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Livestock farmers' perception on effect of climate change on smallholder dairy farming in Fiji

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This study investigated the impacts of climate change on smallholder dairy farming in Fiji through a mixed-methods approach, combining a survey of 242 farmers in Viti Levu's Central Division with long-term meteorological and milk production data. Farmers were predominantly male (94.2%), aged over 54 years (73.1%), with low formal education (83.0% primary or secondary) and annual incomes below FJD 10,000 (43.4%), operating small farms (81.8% on 0.4–8.1 ha) with fewer than 20 milking cows (73.6%). Most farmers perceived rising daytime (70.2%) and nighttime (56.6%) temperatures and declining rainfall amounts and duration in both wet and dry seasons over the past 15 years. They reported substantial climate-induced impacts, including forage disappearance (73.6%), increased parasites and diseases (76.0%), reduced water availability (65.7%), and lower milk production (61.1%), compounded by potential inbreeding effects from disease control measures. Key adaptation challenges included pasture loss (64.9% high effect), deteriorated water quality (55.4%), and reduced milk yield (52.0%). Farmers primarily obtained climate information through peer networks (mean importance 4.5) and media (3.7), with limited input from research institutions or universities. Meteorological analysis (1970–2020) confirmed significant warming trends in maximum and minimum temperatures (Sen's slope 0.01–0.04 °C/year at most stations), aligning with farmers' perceptions, but revealed no significant long-term rainfall trends despite high interannual variability driven by ENSO. Tropical cyclones remained frequent, predominantly lower-intensity categories. National milk production declined significantly from 9.5 million liters in 2012 to 6 million liters in 2021, likely exacerbated by heat stress, rainfall variability, and socio-economic constraints. These findings highlight the vulnerability of Fiji's smallholder dairy sector to climate change and underscore the urgent need for targeted adaptation strategies, including heat-tolerant breeds, resilient pastures, improved water management, enhanced extension services, and inclusive policies addressing demographic and economic barriers in rural area.

KEYWORDS

milk production, climate change, adaptation strategies, smallholder, Fiji

1 Introduction

Climate change has emerged as pressing global challenges with wide-ranging impacts on agricultural systems particularly in developing and small island countries [Intergovernmental Panel on Climate Change (IPCC), 2023]. The Pacific Island nations including Fiji are especially vulnerable due to their geographic location, small land area, and high dependence on climate-sensitive sectors like agriculture and livestock (Nisi et al., 2024; McIver et al., 2015). Among the livestock subsectors, smallholder dairy farming in Fiji plays a crucial role in food security, rural livelihoods, and income (Ahuja and Staal, 2012; Bundi Magiri et al., 2023). However, this subsector is increasingly threatened by the consequences of climate change, such as rising temperatures, erratic rainfall, sea level rise, increase in intensity of tropical cyclones, prolonged droughts, and extreme weather events (Presti, 2022; Singh et al., 2020).

Dairy cattle are sensitive to heat stress and water scarcity, which directly affect animal health, milk production and reproductive efficiency (Thornton and Herrero, et al., 2015). In Fiji, smallholder farmers often lack access to climate-resilient infrastructure, technical knowledge, and financial resources, making them more vulnerable to climate-induced risks (Bundi Magiri et al., 2023). Despite this, there is limited research on how smallholder farmers in Fiji perceive and respond to the effects of climate change. Understanding their perceptions is crucial for designing appropriate adaptation strategies and informing policy decisions that support sustainable dairy production (Mertz et al., 2009).

Fiji's dairy industry is primarily located in the Central and Western Divisions of Viti Levu, where smallholder farmers rear crossbred dairy cattle on relatively small plots of land (Bacolod et al., 2020). These systems are characterized by low-input, pasture-based production methods, often constrained by limited access to veterinary services, feed supplements and market infrastructure such as availability of such as milk collection centers, processing facilities, and reliable transportation networks (Maharaj and Wake, 2019; Bundi Magiri et al., 2023).

Climate change is now recognized as critical challenges affecting the sustainability of smallholder dairy systems in Fiji (Iese et al., 2024; Bundi Magiri et al., 2023). The country has experienced an increase in temperature of approximately 0.6 °C over the past 50 years (Sagero et al., 2025a), with increase in the heatwaves (Sagero et al., 2025b) and projections suggest that this warming trend will continue, accompanied by more frequent extreme weather events such as droughts and cyclones (Australian Bureau of Meteorology and CSIRO, 2020). Recent analyses have revealed a general increase in mean annual rainfall over the past century, with notable intensification in extreme rainfall events, including longer wet periods and more frequent heavy rainfall days (Fernández-Duque et al., 2025; Sagero et al., 2025a). These climatic stressors impact the productivity, health, and reproductive performance of dairy cattle while also affecting pasture growth, water availability, and farm infrastructure (Chang-Fung-Martel et al., 2017; Das et al., 2016). Smallholder farmers, who often lack the financial capacity and technical knowledge to cope with these challenges, are particularly vulnerable.

Farmers' perceptions of climate change are crucial for shaping their adaptive responses (Ricart et al., 2022; Yeleliere et al., 2023). Perceptions influence how farmers interpret climatic risks and determine whether and how they implement adaptive practices (Deressa et al., 2011). However, in Fiji, there is limited empirical data on how smallholder farmers perceive climate-related impacts or what factors influence their perceptions. Such insights are essential for designing locally appropriate climate adaptation interventions and policies that support resilience in the dairy sector.

While climate change impacts on agriculture in Fiji have been studied to some extent, there is a critical gap in understanding how smallholder farmers perceive these changes and how their perceptions influence adaptation practices. Without this knowledge, interventions may fail to address the real needs and constraints faced by the dairy farmers. This undermines efforts to build climate resilience in the dairy sector. Therefore, the main objective of this study was to assess farmers' perceptions on the effects of climate change on smallholder dairy farming in Fiji. Here, we focused on farmers' responses on adaptation strategies to climate change that resonates with the local context (Yeleliere et al., 2023).

2 Materials and methods

2.1 Description of study area

The study was conducted in Fiji, a Pacific Island nation comprising over 300 islands (Figure 1), with Viti Levu being the primary islands with highest concentration of dairy farming. Viti Levu, the largest island, hosts the majority of Fiji's dairy production, particularly in the Central Division, which includes provinces of Tailevu, Naitasiri, Rewa, Serua, and Namosi (Figure 1; Kumar and Reddy, 2008). Vanua Levu, the second-largest island, also supports dairy farming, though on a smaller scale. Fiji's climate is classified as oceanic tropical, with a distinct wet season (November to April) and dry season (May to October; Liligeto and Nakamura, 2022; Sagero et al., 2024). Rainfall in the Fiji Islands is highly variable and is influenced by the island topography and the prevailing south-east trade winds (Sharma et al. 2021; Kuleshov et al., 2014). These features result in a wet zone on Fiji Islands' eastern side and a drier zone on the western side (Terry, 2007). Moreover, tropical cyclones are quite common from November to March, contributing up to 20.00% of the total seasonal rainfall in the South Pacific (Jiang and Zipser 2010). Additionally, the Fiji Islands are affected by global and regional-scale climatic events such as El Niño and La Niña, which influence the variability of rainfall in many Pacific Islands (Deo, 2011; Weir et al. 2021; Kumar et al. 2006).

2.2 Data collection

A mixed-methods approach was used to collect both quantitative and qualitative data, ensuring a comprehensive understanding of the impacts of climate change on smallholder dairy farming in Fiji. The study utilized purposive and simple random sampling techniques to select participants (Neuman, 2007). Simple random sampling was applied to select 242 dairy farmers from lists maintained by Fiji Dairy Cooperatives Company LTD (FCDCL) in Viti Levu, for five provinces (Tailevu, Naitasiri, Rewa, Serua, and Namosi) to ensure randomness.

The primary data used in this study come from a household survey that was conducted in the five provinces (Tailevu, Naitasiri, Rewa, Serua, and Namosi) of central division of Fiji (Figure 1). A total of 242 households were interviewed. The questionnaire was administered to the owner of the farm, but in their absence, the second most influential person in the farm operations was interviewed. The reason for selecting a household survey is that it attracts a wider number of participants, capture a wide range of occurrences, and improves the validity of study results (Moser and Kalton, 2017). Before the start of the interviews, respondents were briefed on the purpose of the study and were informed that their participation in the study was voluntary. Furthermore, respondents were assured that their identity would not be disclosed to any third party. Information collected ranged from household demographics, socio-economic status, landholding, milk production, breeds, annual earnings from sale of milk and climate change awareness and response. The data were collected using a detailed questionnaire that was administered by the first author, supervised by the other authors.

