frontiers | Frontiers in Animal Science

SYSTEMATIC REVIEW
published: 05 July 2022
doi: 10.3389/fanim.2022.868468

A Systematic Review of Climate Change Risks to Communal Livestock Production and Response Strategies in South Africa

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Specialty section:
This article was submitted to Animal Physiology and Management, a section of the journal Frontiers in Animal Science

Received: *02 February 2022*
Accepted: *08 June 2022*
Published: *05 July 2022*

Citation:
Zhou L, Slayi M, Ngarava S, Jaja IF and Musemwa L (2022) A Systematic Review of Climate Change Risks to Communal Livestock Production and Response Strategies in South Africa. Front. Anim. Sci. 3:868468. doi: 10.3389/fanim.2022.868468

Livestock offers substantial opportunities for food security and sustainable development with appropriate adaptation to climate change. Nowadays, climate change is among the critical problems facing less privileged rural people directly depending on livestock to survive. This paper aimed to analyse the existing literature and identify knowledge gaps about climate change impacts and response strategies in rural livestock production of South Africa. The study utilized a systematic literature review with key search terms such as "climate change" (weather, variability), "livestock" (monogastric*ruminants), "impact" (heat stress; feeds; pasture; production; reproduction; health; vector-diseases), and "adaptation" (strategies; vulnerability; risks; resilience). The search was run through scientific databases such as Google scholar, Science direct, Cab direct, Sabinet and Sematic scholar, targeting titles, abstracts and keywords. From the 62 suitable peer-reviewed publications examined in the current paper, five limitations were discovered, namely: (1) limited contextual studies of South Africa's rural livestock farming communities; (2) a silo approach to investigations on impacts and adaptation in rural livestock production; (3) drawbacks on mixed crop-livestock systems as an effective response to climate change; (4) limited studies on monogastric livestock in rural communities; and (5) geographic underrepresentation of research progress in different provinces within the country. The study recommended improving geographic coverage of literature and inclusion of non-ruminants exposed to different climatic shocks. It is further advised that to gain effective responses to climate change impacts, mitigation strategies should be context-specific and holistic to improve livestock production in rural farming communities.

Keywords: climate change stressors, drought, livestock production, rural communities, South Africa, systematic review, vulnerability

INTRODUCTION

Climate change is becoming a major developmental challenge globally, with more effects expected to be felt in Sub-Saharan Africa (SSA) due to limited resources and coping capacity (Lottering et al., 2020a). It has been exhibited in extreme floods, storms, heatwaves and droughts (Ngarava et al., 2020; Archer et al., 2021). In South Africa, various climatic models predict that the country will experience higher temperatures, with increases expected to range from 5°C to 8°C by 2050 (Popoola et al., 2020). The country is also projected to experience more hot days and fewer cold and frost days, reduced annual rainfall, as well as the possibility of increased rainfall in certain regions, particularly along the south coast (Maluleke and Mokwena, 2017). Agriculture is seriously affected by climate change because it is highly dependent on climate (Mpandeli et al., 2015). This is further worsened by the fact that agriculture is one of the pivotal constituents of the South African economy and contributes about 3% of its Gross Domestic Product (Nyoni et al., 2021). Over 80% of South Africa's total land area is non-arable and is suitable for livestock production (Dube and Jury, 2000; Oduniyi et al., 2020). Livestock plays a prominent socio-economic role in improving the livelihood of disadvantaged rural people, including landless laborers (Vetter et al., 2020). The country is endowed with a diversity of livestock species with an estimated 12.8 million cattle, 19 million sheep, 1.8 million goats and 1.5 million pigs (Department of Agriculture, Forestry and Fisheries (DAFF), 2019). Due to the magnitude of the livestock sector in South Africa, climate change effects on livestock are anticipated to have long-lasting effects (Lottering et al., 2021). Owing to climate change impacts on livestock, exponential death rates, slow growth rate and a decline in milk production, among others, have become a frequent experience to livestock farmers in South Africa (Maluleke et al., 2020).

More than half of the livestock population in South Africa is kept under smallholder traditional farming systems (Tibesigwa et al., 2017) and is owned by limited-resource farmers (Meissner et al., 2013). In these systems, unemployed and retired men and women, including children, are the main beneficiaries to livestock farming through income stock sales and animal products like meat and milk (Maponya and Mpandeli, 2013). Despite their prominent socio-economic role to improve the livelihoods of poor people, livestock production seems to operate under various harsh environmental conditions resulting in compromised production output (Musemwa et al., 2012). Improving the resilience and efficiency of communally managed livestock is of paramount importance to sustainable production and eliminating food insecurity in the country. Further, livestock has the potential to strengthen resilience to climate change, as it tends to be more resilient than crop-based systems (Oduniyi et al., 2020). However, to enhance livestock resilience to climate change, a better understanding of how the rural farming fraternity is affected is needed (Maluleke et al., 2020). Effective policy and practice require sector-specific data about the nature and magnitude of impacts triggered by climate change (Lottering et al., 2020b; Magandana et al., 2021). As the extent to which climate change impacts vary across different livestock systems (Vetter et al., 2020; Archer et al., 2021), understanding these differences is critical to formulating policy and practices (Maluleke et al., 2020). Aligning knowledge on climate change impacts and adaptation across different scales is also important to identify common concerns that can encourage collaboration among different production systems, and areas which climate change is likely to impact negatively (Maluleke and Mokwena, 2017). Likewise, the unidentified gaps in research relating to climate change impacts and adaptation in rural livestock production limit the understanding and weaken the ability of the sector to deal with future climate change impacts and to monitor adaptation progress over time.

Though livestock is a complex sector in South Africa, literature progress on climate change impact in rural communities is slightly slower than crop production (Mthembu and Zwane, 2017). The available evidence is still unclear (Lottering et al., 2020b). Data on the damage and losses caused by climate change is not systematically collected or reported in South Africa (Mare et al., 2018). In addition, collecting and synthesizing livestock data is always a challenge because of complex production systems, varied agro-ecological zones, and, in most cases, different production objectives (Mandleni et al., 2011; Meissner et al., 2013). There are also a variety of practices across production systems according to cultural, socio-economic, and institutional conditions (Musemwa et al., 2012; Taruvinga et al., 2013). Ultimately, the importance of livestock to a country's development agendas depends on the multiple socio-economic values and the cultural benefits it provides (Maponya and Mpandeli, 2013). A limited number of literature reviews have documented climate change impacts on communal livestock productivity (Thinda et al., 2021; Maluleke et al., 2020). Previous impact studies looked at droughts (Lottering et al., 2021), floods (Ngarava et al., 2020), and heatwaves (Katiyatiya et al., 2017), as well as variations in rainfall and temperature (Maluleke et al., 2020). Despite all these attempts, climate change remains a matter of concern to rural livestock production, requiring urgent attention. The study aimed to fill this knowledge gap by systematically analyzing the existing literature on climate change impact on livestock production and identifying gaps to ineffective adaptation options in rural communities of South Africa.

