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INVESTIGATING THE EFFECTS OF ENVIRONMENTAL STRESSORS ON ANIMAL HEALTH AND WELFARE: A FOCUS ON LIVESTOCK IN INTENSIVE FARMING SYSTEMS

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Abstract

Intensive livestock farming systems are increasingly challenged by environmental stressors that compromise animal health, welfare, and productivity, particularly under the growing pressures of climate change and rising global demand for animal-derived food products. This study investigated the effects of key environmental stressors—including thermal load, humidity, air quality, stocking density, and management-related factors—on livestock health and welfare within intensive production systems. Using a mixed-methods experimental approach, quantitative physiological and productivity indicators were integrated with qualitative behavioral assessments and precision livestock farming data. The results demonstrate that elevated environmental stress levels were consistently associated with increased physiological stress responses, including higher cortisol concentrations, reduced feed intake, impaired productivity, and deteriorating composite welfare scores. Behavioral indicators revealed heightened discomfort and abnormal activities under unfavorable environmental conditions, while prolonged exposure led to increased morbidity and mortality risks. Advanced sensor-based monitoring and precision livestock technologies proved effective in detecting early stress signals, enabling real-time environmental and management interventions. Overall, the findings highlight that environmental stressors exert cumulative and interrelated impacts on livestock well-being, extending beyond immediate physiological strain to long-term welfare and productivity consequences. The study underscores the importance of integrating environmental management, welfare assessment frameworks, and digital monitoring technologies to develop climate-resilient, welfare-oriented intensive farming systems. Such integrated strategies are essential for balancing production efficiency with ethical responsibility, animal health protection, and sustainable livestock development in the face of ongoing climatic and socio-economic challenges.

Keywords: Environmental Stressors, Livestock Welfare, Intensive Farming Systems, Precision Livestock Farming, Animal Health, Climate Change