Secondary data were obtained from multiple sources to provide a historical context for livestock production and diseases in Fiji. Milk production records were sourced from the Fiji Co-operative Dairy Company Limited (FCDCL), while climate data including minimum and maximum temperature, rainfall, and tropical cyclone record from 1970 to 2020 were obtained from the Fiji Meteorological Service

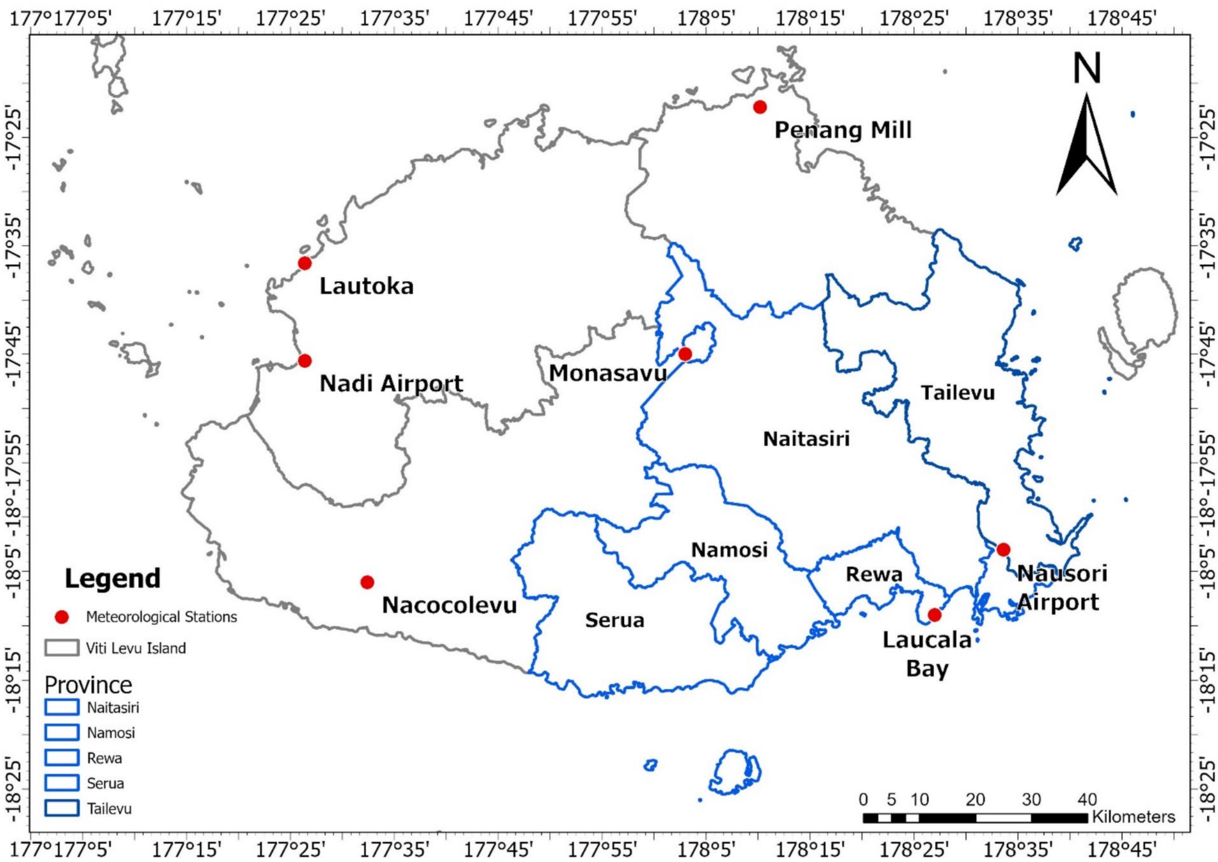

FIGURE 1
Map of Viti Levu Island of showing the boundaries of the five provinces (Blue) where the study was conducted and the meteorological stations (Red dots).

(FMS).[1] Livestock population and disease records were retrieved from the Ministry of Agriculture's Animal Health and Production Division, supplemented by relevant government reports, academic publications, and journal articles. Ethics approval for the study was granted by the FNU Human Research Ethics Committee (FNU-HREC-25-11; S. 1).

2.3 Statistical analysis

This study adopted a survey descriptive method, which combines both qualitative and quantitative approaches to collect and analyze data related to livestock production and climate variability in Fiji. The mixed-methods design enabled the integration of farmers' perceptions and experiences with meteorological data to provide a comprehensive understanding of the study objectives.

The primary data was collected through structured interviews with dairy farmers across the four provinces. A random sampling technique was used to select farmers to ensure that the sample represented different climatological regions. In addition, purposive sampling was used to select key informants including agricultural officers, Officers from dairy cooperative, and community leaders who provided expert insights on dairy production trends, climate impacts, adaptation strategies and policy interventions.

On the Other hand, secondary data on tropical cyclones, temperature and rainfall were obtained from the Fiji Meteorological Service, These data complemented the primary survey results and were used to assess climate change and its relationship to livestock production.

The quantitative data were coded and analyzed using the statistical package for the social science IBM SPSS Statistics Version (SPSS) version 27 (IBM Corp., Armonk, NY, United States; available at https://www.ibm.com/products/spss-statistics). Descriptive statistics such as frequencies, percentages, means, and standard deviations were computed to summarize farmers' perceptions and adaptation responses. Inferential analysis, including chi-square tests, was used to examine associations between farmers' socio- demographic characteristics and their perception of climate impacts (Gilbert, 1987). Trend analysis of secondary climate data was conducted using Sen's slope estimator (Sen, 1968), a non-parametric method for detecting linear trends in time series, with statistical significance determined at $p < 0.05$.

3 Results and discussion

3.1 Descriptive analysis of demographic and farm characteristics

Table 1 shows the demographic and farm-level characteristics of farmers, offering critical insights into the social and economic context within which climate adaptation decisions are made. The data show a significant gender imbalance, with males comprising 94.2% of

1 https://www.met.gov.fj/

respondents and females only 5.8%, suggesting that dairy farming in Fiji remains male-dominated. This reflects broader gender disparities in agricultural labor and land ownership across the Pacific, where women often have limited access to productive resources and decision-making roles in farming (Gaddis et al., 2022; Peralta, 2022).

The age distribution indicates an aging farming population, with over 73.0% of respondents aged above 54 years. This trend is consistent with other studies that point to youth disengagement from agriculture in Fiji and Solomon Islands (Craney, 2022), which poses a sustainability challenge for future food systems. The predominance of older farmers also affects adaptive capacity, as older individuals may have more traditional knowledge but are often less responsive to adopting new technologies (Bryan et al., 2009). Education levels reveal that the majority (83.0%) had only primary or secondary education, and just 13.6% had any form of post-secondary education. This may limit farmers' ability to engage with climate information, financial services, and use of technology, which typically require a basic level of literacy and formal education (Asfaw et al., 2016). However, this can be ameliorated by appropriate farmers training on climate resilient dairy production practices.

Experience in dairy farming was generally high; this was probably because of the age of the farmers parameters. With more than 72.0% having over 20 years of experience. This deep knowledge of local practices is valuable for resilience but may not fully compensate for the limited adoption of modern, climate-resilient practices without institutional support (Ensor et al., 2018). In terms of income, a large proportion (43.4%) of farmers earned less than FJD 10,000 annually, suggesting a high level of economic vulnerability. Regional distribution data show that most farmers were in the central division (85.1%), likely to reflect the concentration of dairy farming infrastructure in this area and access to FCDCL which is the main milk collector and is located in the central division. Landholding size was predominantly small, with 81.8% of respondents operating on 0.4–8.1 ha. Similarly, 73.6% reported having fewer than 20 milking cows, confirming the smallholder nature of Fiji's dairy sector.

These findings are critical for informing targeted policy and extension programs. The combination of aging farmers, low income, small-scale operations, and limited education highlights the need for inclusive and accessible climate adaptation strategies tailored to the specific constraints in Fiji's smallholder dairy producers, to reduce vulnerability and increase the resilience of the farms.

TABLE 1 Socio-demographic characteristics of dairy farmers in Fiji.

Gender	Frequency	Percentage
Male	228	94.2
Female	14	5.8
Age		
Above 54 years	177	73.1
45–54 years	41	16.9
35–44 years	16	6.6
Less than 35 years	8	3.3
Marital status		
Married	212	87.6
Widow/widowed	15	6.2
Single	9	3.7
Divorced/separated	6	2.5
Education level		
Secondary education	123	50.8
Primary education	78	32.2
Certificate/Diploma/Degree/ Post Graduate education	33	13.6
Never went to school	8	3.3
Household size		
3–4 members	103	42.6
5–6 members	79	32.6
More than 6 members	33	13.6
1–2 members	27	11.2
Level of experience		
21–30 years	108	44.6
Above 30 years	67	27.7
11–20 years	53	21.9
Less than 10 years	14	5.8
Income status		
Less than FJD10000	105	43.4
FJD10001–20000	72	29.8
FJD30001–40000	50	20.7
More than FJD40000	15	6.2
Location		
Central	206	85.1
Western	23	9.5
Northern	13	5.4
Size of land		
0.4–8.1 ha	198	81.8
Above 8.1 ha	44	18.2
Number of milking cows		
1–20 cows	178	73.6
Above 20 cows	64	26.5

3.2 Farmers' perception on climate change over Fiji

Figure 2 shows the dairy farmer's perception of changes in day and night time temperature. It indicates that majority of farmers (70.2%) reported a noticeable rise in day temperatures over the past 15 years, while 56.6% observed a similar trend for night temperatures. A smaller proportion, 9.1% for day temperatures and 16.5% for night temperatures, noted a decrease, respectively. Meanwhile, 9.9% (day) and 16.1% (night) experienced no significant change. These findings indicate a dominant perception of rising temperatures, reflecting the changes in the local weather patterns.