MATERIALS AND METHODS

A systematic review approach was adopted to conduct this literature survey. Benefits in using this approach is that it enables transparency, accuracy and replicability as shown in **Figure 1**. The selected procedure is in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Cooper, 2010; Monroe et al., 2017), which have also been used in previous climate science-related

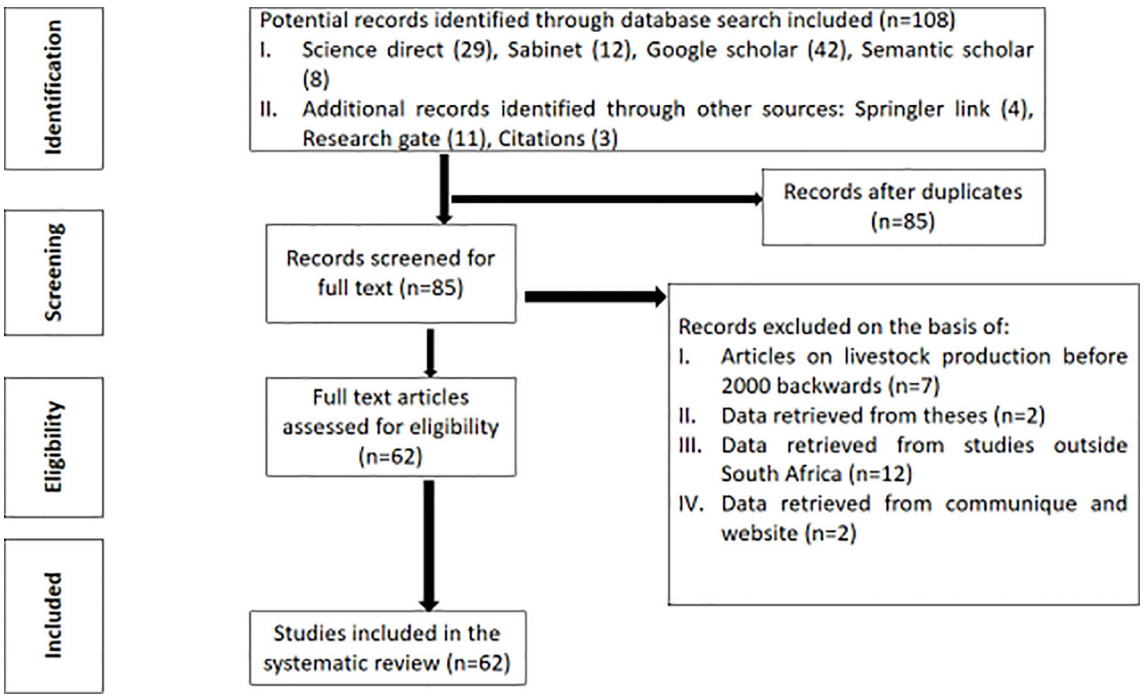

FIGURE 1 | Flow diagram of the screening process of the literature.

systematic reviews (Barth and Thomas, 2012; Berrang-ford et al., 2015). The data gathering process used two main approaches, which included (1) searching and selecting literature; and (2) data management, coding and analysis.

Literature Search and Selection

An extensive literature survey was conducted using various search databases between 1 June and 31 August 2021. Two researchers were assigned to do the literature search and selection. Data searches used in the current paper include Google scholar, Science direct, Cab direct, Sabinet and Sematic scholar. The search was only limited to published articles conducted post year 2000 in South Africa. Only literature published in the English language was considered for the paper. The study only selected articles that covered impact of climate change on livestock production. Furthermore, literature on climate change mitigation and adaption options in rural livestock farming were also considered. The search strategy was only targeting full-text articles. A combination of various key search terms were used to gather the data. For climate change data, terms such as "weather", "heat wave", "drought" and "floods" were used. On the other hand, to search for livestock literature, the assigned researchers used terms such as "poultry" and "ruminants", while impact search was conducted through key terms search "heat stress", "forage availability", "production", "reproduction" and "disease outbreaks". Initially the search resulted in one hundred and eight articles (including duplicates). However, after the inclusion and exclusion criteria were applied to these 108 articles, sixty-two articles were considered relevant to the literature synthesis in terms of context and content (**Figure 1**).

Data Synthesis

The selected articles were uploaded on Mendeley referencing tool to reduce human error in data coding and content analysis. One of the benefits of using this referencing software is that it automatically generates the bibliographic information once imported. Microsoft Excel was used to sort and organize the data according to individual articles. The information of interest included type of the manuscript (review, experimental, or survey), year of publication, the province where the research was conducted, livestock species, etc. Data summary was transformed into quantitative measures and the results were presented in the form of tables and graphs.

RESULTS

Research Progress on Climatic-Risks to Livestock Production in Rural Areas of South Africa

Climate change impact and mitigation on livestock production has received partial research attention in the past two decades in South Africa. Publications of these