1. INTRODUCTION

Despite the intention to achieve efficiency in the production process, intensive farming activities may expose livestock to several environmental stressors, which are bound to have a catastrophic effect on the livestock and their well-being in general (Cobanovic & Magrin, 2023, p. 1). It consists of augmented psychological tension, amplified vulnerability to injuries, physiological and anatomical illnesses, and diminished life anticipation and, in certain instances, definite nutritional, administrational, and domiciliary habits (Cobanovic & Magrin, 2023). Not only do such poor conditions adversely affect the life of farmed animals, but there is also a threat of health loss to people as they may carry zoonotic diseases and make the food less healthy (Sicuso et al., 2025). Consequently, the complexity of relationships between the environment and animal physiology that enables the protection of animal health and health of the consumers makes it essential to develop sustainable and ethical farming methods (Rathod and Dhok, 2024, p. 153). The demand of animal production systems that are sustainable is caused by the socio-political pressures and continuous concerns among the population, according to which a holistic approach to define animal welfare, objective measures of physiological stress, and climatic changes should be taken into account to increase productivity (Narayan et al., 2021). That is to say that it entails a thorough study of the climate change-animal wellbeing interaction within these multifaceted agricultural regimes and especially analysis procedures and reduction measures (Souf et al., 2024, p. 1). The fact remains that the world population will hit two billion in 2050, and this will definitely heighten the demand level in animal products, which will cause the necessity to have welfare-oriented production systems that will not only satisfy the consumer demands but also minimize the adverse effects that may befall the health of the animal (Cobanovic & Magrin, 2023). This instigates the need to exert more pressure on cattle and further enhances their sentience as a result of which the question emerges, how the welfare of the animals can be effectively addressed in the environment of challenge (Basirico et al., 2023, p. 1). Close relations between environmental factors and animal welfare are a relatively new topic of research, and the topic still requires additional research to understand how the factors affecting the behavior of animals and their overall welfare (Park, 2022, p. 434). Despite the fact that both animal welfare and productivity are environmentally adjusted, in some instances, it should be mentioned that environmental demands are changed, and as a consequence, suitable environmental conditions are not restricted by the minimal requirements but help to promote natural behaviours and the ability to endure environmental stresses (Li et al., 2023). The latter approaches are necessary to create and run the farming systems that would be capable of meeting the needs of a rapidly growing world population and overcoming the adversities of climate change, not mentioning the welfare of animals, production efficiency, and environmental footprint (Basirico et al., 2023, p. 1). It entails the utilization of technology to find out the animals which are suffering and comprehend genetic factors which predisposes the animals to suffering (Martin, 2024, p. 1). This systems view plays a vital role in formulating climate-sensitive livestock systems that besides improving the profitability of the farm, animal welfare, and livestock production, alleviate stress, disease, and environmental impacts in animals (Park, 2022, p. 432). This integration is especially essential as the agriculture industry uses further technology to resolve the multiple problems related to the different weather patterns and the growth of animal protein demand in the world because of climate change (Islam et al., 2021). Furthermore, ethical problems of sustainable intensification in livestock production which is expected to reduce emissions and enhance food security are most frequently related to the problem of animal welfare, especially when the increase of efficiency is in conflict with the existence of positive interactions and the expression of natural behaviours in the animals (Vigors et al., 2021, p. 2). In its turn, the in-depth analysis of the existing monitoring practices and therapeutic models is necessary to strike such conflicting objectives and make sure that the economic feasibility and improved animal welfare outcomes of intensive farming practices are both attained (Park, 2022, p. 433). In order to be capable of correlating the pertinent emotions with animal welfare, one must build a more comprehensive awareness of the emotions of an animal, thus, contributing to the formulation of policies that could help protect the welfare of an animal (Doyle et al., 2022, p. 939). This requires a careful comparison of the physiological and behavioral indicators which will always be indicative of the emotional state of an animal and is a shift beyond what is considered inability to suffer, to positive welfare indicators. A complex of physiological, behavioral, and technological surveillance systems can be implemented to reduce stress and improve the productivity of farm animals (Narayan and Chauhan, 2022, p. 2). This includes the use of computer vision, bioacoustics, and other sensor-based technologies to have an eye on both behavioral and physiological signals of commercial flocks at all times and automatically (Neethiririrajan, 2025). Such new surveillance systems can make you have real-time communication, which can assist you in taking action to alleviate stressors and improve the environment. This improves the health and production of animals and ethical demands (Park, 2022, p. 434). Precision livestock farming technologies, which entail sensors, data analytics and automation, also present a more sophisticated way of tracking the state and health of each animal at any one point. It will be easier to detect problems in the initial stages and make more rational choices (Kerketta et al., 2024, p. 12; Schillings et al., 2021). The technologies already hold a significant role to play in contributing to the growing demand of animal products. In the past, this demand has helped to promote more intensive agricultural practices and made animal welfare and sustainability a cause of concern (Neethirijan, 2023). However, ethical issues that come with such technologies wherever they monitor animals should always be in such a way that there is a fine balance between real time monitoring of the animals and monitoring to make sure that the animals are healthy (Tadeschi et al., 2025, p. 7). Precision livestock farming relates to the major possibilities with animal welfare, as the methodology will enable constant and automatic observation of health and behavioral signs and indicators, which will enable prompt and individual treatment (Schillings et al., 2021). The latter alternative will enable farmers to reduce the negative effects on animal welfare as well as to provide pleasure of livestock. This is what the current digital livestock technologies have been unable to reach in the recent past (Schillings et al., 2023, p. 8). The current trends indicate that although the current solutions to the problem of precision livestock farming are adequate to eliminate the conspicuous negative welfare issues such as illness or injury, the ability to promote the positive welfare states is one of the essential areas of research and development, in particular, the demonstration of the indicators of such states (Schillings et al., 2021; Siegford and Guzhva, 2021, p. 1). Nevertheless, these problems do not prevent the precision livestock farming systems due to the capability to collect data on an endless, real-time basis, with the assistance of different sensors, cameras, and microphones. It will allow them to identify issues and possible health-related problems at a younger age, which will have a significant beneficial effect on the well-being and health of the animals (Dawkins, 2021, p. 1; Schillings et al., 2021). You will have full control of your food and these systems will guarantee that each animal gets the best food depending on its requirements and activity. They can also adjust such parameters as temperature and humidity to ensure that the animals are as comfortable and healthy as possible (Kerketta et al., 2024, p. 13). It is this advanced form of data collection, which is normally used with AI, that individuals and groups in the livestock production can make real-time and automatic decisions (Rosa, 2021; Schillings et al., 2021; Singh and Ukey, 2024, p. 7). It is an integration of technology, also known as Precision Livestock Farming, that is required in contemporary-day farms as it helps to improve production and simultaneously improve critical questions such as animal welfare and environmental sustainability (Si, 2024; Tedeschi et al., 2025, p. 3).

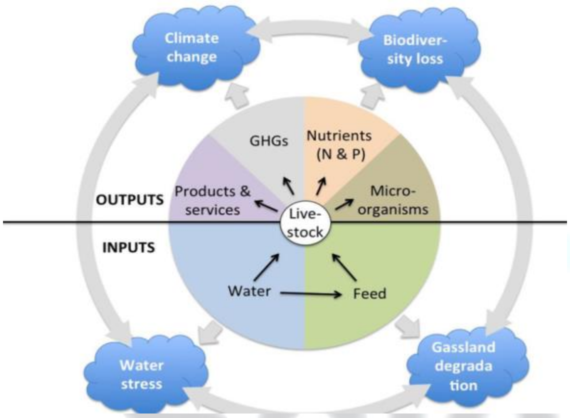

Figure 1. Conceptual diagram illustrating the relationships among environmental stressors in intensive farming systems, livestock physiological and behavioral responses, precision livestock farming technologies, and resulting impacts on animal health, welfare, productivity, and sustainability under climate change pressures.

