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Extreme heat and drought in Sub-Saharan dairy production systems: A systematic map protocol using a One Health approach.

A Protocol for Systematic Evidence and Gap Map

Contents

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Heat stress, dairy cow health, occupational health, environmental health, Sub-Saharan Africa

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Background

Approximately 12–14% of the global population relies, to varying degrees, on dairy farming for their livelihoods (FAO, 2010). In Sub-Saharan Africa (SSA), dairy production systems are predominantly operated by smallholder farmers within mixed crop–livestock or pastoral systems (FAO, 2010; Nyameasem et al., 2018; Walshe et al., 1991). These systems play a critical role in delivering high-quality food, strengthening economic resilience, and sustaining rural livelihoods, especially among vulnerable populations in low-income countries (Tricarico et al., 2020). However, these systems face increasing threats from climate change and associated extreme weather events, notably extreme heat and drought. Adopting a One Health approach—which emphasizes the interdependence of human, animal, and environmental health (Mettenleiter et al., 2023)—is crucial for understanding how heat and drought impact the entire dairy production system, encompassing dairy cattle, the personnel working with them, and the ecosystems on which they depend.

In dairy cattle, heat stress occurs when animals are unable to dissipate excess body heat due to high ambient temperatures and humidity (Wankar et al., 2021). Physiological effects include metabolic strain, reproductive dysfunction, immune suppression, and increased mortality. The severity of these health impacts varies according to lactation stage, production phase, and breed-specific thermotolerance (Oliveira et al., 2025). From a production perspective, heat stress results in reduced feed intake, increased water demand, and declines in milk yield and quality. The consequences extend beyond the immediate production cycle: long-term, intergenerational consequences for calf development and future productivity have been shown in cows exposed to heat during late gestation (Ouellet et al., 2020). Heat and humidity jointly determine thermal comfort in animals. This relationship is commonly quantified using the Temperature–Humidity Index (THI) or related comfort indices (Schoen, 2005; Thom, 1959). Elevated THI increase heat stress in the cow – with susceptibility further modulated by factors such as breed and lactation status (de Castro Júnior et al., 2024). On the other hand, drought and changes in rainfall patterns usually reduce pasture growth, lowering fodder yields, and diminishing forage nutritional value (Brychkova et al., 2022), further compounding heat stress, dehydration, and production losses. In addition, heat stress may indirectly increase the environmental footprint of dairy production by raising greenhouse gas (GHG) emissions per unit of milk, thus intensifying environmental pressures (Tricarico et al., 2020).

Extreme heat also poses direct health risks to dairy farmers. Heat-related illnesses in humans range from heat stroke and dehydration to cardiovascular and respiratory strain, pregnancy and developmental risks, kidney diseases, and mental conditions (Ebi et al., 2021; Liu et al., 2022; Romanello et al., 2025; Yüzen et al., 2023). Outdoor workers are typically more exposed to heat stress and tend to have a lower capacity to adapt to heat (Slesinski et al., 2025). They often have limited access to protective measures such as adequate hydration, shaded areas, or cooled rest breaks (Ebi et al., 2021). For smallholder farmers, these vulnerabilities are further intensified by economic dependence on livestock productivity (Talukder et al., 2021). Heat exposure can lead to unsafe work conditions, reduced labor capacity and productivity as well as food and income insecurity (Talukder et al., 2021). Drought conditions constrain water availability for humans, animals and pastures. While commercial dairy farms have limited capacity to adapt to prolonged pasture degradation, pastoralist systems retain greater flexibility through mobility; however, herders are increasingly forced to travel longer distances in search of water and grazing resources, intensifying physical strain and competition (Goldman & Riosmena, 2013).

Rising climate-related stressors also cause a series of hydrological and ecological disruptions, significantly threatening environmental stability. Extreme heat and drought cause rising temperatures and precipitation deficits, accelerating evapotranspiration, rapidly depleting soil moisture, and lowering water table levels in critical boreholes and surface water points (Gebremeskel Haile et al., 2019). This hydrological stress triggers significant

degradation of rangelands, resulting in reduced pasture biomass and a decline in the nutritional quality of fodder, directly undermining the primary feed source for dairy herds (FAO & Global Dairy Platform, 2019). At the same time, these disturbances cause harmful changes in plant communities; native, edible plants show reduced growth potential and are increasingly replaced by dry, invasive species. This process decreases biodiversity and weakens ecological resilience (IPCC, 2022). In the long run, these changes create feedback loops such as faster soil organic matter decomposition due to higher temperatures, which raise GHG emissions relative to dairy production, further contributing to global environmental challenges (Liu et al., 2020).