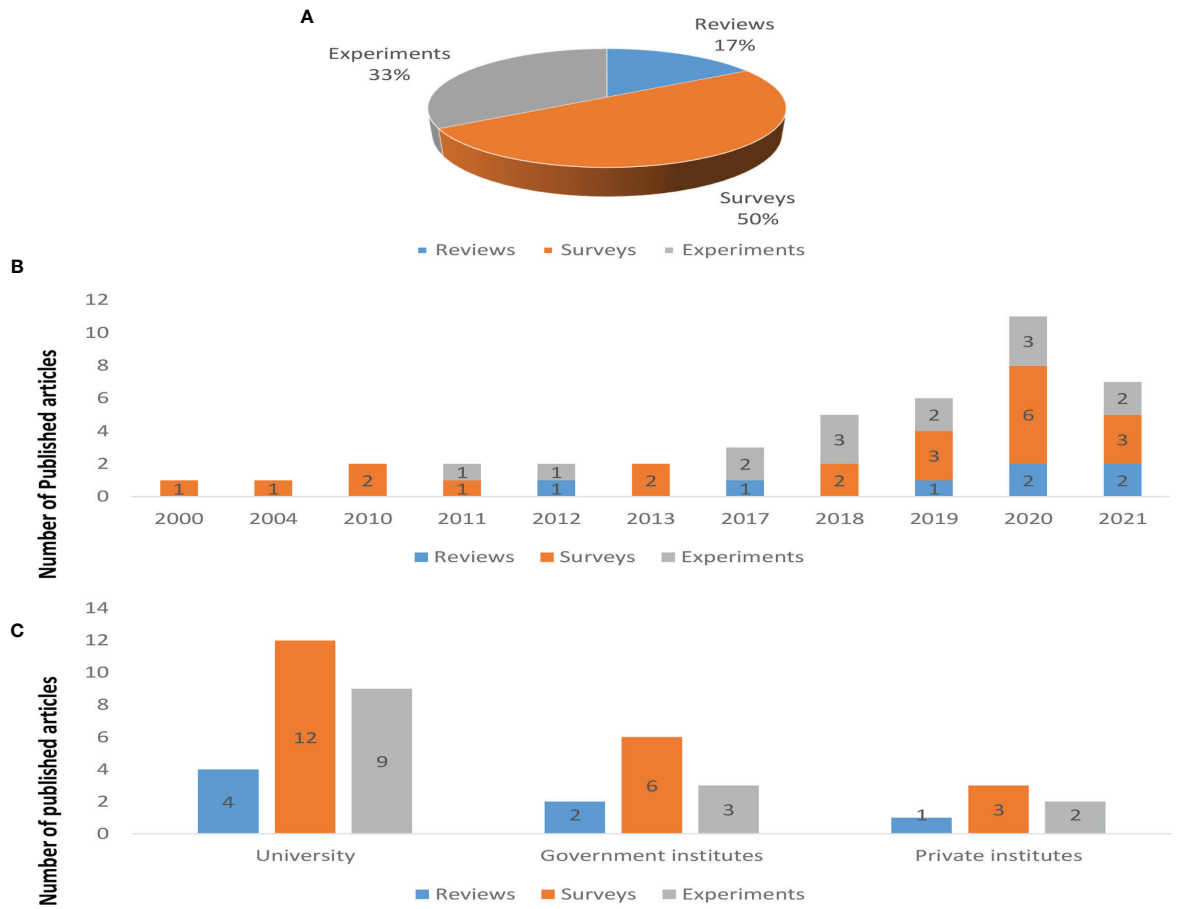

FIGURE 2 | Type of available climate-related research material on livestock production according to **(A)** number of published articles per year **(B)**, and **(C)** affiliation of the principal author per published article.

works have been conducted and shared in various academic platforms in surveys (50%) and experimental investigations (33%). In comparison, the rest has been conducted through literature reviews (17%), as shown in **Figure 2A**. A notable difference amongst these published articles has been observed in yearly contributions since the year-2000 (**Figure 2B**). Only 4 survey articles have been published from the year 2000 to 2010. A slight increase in publication pattern for experimental investigations and literature reviews was recorded from the year-2011 to 2021, with survey articles constituting a large proportion of the publications. The type of published articles were noted to vary according to the principal author's affiliation (**Figure 2C**). More than half of the published articles (17 surveys, 14 experiments and 4 literature reviews) have been documented using universities as a principal author's affiliation or research station. In contrast, the rest has been published through government research institutes (11 survey articles, 8 experiments, and 2 literature reviews) and private research organizations (3 surveys, 1 literature review and 2 experiments). Overall, **Figure 2** indicates that climate change research, mainly surveys carried out by research and higher education institutions, has been increasing over the past two decade. This has a bearing on the quality and utilization of the studies.

Framing the Literature on Climate Change Impact on Communal Livestock Production

Research attention and published articles on climatic shocks to livestock production is gaining momentum in various communities of South Africa (**Figure 3A**). The analysis shows that 59% of the available literature has looked at multiple climate variables impacting livestock production in rural communities. On the other hand, drought (19.05%) and increasing temperatures (14.23%) are becoming an area of concern from various country's researchers and academic role players. Few studies solely focused on rain variability (4.76%) and weather extremes (2.38%).Therefore studies have taken a more generalist approach, tending to combine multiple climate variables. Climate change risks to livestock