Figure 3 shows that most small-scale farmers observed a reduction in both wet season rainfall (43.8%) and dry season rainfall (43.0%) amounts over time, reflecting a significant change in rainfall over the study area. A smaller proportion reported increased rainfall, with 30.2% for wet season and 27.7% for dry season. Meanwhile, 26.0% (wet) and 29.3% (dry) indicated no noticeable changes.

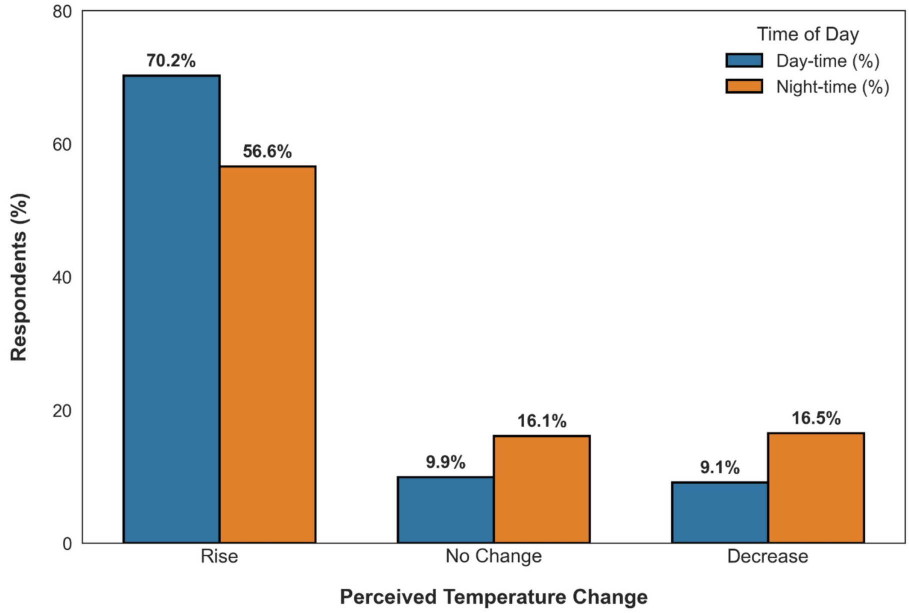

FIGURE 2
Percentage of respondents perceived temperature change during the daytime and nighttime over the past 15 years.

On the other hand, Figure 4 indicates that a significant proportion of farmers observed a reduction in the duration of rainfall, with 48.3% reporting reduced duration for the wet season and 47.5% noting reduced dry season. Meanwhile, 26.4% (wet seasons) and 30.6% (dry seasons) reported no change in duration. A smaller group, 25.2% (wet seasons) and 21.9% (dry seasons), observed an increase in rainfall duration. From these results, the general trend from farmers' perception is that rainfall has reduced both in amount and duration for both seasons. However, some farms also perceive that rainfall has not changed for the last 15 years. These indicate the high variability of rainfall in the study area, which is linked to large scale climatic phenomena, e.g., ENSO events (Sagero et al., 2025b; Sagero et al., 2025a).

3.3 Impact of climate change on dairy farming in Fiji

The results on farmers' perceptions regarding the effects of climate change as shown in Figure 5 reveal significant insights into the challenges posed to dairy farming. A large proportion of respondents acknowledged critical impacts such as forage disappearance (73.6%) and emergence of poisonous forages (59.9%). The difficulties in managing parasites (76.0%) and diseases (76.0%) also received high affirmation, indicating these are widespread concerns among farmers. These challenges are compounded by reduced milk production (61.1%) and water availability (65.7%), highlighting the strain on essential resources. Farmers also noted the low performance of breeds (57.9%), further underscoring the vulnerability of livestock to climate-induced stresses. However, this could have been caused by inbreeding due to strict measures adopted by Brucellosis and tuberculosis eradication campaigns which restricts movements of animals from farm to farm in Fiji. The inbreeding depression has been shown to reduce production and fitness traits in livestock (Leroy, 2014) and to interact with environmental stressors such that inbred animals are disproportionately vulnerable under adverse conditions (Fox et al., 2010). The inbreeding reduce the capacity to tolerate heat stress, drought, and disease outbreaks. Studies show that inbred individuals are generally more sensitive to environmental stress (Hedrick and Kalinowski, 2000; Fox et al., 2010).

In contrast, when farmers were asked whether climate change had not significantly impacted specific areas, the responses highlighted diverse perceptions. A minority of respondents affirmed (Yes) for areas such as types of forages (31.4%), water quality (23.1%), types of parasites (26.1%), and diseases (40%), suggesting that these aspects are perceived to be less affected by climate change. Similarly, a smaller proportion of respondents acknowledged that significant effects were minimal in areas like milk production impacts (34.3%), milk sales (40.5%), and breeds adaptation (48.8%). These findings illustrate that while certain aspects of dairy farming are perceived to be less affected, dairy farmers largely agree that climate change has significantly influenced their operations reflecting a broad acknowledgment of its varied impacts. With respect to disease, the outbreak of bovine tuberculosis (bTB) in Fiji had an in impact to dairy farmers. This is because the general control was test and cull, with controlled animal movements, and size of the farm (Garcia et al., 2022), These changes had some economic consequences for the dairy industry, such as a reduction of herd size on some farms due to culling of bTB positive animals (also called reactors) and led to concern about the limited replacement stock being available in Fiji. The restriction of cattle has also reduced the ability of farmers to restock. This has affected the small scale farmers and has increased inbreeding and as result reduced milk production (Gutiérrez-Reinoso et al., 2022; Mugambe et al., 2024). The dairy farming system exhibits a varied interaction of operational processes, where external variables including disease outbreaks and climatic shifts significantly influence productivity and sustainability (Bundi Magiri et al., 2023). At the core of this system lies

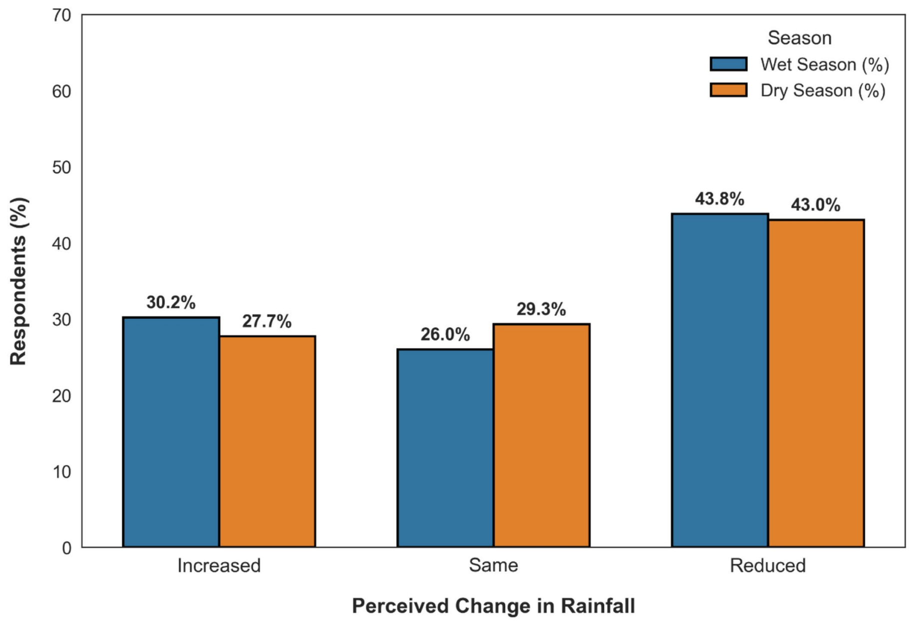

FIGURE 3
Comparison of the perceived changes in rainfall amount during wet and dry seasons by farmers.

