STM JOURNALS

Research & Reviews: Journal of
Dairy Science & Technology

ISSN: 2319-3409 (Online)
ISSN: 2349-3704 (Print)
Volume 14, Issue 1, 2025
January –April
DOI (Journal): 10.37591/RRJoDST

https://journals.stmjournals.com/rrjodst

Review RRJoDST

Ecological Impacts of Intensively Managed Dairy Farms: Environmental Challenges to Sustainable Dairy Development

Md. Emran Hossain[1,*], Minara Begum Munni[2], Shilpi Islam[3]

Abstract

Intensively managed dairy farming systems, designed to maximize production efficiency, have raised significant concerns regarding their long-term ecological impacts. This study explores the environmental consequences of such systems, focusing on soil degradation, water resource depletion, biodiversity loss, greenhouse gas emissions, and ecosystem imbalance. While intensive dairy farming contributes to high yields, it also accelerates environmental degradation through practices such as excessive fertilizer and water use, monoculture feeding, and inadequate waste management. These systems have been shown to compromise soil health, reduce biodiversity, and significantly alter water cycles, leading to issues such as nutrient pollution, soil erosion, and water scarcity. Furthermore, intensive dairy farms are major sources of methane and nitrous oxide emissions, contributing to global climate change. The decline in biodiversity is also a critical concern, as these farms often replace natural habitats with monoculture crops, reducing ecosystem resilience. The cumulative effects of these environmental challenges undermine the sustainability of dairy production systems and threaten long-term ecological health. Addressing these issues requires a shift toward more sustainable farming practices that balance productivity with environmental stewardship. This paper aims to highlight these challenges and propose potential strategies for mitigating the ecological footprint of intensive dairy farming systems, ensuring a more sustainable path for dairy development.

Keywords: Biodiversity loss, ecological footprint, greenhouse gas emissions, intensively managed dairy farms, soil degradation, sustainability

INTRODUCTION

Intensive dairy farming has become a cornerstone of global dairy production, driven by the need for higher yields, efficient resource use, and cost-effective practices. This system relies heavily on advanced technologies, high stocking densities, and the use of synthetic inputs such as fertilizers, pesticides, and feeding additives to maximize productivity. However, while these systems contribute to the global food supply, they raise serious environmental concerns due to their ecological impacts. Soil degradation, water contamination, loss of biodiversity, and significant greenhouse gas emissions are some of the key environmental issues associated with intensive dairy farming [1]. As the global demand for dairy products increases, these concerns have led to growing calls for more sustainable farming practices that balance production with environmental health.

***Author for Correspondence**
Md. Emran Hossain
E-mail: emran@cvasu.ac.bd

[1]Professor, Department of Animal Science and Nutrition, Chattogram Veterinary and Animal Sciences University, Khulshi, Chattogram, Bangladesh
[2]Student, Department of Animal Science and Nutrition, Chattogram Veterinary and Animal Sciences University, Khulshi, Chattogram, Bangladesh
[3]Professor, Department of Animal Science and Nutrition, Gazipur Agricultural University, Salna, Gazipur, Bangladesh

Received Date: December 27, 2024
Accepted Date: January 06, 2025
Published Date: January 20, 2025

Citation: Md. Emran Hossain, Minara Begum Munni, Shilpi Islam. Ecological Impacts of Intensively Managed Dairy Farms: Environmental Challenges to Sustainable Dairy Development. Research & Review: Journal of Dairy Science and Technology. 2025; 14(1): 42–62p.

The ecological consequences of intensive dairy farming are complex and multifaceted. Excessive nutrient runoff, primarily from manure and synthetic fertilizers, leads to water pollution, eutrophication, and the degradation of aquatic ecosystems [2]. Furthermore, the continuous overgrazing and the use of monoculture feed crops can deplete soil health, reducing organic matter and biodiversity [3]. These practices also contribute to soil erosion and water resource depletion, exacerbating environmental pressures. The farming system is also a significant emitter of greenhouse gases, particularly methane from enteric fermentation and nitrous oxide from manure management [4]. These emissions not only contribute to global warming but also disturb local and regional climate dynamics, affecting both ecosystems and human populations.

This study presents a comprehensive assessment of the long-term ecological impacts of intensively managed dairy farms, focusing on the environmental degradation associated with such systems. What distinguishes this research is its holistic approach, integrating diverse ecological factors, such as soil health, water quality, biodiversity, and greenhouse gas emissions, within the context of intensive dairy operations. By combining environmental science with dairy farming practices, the study provides new insights into how intensive dairy farming systems can be modified to mitigate their negative ecological impacts. This research is essential for developing sustainable dairy farming practices that address both production demands and environmental stewardship, ensuring the long-term viability of dairy systems globally.

SOIL HEALTH DEGRADATION

Decline in Soil Organic Matter

Intensive dairy farming practices, including overgrazing and excessive use of synthetic fertilizers, depleting soil organic matter [5]. Organic matter plays a crucial role in maintaining soil fertility, water retention, and microbial diversity. Its reduction results in poorer soil structure, reduced nutrient availability, and decreased soil resilience, leading to long-term degradation of soil quality and productivity [6].