A One Health perspective is essential to understanding and addressing heat stress in agricultural production systems (Mikó et al., 2025). However, existing reviews in the field rarely integrate the One Health approach (Cheng et al., 2022; Dash et al., 2016; El Khayat et al., 2022; Florez-Acevedo et al., 2025; Giannone et al., 2023; Gupta et al., 2022; Liu et al., 2022; Oliveira et al., 2025; Sampath et al., 2023; Slesinski et al., 2025; Talukder et al., 2021; Tricarico et al., 2020; Van Selm et al., 2025). Especially in the Global South, knowledge on the impact of extreme heat and drought on the health of humans, animals in the dairy production system is lacking (El Khayat et al., 2022). To address this critical gap, this Scoping Review aims to systematically map and synthesize existing research on the impacts of extreme heat and drought on animal and human health within SSA dairy production systems. It will identify the extent, nature, and distribution of current evidence; highlight gaps in knowledge; and assess how these impacts have been studied, thereby providing a structured foundation for a subsequent evidence synthesis through a Systematic Review and meta-analysis, as well as for informed policy development.

Causal model

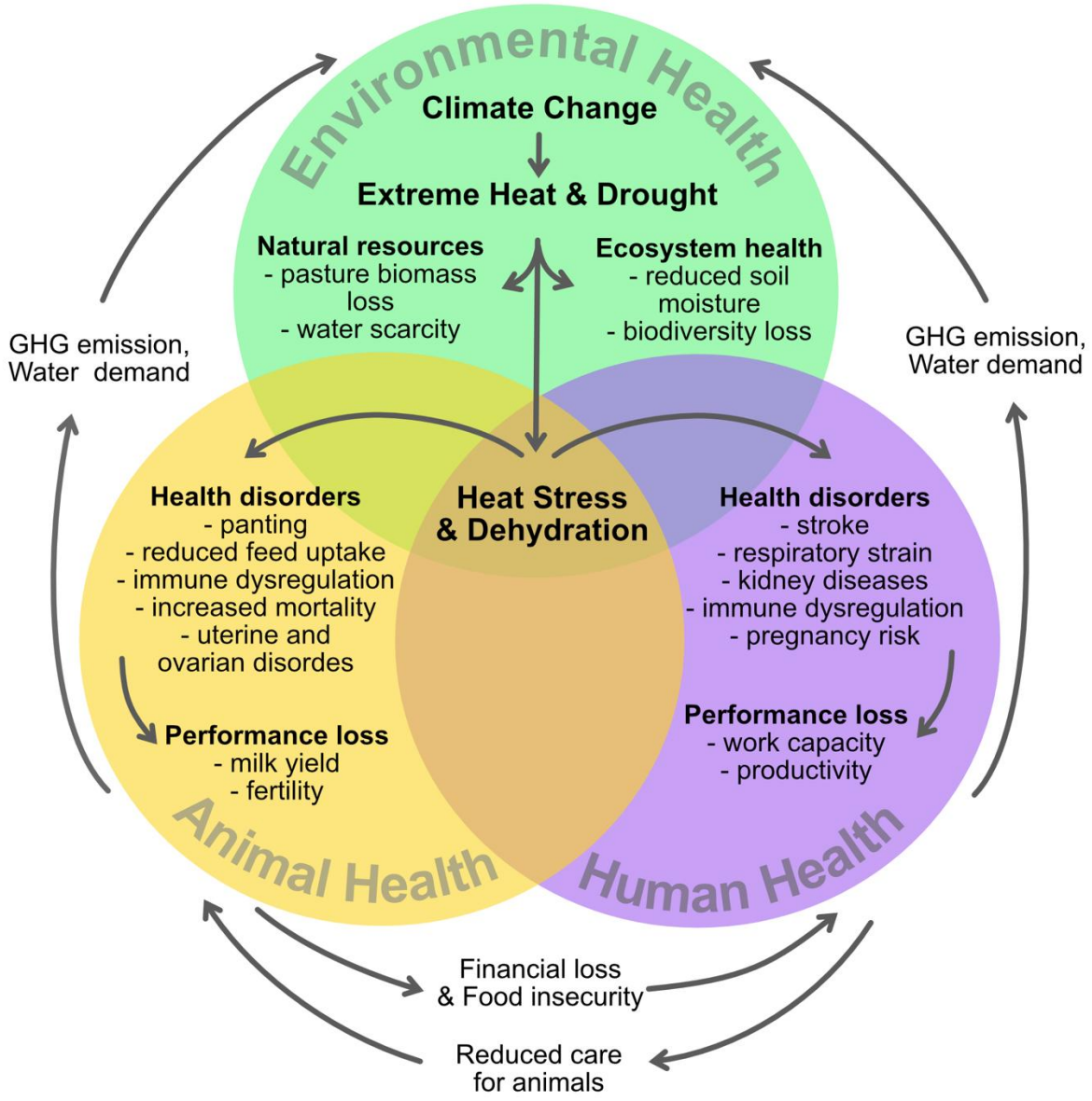

Figure 1. Causal One Health Model

Extreme heat events exert complex, interlinked effects across animal, human, and environmental health domains—necessitating an integrated One Health approach. The diagram (Figure 1) illustrates how climate-driven extreme heat and drought generate linked effects across the One Health domains, shaping the resilience of dairy production systems in Sub-Saharan Africa.

At the apex of this system lies the environmental health domain, where extreme heat and drought degrade dairy production landscapes, leading to decreased soil moisture, biodiversity loss, declining pasture biomass, and water scarcity.