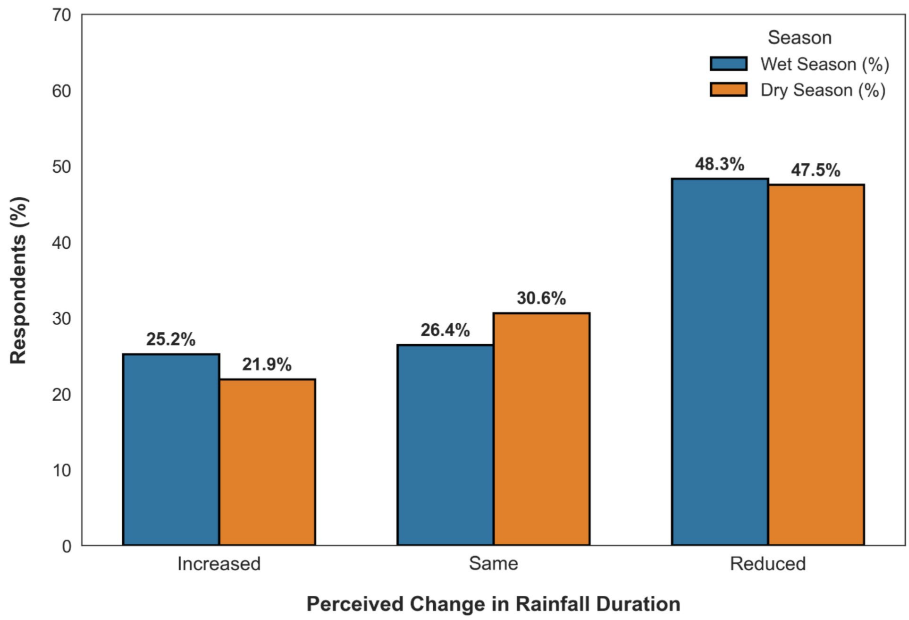

FIGURE 4
Comparison of perceived changes in rainfall duration during the wet and dry season by farmers.

the dairy farm itself, which is shaped by key inputs such as livestock, water and feed, which is the main concern for small scale farmer.

3.4 Source of information on climate change in Fiji

Table 2 show results of sources of climate information among dairy farmers. Farmers to farmer information sharing emerged as the most critical source, with a mean importance score of 4.5, ranking first. Media, including radio, internet, television, and newspapers, ranked second with a score of 3.7, reflecting its widespread reach and influence. Extension agents was ranked third with a mean score of 2.6, indicating their significant yet less dominant role compared to the media and farmers to farmers' information sharing. Research institutions were ranked fourth with a score of 1.7, suggesting a gap in the direct dissemination of scientific knowledge to farmers. Finally, public universities were rated least important, with a mean score of

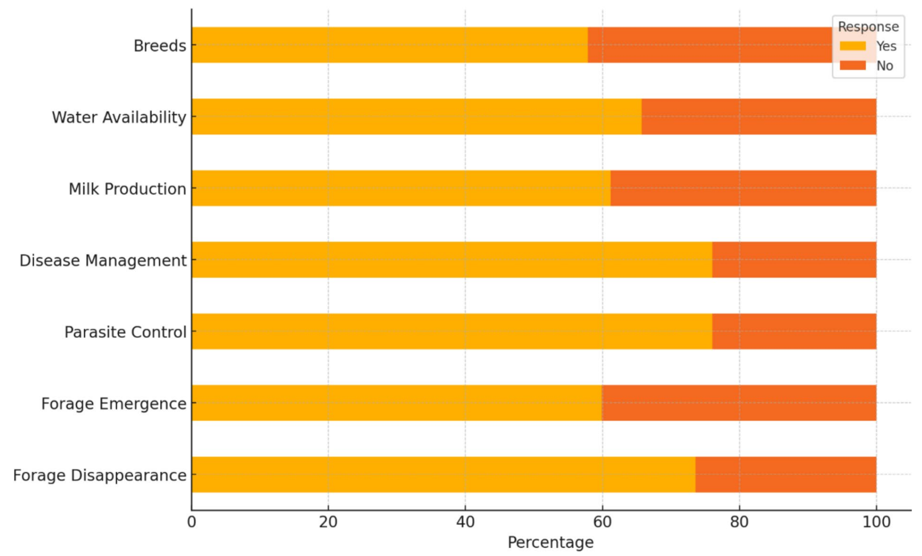

FIGURE 5
Farmer' perception on knowledge of climate change effects on smallholder dairy farming in Fiji.

TABLE 2 Ranking of the most important sources of information on climate change.

Sources	Mean importance	Rank
Farmers	4.5	1
Media	3.7	2
Extension agents	2.6	3
Research institutions	1.7	4
Public university	1.4	5

1.4, possibly due to limited direct interaction with farmers. The results indicate high level of peer influence among farmers and the Pacific culture of '*Talanoa* session' which has been revealed as a powerful way of increase in climate awareness and increasing resilience through sharing of climate information (Hollis and Halapua, 2025; van Ingen and Termeer, 2022).

3.5 Challenges faced by small holder farmers in adapting to climate change

Table 3 show that smallholder dairy farmers perceive climate variability and change as a significant threat to their livelihoods, with pasture loss (64.9% high effect, Mean = 2.5, SD = 0.7), decreased water quality due to runoff (55.4% high effect, Mean = 2.4, SD = 0.7), and reduced milk production (52.0% high effect, Mean = 2.4, SD = 0.7) identified as the most severe challenges. These issues, driven by erratic rainfall, droughts, and flooding, directly impact feed availability, animal health, and farm productivity, aligning with findings that climate variability exacerbates resource scarcity in tropical regions (Food and Agriculture Organization of the United Nations, 2018; IPCC, 2022). Other notable concerns include increased disease and pest prevalence (45.9% high effect, mean = 2.2, SD = 0.8) and livestock mortality (39.7% high effect, mean = 2.1, SD = 0.8), which are linked to warmer temperatures and extreme weather events such as cyclones (Nardone et al., 2010). The relatively low standard deviations for pasture loss and water quality suggest a strong consensus among farmers on their severity, this might be due to open grazing system that is most commonly practices by small scale farmer in Fiji (Nadan and Baroutian, 2023). While, higher variability for livestock mortality indicates differing experiences, possibly due to variations in farm management or access to veterinary services.

The economic and social impacts of these challenges are also significant, with 36% of farmers noting the high effect of selling livestock at throw-away prices (Mean = 2.0, SD = 0.8) and.

41.7% rate poor markets for livestock products as a moderate issue (Mean = 2.0, SD = 0.8), reflecting disrupted supply chains and financial stress (Herrero et al., 2016). Overgrazing (41.7% moderate effect, mean = 1.8, SD = 0.7) and increased human labor demands (47.9% low effect, Mean = 1.7, SD = 0.8) are perceived as less severe but still contribute to long-term sustainability challenges. These findings underscore the need for adaptive strategies, such as climate-resilient pasture varieties, improved water management, and enhanced market access, to bolster resilience in Fiji's dairy sector (Thornton et al., 2009).

3.6 Meteorological data on rainfall and temperature trend

The results in Figures 6–9 shows the time series and the trends of maximum temperature (Tmax), minimum temperature (Tmin), and rainfall for seven stations in Viti levu island of Fiji (Nausori, Laucala Bay, Monasavu, Nadi, Lautoka, Nacocolevu, and Penang Mills; Figure 1) for annual and seasonal. This analysis examines the trends and variability of temperature and rainfall in the study area to compare with the farmers' perception.

TABLE 3 Statistical summary on challenges faced by smallholder farmers in adapting to climate change effects.

Challenges	High effect	Low effect	Moderate effect	Mean	Std deviation (SD)
Pasture loss	64.9	13.2	21.9	2.5	0.7
Decreased water quality due to runoff	55.4	14.9	29.7	2.4	0.7
Loss of livestock (death)	39.7	28.5	31.8	2.1	0.8
Under feeding of livestock	39.3	27.3	33.5	2.1	0.8
Increase in disease and pests	45.9	26.0	28.1	2.2	0.8
Selling livestock at throw away prices	36.0	32.6	31.4	2.0	0.8
Overgrazing	21.5	36.8	41.7	1.8	0.7
Poor markets of livestock products	27.3	31.0	41.7	1.9	0.8
Human labor demands	21.1	47.9	31.0	1.7	0.8
Milk production	52.1	15.3	32.6	2.4	0.7

3.6.1 Maximum and minimum temperature trend

Figure 6 shows the annual Tmax for the seven stations, it indicates a significant warming trend for all the stations. The Tmax across Fiji vary, ranging from 22.5–24.5 °C at Monasavu to 29.0–31.5 °C in Lautoka. Most stations show statistically significant warming trends at $p > 0.05$, with Sen's slopes ranging from 0.01 °C/year to 0.04 °C/year, except Nadi, which shows no significant change. These warming trends align with recent studies on the temperature trend in Fiji (Sagero et al., 2025b; Sagero et al., 2025a) and global climate change patterns where rising temperatures are driven by increased greenhouse gas emissions (Shrestha and Aryal, 2010).

On the other hand, in Figure 7, the Tmin ranges from 16.5–18.0 °C at Monasavu to 21.0–23.5 °C at Laucala Bay, with cooler values generally observed at higher elevations. All stations except Nadi show statistically significant warming trends in Tmin, with the highest rate recorded at Monasavu (0.04 °C/year), indicating a more pronounced increase in nighttime temperatures, which aligns with the study done by Sagero et al. (2025a,b).

The observed warming trends in both Tmax and Tmin across Fiji align with farmers perception of increase in daytime and nighttime temperatures. Rising Tmax, particularly in the western division where temperatures reach up to 31.5 °C with significant warming trends (up to 0.03 °C/year), can intensify heat stress in dairy cows, reducing feed intake, milk yield, and reproductive performance (Chen et al., 2024). Similar, persistent high night temperatures can also disrupt cattle physiological metabolism and contribute to chronic stress which may lead to decreased milk production (Polsky and von Keyserlingk, 2017). For smallholder farmers, who often lack climate- resilient infrastructure such as shaded housing, cooling systems, or improved water supply, these rising temperature trends can threaten both productivity and livelihoods. Adaptive measures such as proper housing systems, heat-tolerant breeds, and better farm planning are increasingly critical for sustaining dairy production under changing climatic conditions (Aggarwal, 2022).