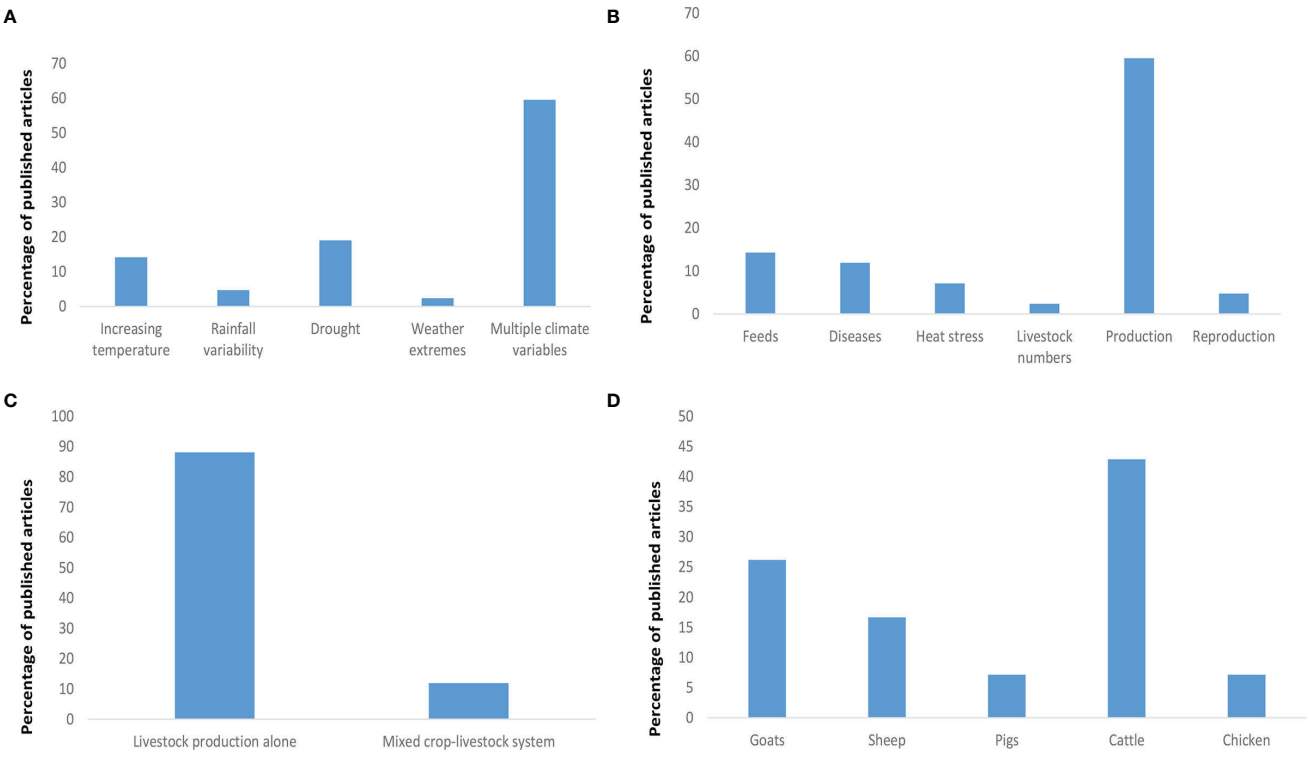

FIGURE 3 | Proportion of reviewed publications according to **(A)** climate change shocks, **(B)** domain impact, **(C)** livestock production system; and **(D)** livestock species.

production have been part of many impact studies in the past twenty-one years. A proportion of 59.52% of the published articles simultaneously looked at multiple impacts of climate change on livestock production in rural communities (**Figure 3B**). At the same time, a limited number of articles solely looked at impact domains such as feed availability (14.29%), disease outbreaks (11.91%), heat load (7.14%), reproduction (4.76%), and livestock records (2.38%). **Figure 3C** shows that 88.09% of the reviewed publications mainly focused on livestock production alone, while the rest of the articles (11.91%) looked at the mixed crop-livestock systems. **Figure 3D** shows that a large proportion of the reviewed publications focused on cattle (42.88%), goats (26.19%) and sheep (16.67%). Few published articles were on chicken (7.14%) and pigs (7.14%). A summary of the documented effects of different climate shocks on livestock production is presented in **Table 1**. It appeared that these impact areas have various interactions with one another and imply that climate change affects livestock in numerous ways. For instance, heat stress directly impacts animals through production, reproduction, livestock numbers, disease occurrences, and product quality. At the same time, production aspects and livestock statistics were most likely affected by the indirect effects of heat stress, outbreak of diseases, reproduction, production, and feeds. The climate change impact studies on livestock production have thus been generalized. However, they have exhibited that conceptually, the impact of climate change on livestock production is complex and intertwined.

Geographic Update of Research Done on Climatic Risks to Communal Livestock Production

The geographic distribution of the published literature on climate change impact on livestock production is presented in **Figure 4**. It was noted that 38.10% of the published articles is from the Eastern Cape, while KwaZulu Natal and Limpopo contribute 19.05% each, respectively. Few publications have been documented from Western Cape (9.52%), Free State (7.14%), Mpumalanga (4.76%), and Northern Cape (2.38%). None of the publications on climate change risks to rural livestock production have been recorded in Gauteng and the North West province of the country. It was further noted that the published articles on various climatic shocks were unevenly distributed across the country's provinces. Of the 16 publications conducted in the Eastern Cape Province (EC) of the country, 8 articles were on multiple climate variables while the rest were on temperature variation (4) and weather extremes (1). None of the publications conducted in the Eastern Cape were solely focused on drought. On the other hand, 4 published articles from Limpopo were done on multiple climate variables, while two papers were focused on temperature variation. Furthermore, two papers documented drought (1) and rainfall (1) impacts on livestock production. KwaZulu Natal had 5

TABLE 1 | Framing the areas of concern highlighted on reviewed impact studies on climatic risks to livestock production in South Africa.