Compaction Due to Heavy Machinery

Frequent use of heavy machinery for grazing management, feed harvesting, and manure spreading compacts soil, reducing its porosity. Compacted soil restricts root growth and water infiltration, impeding plant development [7]. This leads to reduced agricultural productivity, higher vulnerability to erosion, and poor water retention, which further exacerbates the degradation of soil health in intensive dairy systems.

Reduced Water Infiltration Capacity

Soil compaction, loss of organic matter, and poor management practices significantly reduce soil's ability to absorb water. This decreased infiltration capacity leads to surface runoff, erosion, and increased vulnerability to droughts [8]. Additionally, poor water retention contributes to inefficient irrigation practices, further depleting water resources and negatively impacting surrounding ecosystems in intensive dairy farming areas.

Increased Risk of Soil Erosion

Intensive grazing and improper manure management contribute to the degradation of soil structure, making it more susceptible to erosion. The loss of vegetation cover and soil compaction further exacerbate this process [9]. Erosion removes valuable topsoil, decreases soil fertility, and disrupts local ecosystems, leading to reduced agricultural yields and long-term ecological damage in areas dominated by intensive dairy farming [10, 11].

Salinization From Overirrigation

Overirrigation in intensive dairy systems leads to the accumulation of salts in the soil, a process known as salinization. Excess water leaches essential minerals from the soil, causing an increase in salt concentrations. Salinization reduces soil fertility, inhibits plant growth, and worsens the long-term viability of farmland, making it increasingly unproductive and unsustainable for agricultural use [12].

Acidification Due to Excessive Fertilizer Use

Overuse of nitrogen-based fertilizers in intensive dairy farming systems acidifies the soil, disrupting its natural pH balance [13]. Soil acidification hinders nutrient availability, particularly for crops and pasture, and damages soil microbial communities [14]. This not only reduces agricultural productivity but also worsens environmental pollution by leaching harmful substances into surrounding water systems, contributing to ecosystem degradation.

Heavy Metal Accumulation From Manure Application

The application of manure as fertilizer in intensive dairy farming can lead to the accumulation of heavy metals, such as copper and zinc, in the soil. Over time, these metals build up, threatening soil and water quality, and impacting plant and microbial health [15]. Accumulation of heavy metals can also enter the food chain, posing health risks to humans and animals.

Alteration of Soil Microbial Communities

Intensive dairy farming practices, including the use of synthetic chemicals, antibiotics, and monoculture cropping, alter the composition and diversity of soil microbial communities [16]. Healthy microbial communities are essential for nutrient cycling, disease suppression, and soil structure maintenance. Disrupting these communities reduces soil fertility, weakens plant resilience, and diminishes the long-term sustainability of the farming system.

Loss of Soil Biodiversity

Intensive dairy farming practices such as monocropping, overgrazing, and pesticide application reduce soil biodiversity [17]. The loss of a variety of species impairs soil ecosystem functions, including nutrient cycling, pest regulation, and soil structure maintenance [18]. This decline in biodiversity reduces the resilience of farming systems, making them more susceptible to diseases, pests, and environmental stressors, ultimately threatening long-term sustainability.

Deterioration of Soil Structure

The soil structure in intensive dairy farming systems often deteriorates due to practices like overgrazing and heavy machinery use [19]. Compaction, reduced pore space, and loss of organic matter weaken soil structure, limiting its ability to retain water and nutrients. This leads to poor plant growth, increased runoff, and heightened vulnerability to erosion, ultimately compromising the long-term productivity and sustainability of the land [19].

WATER RESOURCE DEPLETION

Overextraction of Groundwater for Irrigation

Intensive dairy farming often requires large amounts of water for irrigation to sustain pastures and feed crops. Overextraction of groundwater from aquifers to meet these demands can lead to the depletion of water reserves, especially in regions with limited rainfall or where surface water is insufficient [20]. This practice threatens long-term water availability for agricultural and ecological purposes, exacerbating water scarcity issues.

Contamination of Surface Water with Nutrients

Runoff from dairy farms, including manure, fertilizers, and feed additives, introduces excessive nutrients, particularly nitrogen and phosphorus, into nearby surface waters. These nutrient pollutants can degrade water quality, leading to the eutrophication of lakes, rivers, and streams [1]. This contamination disrupts aquatic ecosystems, harms biodiversity, and reduces the suitability of water sources for human consumption and irrigation.

Groundwater Nitrate Pollution

Manure and synthetic fertilizers used in intensive dairy farming systems are significant sources of nitrates, which leach into groundwater [21]. High nitrate concentrations in drinking water can pose serious health risks, particularly for infants, including methemoglobinemia (blue baby syndrome)

[22]. Groundwater pollution also threatens agricultural productivity by reducing water quality and necessitating expensive treatment technologies for safe water use.

Increased Water Demand for Cleaning Facilities

Intensive dairy operations require substantial amounts of water not only for animal hydration and irrigation but also for cleaning barns, milking facilities, and equipment [23]. The high-water demand for cleaning purposes places additional stress on local water resources, particularly in areas with limited freshwater availability, further intensifying competition for water between agricultural, industrial, and domestic uses.