Within the animal health domain, heat stress and dehydration manifest as health disorders, including panting, immune dysregulation, increased mortality, and reproductive issues such as uterine and ovarian disorders, leading to performance loss and affecting milk yield and fertility.

Similarly, dairy farmers—especially those engaged in labor-intensive smallholder systems—experience occupational heat stress. The human health domain closely parallels the animal domain, with health issues such as stroke, respiratory problems, kidney disease, and pregnancy risks. These physiological challenges result in noticeable declines in work ability and overall productivity.

Collectively, these interlinked effects create a reinforcing cycle of reduced livestock care, lower milk yields, financial losses, and food insecurity. As milk production declines, the GHG emissions per liter of milk increase because maintenance emissions persist while output falls, reducing system efficiency. This imbalance, coupled with greater water demand, illustrates how climate-induced heat stress progressively undermines sustainability across all One Health domains.

Stakeholder engagement

Throughout the review process, we will actively involve stakeholders from diverse sectors relevant to animal health, occupational health, and environmental health in Sub-Saharan Africa. These stakeholders—including representatives from farmer associations, veterinary and environmental sciences, occupational health, and regional pastoralist communities—have been identified in collaboration with CGIAR. Stakeholder engagement will be structured through three planned meetings spanning the review stages from scoping through interpretation to translation of findings. During the initial meeting, stakeholders will co-develop the protocol, validate the scope, refine the research questions, and optimize the search strategy. In the subsequent steps of the review, stakeholders will provide thematic expertise, offer critical contextual insights to ensure depth and relevance, help identify evidence gaps, and support the dissemination and uptake of results.

Objectives and review question

This systematic map aims to identify and characterize existing evidence on the impacts of extreme heat and drought on dairy cows and dairy farmers within SSA, using a One Health framework that integrates animal, human, and environmental health perspectives. The following primary research question will guide the review:

What evidence exists on the impacts of extreme heat and drought on dairy cows and dairy farmers in Sub-Saharan Africa?

Secondary research questions will include:

- **Exposure and outcome metrics**: What indicators and metrics are used to quantify exposure to extreme heat and drought, and how are these linked to health and productivity outcomes in dairy cows and dairy farmers?
- **Geographic and Climatic Coverage**: Which geographic regions, countries, and climate zones within Sub-Saharan Africa are represented in the existing evidence base?
- **One Health Integration**: To what extent do existing studies adopt or reflect a One Health approach?

Definitions of the question components

The review is structured according to the Population–Exposure–Comparator–Outcome (PECO) framework, applied across the One Health domains of animal and human health (Table 1). This framework defines the scope of the review and guides the development of the search strategy, screening criteria, and data extraction. It captures how climate-related extreme heat and drought affect dairy cows and dairy farmers in Sub-Saharan Africa, encompassing both animal health and productivity, as well as occupational health outcomes.

Table 1. PECO framework for the One Health domains

	Animal health domain	Human health domain	Environmental health domain
Population	Dairy cows in Sub-Saharan Africa	Dairy farmers in Sub-Saharan Africa	Dairy production landscapes in Sub-Saharan Africa
Exposure	Climate change-driven extreme heat and drought		
Comparator	Exposed vs. unexposed animals	Exposed vs. unexposed individuals	Exposed vs. unexposed geographical areas
Outcomes	Dairy cow health and performance	Occupational health and productivity	Natural resource and ecosystem health
Study types	Primary research		

The following key definitions will be applied:

Sub-Saharan Africa: Sub-Saharan Africa will be defined according to the United Nations Statistics Division Standard Country or Area Codes for Statistical Use (M49), region code 202, which includes all 51 countries geographically located south of the Sahara Desert (see Annex 1).

Extreme Heat: Climate change-driven “episodic high surface air temperature events potentially exacerbated by humidity”, as defined by the IPCC as a climatic impact driver (IPCC, 2021).

Drought: Climate change-driven “Episodic combination of soil moisture supply deficit and atmospheric demand requirements that challenges the vegetation’s ability to meet its water needs for transpiration and growth (IPCC, 2021).

Dairy cow: A dairy cow is a female bovine, managed primarily for milk production. For this review, the term includes cows at different productive and reproductive stages.

Dairy cow health and performance: Dairy cow health reflects the animals’ overall physiological condition and well-being. In the context of exposure to extreme heat and drought, this includes increased respiration rate, impaired immune function, metabolic and reproductive disorders, altered behavior, and reduced feed or water intake. Morbidity and mortality directly attributable to heat or drought are also key indicators of thermal and environmental stress in dairy cows. Dairy cow performance refers to the animal’s functional productivity, particularly milk yield—the quantity of milk produced over a defined period—and reproductive performance, which reflects fertility and successful breeding outcomes.

Dairy farmer: An individual engaged in the management, care, or daily operations of dairy cattle for milk production. In Sub-Saharan Africa, this includes smallholder, pastoralist, and commercial dairy producers, as well as hired farm workers involved in dairy-related tasks.