Impact domain	Documented impacts of concern	Climatic shocks	References
Feed availability	1. Decline in pasture, rangelands, crops and forage productivity	1,3,5	Clarke et al., 2012; Muller and Shackleton, 2014; Mare et al., 2018; Bahta, 2020; Magandana et al., 2021
	2. Deterioration of feeds quality, e.g. herbage and forage digestibility	1,2,3	Mandleni and Anim, 2011; Mthembu and Zwane, 2017; Popoola et al., 2019
	3. Altered grazing systems and temporal pattern of grassland production	2,3,5	Mandleni and Anim, 2011; Dube and Jury, 2000; Lottering et al., 2020a; Lottering et al., 2020b; Lottering et al., 2021
	4. Reduced quantity and availability of forage and grain feedstuffs	1,3,5	Musemwa et al., 2012; Mpandeli et al., 2015; Ngarava et al., 2021; Mandleni and Anim, 2011; Magandana et al., 2021
Disease outbreaks	1. Shift in disease pattern and distribution of infectious diseases	1,2	Slayi et al., 2014; Nyangiwe et al., 2018; Jansen et al., 2020
	2. Change in abundance and activity of disease vectors. e.g., ticks	5	Musemwa et al., 2012; Nyangiwe et al., 2018; Archer et al., 2021; Thinda et al., 2021; Smith, 2002
	3. Increase persistence and survival of pathogens and parasites	1,2	Muller and Shackleton, 2014; Slayi et al., 2014; Maluleke and Mokwena, 2017; Jansen et al., 2020
	4. Higher prevalence of endemic diseases e.g., helminths in ruminants	1,2	Maluleke and Mokwena, 2017; Jansen et al., 2020; Sebei et al., 2004; Musemwa et al., 2012; Slayi et al., 2014
	5. Increasing prevalence of respiratory infections in poultry	1,2	Popoola et al., 2019; Popoola et al., 2020; Jansen et al., 2020; Nyoni et al., 2021; Nyoni et al., 2018
	6. Higher incidence of mastitis in dairy animals	1	Dodzi and Muchenje 2012; Thinda et al., 2021; Vetter et al., 2020
	7. Changing severity in human-livestock diseases	5	Muller and Shackleton, 2014; Archer et al., 2021;
Heat stress	1. Alters physiological and behavioural functions of livestock	1	Katiyatiya et al., 2017; Mapfumo et al., 2017; Maluleke et al., 2020; Slayi et al., 2021
	2. Decrease forage intake, nutrient absorption, and feed conversion efficiency	1,3	Mapfumo et al., 2017; Nyoni et al., 2021; Scholtz et al., 2014; Mandleni and Anim, 2011; Magandana et al., 2021
	3. Body temperature beyond 45-47°C is lethal in most livestock species	1	Dube and Jury, 2000; Maponya and Mpandeli, 2012; Katiyatiya et al., 2017; Bahta, 2020; Lottering et al., 2021
	4. Negative implication on animal's reproductive and breeding performance	1	Musemwa et al., 2012; Maponya and Mpandeli, 2012; Maluleke and Mokwena, 2017; Mapfumo et al., 2017; Vetter et al., 2020; Mare et al., 2018; Slayi et al., 2022
	5. Alters composition of products, e.g., milk lipid profile	1	Meissner et al., 2013; Lottering et al., 2021; Maponya and Mpandeli, 2013; Popoola et al., 2019
	6. Increased concerns on animal welfare, e.g., cattle feedlots	1	Mapfumo et al., 2017; Malusi et al., 2021
Livestock statistics	1. Increased death rate of animals in pasture-based production system	3	Ngarava et al., 2020; Maluleke et al., 2020; Lottering et al., 2021; Archer et al., 2021; Maponya and Mpandeli, 2013
	2. Disproportionate decrease in stocking density	1,3	Katiyatiya et al., 2017; Mapfumo et al., 2017; Maluleke et al., 2020; Lottering et al., 2021; Talanow et al., 2021
	3. Increased in still births, embryo mortality and abortions	1,3	Musemwa et al., 2012; Mpandeli et al., 2015; Nyangiwe et al., 2018; Archer et al., 2021; Smith, 2002
	4. Higher rates of preslaughter mortality in broiler chickens	1	Mapfumo et al., 2017; Nyoni et al., 2021
Production	1. Decline in milk yield and meat production	1,3	Zwane, 2019; Mandleni and Anim, 2011; Mthembu and Zwane, 2017; Popoola et al., 2019; Bahta, 2020
	2. Low production efficiency in poultry and cattle	1	Zwane, 2019; Nyoni et al., 2019; Nyoni et al., 2021
	3. Reduced wool production	1,3	Mandleni and Anim, 2011; Musemwa et al., 2012
	4. Poor growth and liveweight losses, e.g., beef cattle and sheep	1,3,5	Popoola et al., 2019; Nyoni et al., 2019; Popoola et al., 2020; Nyoni et al., 2021; Talanow et al., 2021
Reproduction	1. Decrease conception rates	1,5	Taruvinga et al., 2013; Malusi et al., 2021
	2. Decease animal fertility, general fitness and longevity	1,5	Katiyatiya et al., 2017; Dodzi and Muchenje, 2012; Tibesigwa et al., 2017; Mthembu and Zwane, 2017; Popoola et al., 2019
	3. Reduced birthing rates, increase in age at first calving in beef cattle	1,5	Maluleke and Mokwena, 2017; Jansen et al., 2020; Sebei et al., 2004

As it links to climate parameters: [1]temperature; [2]rainfall/precipitation variation; [3]drought; [4]weather extremes; [5]multiple climate variables.

publications on drought while the rest were on multiple climate variables (2), rainfall variation, and increasing temperature (1). About 3 of the selected publications in Free State were done on multiple climate variables while Mpumalanga had two papers on the same subject. Only 1 published article was documented in Northern Cape, with drought as a climate change risk of interest. The distribution of the studies also reflects the livestock distribution within the country. Most livestock are found in the Eastern Cape, KwaZulu-Natal and Limpopo Provinces. Consequently, climate change will have higher impact on

