productivity to full capacity and enhance their resilience towards agricultural drought. This study suggested that the government should improve access to information, training related to agricultural drought resilience, affordability of veterinary service, financing, irrigation and land, and should strengthen investment in a fodder bank. In another study, Pradhan *et al* (2017) reported farmer perceptions of the effectiveness of policies implemented to deal with drought. This study use access to resources, water use efficiency

projects, market demand, local government funds, drought knowledge and technology, community participation in planning, social capital networks and governance structures, leadership, and income diversification and improvement as metrics to evaluate the effectiveness of policy implementation for local level drought management.

Among the SEVI and pure economic indicators, Kar and Roy (2012) identified SEVI indicators for smallholders to cope in arid regions, which included using mixed cropping, agroforestry, increasing herd sizes, changing the livestock composition, livestock migration, and access to secondary occupations for human survival during different drought intensities. In another study, Wens *et al* (2022) introduced suitable interventions that have positive effect on the uptake of adaptation measures thereby reducing drought risks to maize and reducing the need for external aid. Some of the interventions included (i) extension services increasing the adoption of low-cost lesser known drought adaptation measures, (ii) supporting credit schemes for cost effective but expensive drought adaptation measures, (iii) *ex ante* cash transfers allowing less endowed households to adapt low-cost but popular drought adaptation measures, and (iv) early warning systems being more effective if used as a tool to create awareness and risk perception of climate risks. Pili and Ncube (2022) identified drought coping and adaptation strategies for the crop sector which included the use of boreholes, selling livestock, purchasing fodder, and transporting water from rivers and dams to the farms for livestock as well as including low-cost drip irrigation systems, mulching, short duration crops and changing planting dates. Sain *et al* (2017) explored economic assessment of selected climate smart agricultural (SMA) practices which included agroforestry (hedgerows), agronomic (conservation tillage with mulch, contour ditches, crop rotation, planting water stress tolerant and disease tolerant cultivars, stone barriers and water reservoirs/ponds with drip irrigation) in a maize-bean cropping system. For each intervention, their probabilistic cost benefit analysis (CBA), average profitability and investment payback period were estimated to provide best options to address food security and resilience. Similar strategies were also suggested by the FAO (2019) which focused on smallholders receiving SCF information where they were more likely to adopt climate resilient agricultural practices as an *ex-ante* coping strategy including drought tolerant cropping systems, changes in hybrid seed use and fertilizer application. As part of the adaptation process, the FAO (2016) also focused on training and capacity building to increase extension officer awareness of GIS for generating more visually appealing training materials on climate smart and conservation agriculture.

Finally, among the economic indicators, Lawes and Kingwell (2012) evaluated business equity, operating profit per hectare, return on capital, and debt to income ratio to assess the impact of farm economic performance to drought. Their research found that business equity displayed a downward trend compared to other indicators that showed small or non-existent trends. It also suggested that the performance of economic indicators directly depend on seasonal yield and rainfall, cropped areas and enterprise diversity.

### 3.4. Indicators that could support resilience frameworks to inform policy responses to drought risks

A limited number (5 of 35) of SEVI focussed studies reported on the use of indicators that could support the development of a resilience framework and/or inform policy responses to climate risks. Among the VI used included the IPCC-DVI, LVI, SVI and DVIs, and DRIs (drought exceedance probability index (DEPI) and DCSI. In addition, local information including indigenous knowledge, local perception, LPCIEA and SEVI indicators could also contribute to resilience frameworks to inform policy responses to drought and climate risks. For example, Jiri *et al* (2017) used VIs to understand the exposure and sensitivity of a community to a natural hazard with limited adaptive capacity, whilst Ho *et al* (2022) provided evidence of the factors influencing the vulnerability of rice farming households in the Mekong Delta in Vietnam, which could inform policies for improving the resilience and adaptive capacity in coping with climatic shocks. The main limitation of this study was its reliance on cross-sectional data and use of dummy variables to represent experience with drought and flood, which might not fully reflect the extent of climatic shocks. Asfaw *et al* (2021) mapped drought vulnerability of smallholder farmers with both socio-ecological and biophysical determinants that provided a more holistic assessment of vulnerability and its driving factors, whilst Dumenu and Takam Tiamgne (2020) integrated SVI as a metric for assessing social dimensions of climate vulnerability that was more appropriate at the community, district, or social grouping (e.g. smallholder farmer) scales. This study also provided insights into the nature of vulnerability, coping strategies and adaptation measures of relevance to policy actions. It recommended crop diversification and promotion of conservation and climate-smart agriculture. Jacobi *et al* (2016) used resilience indicators including buffer capacity (species diversity, soil status, cocoa yield, diseases and diversified sources of income), self-organization (affiliation to organization, subsistence level and annual family income) and adaptive capacity (participate to gain new knowledge) to evaluate two cocoa (organic and non-organic) farms. That study concluded that awareness about the

benefits of a socio-ecological farming system, support from farmer organizations, market linkages, coproduction and exchange of knowledge all played a critical role in achieving sustainable livelihoods as well as in providing young people with a perspective for the future.