Diminished Freshwater Availability for Ecosystems

The intensive water demands of dairy farming often result in the diversion of freshwater resources for irrigation and facility cleaning, reducing the availability of water for natural ecosystems [24]. The depletion of freshwater in rivers, lakes, and wetlands can have detrimental effects on aquatic species, plant growth, and overall ecosystem health, diminishing biodiversity and disrupting local ecological balance [25, 26].

Accumulation of Heavy Metals in Water Bodies

The improper disposal of manure and industrial waste from dairy farms can result in the accumulation of heavy metals such as cadmium, copper, and zinc in nearby water bodies [27]. These contaminants can degrade water quality, harm aquatic life, and pose serious risks to human health when they enter the food chain. Long-term exposure can result in bioaccumulation and toxicity in fish and other organisms.

Aquifer Depletion in High-Production Areas

In regions with intensive dairy farming, especially where water resources are already strained, the overuse of groundwater for irrigation and farming operations leads to aquifer depletion. As aquifers are exhausted, it becomes increasingly difficult to maintain water availability for both agricultural and ecological needs. Aquifer depletion also causes land subsidence and the intrusion of saline water into freshwater aquifers, further exacerbating water scarcity [28].

Increased Sedimentation in Water Bodies

Soil erosion, often caused by intensive dairy farming practices such as overgrazing and poor land management, increases sedimentation in nearby water bodies. Sediment can clog waterways, reduce water clarity, and interfere with the respiration of aquatic organisms [10]. This disruption harms aquatic ecosystems, reduces water storage capacity in reservoirs, and negatively affects water quality for both agricultural and domestic use.

Eutrophication of Rivers and Lakes

The excessive nutrient runoff from manure and fertilizers in intensive dairy farming systems often leads to eutrophication in rivers and lakes. This process causes the rapid growth of algae, which depletes oxygen levels in the water, creating hypoxic zones that are detrimental to fish and other aquatic organisms [29]. Eutrophication also reduces the aesthetic and recreational value of water bodies, impacting local economies.

Spread of Pathogens into Aquatic Systems

Improper manure management and inadequate sanitation in dairy farming operations can lead to the spread of pathogens, including bacteria, viruses, and parasites, into nearby aquatic ecosystems. These pathogens contaminate water sources, threatening public health, aquatic biodiversity, and water quality [30]. Pathogen contamination can also cause outbreaks of waterborne diseases, further burdening public health systems and local communities.

BIODIVERSITY LOSS

Habitat Destruction from Land Conversion

Intensive dairy farming often requires converting natural habitats, such as forests, wetlands, or grasslands, into agricultural land for grazing or feeding crops [31]. This land conversion leads to habitat destruction, which threatens species that rely on these ecosystems for survival. As habitats are lost, local biodiversity declines, and many species face extinction due to reduced living space and resources.

Monoculture Grazing Reducing Plant Diversity

The practice of monoculture grazing in intensive dairy systems involves using the same plant species over large areas. This limits plant diversity, as native vegetation is replaced by a few high-yielding species [32]. The reduction in plant variety not only depletes soil health but also decreases the variety of habitats and food sources available to wildlife, leading to a loss of ecosystem services.

Disruption of Pollinator Habitats

Intensive dairy farming, particularly when it involves large-scale monoculture crops and pesticide use, disrupts pollinator habitats [33]. The loss of native plants and flowers, which provide food and shelter for pollinators, like bees and butterflies, reduce pollinator populations [34]. Pollinators are crucial for crop pollination, and their decline affects both biodiversity and agricultural productivity, leading to long-term ecological consequences.

Decrease in Native Flora Due to Invasive Species

The introduction of non-native forage crops in intensive dairy farming systems can lead to the spread of invasive species. These invasive plants often outcompete native flora for resources, resulting in a loss of plant diversity [35]. This reduction in native plant species affects local wildlife that depend on them for food and habitat, disrupting the ecological balance of the area.

Reduced Wildlife Corridors

Intensive dairy farming often leads to the fragmentation of landscapes, reducing the availability of wildlife corridors. These corridors are essential for animal movement, allowing species to access food, water, and breeding grounds. The disruption of these corridors isolates animal populations, reducing genetic diversity, and increasing the risk of inbreeding and local extinctions in fragmented ecosystems.

Altered Migratory Patterns of Birds and Animals

Land conversion for dairy farming, combined with changes in habitat and climate, can alter the migratory patterns of birds and animals [36]. Migration routes that were once used for seasonal food and shelter may no longer be viable due to habitat destruction and the depletion of resources. This disruption can lead to decreased survival rates, affecting species that rely on migratory behavior for breeding and survival.

Loss of Aquatic Biodiversity from Water Pollution

Nutrient runoff, pesticide contamination, and sedimentation from intensive dairy farming practices lead to water pollution, which adversely affects aquatic biodiversity [37]. The accumulation of pollutants in rivers, lakes, and wetlands degrades water quality, disrupts aquatic ecosystems, and harms species dependent on these habitats. Fish, amphibians, and other aquatic organisms face a decline in population and diversity because of these pollutants.