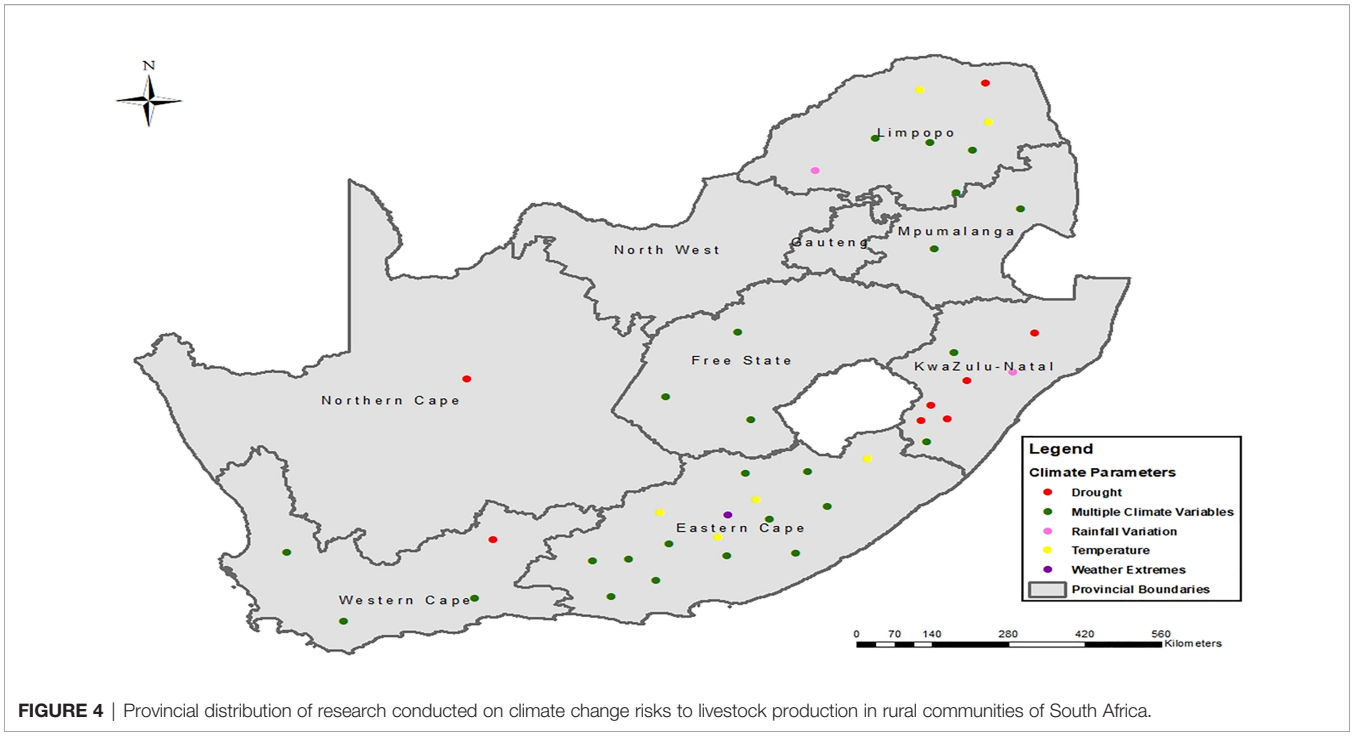

FIGURE 4 | Provincial distribution of research conducted on climate change risks to livestock production in rural communities of South Africa.

livestock production based on their distributions. The temperature variations were topically in these major livestock production provinces.

Responses to Climate Change Adaptation and Mitigation in Rural Communities

Various adaptation options to climate change impact on livestock production were reported on 42 publications selected in the current study (**Table 2**). Destocking or selling of a certain portion of livestock during dry months appeared as the most common response, followed by buying feeds to supplement animals during drought and dry months of the year chosen by farmers to avoid further production and financial losses. However, only farmers with improved socio-economic status purchased supplementary feeds. From the selected articles, it was pointed out that farmers resort to

TABLE 2 | Summary of adaptation options in response to climatic shocks in livestock from existing literature in rural communities of South Africa.

Adaptation option	Specific strategies adopted	Climatic shocks	References
Production adjustments	1. Diversification, intensification and/or integration of pasture management, livestock and crop production	3,5	Maluleke et al., 2020; Lottering et al., 2021; Mandleni and Anim, 2011; Zwane, 2019
	2. Changing land use and irrigation	2	Musemwa et al., 2012; Taruvinga et al., 2013; Mandleni and Anim, 2011
	3. Altering the timing of operations	1,2,3,5	Maponya and Mpandeli, 2013; Archer et al., 2021; Mare et al., 2018; Lottering et al., 2021
	4. Modifying stock routings and distances;	1,3,5	Dube and Jury, 2000; Zwane, 2019
	5. Introducing mixed livestock farming systems, such as stall-fed systems and pasture grazing	3	Taruvinga et al., 2013; Meissner et al., 2013; Mthembu and Zwane, 2017; Mapfumo et al., 2017
Breeding strategies	1. Identifying and strengthening local breeds that have adapted to local climatic stress and feed sources	1,3,5	Maluleke and Mokwena, 2017; Popoola et al., 2020; Maponya and Mpandeli, 2013; Mpandeli et al., 2015; Nyoni et al., 2019; Malusi et al., 2021
	2. Improving local genetics through cross-breeding with heat and disease-tolerant breeds.	1,5	Mandleni and Anim, 2011; Oduniyi et al., 2020; Mare et al., 2018; Dube and Jury, 2000; Below et al., 2010; Zwane, 2019; Slayi et al., 2022
Livestock management systems	1. Provision of shade and water to reduce heat stress from increased temperature	1	Taruvinga et al., 2013; Katiyatiya et al., 2017; Nyoni et al., 2021; Maponya and Mpandeli, 2013
	2. Reduction of livestock numbers through unplanned sales	3	Dube and Jury, 2000; Below et al., 2010; Zwane, 2019
	3. Improved management of water resources through the drilling of boreholes and buying tanks to harvest and preserve water	2,3	Mandleni and Anim, 2011; Oduniyi et al., 2020; Mare et al., 2018; Dube and Jury, 2000; Below et al., 2010; Zwane, 2019
	4. Changes in livestock/herd composition (selection of large animals rather than small)	3,5	Musemwa et al., 2012; Taruvinga et al., 2013; Meissner et al., 2013; Mthembu and Zwane, 2017; Mapfumo et al., 2017

As it links to climate parameters: [1]temperature; [2]rainfall/precipitation variation; [3]drought; [4]weather extremes; [5]multiple climate variables.

complementary breeding of indigenous or local breeds with improved animal genotypes to better the resilience of their livestock towards the prevailing harsh climatic conditions in rural communities. Some published articles reported that farmers planted trees and constructed shades to protect their livestock against the increasing temperatures and other problematic weather extremes in rural communities. Drilling boreholes and buying water tanks became a common response adopted by resource-constrained farmers to obtaining and preserving water for use during drought periods. Seeking veterinary advice and extension services from agricultural institutions and research institutes is gaining popularity from many rural resource constraint farmers across the provinces of South Africa. Transformations of production systems and farmers' livelihoods have evolved as another adaptation option in livestock systems. Some examples include the shifting in choice of livestock and other species and moving from cropping to livestock farming in response to changing rainfall and more frequent drought occurrences. Thus, drought has been a major climatic shock that has received multiple responses such as destocking, supplementary feeding, breed improvement and diversification.

DISCUSSION

Global climate change concerns are increasingly gaining momentum in many countries (Archer et al., 2021; Lottering et al., 2021). Supporting evidence claim that no region or country is immune to the impacts of climate change. However, the extent of vulnerability differs within countries (Oduniyi et al., 2020). South Africa is no exception to this crisis. The climate change phenomenon is defined by the long-term change and significant variation in temperature, precipitation and wind pattern (Mare et al., 2018). In the past two decades, increasing surface temperature and global sea level have been characterised as major aspects of climate change (Maluleke et al., 2020). Livestock production has been reported as the most vulnerable agricultural sector in the country due to its over-reliance on climate and other natural resources (Vetter et al., 2020). Production of livestock in rural communities is defined as the most risky venture to climate change despite its prominent role in rural people's socio-economic livelihoods (Popoola et al., 2020). Due to its dire consequences, climate change impact on rural livestock production is partially gaining attention from various researchers, policy makers and animal rights activists in South Africa (Lottering et al., 2020a). The extent and distribution of the existing literature reflect the importance of livestock to various resource-constrained communities in South Africa. The prominent role of livestock in improving the livelihoods of rural people calls for urgent attention and adaptation to the identified risks of climate change in the country. Systematic analysis of the available literature on climatic shocks and adaptation responses is of paramount importance in determining which aspect of livestock production require urgency and, consequently, need relevant adaptation strategies.