In addition to the VTs described above, various studies reported on the use of DEPI and DCSI as indicators to support development of drought resilience frameworks. For example, Jordaan *et al* (2019) reported that DEPI could be used by governments to prioritize and implement national resource management policy measures in response to drought and to inform strategies to reduce drought vulnerability. Bahta and Myeki (2022) indicated that smallholder livestock farmers' low resilience was linked to the lack of access to land and property rights. Murendo *et al* (2011) included the sale of assets, loans and support offered by informal networks and temporary migration to look for employment opportunities as *ex-post* coping strategies to reduce impacts and improve drought risk management strategies. It also suggested that suitable policies are needed to access information on drought, while training to use such information is important to strengthen farmers capacity to adapt to and cope with actual drought events.

Jiri and Mafongoya (2018) recognized the value and suitability of IKS indicators for use in resilience frameworks. Bahta (2021) recommended that coordination and cooperation was essential amongst all key players to reinforce strategies to enhance smallholder livestock farmers' resilience. This included coordination between local and provincial governments, the African Farmers' Association of South Africa, extension officers, the private sector, monitoring agencies in terms of providing reliable early warning information, and communication amongst decision-makers. Collaboration amongst government departments at the national and provincial levels should also be strengthened to enhance farmer resilience. Smallholder livestock farmers' awareness of the significance of social networking and government participation also needs to be promoted. Hawkins *et al* (2022) utilized a qualitative approach for in-depth understanding of perceptions, experiences, and decision-making processes of smallholder farmers. This is critical for developing practical and contextualized future policies. The smallholder communities in that study responded to drought by changing their dietary habits in ways that may have compromised health outcomes in the long-term, but no consumption data or nutritional status assessment was recorded. Therefore, further information on consumption and nutritional status related to the perceived changes in crop production and consumption, due to drought, are needed to assess potential impacts on public health nutrition. Ebrahimi (2022) integrated the LPCIEA indicator in their quantitative methodology using a combination of criteria to evaluate the resilience of a village to drought. Based on the analysis, resilience and viability scores for the study area were determined, so decision-makers could modify access to water and allocation for reinforcement in less resilient villages to adapt to drought. Lawes and Kingwell (2012) reported structural indicators including the percentage of areas cropped which had a significant effect on business performance during a drought. However, farm size did not influence business performance. Farm businesses which cropped more than 50% of their farm area were drought resilient as they were prudent in their expenditure, maintained farm diversity and generated steady crop yields. In another study, Muthelo *et al* (2019) suggested the inclusion of human, social, economic, institutional, natural and political forms of capital as determinants of farmers choice of adaptation and coping measures to drought.

Sain *et al* (2017) reported that decision making for climate SMA adaptation required an understanding of the trade-offs between different practices. This included CBA as an economic indicator linked to profitability, risk, and the impact of an adaptation practice, which could be strengthened by including associated environmental and social externalities. In relation this this, the FAO (2019) suggested a two-stage framework including (i) understanding smallholder perceptions to climate change and the associated impacts on their livelihoods and incomes, and (ii) connecting these impacts to active actions (e.g. providing early warning information) to adopt practices that were most resilient.

Finally, some studies suggested frameworks that could integrate indicators as part of early warning systems. For example, Pili and Ncube (2022) included a Hyogo Framework (HFA, 2000–2015) for prioritizing actions that help to evaluate the implementation of DRR strategies. This included five priority actions (i) making risk reduction a priority, (ii) improving risk information and early warning, (iii) building a culture of safety and resilience, (iv) reducing underlying risk factors, and (v) strengthening the preparedness for an effective response. Haigh (2019) proposed an integrated vulnerability and resilience conceptual model which included nested cognitive-social-ecological components to evaluate the adaptive capacity of rangeland managers and their decision making in response to drought risks. Andersson *et al* (2020) used an analytical framework containing factors which were organized into three themes (i) communication and mediation, (ii) translation and (iii) adaptive capacity. These were linked to improve the useability of a local participatory early warning system for drought monitoring and forecasting.

This synthesis was inevitably subject to several methodological limitations which need to be recognized. There was difficulty in evaluating indicators according to the three sub-questions due to the heterogeneous nature of the indicators. Studies utilized different definitions, methodologies and contexts for the indicators resulting in complexity in categorising and comparing indicators and creating overlaps in the assessment of drought impact, vulnerability and resilience. Many studies also utilized the indicators as an aggregation of different local evidence that may not be applicable to other conditions, therefore developing a standard indicator for exposure, sensitivity and available capacities to be drought resilient may not be feasible or may eliminate local contextual information. Notwithstanding these limitations, this synthesis does provide invaluable insights into the range of indicators being developed and used to inform drought risk management.

## 4. Conclusions

This review evaluated evidence on the utility and application of SEVI indicators to assess the resilience of smallholder agriculture to drought in Africa. The literature was then analysed within the context of three main domains, including what indicators have been used to understand the SEVI impacts of drought, what indicators are relevant in understanding the effectiveness of specific strategies to support absorptive, adaptive and transformational capacities to drought risk, and finally, how can indicators be usefully integrated into resilience frameworks to inform policies to reduce impacts and improve drought risk management. The research also identified knowledge gaps including the need for studies to focus more on the linkages between environmental-ecological impacts and SEVI indicators, and for further research to identify suitable indicators that can be used to support development of resilience frameworks for drought risk management. Drought indicators are increasingly used among scientific and research communities for drought monitoring and early warning systems but with a little emphasis on which are most meaningful for assessing impacts and community resilience to drought.

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## Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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## **Evaluating the utility of socio-economic indicators to assess the resilience of smallholder agriculture to drought in Africa**

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