3.6.2 Rainfall trend

Figure 8 shows the time series of annual rainfall across different station in Viti Levu Island in Fiji from 1970 to 2020. It indicates that the trend is not significant ($p > 0.05$) and reflecting high interannual variability. Most stations exhibit slight increase or decrease, with Monasavu being the wettest (3500–6,500 mm) and Penang Mills showing the largest decline, these trends remain statistically not significant ($p > 0.05$), underscoring the dominance of natural climate variability over long-term rainfall changes exhibits. Therefore, farmers' perception of decreasing rainfall trend for both wet and dry seasonal rainfall is not in line with in the recorded meteorological data.

The absence of statistically significant trends in both annual and seasonal rainfall presents a complex scenario for small-scale dairy farming in Fiji. Although rainfall amounts remain within ranges sufficient for pasture growth, the high interannual and seasonal variability driven largely by ENSO cycles makes the small-scale dairy farmer vulnerable to extreme weather events (drought and floods) as result of rainfall variability. The occurrence of extreme rainfall events, even in the absence of long-term increasing trends, poses significant risks for small-scale dairy farming in Fiji. Short duration but intense rainfall, common during strong La Niña phases can lead to flash floods or waterlogged pastures, particularly in low-lying or poorly drained areas like parts of central Division where most of the farmers are located. These conditions can damage pasture, reduce grazing availability, contaminate water supplies, and increase the risk of diseases in cattle (Gaviglio et al., 2021).

3.6.3 Tropical cyclone trend

The South Pacific region experiences tropical cyclones of varying intensity, which exert significant influence on local climate extremes, infrastructure, and agricultural systems (Noy et al., 2023). Based on the Australian tropical cyclone intensity scale (Bureau of Meteorology, 2025), cyclone strength is categorized from 1 to 5 according to maximum sustained wind speeds. Category 1 cyclones (63–88 km/h) are characterized by gale-force winds causing minimal damage, while Category 2 events (89–117 km/h) generate destructive winds that can uproot trees and damage weak structures. Category 3 cyclones (118–159 km/h) mark the onset of severe tropical cyclones with very destructive winds and notable coastal impacts. Category 4 (160–199 km/h) and Category 5 (≥200 km/h) cyclones are extremely destructive, often associated with widespread structural damage, storm surges, and long-term disruption to livelihoods and ecosystems.

Figure 9 illustrates the frequency of tropical cyclones by intensity category over the 1980–2023 period in the South Pacific region. Nearly half (48.1%) of all recorded cyclones were Category 1 events, followed by 20.3% in Category 2 and 17.7% in Category 3. Severe cyclones of Category 4 and 5 comprised 8.9 and 5.1% of total occurrences, respectively. This distribution suggests that while

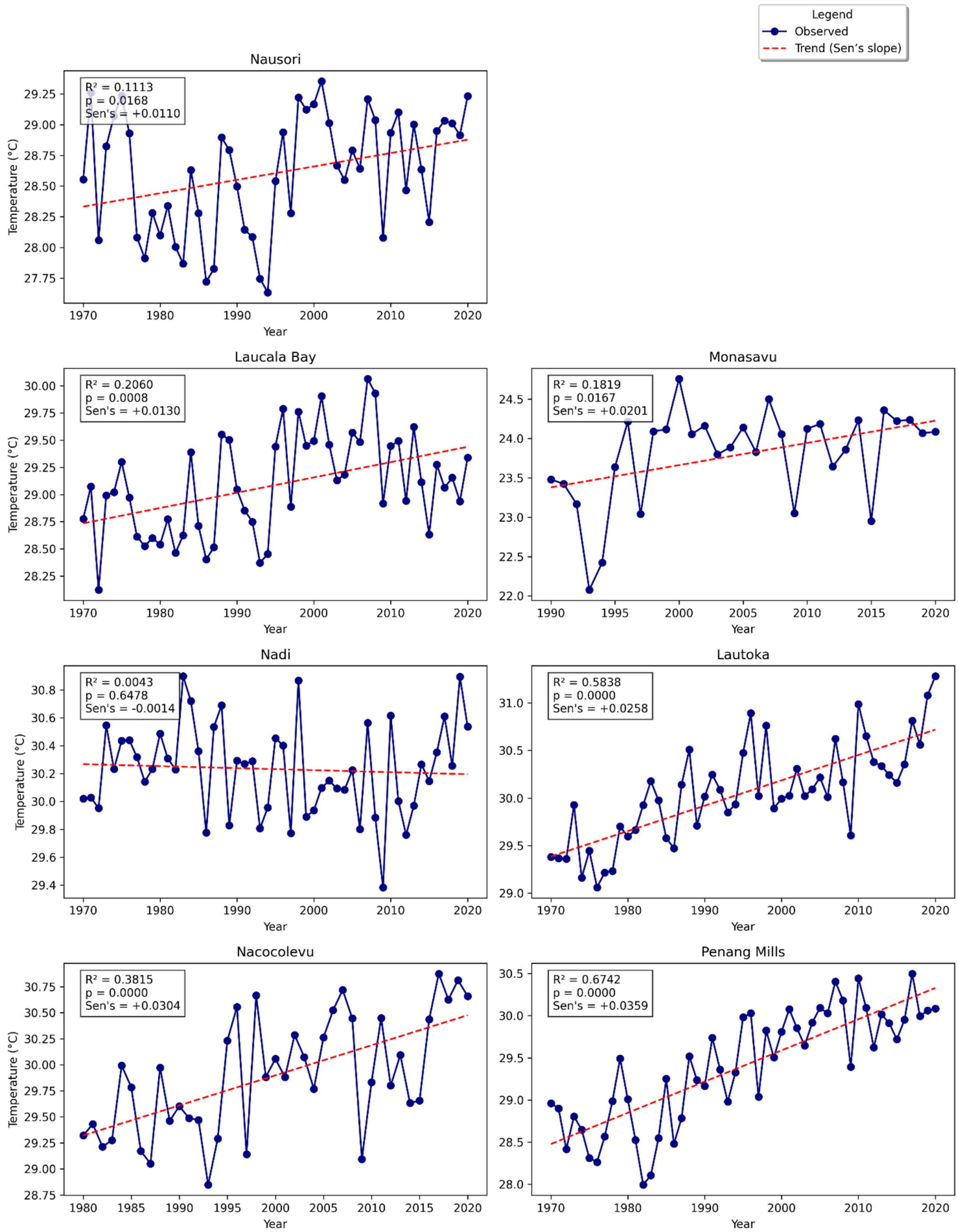

FIGURE 6
Annual time series and sen's slope trend for the maximum temperature for observed station in Viti Levu Island of Fiji (1970–2020).

low- to moderate-intensity cyclones are most common, they still pose significant challenges to farming systems by triggering disease outbreaks, flooding, power outages, and wind damage that disrupt operations, reduce pasture availability, and affect livestock productivity (Paulik et al., 2021). These findings are consistent with regional analyses indicating a potential shift toward