Occupational health and productivity: Occupational health encompasses the physical, mental, and social well-being of workers, including their overall health status and work capacity. Productivity refers to the efficiency and output of work performed under given conditions. In the context of dairy farmers' exposure to extreme heat and drought, outcomes include heat stress symptoms, fatigue, dehydration, metabolic, reproductive, respiratory, and renal disorders, as well as morbidity and mortality directly attributable to heat or drought exposure, workplace accidents, reduced work capacity, and decreased productivity in dairy milk production and herd management.

Dairy production landscapes: Ecological, physical, and managed environments that support dairy farming. These landscapes encompass the interconnected systems of soil, water resources, pastures, and rangelands that surround ecosystems that sustain dairy cattle and influence the environmental footprint, productivity, and resilience of dairy production systems.

Natural resource and ecosystem health: The condition and functionality of the natural systems that sustain dairy production landscapes under climatic stress. In the context of exposure to extreme heat and drought, it encompasses changes in water table levels, soil moisture, pasture biomass and quality, and local biodiversity, which together indicate the capacity of soils, vegetation, and ecosystems to support dairy productivity and recover from environmental stress.

Primary research: Studies that generate and analyze original empirical data collected through observation, measurement, experimentation, or field-based investigation. This includes, for example, observational, experimental, and longitudinal studies examining physiological or production responses of dairy cattle to extreme heat or drought; cross-sectional, cohort, and qualitative studies exploring occupational, physiological, or psychosocial effects of extreme heat among dairy farmers and farm workers; and ecological surveys, remote sensing analyses, and environmental impact assessments quantifying environmental changes such as pasture productivity, soil moisture, or water availability. Studies may be peer-reviewed or constitute grey literature.

Search strategy

A comprehensive and reproducible search strategy will be deployed to capture both peer-reviewed and grey literature relevant to extreme heat impacts on dairy systems within a One Health framework in SSA. Searches will include major bibliographic databases across human and animal health sciences, environmental and agricultural sciences, as well as multidisciplinary academic search engines and institutional repositories. Boolean operators, synonyms, and wildcard characters were tailored for each source. All searches will be limited to studies published from 2000-2026 to ensure that included studies reflect contemporary climate conditions, dairy production systems, and research practices in SSA. Climatic extremes have intensified, data availability has improved, and integrated approaches such as One Health have become more prominent in the 21st century, making earlier studies less comparable to current contexts. Furthermore, searches will be limited to English and French, the main publication languages in Sub-Saharan Africa and those spoken by the review team. Search strings will use combinations of population, exposure, outcome, and geographic terms (Table 2).

Table 2. Search strings for Web of Science

	Search string
1	Animal health - population cattle OR cow OR bovine OR ruminant OR dairy OR lactating OR lactation OR "bos taurus" OR "bos indicus" OR zebu OR holstein OR friesian OR jersey OR Ayrshire

	OR Ankole OR Sahiwal* OR "Red Sindhi" OR sanga OR Horro OR heifer OR livestock OR husbandr* OR farm*
2	Animal health – exposure : heat OR weather OR "climat* change" OR temperature OR hot OR warm* OR humid* OR WBGT OR drought OR dry OR drying OR precipitation OR rainfall OR desertificat* OR desiccat* OR "climat* varia*" OR arid* OR semi-arid OR "sun exposure" OR "solar radiation" OR "environmental change" OR meteorolog* OR "bulb temperature" OR psychometr* OR heatwave OR dryland OR enthalp* OR "thermal comfort" OR "thermoneutral zone" OR "upper critical temperature" OR "lower critical temperature" OR "discomfort index"
3	Animal health - outcome and comparator: hyperthermia OR physiolog* OR morbid* OR immun* OR metabol* OR biomarker OR "negative energy balance" OR respirat* OR panting OR breath* OR mortalit* OR surviv* OR cull* OR reprod* OR fertility OR concept* OR gestation OR pregnan* OR calving OR fetal OR foetal OR estrus OR progen* OR oocyte OR "days open" OR return* OR ruminat* OR activ* OR performance* OR "milk yield" OR "milk output" OR "milk production" OR ECM OR "dry matter intake" OR "feed intake" OR "feed consumption" OR "water intake" OR dehydrat* OR hydrat* OR "milk composition" OR protein OR fat OR (kilogram AND milk) OR "body weight" OR "herd size" OR "body condition score" OR pasture OR rangeland* OR grassland OR fodder OR forage OR nutrient* OR food OR toleran* OR behavio$r OR "fat-to-protein ratio" OR milkability OR lying OR grazing OR "thermal comfort" OR "thermoneutral zone" OR "upper critical temperature" OR "lower critical temperature" OR "body temperature" OR mobilit* OR movement* OR colo$r* OR fur OR coat OR pigment* OR hair OR breed* OR genet* OR cooling OR epigenet* OR health-status OR "milk quality" OR "water consumption" OR syndrom* OR symptom* OR discomfort
4	Human health – population: (work* AND (farm* OR agricultur* OR rural OR dairy OR milk* OR cattle OR livestock OR herd* OR outdoor)) OR (employee AND (farm* OR agricultur* OR rural OR dairy OR milk* OR cattle OR herd* OR livestock OR outdoor)) OR (labor* AND (farm* OR agricultur* OR rural OR dairy OR milk* OR cattle OR herd* OR livestock OR outdoor)) OR (labour* AND (farm* OR agricultur* OR rural OR dairy OR milk* OR cattle OR herd* OR livestock OR outdoor)) OR (farm* AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (keeper AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (keeping AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (herder AND (dairy OR milk* OR cattle OR livestock)) OR (manager* AND (farm* OR agricultur* OR dairy OR milk* OR cattle OR herd* OR livestock)) OR (holder AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (holding AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (producer AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR (producing AND (dairy OR milk* OR cattle OR herd* OR livestock)) OR smallholder OR “small holder” OR pastoral* OR nomad OR transhumance OR husbandr*
5	Human health – exposure : heat OR weather OR "climat* change" OR temperature OR hot OR warm* OR humid* OR WBGT OR drought OR dry OR drying OR precipitation OR rainfall OR desertificat* OR desiccat* OR "climat* varia*" OR arid* OR semi-arid OR "sun exposure" OR "solar radiation" OR "environmental change" OR meteorolog* OR "bulb temperature" OR psychometr* OR heatwave OR dryland OR enthalp* OR "thermal comfort" OR "thermoneutral zone" OR "upper critical temperature" OR "lower critical temperature" OR "discomfort index"
6	Human health - outcome and comparator: “heat stress” OR “thermal stress” OR “heat stroke” OR heat-shock OR "heat shock" OR "heat strain" OR "thermal comfort" OR occupation* OR productiv* OR "work time" OR labo*r OR hydrat* OR dehydrat* OR mortalit* OR morbid* OR health OR illness* OR disease OR cardio* OR vascul* OR mental OR psycholog* OR physic* OR