Decline in Insect Populations from Pesticide Runoff

Pesticide use in intensive dairy farming not only targets pests but also harms beneficial insect populations, such as pollinators and natural pest predators. Runoff from treated fields introduces these chemicals into surrounding ecosystems, leading to a sharp decline in insect diversity [38]. The loss of insects disrupts food webs and reduces the availability of pollination and pest control services, further harming biodiversity.

Reduced Genetic Diversity in Forage Crops

Intensive dairy farming often relies on a limited number of forage crops, such as alfalfa or ryegrass, to feed livestock. This practice reduces genetic diversity within these crops, making them more susceptible to diseases, pests, and changing environmental conditions. Reduced genetic diversity in forage crops can also result in a lack of resilience in farming systems, affecting both crop yield and biodiversity in surrounding ecosystems.

Displacement of Native Species

Intensive dairy farming, through land conversion, monoculture grazing, and pesticide use, displaces native species from their natural habitats [39]. These displaced species, often unable to adapt to altered conditions or competing with introduced species, face population declines. The loss of native species reduces ecosystem functionality, leading to less resilient ecosystems and contributing to an overall loss of biodiversity.

GREENHOUSE GAS EMISSIONS

Increased Methane Emissions from Enteric Fermentation

Enteric fermentation in ruminants, particularly dairy cows, is a major source of methane, a potent greenhouse gas. Methane is produced during digestion as a byproduct of microbial fermentation in the rumen. The large-scale use of dairy cows in intensive farming significantly increases methane emissions, contributing to global warming and climate change, given the gas's higher heat-trapping potential compared to CO_2 [40, 41].

Nitrous Oxide Emissions from Manure Management

Manure management in intensive dairy farming systems, including storage, handling, and application, leads to significant nitrous oxide (N_2O) emissions [42, 43]. N_2O, another potent greenhouse gas, is released from manure as it decomposes or when applied to fields. The use of nitrogen-rich fertilizers and improper manure management practices further exacerbate these emissions, negatively impacting the environment and climate.

CO_2 Emissions from Energy-intensive Practices

Intensive dairy farming operations, from feeding to milking and manure management, often rely on energy-intensive practices. The use of electricity and fossil fuels for various farm activities results in carbon dioxide (CO_2) emissions [44, 45]. High energy consumption from processing, cooling milk, and running farm equipment contributes to the carbon footprint of dairy farming, further exacerbating the global climate crisis.

Emissions from Fertilizer Production and Use

The production and use of synthetic fertilizers in dairy farming systems contribute significantly to greenhouse gas emissions. Fertilizer production is energy-intensive, and the application of fertilizers releases nitrous oxide into the atmosphere [46]. Excessive fertilizer use also leads to nutrient runoff, polluting nearby water bodies, and worsening the environmental impact of intensive dairy farming systems.

Carbon Loss from Deforestation for Grazing

In regions where intensive dairy farming is expanding, forests are often cleared for grazing land or feed crop production [47]. Deforestation releases stored carbon in trees and soil into the atmosphere as CO_2, contributing to global warming [48]. This carbon loss reduces the planet's ability to sequester carbon, thereby exacerbating the effects of climate change and the environmental footprint of dairy farming.

Inefficient Feed Conversion Contributing to Emissions

Inefficient feed conversion in dairy cows' results in higher greenhouse gas emissions per unit of milk produced. Poor-quality feed or overfeeding leads to increased methane production during

digestion and higher carbon emissions from manure. Improving feed efficiency and optimizing nutrient intake can help reduce emissions, making dairy farming more sustainable and environmentally friendly in the long run [49].

Decomposition of Organic Waste Emitting GHGs

Organic waste from dairy operations, such as manure, bedding materials, and leftover feed, decomposes and releases greenhouse gases like methane and nitrous oxide [50]. Improper storage or handling of this waste increases emissions, particularly when it is left in anaerobic conditions. Effective waste management practices, such as composting or biogas capture, can mitigate these emissions and improve the sustainability of dairy farming [51].

Emissions from Transportation of Dairy Products

Transportation of milk and dairy products from farms to processing facilities and distribution points contribute to greenhouse gas emissions. The use of diesel-powered trucks and refrigerated vehicles, which are essential for transporting perishable goods, generates CO_2 emissions [52]. A reduction in transportation distances and the adoption of greener transportation technologies can help mitigate emissions associated with dairy product logistics.

Burning of Crop Residues for Feed Production

In some intensive dairy farming systems, crop residues, such as straw and corn stalks, are burned to clear fields or to provide feed. This practice releases carbon dioxide, particulate matter, and other harmful pollutants into the atmosphere [53]. Burning crop residues exacerbate air pollution, contributes to greenhouse gas emissions, and reduces soil fertility, making it an unsustainable practice for long-term farming systems [54].

Fossil Fuel Use for Farm Operations

Intensive dairy farms rely heavily on fossil fuels for various operations, including powering machinery, irrigation systems, and farm vehicles. The combustion of these fuels releases significant amounts of CO_2 into the atmosphere, contributing to climate change [55]. Reducing fossil fuel dependency through renewable energy sources, such as solar or wind, and adopting energy-efficient technologies can help lower the carbon footprint of dairy farming [56].