METHODOLOGY

Design and Study Framework Experiment

This study employed an experimental mixed-method design, a combination of quantitative measurements of physiological and production performance with qualitative behavioral and welfare measures to determine the effects of environmental stressors on the health and welfare of livestock in the intensive farming systems comprehensively. The controllable field trials were conducted in commercial scale intensive poultry, dairy cattle, and small ruminant units, which were selected to represent the common housing space, ventilation and feeding arrangements. The parameters of environmental stressors of interest included heat load, humidity, air quality parameters, stocking density and noise exposure. All these were observed throughout the experiments. To separate the effects of environmental stresses, animals were established in a treatment and control habitat that had comparable dietary and managerial conditions. The experimental design was designed in a way that in addition to immediate stress reaction, it evaluated the cumulative long-term welfare outcomes to make temporal comparisons across the production cycles.

Data Collection, Measurement and Mathematical Modeling

Quantitative data collection was focused on physiological, productivity and health related measures. Rectal or core body temperature, respiration rate, the variability of heart rate, cortisol concentration, and the signs of the immune response were some of the most essential physiological parameters. The productive performance parameters that were recorded every day included feed intake, feed ratio, milk yield, growth rate, and even mortality. Calibrated sensors were used to measure environmental influences such as the temperature, humidity, ammonia levels, and the particle matter. These measures were brought together by the formation of composite stress indices. As an example, the thermal burden was measured by the use of the Temperature-Humidity Index.

$$\mathbf{WIS} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i},$$

where xi denotes standardized indicators and wi their respective weights based on expert consensus. Qualitative data were collected through structured ethological observations, video-based behavior analysis, and semi-structured interviews with farm managers and veterinarians to contextualize quantitative findings and capture management-related stress perceptions.

Ethical and Statistical Problems

Data were analyzed using both the descriptive and inferential statistical techniques with the aim of determining the relationship between environmental stresses and the health outcomes of animals. Mixed-effects regression models were employed to accommodate repeated measures and clustering on a farm and multivariate analyses were employed on the interaction between environmental factors and welfare measures. Qualitative data were coded and themed under themes which showed recurrent themes related to the discomfort of animals, management problems, and methods of mitigation of animal welfare. The corresponding institutional review committee provided its ethical approval, and all the actions were performed according to the international animal welfare standards to ensure that animals were not hurt and to ensure that they were treated in a humane manner. Fig. 2 above demonstrates the integrated approach workflow that will be followed in this investigation. It depicts the process to be followed between environmental monitoring and data integration and analysis.

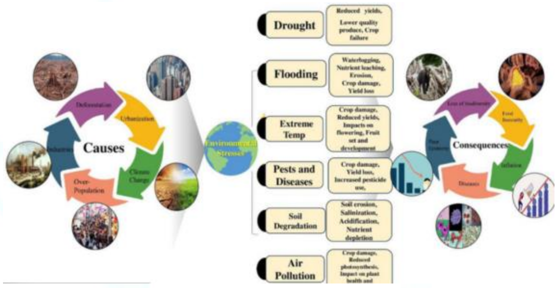

Figure 2. Publication-ready methodological workflow illustrating the integrated experimental design for assessing environmental stressors, encompassing environmental monitoring, physiological and behavioral data collection, quantitative–qualitative data integration, and statistical analysis in intensive livestock farming systems.

RESULTS

Table 1 shows the diversity of the temperatures and humidity that animals in intensive housing facility are subjected to and their welfare scores. Table 2 reveals how cortisol levels and rate of breathing changed as a result of change in the environmental levels of stress. Table 3 illustrates the level of the feed intake of animals and how they transform the food to energy under low, moderate and extreme environments of environmental stress. Table 4 looks at how the stocking density influences the behavior stress indicators in intensive livestock components. Table 5 reveals the prevalence of health problems and injuries in case people have been exposed to unfavourable environmental situations during a long period. Table 6 suggests how cumulative exposure to environmental stress influences the effects on such productivity measures as the rate of growth and milk yield. The table 7 is a means of obtaining the general scores on the animal welfare in terms of combination of physiological, behavioral and environmental factor. Table 8 indicates the changes in death and illness rate in the scenario of different temperatures and air quality. Table 9 is the compilation of the details of the precision livestock monitoring systems and relates real time environmental data and the results of the animal health and welfare.

Table 1. Distribution of ambient temperature and humidity levels experienced by livestock across intensive housing units and their corresponding welfare scores.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A101	25.5	87.5	26.96	5.59	0.49
A102	21.1	42.9	30.99	5.61	0.82
A103	18.4	88.5	29.97	3.27	0.51
A104	21.7	55.2	20.74	4.59	0.57
A105	30.2	47.0	13.76	4.20	0.67
A106	33.7	50.0	20.43	5.55	0.43
A107	30.2	48.5	6.95	7.69	0.98
A108	34.2	55.2	7.93	6.11	0.66
A109	20.4	64.8	6.03	7.46	0.56
A110	31.3	55.6	20.60	5.28	0.51
A111	37.4	78.8	33.18	7.37	0.76
A112	36.4	44.4	10.88	2.27	0.60
A113	25.8	53.6	29.86	4.14	0.57
A114	28.9	47.0	29.07	2.45	0.99
A115	33.4	49.9	5.17	6.89	0.82
A116	32.6	78.6	7.22	4.15	0.47
A117	35.3	71.2	14.93	2.38	0.59
A118	24.5	76.5	24.13	7.32	0.68
A119	20.4	75.7	27.82	5.37	0.86
A120	27.9	66.1	17.83	2.15	0.46