	fatigue OR performance OR capacity OR absent* OR present* OR limitation OR impair* OR electrolyt* OR dysfunction* OR exhaust* OR renal OR kidney* OR sweat* OR "non-communicable disease*" OR NCD OR NCDs OR comorbid* OR respirator* OR pulmonary OR lung* OR asthma OR bronchit* OR COPD OR metabolic OR diabet* OR "glucose intolerance" OR "insulin resistance" OR "financial loss*" OR "financial pressure" OR poor OR "food secur*" OR poverty OR income OR livelihood OR stress OR psychosocial OR "social factor" OR traditional OR cultural OR pregnancy OR pregnant OR maternal OR reproductiv* OR fertility OR miscarriage OR "pre-term birth" OR conception OR conceptive OR vulnerab* OR toleran* OR behavio*r OR "body temperature" OR discomfort OR mobilit* OR movement OR "occupational safety" OR ill OR "discomfort index" OR "physical workload" OR "manual labor" OR "manual labour" OR "work intensity" OR clothing OR "personal protective equipment" OR PPE OR "occupational accident" OR "workplace accident" OR "work-related injur*" OR health-status OR "milk yield" OR "milk quality" OR syndrome OR symptom OR (kilogram AND milk) OR "thermoneutral zone" OR "upper critical temperature" OR "lower critical temperature" OR cooling
7	Environmental health - population (cattle OR cow OR bovine OR ruminant OR dairy OR milk OR zebu OR holstein OR friesian OR jersey OR Ayrshire OR Ankole OR Sahiwal OR "Red Sindhi" OR sanga OR Horro OR heifer OR livestock OR pastoral) AND (rangeland OR pasture OR grassland OR savanna OR grazing OR agroecosystem OR agro-ecosystem OR landscape OR ecosystem OR habitat OR "natural resource" OR "water source" OR "water table" OR borehole OR groundwater OR “ground water” OR "surface water*" OR "soil moistur*" OR biomass* OR "vegetation" OR biodivers* OR forage OR fodder OR "catchment area" OR "water point" OR "land resource")
8	Environmental health – exposure : heat OR weather OR "climat* change" OR temperature OR hot OR warm* OR humid* OR WBGT OR drought OR dry OR drying OR precipitation OR rainfall OR desertificat* OR desiccat* OR "climat* varia*" OR arid* OR semi-arid OR "sun exposure" OR "solar radiation" OR "environmental change" OR meteorolog* OR "bulb temperature" OR psychometr* OR heatwave OR dryland OR enthalp*
9	Environmental health - outcome and comparator: "aquifer recharge" OR biomass* OR "borehole yield" OR "canopy cover" OR "land cover" OR "land use" OR control site OR resilien* OR EVI OR flora OR forage OR fodder OR fauna OR "habitat loss" OR organic OR environment OR LAI OR "leaf area" OR irrigation OR NDVI OR microbial OR pasture OR plant-soil OR soil OR nutrient OR recovery OR "reference site" OR resource OR desertific* OR erosion OR moisture OR degradation OR salin* OR SOC OR "species composition" OR "species richness" OR "spatial variation" OR "temporal change" OR vegetation OR well OR water OR manure OR slurry OR effluent OR agroecosystem OR "weed encroachment" OR biodivers* OR nitrogen* OR phosphor* OR microorganism OR carbon OR sustainab* OR plant OR emission OR methane OR "greenhouse gas*" OR CH4 OR GHG OR "thermal stress" OR "heat stress" OR ecosystem OR agro-ecosystem OR agroecosystem OR bushland OR wetland OR grassland OR forest OR "bare ground" OR woodland OR deforestation OR ecologic* OR rewetting
10	sub-Sahar* OR "Africa south of the Sahara" OR SSA OR "East* Africa*" OR "South* Africa*" OR "West* Africa*" OR "Central Africa*" OR "British Indian Ocean Territory" OR "Territoire britannique de l'océan Indien" OR Burundi OR Burundian OR Comoros OR Comoro OR Comores OR Comorian OR Djibouti OR Djiboutian OR Eritrea OR Érythrée OR Eritrean OR Ethiopia* OR "French Southern Territories" OR Kenya* OR Madagascar OR Malagasy OR Malawi OR Malawian OR Mauritius OR Mauritian OR Mayotte OR Mahoran OR Mozambique OR Mozambican OR Réunion OR "La Réunion" OR Réunionese OR Rwanda* OR Seychelles OR Seychellois OR Somalia