AIR QUALITY DETERIORATION

Ammonia Volatilization from Manure

Ammonia is released from manure in intensive dairy farming systems through volatilization, particularly during manure storage and application [57, 58]. Gaseous ammonia can contribute to air pollution, creating harmful effects on both human and environmental health. It can also acidify nearby soils and water bodies, leading to ecosystem imbalances and a decline in biodiversity [59].

Odor Pollution from Waste Lagoons

Waste lagoons used to store manure in intensive dairy farming systems are a major source of odor pollution [60]. The anaerobic decomposition of organic matter in these lagoons produces unpleasant odors, which can affect nearby communities and ecosystems. This air quality degradation is a significant concern for residents and wildlife living in proximity to dairy farms, impacting quality of life and local health.

Increased Particulate Matter from Feeding Areas

Feeding areas in dairy farms often generate dust and particulate matter due to the handling of feed, movement of animals, and the dry conditions of overgrazed land. The accumulation of particulate matter in the air can cause respiratory problems for workers, animals, and nearby populations [61]. This dust also carries bacteria and pathogens, further complicating air quality concerns in these environments.

Dust from Dry Soil in Overgrazed Lands

Overgrazed lands in intensive dairy farming systems contribute to soil degradation, leading to the creation of dry, dust-prone areas [62]. Wind erosion of these soils releases fine dust particles into the atmosphere, which negatively affects air quality. The increased dust levels can harm respiratory health, reduce visibility, and contribute to broader environmental issues, including poor plant growth and diminished soil fertility.

Release of Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are emitted during manure decomposition, feed storage, and the use of pesticides and fertilizers in intensive dairy farming. VOCs contribute to air pollution, forming ground-level ozone and smog, which have harmful effects on both human health and the environment [63, 64]. These compounds can cause respiratory issues and damage plant life in surrounding areas, exacerbating the overall impact on air quality.

Elevated N_2O Affecting Local Climates

Nitrous oxide (N_2O) emissions from manure management and fertilization processes in dairy farming contribute to air quality deterioration [65]. N_2O is a potent greenhouse gas with a higher heat-trapping potential than CO_2, and its release can exacerbate climate change [66]. The elevated levels of this gas in the atmosphere can also influence local climate patterns, creating regional air quality problems that affect both human and ecological health.

Spread of Aerosolized Pathogens

Intensive dairy farming systems can lead to the aerosolization of pathogens from manure and feed handling, which are then spread through the air. These pathogens can affect both humans and animals, increasing the risk of disease transmission and infection [67]. The presence of these pathogens in the air worsens air quality and poses a significant public health risk for nearby populations.

Increase in Regional Smog Formation

Air pollution from intensive dairy farms, including ammonia, VOCs, and particulate matter, can contribute to regional smog formation [68]. The reaction of these pollutants in the atmosphere creates ground-level ozone, which is a key component of smog. Smog can significantly degrade air quality, harm respiratory health, reduce visibility, and affect ecosystems through increased acid rain and reduced plant growth.

Sulfur Dioxide Emissions from Animal Feed Additives

Certain animal feed additives used in intensive dairy farming, such as those containing sulfur compounds, can lead to the emission of sulfur dioxide (SO_2). This gas contributes to air quality deterioration by combining with other atmospheric components to form acid rain [69]. Sulfur dioxide can also irritate respiratory systems and negatively impact plant and soil health in surrounding areas.

Poor Air Quality Impacting Neighboring Ecosystems

The deterioration of air quality from dairy farming activities, such as the release of ammonia, particulate matter, and VOCs, has direct consequences on neighboring ecosystems [70]. Pollutants can harm vegetation, reduce plant biodiversity, and disrupt wildlife habitats. Additionally, poor air quality can affect the health of aquatic systems, as airborne pollutants can settle in water bodies, leading to nutrient imbalances and toxic conditions for aquatic species.

HYDROLOGICAL CYCLE DISRUPTION

Altered Regional Rainfall Patterns Due to Emissions

Emissions from intensive dairy farming, including greenhouse gases and particulate matter, can alter regional weather patterns, including rainfall. The presence of pollutants in the atmosphere can affect cloud formation and precipitation patterns, leading to changes in the timing and intensity of rainfall [1]. These alterations can disrupt local water availability and agricultural productivity, exacerbating water scarcity issues.

Increased Risk of Flooding from Reduced Soil Absorption

Intensive dairy farming often leads to soil compaction and degradation, which reduces the soil's ability to absorb water. As a result, stormwater runoff increases, leading to a higher risk of flooding [9]. This can overwhelm local drainage systems, damage infrastructure, and increase the likelihood of soil erosion, further impacting the landscape and water quality in surrounding areas.

Lowered Water Table Levels from Overirrigation

Overirrigation for intensive dairy farming can lead to a gradual depletion of groundwater resources, lowering water table levels [71]. Excessive extraction of groundwater for irrigation and livestock water needs disrupts the natural hydrological cycle [72]. As water tables drop, access to water for other agricultural uses and ecosystems becomes more difficult, leading to water scarcity and ecosystem degradation.