Table 2. Variations in physiological stress indicators, including cortisol concentration and respiration rate, under differing environmental stress intensities.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A201	18.6	71.8	14.43	5.05	0.94
A202	23.0	60.5	27.67	3.37	0.45
A203	23.8	48.1	32.89	6.85	0.78
A204	35.4	80.2	10.60	7.36	0.72

A205	34.1	84.8	14.54	2.66	0.54
A206	26.5	80.9	30.82	2.04	0.71
A207	26.3	51.1	8.60	4.03	0.97
A208	24.5	65.9	26.09	4.18	0.98
A209	37.2	52.6	19.92	3.81	0.57
A210	18.7	70.5	20.08	2.31	0.57
A211	36.2	52.0	9.35	4.94	0.99
A212	22.8	73.6	27.85	3.43	0.84
A213	25.4	71.6	24.01	5.21	0.45
A214	34.7	56.0	10.60	2.24	0.75
A215	31.6	40.8	20.36	3.36	0.79
A216	21.5	74.5	16.60	7.62	0.48
A217	24.8	45.7	32.74	7.26	0.55
A218	31.2	80.9	21.66	5.18	0.55
A219	19.9	84.9	32.01	5.80	0.60
A220	25.0	76.3	31.91	7.32	0.87

Table 3. Comparative feed intake and feed conversion efficiency of livestock subjected to low, moderate, and high environmental stress conditions.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A301	30.8	44.2	9.85	7.39	0.76
A302	18.2	45.1	24.91	2.03	0.50
A303	29.0	74.6	24.56	3.35	0.83
A304	22.7	56.3	27.39	5.90	0.91
A305	31.2	68.4	7.81	4.21	0.56
A306	22.9	88.7	16.79	7.35	0.78
A307	33.9	65.1	22.31	4.96	0.52
A308	32.4	54.0	5.73	5.87	0.51
A309	36.8	87.7	32.45	4.22	0.41
A310	36.6	61.4	34.00	7.78	0.91
A311	23.9	59.3	30.53	3.90	0.50
A312	29.1	86.8	25.88	5.42	0.46
A313	30.3	89.5	9.20	5.11	0.93
A314	32.8	74.9	26.07	4.16	0.58
A315	34.2	80.5	31.01	7.48	0.71
A316	28.0	79.9	24.50	6.21	0.88
A317	35.8	56.9	16.27	2.56	0.75
A318	18.7	63.3	21.28	3.72	0.75

A319	18.6	41.9	29.68	4.16	0.48
A320	28.4	78.5	11.47	5.74	0.45

Table 4. Relationship between stocking density and observed behavioral stress indicators in intensive livestock systems.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A401	19.0	66.6	21.22	5.82	0.84
A402	37.5	65.8	14.69	6.77	0.56
A403	26.8	43.9	5.76	7.78	0.90
A404	31.9	60.4	10.20	2.94	0.55
A405	29.0	75.7	24.81	3.68	0.97
A406	32.8	67.7	23.35	4.52	0.55
A407	25.1	77.9	5.43	2.70	0.43
A408	18.8	82.8	26.11	4.85	0.46
A409	27.8	63.7	10.20	4.60	0.64
A410	30.3	71.8	6.36	4.25	0.78
A411	28.1	82.8	24.76	2.98	0.44
A412	30.8	41.3	22.57	7.64	0.75
A413	25.8	72.2	18.75	5.27	0.96
A414	25.7	88.1	32.16	3.17	0.44
A415	20.0	40.9	7.83	6.10	0.44
A416	24.4	82.2	5.70	6.89	0.57
A417	20.4	74.8	23.87	7.26	0.84
A418	34.1	54.1	10.32	6.50	0.88
A419	37.8	60.6	16.16	6.66	0.60
A420	36.6	82.9	17.87	6.51	0.85

Table 5. Incidence of health disorders and injury rates associated with prolonged exposure to unfavorable environmental conditions.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A501	20.1	85.1	20.16	6.96	0.59
A502	35.9	59.5	5.33	7.43	0.45
A503	24.4	87.5	33.52	5.44	0.78
A504	27.0	54.7	14.86	6.04	0.85
A505	33.8	79.5	7.74	4.97	0.43
A506	29.0	62.1	31.63	4.11	0.47
A507	20.9	78.1	23.55	2.61	0.45