OR Somalie OR Somalian OR Sudan OR Soudan OR Sudanese OR Uganda OR Ouganda OR Ugandan OR Tanzania* OR Zambia* OR Zimbabwe* OR Angola* OR Cameroon OR Cameroun OR Cameroonian OR Chad OR Tchad OR Chadian OR Congo OR Congolese OR Gabon OR Gabonese OR "Sao Tome and Principe" OR São Toméan OR Santomean OR Botswana* OR Eswatini OR Swaziland OR Swazi OR Lesotho OR Basotho OR Lesothan OR Namibia* OR Benin* OR "Burkina Faso" OR Burkinabè OR "Cabo Verde" OR "Cape Verde" OR Cap-Vert OR "Cape Verdean" OR "Côte d'Ivoire" OR "Ivory Coast" OR Ivorian OR Gambia OR Gambian OR Ghana OR Ghanaian OR Guinea NOT "guinea pig*" OR Guinée OR Guinean OR Guinea-Bissau OR Guinée-Bissau OR Bissau-Guinean OR Liberia OR Liberian OR Mali OR Malian OR Mauritania OR Mauritanie OR Mauritanian OR Niger* OR "Saint Helena" OR "St. Helena" OR Sainte-Hélène OR "Saint Helenian" OR Senegal OR Senegalese

The individual search strings will be combined using Boolean operators to reflect the three One Health dimensions. Each domain incorporated its respective population, exposure, outcome, and geographic strings. The combinations in Web of Science using Title, Abstract, and Author keywords fields, and filtered by custom date retreived the following

Records (as of 29 January 2026):

Animal Health (#1 AND #2 AND #3 AND #10): 11,741

Human Health (#4 AND #5 AND #6 AND #10): 7,570

Environmental Health (#7 AND #8 AND #9 AND #10): 3,059

Overall – combining animal health, human health, and environmental health with the Boolean operator OR - search results retrieved 15,320 hits.

Bibliographic databases

Table 3 illustrates the bibliographic databases searched.

Table 3. Bibliographic databases

Database	Access	Fields Searched
PubMed / MEDLINE	Institutional access through LMU	Title, Abstract, MeSH terms
Web of Science (Science Citation Index Expanded, Social Sciences Citation Index)	Institutional access through LMU	Title, Abstract, Author Keywords
CAB Direct / CABI Digital Library	Institutional access through LMU	Title, Abstract, Descriptor
GeoRef	Institutional access through LMU	Title, Abstract, Subject
AgEconSearch	Open access	Title, Abstract, keywords
ProQuest	Institutional access through LMU	Title, Abstract, keywords

Web-based search engines

A web-based search will be performed on Google scholar (https://scholar.google.com/) to capture additional grey literature not indexed in the bibliographic databases. For the animal health domain, the keywords cow, heat, drought, health, milk yield, fertility, and Africa will be used, for the human health domain dairy farmer, heat, drought, “occupational health”, “work capacity”, and Africa accordingly. The first 100 search results of each domain will be downloaded using the Publish or Perish Software (https://harzing.com/resources/publish-or-perish/).

Organizational websites

We will include grey literature (reports, institutional publications) from organizational websites listed in Table 4.

Table 4. Organizational websites

Organization	URL
CGIAR institutional open-access repository (CGSpace)	https://cgspace.cgiar.org/home
Food and Agriculture Organization of the United Nations: International System for Agricultural Science and Technology (AGRIS)	https://agris.fao.org
World Organisation for Animal Health (WOAH)	https://doc.woah.org/
International Labour Organization (ILO), Labordoc	https://labordoc.ilo.org/
United Nations Development Programme (UNDP)	https://hdr.undp.org/reports-and-publications/
Global Heat Health Information Network	https://heathealth.info/resource-library/
World Bank	https://documents.worldbank.org/

Comprehensiveness of the search

A list of 10 benchmark publications (see Annex 2) was selected by the review team and stakeholders, based on the knowledge and expertise in the field and the review objective. To assess the comprehensiveness of the search strategy, we determined whether all benchmark publications were retrieved during the initial search. The benchmark test achieved a 100% retrieval rate across Web of Science, PubMed, and the CABI Digital Library (10 out of 10 studies).