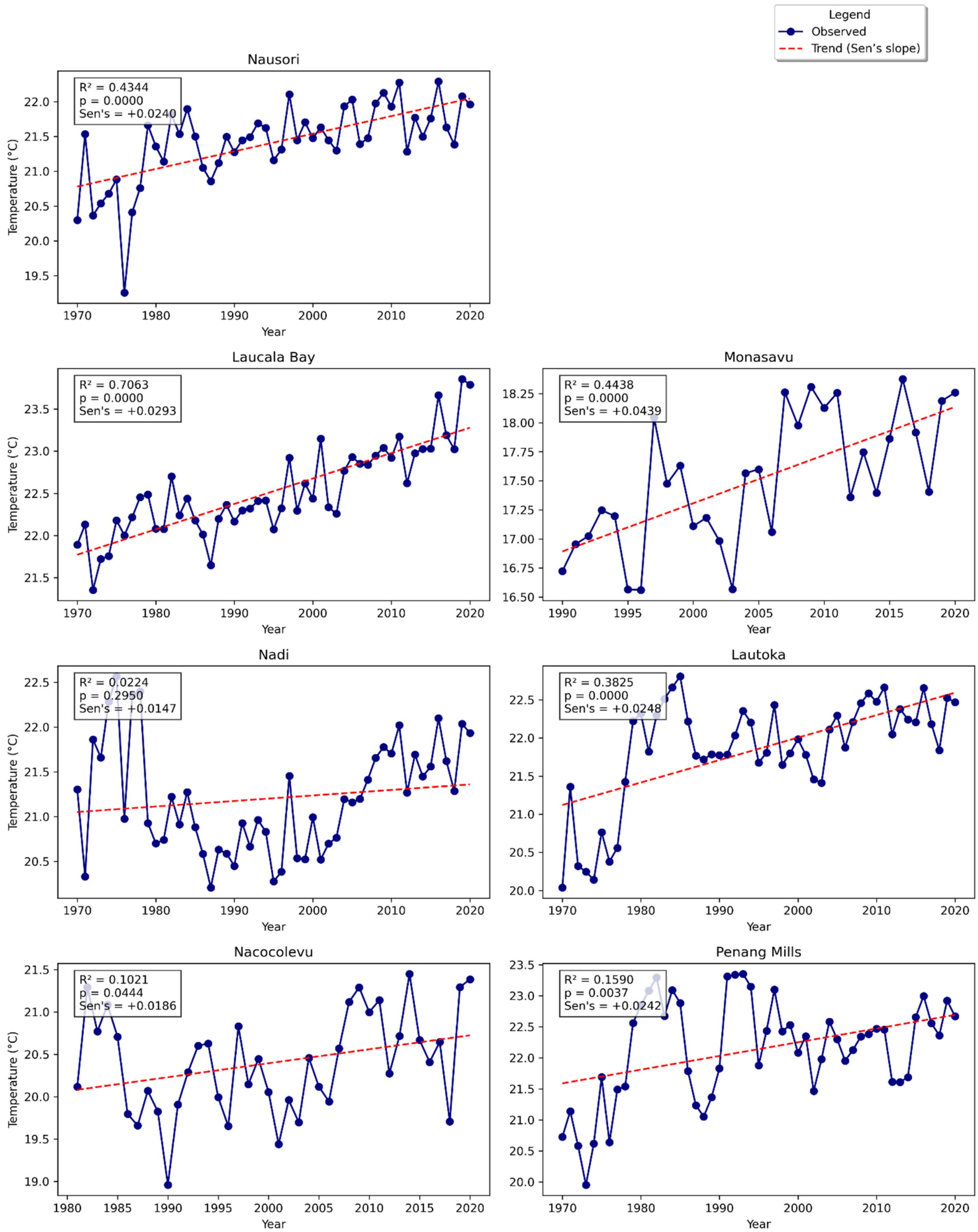

FIGURE 7
Annual time series and sen's slope trend for the minimum temperature for observed station in Viti Levu Island of Fiji (1970–2020).

higher-intensity tropical cyclones under continued ocean warming (Kuleshov et al., 2020; Chand et al., 2022). Therefore, both frequent low-category events and occasional severe cyclones should be considered in resilience planning and climate adaptation strategies for Fiji's dairy sector. The high variability of tropical cyclone is largely driven by large-scale climate drivers, particularly the El

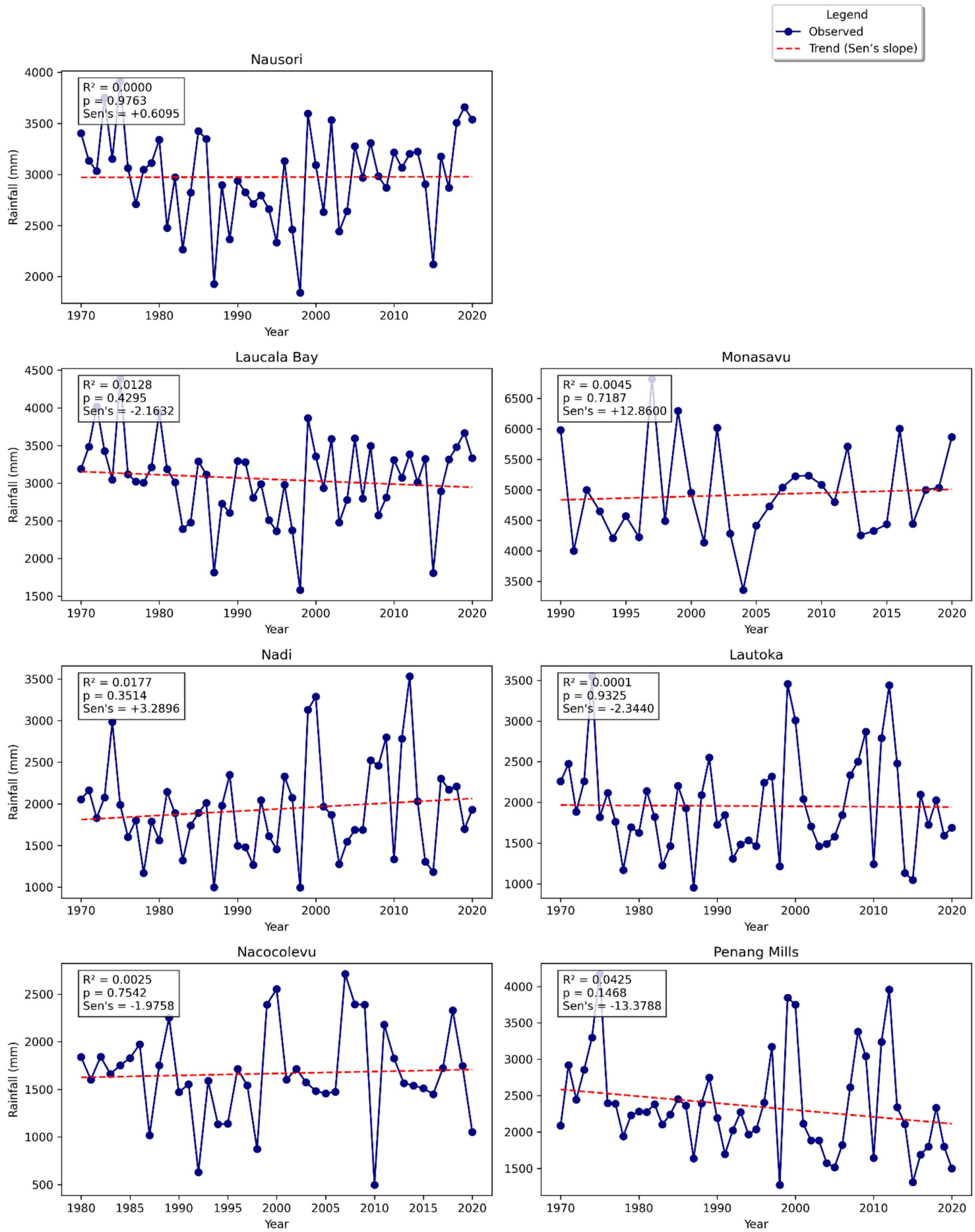

FIGURE 8
Annual time series of rainfall and Sen's slope for the seven stations (1970–2020) in Viti Levu Island of Fiji.

Niño–Southern Oscillation (ENSO) and Madden Julian Oscillation (MJO) which influences both the frequency and intensity of cyclones in the South Pacific region (Chand et al., 2017; Kuleshov et al., 2014).

3.6.4 Trend in milk production

Figure 10 shows the time series of annual milk production in liters from 2012 to 2021. The results indicate a decreasing milk production from approximately 9.5 million liters in 2012 to around 6 million liters

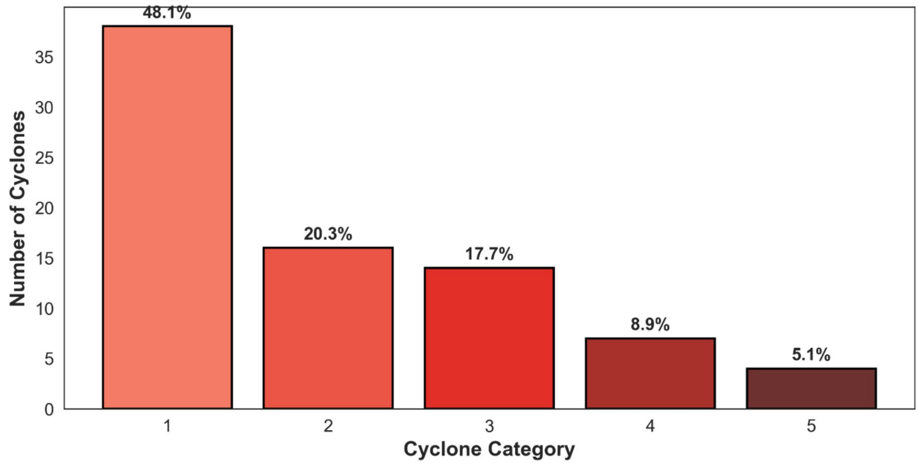

FIGURE 9
Frequency distribution tropical cyclone intensity (Category) that have impacted Fiji from 1969 to 2021.