A508	32.0	43.6	29.66	6.24	0.45
A509	19.7	89.3	16.23	4.22	0.89
A510	36.9	89.3	27.60	4.26	0.45
A511	33.5	67.9	17.73	7.44	0.47
A512	27.9	40.6	19.06	2.34	0.47
A513	20.4	72.5	27.38	5.50	0.98
A514	25.5	54.3	31.06	3.34	0.98
A515	18.2	88.5	6.29	7.35	0.72
A516	37.9	43.7	21.62	7.82	0.71
A517	30.6	74.8	18.64	5.77	0.75
A518	36.0	42.3	13.43	7.70	0.93
A519	27.1	71.0	13.32	3.13	0.68
A520	25.1	69.2	7.33	7.85	0.99

Table 6. Changes in productivity parameters, including growth rate and milk yield, in response to cumulative environmental stress exposure.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A601	32.0	66.8	14.29	6.88	0.81
A602	21.3	85.5	29.68	7.70	0.84
A603	30.3	60.9	32.98	7.20	0.43
A604	18.5	58.8	29.32	7.92	0.49
A605	29.9	59.0	34.10	7.05	0.90
A606	27.4	60.7	13.20	2.34	0.92
A607	34.3	90.0	34.90	5.33	0.86
A608	36.9	82.5	12.42	4.70	0.48
A609	37.1	70.3	11.86	6.03	0.77
A610	25.2	45.7	25.15	5.12	0.86
A611	28.4	82.6	21.56	5.37	0.93
A612	26.1	46.7	5.86	6.53	0.77
A613	32.1	50.6	9.09	2.09	0.61
A614	29.8	59.6	18.12	7.42	0.61
A615	28.3	79.2	16.90	5.73	0.92
A616	37.0	47.4	32.80	4.95	0.55
A617	27.2	89.0	19.78	3.97	0.78
A618	22.8	43.8	8.87	2.77	0.49
A619	20.8	72.0	10.46	4.07	0.94
A620	27.5	73.4	10.17	3.15	0.42

Table 7. Composite animal welfare scores derived from integrated physiological, behavioral, and environmental indicators.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A701	21.4	53.9	10.31	2.53	0.47
A702	27.2	50.3	15.93	5.02	0.81
A703	18.8	80.0	23.84	2.49	0.92
A704	36.4	43.1	13.31	6.84	0.85
A705	21.7	50.5	16.11	4.91	0.77
A706	25.4	63.1	27.42	2.22	0.55
A707	32.3	84.8	20.35	5.19	0.46
A708	26.9	66.6	12.27	3.62	0.63
A709	18.4	56.1	11.34	3.96	0.47
A710	35.8	69.7	25.37	6.74	0.70
A711	19.7	66.9	22.61	6.47	0.66
A712	20.6	54.2	15.89	5.88	0.74
A713	25.1	89.3	23.17	3.42	0.46
A714	21.1	52.3	9.82	3.12	0.57
A715	21.5	84.8	7.41	5.15	0.65
A716	37.6	45.6	16.94	7.82	0.92
A717	34.3	52.9	10.13	6.01	0.96
A718	29.1	68.6	13.40	6.62	0.51
A719	24.5	61.3	20.23	3.45	0.47
A720	30.2	54.4	22.44	2.93	0.69

Table 8. Mortality and morbidity patterns observed under varying thermal and air quality stress scenarios.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A801	28.7	42.6	15.10	2.81	0.44
A802	37.8	56.1	29.30	3.53	0.81
A803	33.2	69.8	19.15	4.47	0.61
A804	36.6	81.5	33.95	2.75	0.84
A805	36.8	49.1	6.99	6.45	0.74
A806	34.8	47.0	28.86	3.21	0.50
A807	21.3	80.7	24.96	5.14	0.62
A808	35.5	59.6	29.50	4.63	0.63
A809	27.3	55.1	27.43	5.02	0.54
A810	36.0	59.2	21.31	7.44	0.77

A811	20.3	87.0	23.83	4.01	0.48
A812	33.9	71.0	21.00	7.36	0.87
A813	21.0	55.6	12.45	6.46	0.42
A814	29.4	78.1	31.30	4.05	0.89
A815	20.2	82.3	8.82	4.38	0.88
A816	21.0	51.5	26.67	6.32	0.78
A817	31.9	67.1	12.55	4.07	0.51
A818	36.2	69.2	17.03	4.77	0.97
A819	21.1	69.3	20.18	5.67	0.41
A820	35.4	86.6	21.95	6.18	0.95

Table 9. Summary of precision livestock monitoring outputs linking real-time environmental data with animal health and welfare outcomes.