Search update

To ensure the systematic map remains current, we will conduct a search update during subsequent stages of the review, using the original search strategy across the same databases, adjusting only the date range to capture newly published studies. Retrieved records will undergo the same screening, eligibility, and coding procedures as the initial set. All additions will be documented in the final report.

Screening strategy

Retrieved studies will be deduplicated in EndNote (Bramer et al., 2016) and then assembled in the *Rayyan* platform. Inclusion and exclusion criteria will be uploaded into the *Rayyan* platform to guide the multi-stage double-blind screening process, in which titles, abstracts, and full texts will be screened sequentially for eligibility. At the first stage, titles and abstracts will be screened independently by two reviewers to exclude records that are clearly irrelevant. Studies for which eligibility cannot be determined from the title will advance to full-text screening. Reasons for exclusion will be recorded. Discrepancies between reviewers will be resolved through discussion or by a third reviewer, ensuring consistency and transparency throughout the process.

Eligibility criteria

Studies meeting the inclusion and exclusion criteria presented in Table 5 will be considered eligible for inclusion in the review.

Table 5. Inclusion and exclusion criteria

Key element	Inclusion	Exclusion
Population	Dairy cows (any breed or production stage), dairy farmers, farm workers, or pastoralists involved in dairy production	Studies focusing exclusively on non-dairy livestock species (e.g., beef cattle, goats, sheep, pigs, poultry, camels), studies not involving dairy production systems or dairy-related occupations.
Exposure	Studies that report or discuss exposure to extreme heat and/or drought, either directly or in the broader context of climate change (e.g., temperature increase, heat waves, precipitation variability)	Studies focusing on unrelated environmental exposures (e.g., floods, cold stress, chemical pollution, greenhouse gas emissions) without reference to extreme heat or drought
Comparator	Comparisons may include baseline or reference conditions, temporal or spatial contrasts (e.g., before/after heat or drought events, normal vs. extreme years), or differences between exposed and unexposed populations.	
Outcome	Studies that report at least one health or productivity-related outcome in the animal or human domain: heat stress symptoms, morbidity, mortality, respiratory or metabolic disorders, renal disorders, reproductive performance, milk yield, feed and water intake, reduced dry matter intake (DMI), fodder shortage or feed availability, body condition, milk yield, occupational illness or injury, work productivity, mental health	Studies without measurable or descriptive outcomes related to dairy cow health, performance, or human health/productivity (e.g., studies that only measure perception, policy or economic analyses without empirical data)

Study type	Primary research studies that present original empirical data collected through observation, measurement, experimentation, or field-based investigation, including peer-reviewed articles and grey literature (e.g., institutional or technical reports, theses) with verifiable data and methods	Review papers, meta-analyses, commentaries, editorials, opinion pieces, policy briefs, conference abstracts, modeling studies using only secondary data, protocols, or media reports lacking primary data or systematic analysis
Geographic scope	Studies conducted in one or more of the 51 countries in SSA, as defined by the United Nations Statistics Division (Region Code 202)	Studies conducted outside Sub-Saharan Africa or in multi-country analyses where SSA-specific data cannot be disaggregated.
Date range	Publications from January 1, 2000, to the present	Publications before the year 2000
Languages	Articles in English or French	Articles in other languages where translation is not feasible

Consistency checking

After double blind screening titles and abstracts of 100 randomly selected articles, Cohen's Kappa coefficient will be calculated. All discrepancies will be reviewed to discuss the inclusion criteria and revise them where necessary. An additional 200 articles will then be re-screened for eligibility using titles, abstracts and full-text, including Kappa assessments. A Kappa value of ≥0.6 will be considered acceptable, below Kappa = 0.6 inclusion criteria will be revisited. All screening discrepancies will be discussed by the two reviewers. If consensus cannot be reached, the disagreement will be resolved through consultation with a third reviewer.

Reporting screening outcomes

A flow-diagram according to the reporting standards for systematic evidence synthesis (ROSES) (Haddaway et al., 2018) will be used, along with inclusion and/or exclusion tables and reasons.

Study validity assessment

A full critical appraisal of methodological quality and risk of bias will be undertaken during the subsequent systematic review and meta-analysis. For the purposes of this systematic map, study validity will not be formally assessed.

Data coding strategy

Data coding will be performed using a structured Excel spreadsheet to ensure consistency and reproducibility across reviewers. Each record will be coded according to a pre-defined set of variables covering bibliographic, geographic, methodological, population, exposure, comparator, and outcome dimensions, as well as indicators of One Health integration. Controlled vocabularies and dropdown menus will be applied where possible to minimize subjectivity, while free-text fields will capture detailed contextual information.