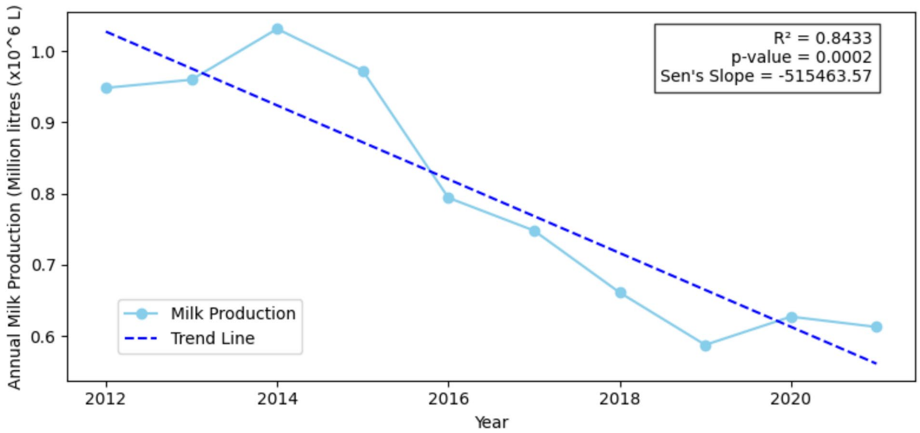

FIGURE 10
Time series of milk production from 2012 to 2021 in Fiji.

by 2021. The trendline shows a clear downward trajectory, indicating a consistent decrease in milk production over the 10-year period, which is statistically significant at $p < 0.05$. The decline in milk production is unlikely to be due to random variation or removal of TB and Brucellosis positive reactors which are generally culled for slaughter. Additionally, the consistent decline in milk production over the decade could be due to various factors, such as changes in farming practices, herd sizes, economic conditions, diseases and environmental challenges (Bundi Magiri et al., 2023). Fiji being a small island, has high humidity when combined with rising Tmin and Tmax, can further increase the Temperature-Humidity Index (THI), pushing it above the threshold (THI > 72) where heat stress impacts fertility and milk production (Wankar et al., 2021; Zimbelman et al., 2009).

4 Conclusion

Fiji's smallholder farmers face severe climate-related challenges, including pasture loss, water quality deterioration, and a significant decline in milk production from 9.5 million liters in 2012 to 6 million liters in 2021, driven by warming trends, rainfall variability, and frequent tropical cyclones. These are compounded by socio-economic vulnerabilities, such as an aging workforce (73.0% above 54 years), gender disparities (94.2% male), and low incomes (43.4% earn less than FJD 10,000 annually). Farmers' reliance on peer networks (mean importance 4.45) and media (3.7) for climate information highlights the effectiveness of informal channels like 'Talanoa sessions" but limited engagement with research institutions and universities indicates a gap in accessing scientific knowledge. To enhance resilience, policymakers should prioritize accessible measures like climate-resilient pasture varieties and high yield and heat-tolerant livestock breeds, supported by strengthened government extension and FCDCL outreach. Investments in water management infrastructure, such as rainwater harvesting, are crucial to address water quality issues. Coordinating research institutions, universities, and media with peer networks can improve climate information dissemination, while gender-inclusive policies and youth engagement programs, coupled with training in modern technologies and financial literacy, can address demographic and economic constraints. Robust market linkages and financial support, such as access to credit are essential to mitigate economic pressures and ensure sustainable livelihoods for Fiji's dairy farmers.

Data availability statement

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

Author contributions

MI: Writing – original draft, Methodology, Data curation. PS: Conceptualization, Writing – review & editing, Methodology. RM: Writing – review & editing, Supervision, Funding acquisition, Investigation, Writing – original draft, Conceptualization.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aggarwal, A. (2022). "Climate resilient dairy farming practices to improve adaptive capacity of farming community" in Analytical approaches for vulnerability and adaptation to climate change in agriculture, 37.

Ahuja, V., and Staal, S. (2012). Poverty, food security, livestock and smallholders: issues and options for the Asia and the Pacific region. *Asian Livest.* 16:97.

Asfaw, S., McCarthy, N., Lipper, L., et al What determines farmers' adaptive capacity? *Empirical evidence from Malawi. Food Sec.* 8, 643–664 (2016). doi: 10.1007/s12571-016-0571-0

Australian Bureau of Meteorology, & CSIRO. (2020). Climate change in the Pacific: scientific assessment and new research (Vol. 2: Country Reports). Available online at: https://www.pacificclimatechangescience.org/publications/reports/ (Accessed May 21, 2025)

Bacolod, E. D., Tabunakawai, N., and Natasiwai, T. (2020). Fiji 2020 agriculture sector policy agenda. Fiji: Ministry of Agriculture.

Bryan, E., Deressa, T. T., Gbetibouo, G. A., and Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science \u0026amp; Policy,* 12, 413–426.

Bundi Magiri, R., Sagero, P., Danmaigoro, A., Rashid, R., and Mocevakaca, W. (2023). Impact of climate change on the dairy production in Fiji and the Pacific Island countries and territories: an insight for adaptation planning: IntechOpen.

Bureau of Meteorology. (2025). Tropical cyclone intensity and impacts. Commonwealth of Australia. Available online at: http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/understanding/intensity/ (Accessed May 21, 2025)

Chand, S. S., Tory, K. J., McBride, J. L., and Wheeler, M. C. (2017). Impact of different ENSO regimes on tropical cyclones in the South Pacific. *Clim. Dyn.* 48, 1461–1473. doi: 10.1007/s00382-016-3143-5

Chand, S. S., Walsh, K. J., Camargo, S. J., Kossin, J. P., Tory, K. J., Wehner, M. F., et al (2022). Declining tropical cyclone frequency under global warming. *Nature Climate Change*, 12, 655–661.

Chang-Fung-Martel, J., Harrison, M. T., Rawnsley, R., Smith, A. P., and Meinke, H. (2017). The impact of extreme climatic events on pasture-based dairy systems: a review. *Crop Pasture Sci.* 68, 1158–1169. doi: 10.1071/CP16394

Chen, L., Thorup, V. M., Kudahl, A. B., and Østergaard, S. (2024). Effects of heat stress on feed intake, milk yield, milk composition, and feed efficiency in dairy cows: a meta-analysis. *J. Dairy Sci.* 107, 3207–3218. doi: 10.3168/jds.2023-24059

Craney, A. (2022). Youth in Fiji and Solomon Islands: Livelihoods, leadership and civic engagement Canberra, Australia: ANU Press. doi: 10.22459/YFSI.2022

Das, R., Sailo, L., Verma, N., Bharti, P., Saikia, J., and Kumar, R. (2016). Impact of heat stress on health and performance of dairy animals: a review. *Veterinary world* 9, 260–268. doi: 10.14202/vetworld.2016.260-268

Deo, R. C. (2011). On meteorological droughts in tropical Pacific Islands: time-series analysis of observed rainfall using Fiji as a case study. *Meteorol. Appl.* 18, 171–180. doi: 10.1002/met.233

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., and Yesuf, M. (2011). Perception of climate change and adaptation of climate change by farmers in the Nile basin of Ethiopia. *J. Agric. Sci.* 149, 23–31. doi: 10.1017/S0021859610000687

Ensor, J. E., Park, S. E., Attwood, S. J., Kaminski, A. M., and Johnson, J. E. (2018). Can community-based adaptation increase resilience?. *Climate and Development*, 10, 134–151.

Fernández-Duque, B., Kumar, R., Kenawy, A. E., and Vicente-Serrano, S. M. (2025). Changes in daily precipitation extremes over the Fiji Islands (1905–2021). *Stoch. Env. Res. Risk A.* 39, 581–598. doi: 10.1007/s00477-024-02883-0

Food and Agriculture Organization of the United Nations (2018). Climate change and food security: Risks and responses. Rome: FAO.

Fox, C. W., Reed, D. H., and Mousseau, T. A. (2010). Inbreeding-environment interactions for fitness: complex relationships between inbreeding depression and temperature stress in a seed-feeding beetle. *Evol. Ecol.* 25, 25–43. doi: 10.1007/s10682-010-9389-9

Gaddis, I., Lahoti, R., and Swaminathan, H. (2022). Women's legal rights and gender gaps in property ownership in developing countries. *Popul. Dev. Rev.* 48, 331–377. doi: 10.1111/padr.12493

Garcia, A. A., Borja, E., Reid, A., Samy, V., Singh, S., Whittington, R. J., et al. (2022). Bovine tuberculosis control in Fiji: retrospective study findings for 2015 to 2020 [original research]. *Front. Vet. Sci.* 9, 972120. doi: 10.3389/fvets.2022.972120

Gaviglio, A., Corradini, A., Marescotti, M. E., Demartini, E., and Filippini, R. (2021). A theoretical framework to assess the impact of flooding on dairy cattle farms: identification of direct damage from an animal welfare perspective. *Animals* 11:1586. doi: 10.3390/ani11061586

Gilbert, R. O. (1987). Statistical methods for environmental pollution monitoring. New York: Van Nostrand Reinhold.