Reduced Wetland Functionality Near Farms

Intensive dairy farming near wetland areas can reduce the functionality of these ecosystems. Excessive nutrient runoff from manure and fertilizers can lead to eutrophication, which diminishes wetland biodiversity [1, 73]. Additionally, altered hydrological cycles from over-irrigation or water extraction can reduce the water levels in wetlands, limiting their ability to provide important ecosystem services, such as water filtration and flood mitigation.

Altered Seasonal Stream Flows

Changes in land use and water extraction for dairy farming can significantly affect seasonal stream flows [74]. The removal of water for irrigation and livestock consumption, combined with altered rainfall patterns due to emissions, can lead to altered flow regimes in rivers and streams. These disruptions can affect the health of aquatic ecosystems and the availability of water for downstream communities.

Decrease in Groundwater Recharge Rates

The intensive use of water resources in dairy farming, particularly through over-irrigation, can reduce the ability of the land to recharge groundwater supplies [75]. Reduced infiltration rates and soil compaction hinder the natural replenishment of groundwater, which is essential for maintaining long-term water availability. This results in a depletion of aquifers, impacting water access for other agricultural sectors and local populations [76].

Increased Evapotranspiration from Altered Vegetation

Alterations in vegetation cover due to intensive dairy farming practices can increase evapotranspiration rates, leading to the loss of more water from the ecosystem [9]. The conversion of natural vegetation to monoculture pastures or feed crops increases water loss through both evaporation and transpiration [77]. This disruption of the hydrological cycle reduces water availability for surrounding ecosystems and increases local water stress.

Spread of Evapotranspiration from Altered Vegetation

Nutrient runoff from dairy farming, particularly nitrogen and phosphorus from manure and fertilizers, can lead to the proliferation of algal blooms in water bodies. These blooms block sunlight and deplete oxygen in water, disrupting aquatic ecosystems [78]. Additionally, algal blooms increase water evaporation, further impacting local water availability and intensifying the effects of droughts in affected regions [79].

Changes in Watershed Dynamics

Intensive dairy farming can alter the natural dynamics of watersheds by disrupting water flow patterns, reducing water retention, and affecting sediment transport. This can lead to changes in the availability and quality of water resources in the watershed. The alteration of these dynamics can impact agricultural practices, water quality, and the resilience of ecosystems within the watershed.

Disruption of Aquatic Ecosystem Services

Water pollution from dairy farming, such as nutrient runoff and pathogens, can disrupt important aquatic ecosystem services, including water filtration, flood control, and habitat provision [80]. Altered stream flows and wetland functionality further compromise these services. The disruption of these services diminishes the overall health of aquatic ecosystems, affecting biodiversity, water quality, and the ability of these systems to support human and ecological needs.

LAND USE CHANGES

Conversion of Natural Ecosystems to Pasture

Intensive dairy farming often leads to the conversion of natural ecosystems, such as forests, wetlands, or grasslands, into pastureland. This land use change reduces biodiversity and disrupts ecosystem functions, such as carbon sequestration and water regulation [81]. The loss of these ecosystems contributes to environmental degradation, climate change, and the depletion of vital natural resources necessary for ecological balance.

Encroachment into Forests for Feed Crop Production

To meet the growing feed demands of intensive dairy farms, forests are sometimes cleared for crop cultivation. This encroachment into forested areas leads to deforestation, loss of biodiversity, and the disruption of carbon sinks [82]. Forest ecosystems, which are crucial for maintaining regional climate stability and habitat provision, are increasingly threatened by the expansion of land used for dairy farming feed production.

Urban Sprawl Linked to Proximity to Intensive Farms

The growth of urban areas near intensive dairy farms is often driven by the expansion of farm operations and the need for agricultural labor. This urban sprawl leads to the loss of agricultural land, reduced green spaces, and increased pressure on local infrastructure [83]. The proximity of urban developments to intensive farms can also result in environmental concerns, such as air and water pollution and health risks to residents.

Fragmentation of Wildlife Habitats

Land use changes associated with intensive dairy farming, such as the conversion of large tracts of natural land into smaller, fragmented plots, leading to habitat fragmentation. This disruption isolates wildlife populations and hinders species migration, affecting biodiversity and ecosystem resilience. Fragmentation reduces the capacity of ecosystems to support wildlife, leading to population declines and altered ecological processes.

Unsustainable Expansion of Dairy Farm Boundaries

Intensive dairy farms often expand their boundaries to accommodate growing livestock populations and feed crop needs. This unsustainable expansion results in the degradation of surrounding land, including the loss of forests, wetlands, and other valuable ecosystems [82]. As farms encroach on previously undeveloped areas, the environmental cost of expansion, such as soil erosion and habitat loss, become increasingly unsustainable.