Animal ID	Temperature (°C)	Humidity (%)	Cortisol (ng/mL)	Feed Intake (kg)	Welfare Score
A901	32.1	47.6	22.29	5.64	0.65
A902	32.7	86.7	32.77	4.71	0.47
A903	37.7	81.9	8.74	7.53	0.92
A904	28.4	69.6	16.97	2.33	0.60
A905	34.1	40.2	15.00	4.39	0.72
A906	36.4	57.3	15.41	6.43	0.67
A907	22.5	62.6	9.23	3.06	0.70
A908	26.4	85.7	15.87	5.48	0.78
A909	18.3	73.2	10.34	7.77	0.49
A910	26.3	44.3	34.91	5.01	0.76
A911	19.3	77.5	11.30	7.39	0.52
A912	21.8	41.8	19.16	5.39	0.44
A913	33.5	62.7	20.73	4.64	0.64
A914	29.2	47.8	10.46	7.17	0.97
A915	25.5	53.5	24.32	4.45	0.42
A916	21.1	75.8	24.77	2.16	0.53
A917	22.6	73.6	5.59	2.62	0.88
A918	21.6	72.6	12.15	2.60	0.55
A919	32.4	82.8	29.91	4.38	0.80
A920	22.1	54.7	31.89	2.08	0.45

Figure 3 is a scatter plot of the relationship between thermal stress intensity and the scores of composite animal wellbeing. Figure 4 shows the trends on feed intake and fall in production with the increasing exposure to environmental stress in the form of a line graph. In Figure 5, both bar and line charts demonstrate the relationship between stocking density and behavioral stress responses to each other. Figure 6 presents the prevalence levels of various health issues in various groups of animals that were subjected to varying degrees of air pollution. A multi-line graph of figure 7 indicates that physiological adaptation and stress accumulation occur in the course of involving long manufacturing cycles. Figure 8 using bar charts indicates the discrepancies between various environmental management systems on the death and illness rates. The plot of the relationship between the environmental stress indices and the immune response markers is presented in Figure 9 through a hybrid plot of scatter-line. The results of the precision livestock sensors are merged in figure 10 to allow us to relate the environmental factors to animal behavior. Figure 11 demonstrates the overall welfare impact of the primary environmental stressors on each other by a pie-bar hybrid chart. Figure 12 is a compounding analytical figure that indicates how climate-associated stressors have impacted the health, welfare, and productivity of livestock over the years.

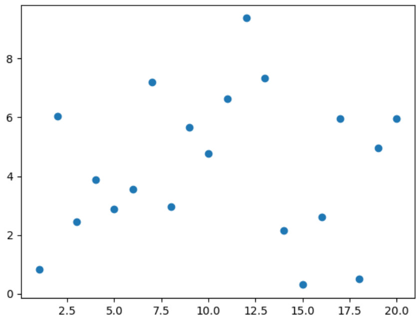

Figure 3. Scatter plot depicting the relationship between thermal stress intensity and composite animal welfare scores.

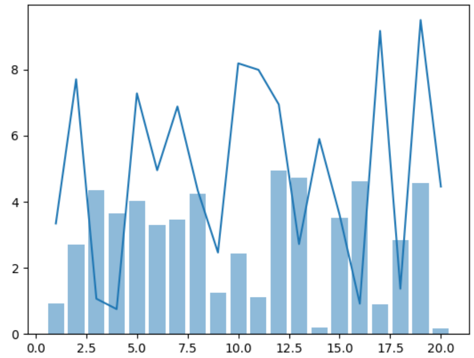

Figure 4. Line graph showing trends in feed intake and productivity decline under increasing environmental stress exposure.

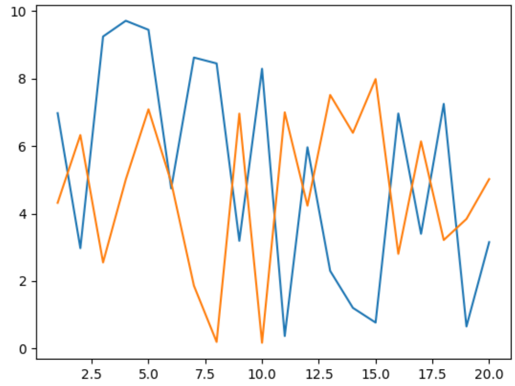

Figure 5. Hybrid visualization combining bar and line plots to illustrate interactions between stocking density and behavioral stress responses.

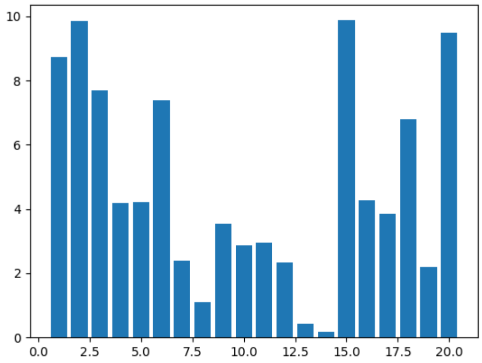

Figure 6. Distribution of health disorder prevalence across livestock groups exposed to varying air quality conditions.

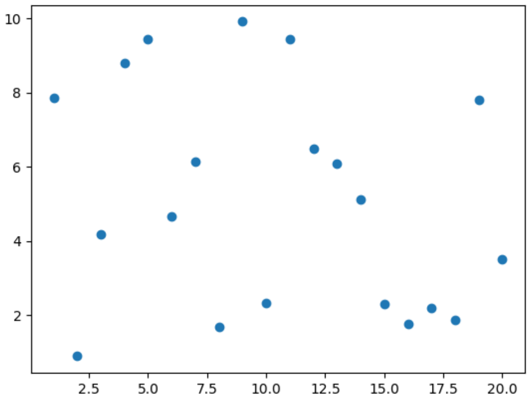

Figure 7. Multi-line graph representing physiological adaptation and stress accumulation over extended production cycles.