Gutiérrez-Reinoso, M. A., Aponte, P. M., and García-Herreros, M. (2022). A review of inbreeding depression in dairy cattle: current status, emerging control strategies, and future prospects. *J. Dairy Res.* 89, 3–12. doi: 10.1017/S0022029922000188

Hedrick, P. W., and Kalinowski, S. T. (2000). Inbreeding depression in conservation biology. *Annu. Rev. Ecol. Syst.* 31, 139–162. doi: 10.1146/annurev.ecolsys.31.1.139

Herrero, M., Addison, J., Bedelian, C., Carabine, E., Havlík, P., Henderson, B., et al. (2016). Climate change and pastoralism: impacts, consequences and adaptation. *Rev. Sci. Tech. Off. Int. Epiz.* 35, 417–433. doi: 10.20506/rst.35.2.2533

Hollis, S., and Halapua, W. (2025). A climate change talanoa: exploring creative possibilities for a hopeful future. *AlterNative* 21, 31–41. doi: 10.1177/11771801241310319

Iese, V., Lako, J., and Molimau-Samasoni, S. (2024). Climate crisis and food security in Pacific Island countries and territories

Intergovernmental Panel on Climate Change (IPCC) (2023). "Small Islands" in Climate change 2022 – Impacts, adaptation and vulnerability: Working group II contribution to the sixth assessment report of the intergovernmental panel on climate change (Cambridge: Cambridge University Press), 2043–2122.

IPCC (2022). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change: Cambridge University Press.

Jiang, H., and Zipser, E. J. (2010). Contribution of tropical cyclones to the global precipitation from eight seasons of TRMM data: Regional, seasonal, and interannual variations. *Journal of Climate*, 23, 1526–1543.

Kuleshov, Y., Qi, L., Fawcett, R., and Jones, D. (2014). On tropical cyclone activity in the southern hemisphere: trends and the ENSO connection. *Geophys. Res. Lett.* 41, 6881–6887. doi: 10.1029/2007GL032983

Kuleshov, Y., Gregory, P., Watkins, A. B., and Fawcett, R. J. B. (2020). Tropical cyclone early warnings for the regions of the Southern Hemisphere: strengthening resilience to tropical cyclones in small island developing states and least developed countries. *Natural Hazards,* 104, 1295–1313. doi: 10.1007/s11069-020-04214-2

Kumar, A., Roberts, D., Wood, K. E., Light, B., Parrillo, J. E., Sharma, S., et al. (2006). Duration of hypotension before initiation of effective antimicrobial therapy is the critical determinant of survival in human septic shock. *Critical Care Medicine*, 34, 1589–1596.

Kumar, S., and Reddy, M. (2008). Fiji's dairy industry: a cost and profitability analysis. *Pac. Econ. Bull.* 23, 27–39. https://devpolicy.org/PEB/2019/06/27/fijis-dairy-industry-a-cost-and-profitability-analysis/

Leroy, G. (2014). Inbreeding depression in livestock species: review and meta-analysis. *Anim. Genet.* 45, 618–628. doi: 10.1111/age.12178

Liligeto, S., and Nakamura, N. (2022). "Farmers' perceptions of climate hazards and coping mechanisms in Fiji" in Climate impacts on extreme weather (Amsterdam, Netherlands: Elsevier), 235–252.

Maharaj, N., and Wake, C. (2019). Livelihood vulnerability and resilience to climate variability in Fiji's dairy farming communities. *Pac. Clim. Change J.* 5, 45–56.

McIver, L., Woodward, A., Davies, S., Tibwe, T., and Iddings, S. (2015). Health impacts of climate change in Pacific island countries: a regional assessment of vulnerabilities and adaptation priorities. *Environ. Health Perspect.* 123, 1321–1327. doi: 10.1289/ehp.1307926

Mertz, O., Mbow, C., Reenberg, A., and Diouf, A. (2009). Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environ. Manag.* 43, 804–816. doi: 10.1007/s00267-008-9197-0

Moser, C. A., and Kalton, G. (2017). Survey methods in social investigation (Taylor & Francis, London, UK). doi: 10.4324/9781315241999

Mugambe, J., Ahmed, R. H., Thaller, G., and Schmidtmann, C. (2024). Impact of inbreeding on production, fertility, and health traits in German Holstein dairy cattle utilizing various inbreeding estimators. *J. Dairy Sci.* 107, 4714–4725. doi: 10.3168/jds.2023-23728

Nadan, M. K., and Baroutian, S. (2023). Prospective of pretreatment and anaerobic digestion of dairy cow manure in Fiji. *J. Chem. Technol. Biotechnol.* 98, 1584–1597. doi: 10.1002/jctb.7388

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., and Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livest. Sci.* 130, 57–69. doi: 10.1016/j.livsci.2010.02.011

Neuman, W. L. (2007). Basics of social research: Qualitative and quantitative approaches. 2nd Edn Boston, MA, USA: Pearson/Allyn and Bacon.

Nisi, N., Barrett, S., Addison, S., and Salman, M. (2024). Climate change, drought and agriculture in Small Island developing states: risks and adaptation options. Rome: Food & Agriculture Org.

Noy, I., Blanc, E., Pundit, M., and Uher, T. (2023). Nowcasting from space: tropical cyclones' impacts on Fiji's agriculture. *Nat. Hazards* 118, 1707–1738. doi: 10.1007/s11069-023-06080-0

Paulik, R., Crowley, K., Cradock-Henry, N. A., Wilson, T. M., and McSporran, A. (2021). Flood impacts on dairy farms in the bay of plenty region, New Zealand. *Climate* 9:30. doi: 10.3390/cli9020030

Peralta, A. (2022). The role of men and women in agriculture and agricultural decisions in Vanuatu. *Asia Pac. Policy Stud.* 9, 59–80. doi: 10.1002/app5.344

Polsky, L., and Von Keyserlingk, M. A. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *Journal of Dairy Science*, 100, 8645–8657.

Presti, E. (2022) Climate change adaptation strategy in developing countries: justice, fairness, and effectiveness. The case of Fiji Venice, Italy: Università Ca' Foscari Venezia.

Ricart, S., Castelletti, A., and Gandolfi, C. (2022). On farmers' perceptions of climate change and its nexus with climate data and adaptive capacity. A comprehensive review. *Environ. Res. Lett.* 17:083002. doi: 10.1088/1748-9326/ac810f

Sagero, P. O., Kumar, N., Magiri, R., and Nakamura, N. (2025a). Observed changes in rainfall and temperature extreme in Fiji. *Aust. Geogr.* 56, 241–263. doi: 10.1080/00049182.2025.2481714

Sagero, P. O., Kumar, N., Sian, K. T. C. L. K., and Ongoma, V. (2025b). Variability of temperature and heatwaves in the South Pacific Islands region under global warming. *Theor. Appl. Climatol.* 156:644. doi: 10.1007/s00704-025-05867-4

Sagero, P. O., Pratap, A., Magiri, R., and Ongoma, V., and Okello, P. (2024). Validation of ERA5 rainfall data over the South Pacific Region: case study of Fiji Islands. *Meteorology and Atmospheric Physics*, 136, 28.

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *J. Am. Stat. Assoc.* 63, 1379–1389.

Sharma, K., Ashrit, R., Kumar, S., Milton, S., Rajagopal, E. N., and Mitra, A. K. (2021). Unified model rainfall forecasts over India during 2007–2018: Evaluating extreme rains over hilly regions. *Journal of Earth System Science*, 130, 82.

Shrestha, A. B., and Aryal, R. (2010). Climate change in Nepal and its impact on Himalayan glaciers. *Reg. Environ. Chang.* 11, 65–77. doi: 10.1007/s10113-010-0174-9

Singh, P., Holland, E., and Morrison, M. (2020). Climate change and agriculture in Fiji: perceptions and adaptation strategies of farmers. *Clim. Dev.* 12, 711–722. doi: 10.1080/17565529.2019.1701401

Singh, S., Bakare, A. G., Iji, P. A., and Zindove, T. J. (2023). Beef cattle production systems and constraints among subsistence farmers across the Fijian windward–leeward divide. *Outl. Agric.* 52, 140–152. doi: 10.1177/00307270231162116

Terry, J. P. (2007). Tropical cyclones: Climatology and impacts in the South Pacific. *Springer*. doi: 10.1007/978-0-387-71543-8

Thornton, P. K., and Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change* 5, 830–836.

Thornton, P. K., van de Steeg, J., Notenbaert, A., and Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. *Agric. Syst.* 101, 113–127. doi: 10.1016/j.agsy.2009.05.002

van Ingen, A., and Termeer, K. (2022). Understanding the influence of Talanoa in the international climate change regime MA thesis. Available online at: https://edepot.wur.nl/640162

Wankar, A. K., Rindhe, S. N., and Doijad, N. S. (2021). Heat stress in dairy animals and current milk production trends, economics, and future perspectives: the global scenario. *Trop. Anim. Health Prod.* 53:70. doi: 10.1007/s11250-020-02541-x

Weir, T, Kumar, R, and Ngari, A. (2021) Interdecadal modulation of the effect of ENSO on rainfall in the southwestern Pacific. *Journal of Southern Hemisphere Earth Systems Science* 71, 53–65. doi: 10.1071/ES19053

Yeleliere, E., Antwi-Agyei, P., and Guodaar, L. (2023). Farmers response to climate variability and change in rainfed farming systems: insight from lived experiences of farmers. *Heliyon* 9:e19656. doi: 10.1016/j.heliyon.2023.e19656

Zimbelman, R. B., Rhoads, R. P., Rhoads, M. L., and Duff, G. C. (2009). "A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows" in Proceedings of the southwest nutrition and management conference, University of Arizona, Tucson, Arizona, USA 158–169.