Meta-data to be coded

The coding framework (Table 6) enables systematic classification of studies by study design, domain, exposure type, and outcome category, and supports the assessment of the extent to which research adopts a One Health approach. One Health integration will be assessed across two dimensions:

- One Health data – representing the domains from which data were directly collected or analyzed (e.g., animal health data such as milk yield, blood samples or disease incidence, human data such as farmer's health-status or labor productivity, or environmental data such as temperature, rainfall, drought indices, water availability)
- One Health knowledge – representing the domains to which the study contributes knowledge, even if no direct data were collected from that domain (e.g., animal production data used to infer effects on farmer income or food security, thereby contributing to the human domain)

Reporting of data across all three domains is critical in One Health research (see Cohere Standards, (Davis et al., 2017)). This approach allows mapping of both the disciplinary data collection and the integrative scope, providing a robust framework to evaluate how One Health principles are conceptually and operationally embedded.

Table 6. Coding framework

Category	Variable	Data Type	Example
Bibliographic information	Citation	Text	Author(s), Year, Title, Journal
	DOI / URL	Text	https://doi.org/...
	Publication year	Numeric	2021
	Publication type	Dropdown	Journal article, report, thesis
	Peer-review status	Dropdown	Yes / No
Geographic information	Study country	Dropdown	Kenya, Ethiopia, South Africa
	Study site	Text	Nakuru County
	Climatic zone (Köppen–Geiger classification)	Dropdown	Aw (Tropical savanna climate, dry winter), BSh (Hot semi-arid (steppe) climate)
Study design	Study type	Dropdown	observational, experimental
	Quantitative/ qualitative methods	Dropdown	Quantitative, qualitative, mixed-methods
	Methods used	Text	Survey, regression analysis
Population	One Health data	Dropdown	Animal, Human, Environmental
	Population description	Text	Multiparous dairy cows, pastoralists
	Sample size	Text	120 cows; 45 households
Exposure	Exposure type	Dropdown	Heat stress, drought
	Exposure metric	Text	THI, temperature, rainfall, duration
	Exposure unit	Text	°C, mm, days
Comparator	Comparator description	Text	baseline climate data (1950-1999)
	Comparator metric	Text	THI difference, rainfall, duration
	Comparator unit	Text	°C, mm, days
Outcome	Outcome description	Text	Milk yield, fertility, mortality, feed intake, physical workload, work-related injuries, morbidity
	Outcome metric	Dropdown	average loss of milk yield, financial loss

Outcome unit	Text	L/cow/day, %
One Health knowledge gain	Dropdown	Animal, Human, Environmental

Consistency checking

Consistency checks will be implemented at the beginning of the coding phase. Two reviewers will independently extract meta-data from a random sample of 5 articles. Discrepancies in coding will be identified and discussed in detail to clarify definitions and harmonize interpretations of the coding framework.

Type of mapping

The primary output of this systematic map will be an open-access interactive geographic evidence map developed using EviAtlas (Haddaway et al., 2019). The map will visualize the spatial distribution of studies across Sub-Saharan Africa based on the study location metadata extracted during the review. Each mapped study will be represented as a point on the map, with filters allowing users to explore the evidence by One Health knowledge, study design, exposure and outcome type, as well as geographic and climatic coverage. This visual representation will help identify areas with high research density and highlight geographic evidence gaps.

Narrative synthesis methods

The narrative synthesis will support the identification of evidence clusters and gaps, enabling a deeper understanding of how extreme heat impacts dairy systems from a One Health perspective. Descriptive statistics and visualizations will be generated using R to summarize key variables. Planned outputs include:

- A summary table detailing study populations, sample sizes, and metrics used for exposure and outcome measurement.
- Several heat maps showing the frequency of studies across climate zones.
- Venn diagram to illustrate the overlap and integration of animal and human health domains across studies.

Knowledge gap identification strategy

The systematic map and narrative synthesis will support identifying knowledge gaps across geographic areas, climate zones, and One Health domains.

Demonstrating procedural independence

In cases where a member of the review team is an author of a paper identified for inclusion, another team member with no prior involvement in that publication will independently conduct all screening, data extraction, and coding for that study.

Supplementary Material

Annex 1: List of 51 Sub-Saharan countries

Annex 2: List of 10 benchmark publications

Competing interests

The authors declare no competing interests.

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Annex

Annex 1, List of 51 Sub-Saharan countries

The United Nations Statistics Division Standard Country or Area Codes for Statistical Use (M49), region code 202, defines Sub-saharan Africa as geographically located south of the Sahara Desert. It includes the following 51 countries:

British Indian Ocean Territory, Burundi, Comoros, Djibouti, Eritrea, Ethiopia, French Southern Territories, Kenya, Madagascar, Malawi, Mauritius, Mayotte, Mozambique, Réunion, Rwanda, Seychelles, Somalia, South Sudan, Uganda, Tanzania, Zambia, Angola, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Botswana, Eswatini, Swaziland, Lesotho, Namibia, South Africa, Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena, Senegal

Annex 2, List of 10 benchmark publications

Byenkya, G. S., Mugerwa, S., Barasa, S., & Zziwa, E. (2014). Land use and cover change in pastoral systems of Uganda: implications on livestock management under drought induced pasture [Journal article]. *African Crop Science Journal*, *22*(Suppl. 4), 1013–1025. http://www.ajol.info/index.php/acsj/article/view/108571/98373

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