Updating Literature Progress on Climatic Risks and Mitigation to Livestock Production

Climate change impact on rural livestock production has become a centre of attention in South Africa since the 2000s (Dube and Jury, 2000). Recently, this attraction has been triggered by the strong *El Nino* phenomenon that resulted in one of the most severe droughts experienced by the country in the past 35 years (Lottering et al., 2021). Eight of the country's provinces were declared disaster areas due to excessive heat and delayed rains (Mare et al., 2018). This assertion had triggered ongoing public debates and agenda on livestock production at the local, district and even at national level (Meissner et al., 2013). These arguments have been strengthened by the ongoing production and financial losses experienced by livestock farmers in rural communities (Mandleni and Anim, 2011). Based on the data published on the International Disaster Database (EM-DAT 2017), the economic damage caused by the South African drought alone in 2015/16 was estimated at US$250 million. Fifteen percent reduction on national livestock herd was recorded in the year-2015 and this includes 40 000 dead cattle recorded in KwaZulu Natal alone (Lottering et al., 2020a). Research carried out on seven of South Africa's nine provinces revealed a 14.4% national cattle herd decline between 2013 and early 2016 due to climate change (Maluleke and Mokwena, 2017). Farming debt in the country escalated by 9%, leading to many farmers being unable to destock or prepare financially (Popoola et al., 2020). At the same time, the cost to farmers increased by 177% (Molieleng et al., 2021), making it very difficult as most of the farmers had to rely on buying feed to sustain their livestock production (Talanow et al., 2021). In most cases, such costs were done to maintain the core herd (Popoola et al., 2019). It has been anticipated that will take years to recover (Tibesigwa et al., 2017).

Attempts to assist with selling stock as climate-related incidents like drought develop typically failed as many livestock farmers resisted reducing their capital assets under pressure (Vetter et al., 2020). Uncertainty in drought forecasting made things worse and brought disastrous consequences (Lottering et al., 2020b), because by the time livestock are marketed, the body condition is poor. The numbers are too large to be readily immersed by marketing channels (Slayi et al., 2021), resulting in very low prices, lack of sales and eventually deaths (Taruvinga et al., 2013). Predicting the timing, duration, and magnitude of climate change risks remains challenging, but the magnitude of livestock losses and livelihood impacts also depends on other climatic, ecological and socio-economic factors (Popoola et al., 2020). Complex interactions amongst contributing factors to climate change is a big challenge for livestock farmers and those offering support services (Musemwa et al., 2012). Insufficient literature and

reliability of the existing data on the effects of climate change on communal livestock farming is questioned mainly by various climate scientists and policy makers (Scholtz et al., 2014; Mare et al., 2018). The current study identified 62 published articles on climate change impact on livestock production in the country. Given the continued socio-economic role of livestock in the country, their substantial share of the country's livestock holdings (some 5.6 million cattle herd, or 41% of the national total), and the large proportion of households directly involved, this is a prominent knowledge gap. Currently, a large proportion of published articles were survey data rather than experimental investigations. This variation has raised a lot of public debates among climate scientists in the past two decades. Other researchers claim that most experiments are unrealistic because they do not correspond to the projected climate scenarios for a specific region (Clarke et al., 2012). The debate on the reliability of experimental studies on climate change scenarios calls for common procedures for future experiments. Survey research has been promoted as a suitable method to determine the socio-economic aspect and background information of climate change impact on livestock production. However, this has raised some disagreements between climate scientists and policy developers to develop climate change policies and proper mitigation strategies. It has been noted that universities are at the forefront of climate change research in South Africa. This finding agrees with Mpandeli et al. (2015), highlighting that universities are vital hubs of research and teaching on climate change. Besides conducting scientific research and promoting innovation on climate change and sustainability, institutions of higher learning have a duty to engage communities on climate change impact and support community mitigation and adaptation interventions.

Knowledge Gaps and Specific Areas of Concern

Although the literature on climate change impact and mitigation in livestock production systems is gaining more research attention, five areas of concern and needs were noted in the current review article on rural communities of South Africa.

Limited Background Studies of South Africa's Rural Communities

There seems to be a significant imbalance in climate change literature in communal livestock production than in the commercial sector in South Africa. More than 60% of the existing publications in the country have considered commercial livestock production as the priority research area requiring urgent attention to climate change adaptation and mitigation (Thinda et al., 2021). Limited research attention given to rural communities does not reflect the on-going claims that practicing livestock production in communal areas is a risky business due to its vulnerability to climate change. Rural communities are highly dependent upon natural resources affected by climate change (Maponya and Mpandeli, 2013). These communities also face particular geographic and demographic obstacles in responding to climate change, increasing their vulnerability to its impacts (Mpandeli et al., 2015). In particular, physical isolation, limited economic diversity, and higher poverty rates, combined with an aging population, increase the vulnerability of rural communities (Maponya and Mpandeli, 2012). These obstacles added more pressure as the systems of fundamental importance to rural people are already stressed by remoteness and limited access (Mare et al., 2018; Archer et al., 2021). Climate change impacts in rural communities are projected to increase in the coming years and will put more strain on rural economic activities like livestock production (Maluleke et al., 2020). This observation calls for further research activities on climate change impact and mitigation in communal livestock production of the country.

The Silo Approach to Investigate Climate Change Impacts on Livestock Production

Adaptation responses are mainly documented as a synthesis of what is already being done, the measures undertaken or is continuing across different production systems. These are generic autonomous adaptation responses that take little or no account to specific climate change impacts. Only a few have associated adaptations to specific climate change impacts [e.g., (Maponya and Mpandeli, 2012; Mthembu and Zwane, 2017)]. To develop effective adaptation strategies and ensure adaptation success, research on climate change adaptation must not be approached separately but should instead be integrated within the framework of impact assessments (Popoola et al., 2019; Oduniyi et al., 2020). The documented adaptation responses are mostly incremental through management and technology adjustments to reduce the impacts, and less on systemic measures such as institutional and policy changes. More research on anticipatory adaptation is needed, targeted for specific impacts, especially in rural communities of South Africa. This is due to grim predictions on climate change impacts. As a result, many farmers are constrained to spontaneous responses even in cases of extreme events, rather than being able to develop planned adaptation. Moreover, no adaptation option stands out as having high potential without considering local conditions and realities (Maponya and Mpandeli, 2012). For example, under the same grassland-based systems, the intensive rangelands and pastoral systems occur in contrary social and economic conditions and face different challenges. Thus different methodological assessments may apply. Limited evidence accounting for social variables has been similarly raised as concerns and needs to be considered further in climate change adaptation research (Dube and Jury, 2000; Tibesigwa et al., 2017).