Overgrazing Reducing Land Recovery Rates

Overgrazing in intensive dairy systems leads to the depletion of vegetation cover and soil compaction, making it difficult for the land to recover naturally [84]. This hampers the regeneration of grasslands and increases the susceptibility of soils to erosion. Reduced recovery rates result in long-term degradation, reducing the land's ability to support healthy pasture, enhance biodiversity, or act as a carbon sink.

Loss of Riparian Zones for Grazing

Riparian zones, which are critical for maintaining water quality and supporting diverse ecosystems, are often lost to dairy farming, particularly as livestock are allowed to graze near water sources [85],

[86]. The loss of these buffer zones leads to increased water pollution from manure runoff, decreased water filtration, and the destruction of habitat for aquatic and terrestrial species. This degradation negatively impacts the entire watershed.

Shift in Regional Land Use Priorities

Intensive dairy farming often drives a shift in regional land use priorities, favoring agricultural expansion over conservation or natural habitat preservation [87]. This shift can lead to reduced attention to sustainable land management practices, conservation efforts, and ecosystem restoration. The increased focus on maximizing dairy farm production diminishes the long-term sustainability of land resources and alters the balance of local ecosystems.

Abandonment of Degraded Lands

In some cases, the expansion of intensive dairy farming leads to the abandonment of degraded lands that can no longer support productive agriculture. These lands often experience soil erosion, desertification, and loss of fertility, leaving them unproductive. Abandoning these lands exacerbates environmental degradation and reduces the land's potential for future restoration or sustainable agricultural use, contributing to the loss of arable land.

Permanent Loss of Arable Land

The expansion of dairy farming into ecologically sensitive or marginal lands can lead to the permanent loss of arable land. Poor land management practices, including overgrazing, soil erosion, and nutrient depletion, make it increasingly difficult for these lands to be restored for future agricultural use [6]. The permanent conversion of arable land into degraded or non-productive areas reduces the overall capacity for food production and ecosystem services.

ECOSYSTEM IMBALANCE

Disruption of Food Webs from Pesticide Use

The use of pesticides in intensive dairy farming disrupts local food webs by eliminating beneficial insects, such as pollinators and natural predators, while allowing pests to proliferate [88]. This imbalance alters the composition of species within ecosystems, reducing biodiversity and affecting the availability of food for higher trophic levels. The resulting disruption cascades through the food web, affecting ecosystem stability.

Overgrowth of Algae Due to Nutrient Runoff

Nutrient runoff from manure and fertilizers used in dairy farming leads to eutrophication, causing the overgrowth of algae in water bodies. These algal blooms deplete oxygen levels in aquatic systems, harming fish and other aquatic organisms [78]. The overgrowth also disrupts aquatic food webs, reducing biodiversity and altering ecosystem services like water purification and habitat provision for aquatic species.

Decline in Scavenger Populations from Antibiotic Residues

Antibiotic residues in manure from intensive dairy farming can lead to the decline of scavenger populations, such as vultures and other carrion feeders. These species depend on animal remains for food, but exposure to antibiotics can alter the microbial communities in their digestive systems, leading to reduced reproductive success and population declines [89]. This disrupts scavenger-based food webs and ecosystem functions.

Loss of Keystone Species

Keystone species, which play critical roles in maintaining ecosystem structure and function, can be lost due to the environmental pressures exerted by intensive dairy farming. Habitat destruction, pollution, and the introduction of invasive species all contribute to the decline of these key organisms [90]. The loss of keystone species can cause cascading effects, leading to ecosystem instability and a reduction in biodiversity.

Altered Predator-Prey Dynamics

Intensive dairy farming can alter predator-prey dynamics by changing habitat availability and food sources. For example, land clearing for pasture or crop production disrupts habitats for predators and prey alike, leading to population imbalances. The displacement or decline of either predator or prey species can lead to a breakdown of natural controls on pest populations and other ecosystem processes, altering the entire food web.

Shifts in Ecosystem Nutrient Cycles

Intensive dairy farming introduces large amounts of nutrients, such as nitrogen and phosphorus, into ecosystems. These nutrient inputs can alter the natural nutrient cycles, shifting the balance between different components of the ecosystem [91]. Excess nutrients can lead to nutrient overload, causing imbalances in plant growth, microbial activity, and overall ecosystem functioning, affecting the health and resilience of the ecosystem [92].

Overabundance of Pest Species

The disruption of natural predator-prey relationships and the use of chemical inputs in intensive dairy farming can lead to an overabundance of pest species [16]. Pesticides and herbicides target non-target organisms, allowing pest populations to increase unchecked. This imbalance can result in crop damage, the spread of disease, and further degradation of the ecosystem, as pest species outcompete other organisms for resources.

Collapse of Microbial Ecosystems in Waterways

Nutrient runoff, pollutants, and antibiotic residues from dairy farming can disrupt the delicate balance of microbial ecosystems in waterways [93], [94]. The decline of beneficial microbial populations, such as bacteria that break down organic matter, leads to a collapse of ecosystem services, including water purification and nutrient cycling. The resulting degradation of water quality can have long-term negative effects on aquatic ecosystems and their inhabitants.