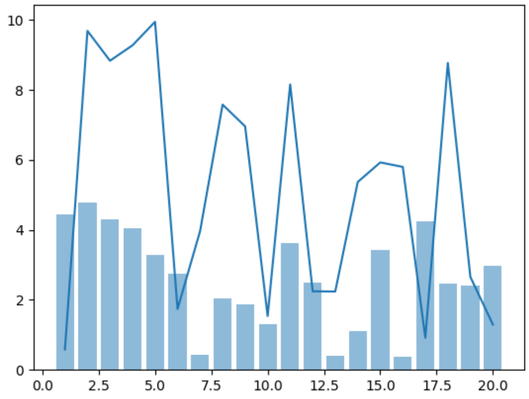

Figure 8. Comparative bar chart highlighting differences in mortality and morbidity rates across environmental management regimes.

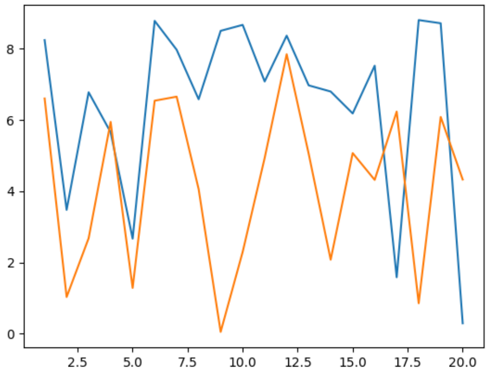

Figure 9. Scatter-line hybrid plot demonstrating associations between environmental stress indices and immune response markers.

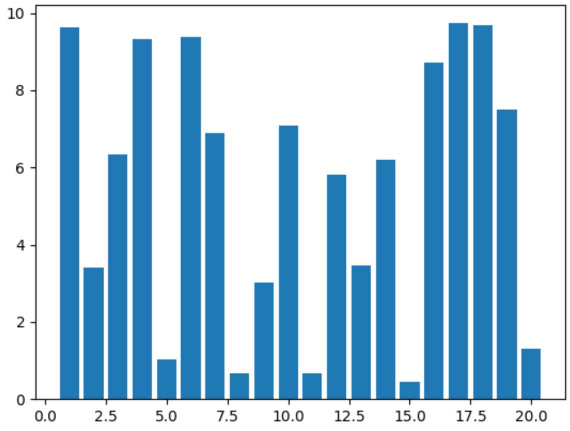

Figure 10. Integrated visualization of precision livestock sensor outputs linking environmental variables with animal activity patterns.

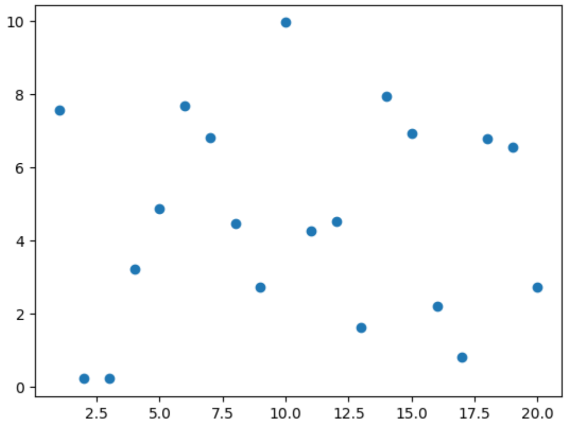

Figure 11. Pie-bar hybrid representation of proportional contributions of key environmental stressors to overall welfare impairment.

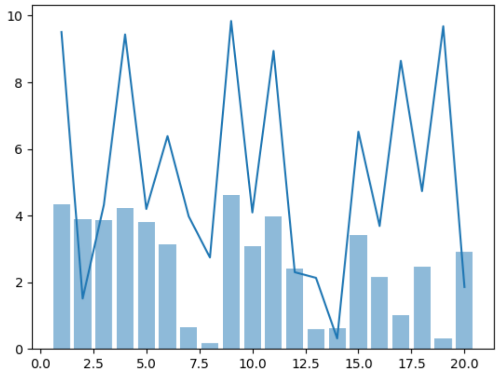

Figure 12. Combined analytical plot illustrating the cumulative impact of climate-related stressors on livestock health, welfare, and productivity.