Drawbacks on Mixed Crop-Livestock Systems as an Effective Response to Climate Change

Livestock production in rural communities is practiced under harsh and challenging environmental conditions (Maluleke et al., 2020). Temperature extremes and changes in rainfall have become a norm in South Africa, accompanied by frequent occurrence of climate chocks such as drought, floods and

heatwaves (Archer et al., 2021; Nyoni et al., 2021). Over-reliance of communally managed livestock production to natural resources has become a major setback as they solely rely on natural pastures and dams to sustain themselves (Mandleni et al., 2018). Increased death rates and unplanned sales have become a norm in many rural communities, where farmers are compelled to sell a portion of their stock during dry months (Slayi et al., 2021). In most instances, the selling price puts farmers at a disadvantage to avoid further production losses through mortality (Lottering et al., 2021). There are growing calls from various scientists and policy makers suggesting a mixed crop-livestock system as a mitigation strategy to the current climate crisis (Mthembu and Zwane, 2017). Half of the food products in South Africa and other developing countries are produced in mixed crop-livestock systems (Thinda et al., 2021). Mixed crop-livestock production is an old neglected farming practice with a great history of sustaining many poor households in rural communities (Maponya and Mpandeli, 2013). Unfortunately, the full range of climate change impacts on the mixed crop-livestock systems in both commercial and communal levels is poorly understood. Reintroducing this practice in communal areas could benefit the sustainability of livestock farming and the sustenance of disadvantaged people under changing climate. Research initiatives investigating the role of mixed crop-livestock systems in climate change mitigation are highly recommended.

Uneven Geographic Distribution of Climate Change Research in South Africa

South African literature on climate change's impact on livestock production shows a huge gap regarding published articles of research done on different regions within provinces. Such progress could be misleading as it does not represent the actual sensitivity of other provinces to climate change. This finding agrees with Muller and Shackleton (2014) who reported an imbalance on geographical coverage of literature on climate change. Explanation to this finding could be allocation number or proximity of research institutions within the provinces in the country. Another reason could be the history of the region or province regarding livestock production. For instance, high proportion of the published articles in South Africa is from the Eastern Cape Province, KwaZulu Natal and Limpopo. All the mentioned provinces are for significant livestock production with a large population in the country (Maluleke et al., 2020). Livestock in rural communities of South Africa contributes a much higher share of people's income and plays a prominent socio-economic function (Musemwa et al., 2012; Taruvinga et al., 2013). Eight of the nine provinces in South Africa have been declared as disaster areas due to different climate change scenarios (Archer et al., 2021). Rural communities within these provinces are more vulnerable to climate change, and livestock are more likely to suffer from climate extremes, with less infrastructure to ensure the safety of the animals (Lottering et al., 2020a; Maponya and Mpandeli, 2013). This fundamental research gap requires urgent attention as livestock are found throughout the country.

Limited Studies on Monogastric Livestock Over Ruminants in Rural Communities

Though climate change poses greater risks and challenges to livestock production in South Africa, most impact studies focus on ruminant animals such as beef cattle and goats than the chicken and pigs (Mapfumo et al., 2017; Mandleni and Anim, 2011). South Africa has minimal number of studies that have examined the effects of climate change on chickens and pigs despite their alleged sensitivity and significant role in the livelihoods of rural people (Nyoni et al., 2019). Health-wise, chickens and pigs are less tolerant of climate change, and their productivity is even more affected than cattle and goats (Nyoni et al., 2021). Increased temperatures and heat stress have been ranked as the main contributors to losses in poultry through death, low egg production and slow growth rate (Vetter et al., 2020). Though not as visible in the literature, monogastric have lower environmental impacts than ruminants, with their indigenous genotypes or strains showing the greater capacity to adapt to climate change (Mare et al., 2019; Meissner et al., 2013; Zwane, 2019). Ruminants are crucial in pastoral and subsistence production as a main source of food in areas that cannot sustain crop production due to long periods of droughts and water scarcity [e.g., (Dube and Jury, 2000)]. Thus, while more research on monogastric, ruminant production should remain important in challenging environmental conditions where pig and poultry farming might become impossible. Goats have been identified as a climate-resilient model and adaptation strategy suitable under harsh and challenging environmental condition prevalent in rural communities of South Africa. This could be attributed to their short production cycle, which make them ideal for recovering after a climate disaster shock and being hardy to extremes of climate change.

CONCLUSION AND RECOMMENDATIONS

The current study found that climate change research has gained momentum over the past two decades, with universities at the forefront. However, biasness has been observed in the collected data, with more publications in the form of surveys rather than experimental work and literature reviews. This has a bearing on the quality and utilization of the studies. Therefore, studies have taken a more generalist approach, tending to combine multiple climate variables and impacts. However, the studies have shown that climate change impact on livestock production is complex and intertwined. Drought has been a major climatic shock that has received multiple responses including destocking, supplementary feeding, breed improvement, and diversification. There is a need to improve geographic coverage of studies to other limited livestock regions. To gain relevance and effectiveness, responses to climate change should be context-specific and holistic. Diversification in research should be encouraged to accommodate the impacts of climate change on non-ruminants. An important highlight of this paper is if the magnitude of climate change impacts remains unclear, the capacity to respond will consistently be underestimated. More detailed adaptation and mitigation

research is needed to develop effective options suitable for rural livestock farming communities.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization, LZ, LM and MS.; Methodology, LZ, SN and MS; Data curation, LZ, IJ and MS.; writing-original draft preparation, LZ.; writing-review and editing, MS, IJ and SN. All authors have read and agreed to the published version of the manuscript.

FUNDING

This research was funded by National Research Foundation, grant number TS64 (UID: 99787).

ACKNOWLEDGMENTS

Financial support received from National Research Foundation is acknowledged.

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