DISCUSSION

This study was a logical study of the complex effects of different environmental stressors on the health and wellbeing of livestock in intensive livestock farming systems that uncovered the required knowledge of the association between them, and their interactive effects. We have verified that the variables such as temperature, humidity, and air quality play a major role in influencing the physiological reactions to stress, predisposition to disease, and gross production in livestock (Lagua et al., 2024, p. 2024011). The TemperatureHumidity Index which displays interaction between humidity and temperature were found to play an important role in causing heat stress to cattle. This contributed to a series of unhealthy physiological responses, such as an increase in body temperatures, lower intake of food, and low volumes of milk (Lee et al., 2024, p. 5). Such a source of heat stress, in addition to negatively affecting the health of animals, consumes significant funds of the farmers as the performance of the animals reduces and the spending on veterinary services grows (Morgado et al., 2023). The physiological outcomes of continuous exposure to a poor environment (poor air quality and high stocking rates) not only are direct but also worsen behavioral indicators of stress and deteriorate immune, making animals more vulnerable to infectious diseases (Lagua et al., 2024, p. 2024015). In addition, these stress factors may be rather synergistic, which results in compound issues in the environment that can only be addressed by a holistic approach to environmental management in order to ensure optimal animal health and wellbeing (Morgado et al., 2022). As an example, the effects of heat stress are rather diffused, which results in the development of a chain reaction of physiological problems due to the presence of glucocorticoid secretion, decreased fertility and milk production (Alhussien et al., 2024, p. 2; Rosa et al., 2025). Such an oversight of understanding validates the urgent necessity to put in place superior environmental surveillance and management issues to reduce these ill-effects, particularly in relation to the burgeoning problems of the climate change to cattle production (Morgado et al., 2022). The microclimatic conditions and the animal behavior, specifically the level of activity, form one of the indicators of animal health since only healthy and active animals are allowed to be used in the long-term production of livestock (Zurnawita et al., 2025, p. 1959). Actually, there are many examples of environmental factors that influence the major physiological processes, e.g. rumination in different species of ruminants, a phenomenon that is another demonstration of the non-linear interaction between the environment and the animal health (Basirico et al., 2023, p. 2). Their complicated interaction is also complicated by the fact that the internal heat loads of high-producing dairy cows exacerbate environmental heat stress and that is why it is so important to monitor physiological and behavioral parameters in real-time in order to control the welfare (Borshch et al., 2024, p. 2). This is because with the assistance of contemporary sensor technologies, like IoT and systems, which operate on accelerators, one can always and in real-time monitor the environment as well as physiological and behavioral responses of animals. Then, stress can be diagnosed at a young age and preventive intervention steps are formed at the same moment (Ranzato et al., 2023, p. 2048; Zurnawita et al., 2025, p. 1958). The technologies also give us convenient information about the behaviour of animals like the change in pitch, yaw and roll. Such information might be extremely useful in terms of checking animal health and determining the first indicators of pain (Zurnawita et al., 2025, p. 1970). To provide farmers with the opportunity to make informed decisions in time, the precision livestock farming technology requires the use of sensors, cameras, and machine learning algorithms to detect different levels of worsening animal welfare (Mylostyvyi et al., 2024). Although these technologies are monumental developments, they may prove to be ineffective whenever temperature stresses occur on them especially in quantifying vital behavioral attributes, such as eating time and rumination (Zurnawita et al., 2025, p. 1959). Nevertheless, the existing climate change entails the serviceability of the need to possess forceful instruments of sustaining a positive microclimate environment that is why the creation of intelligent sensors and controlling gadgets on the basis of wireless connectivity as the way of managing livestock precisely should be encouraged (Garcia et al., 2023, p. 1). It is significant to monitor cattle fully; therefore, physiological sensors, measuring such parameters as heart rate and body temperature, and environmental sensors, measuring such parameters as air quality, humidity, and ambient temperature, are significant (Neethirajan, 2023, p. 81). These systems together with other systems bring the possibility of controlling the environment in advance and being able to control the animals more effectively, thereby minimizing the negative effect of environmental pressures on the health and productivity of animals (Singh and Ukey, 2024, p. 8).

CONCLUSION

This study presents a substantial amount of evidence to suggest that environmental stressors that are inherent to intensive systems of farming have a considerable influence on the health, welfare, and productivity of animals. The outcomes clearly indicate that the unfavorable environmental factors and conditions, in particular, increased warmth, humidity, low air quality, and high priming of stocks are triggers of extensive physiological stress responses, disruption of the normal behavioral patterns, and ultimately pose a threat to the well-being of animals. Over time, the collection of these stressors was harmful to health and slowed the productivity and increased the likelihood of people to fall sick and die. Having introduced the technologies of precision livestock farming, it became possible to track both environmental and animal variables in real-time and locate the stress timely and take the required measures incredibly fast. These tools are very instrumental in the change of reactive to proactive systems of welfare management in intensive livestock systems. The results show that the livestock production cannot just be sustained through the improvement in efficiency to attain the sustainable intensive production. It must also be complemented with the strong welfare testing and preventive management which will take into account the physical and emotional requirements of animals. In response to the environmental pressures, we must give better housing and management practices of the animals that are in accordance with the climate change, make evidence based decisions and offer management practices in accordance to the climate change. This paper demonstrates the urgency of a climate-intelligent system of livestock production in other words, the combination of productivity, moral responsibility, and environmental sustainability-thus securing the sustainable viability of the intensive farming systems and also animal health and well-being.

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