Altered Ecosystem Productivity

The intensive agricultural practices of dairy farming can alter the productivity of surrounding ecosystems. Changes in land use, nutrient inputs, and water availability can affect primary productivity, such as plant growth, and disrupt food sources for herbivores and higher trophic levels [95]. This reduction in ecosystem productivity can lead to reduced biodiversity and overall ecosystem function, affecting both natural and agricultural systems.

Imbalance in Carbon and Nitrogen Cycles

Intensive dairy farming disrupts the natural carbon and nitrogen cycles by introducing large amounts of manure and synthetic fertilizers. The excessive release of nitrogen into the environment, through manure and fertilizer runoff, leads to soil and water contamination [96, 97]. This imbalance can cause soil acidification, reduced soil fertility, and the release of greenhouse gases, such as nitrous oxide, contributing to climate change and further ecosystem degradation.

PUBLIC HEALTH RISKS

Increased Antimicrobial Resistance from Overuse in Cattle

The overuse of antibiotics in dairy cattle contributes to the development of antimicrobial resistance (AMR). Resistant bacteria can spread through animal manure, entering the environment and the food chain [98, 99]. This creates significant public health risks, as infections that were previously treatable with antibiotics become harder to manage, complicating treatment options for both humans and animals.

Spread of Zoonotic Diseases from Polluted Water

Polluted water sources on dairy farms can serve as reservoirs for zoonotic diseases, which are infectious diseases that can be transmitted from animals to humans. Contaminated water, often laden

with pathogens, like *E. coli* or *Salmonella*, increases the risk of outbreaks [100, 101]. These diseases can spread through direct contact with water or consumption of contaminated produce, creating a public health threat.

Airborne Pathogens Affecting Communities

Intensive dairy farming, with its high concentrations of animals and waste, generates airborne pathogens, such as bacteria and viruses, which can affect nearby communities. These pathogens can be inhaled by humans, leading to respiratory infections and other health issues [67]. Communities living near such farms may be more vulnerable to outbreaks of diseases, such as pneumonia or other zoonotic infections.

Bioaccumulation of Toxins in Food Chains

The use of pesticides, heavy metals, and other chemicals in dairy farming can lead to bioaccumulation, where toxins accumulate at higher trophic levels within food chains. These toxins, when consumed by humans, can lead to serious health risks, such as cancer, neurological disorders, and reproductive issues [102]. The persistence of these chemicals in the environment exacerbates these health concerns.

Increased Nitrate Levels in Drinking Water

Nitrate contamination in drinking water is a significant concern in areas with intensive dairy farming. Nitrates, often leached from manure and fertilizers, can contaminate groundwater sources [103]. Elevated nitrate levels in drinking water are linked to serious health issues, such as methemoglobinemia (blue baby syndrome) in infants, and increased risks of thyroid cancer and other chronic health conditions in adults [104].

Malodor Affecting Mental Well-Being of Nearby Residents

The strong odors emanating from intensive dairy farms, including ammonia and hydrogen sulfide, can have significant effects on the mental and physical well-being of nearby residents [105]. Prolonged exposure to these smells has been linked to stress, anxiety, and depression. Additionally, the unpleasant odors can reduce the quality of life and lead to social conflicts between farming communities and residents.

Elevated Heat Islands from Land-Use Intensification

Intensive dairy farming and associated land-use changes, such as deforestation and urban sprawl, contribute to the formation of urban heat islands [95]. These heat islands result in higher temperatures in farm regions, which can worsen the effects of climate change, reduce air quality, and increase the frequency of heat-related illnesses in both humans and livestock.

Increased Allergen Exposure from Dust

Dust generated from intensive dairy operations, including feed, bedding, and manure, can contribute to increased allergen exposure in surrounding areas [106]. Dust particles may carry allergens, bacteria, and other harmful substances into the air, leading to respiratory issues, asthma, and other allergic reactions in people living near dairy farms, particularly in communities with sensitive populations [107].

Soil and Waterborne Pathogen Risks to Agriculture

Manure and wastewater from dairy farms can introduce soil and waterborne pathogens into surrounding agricultural areas. These pathogens can contaminate crops, irrigate water, and soil, leading to public health risks, such as foodborne illnesses [108]. The presence of pathogens in agricultural environments poses a significant challenge to food safety and the health of farm workers and consumers.

Spread of Endocrine-disrupting Chemicals

The use of hormones and endocrine-disrupting chemicals in dairy farming, particularly those related to growth promotion and reproductive management, raises concerns about human exposure [109]. These chemicals can enter the food chain through dairy products and water, leading to potential health risks, such as reproductive abnormalities, developmental issues, and increased susceptibility to certain cancers in humans.

ECONOMIC AND SOCIAL IMPACTS

Marginalization of Small-Scale Farmers

Intensive dairy farming practices often favor large-scale operations, which can marginalize small-scale farmers who struggle to compete due to limited resources and access to markets [110]. This marginalization leads to economic inequalities and can contribute to the consolidation of land and agricultural production in fewer hands, exacerbating social and economic disparities in rural communities.

Over-Reliance on Synthetic Inputs for Sustainability

The over-reliance on synthetic fertilizers, pesticides, and antibiotics in intensive dairy farming undermines long-term sustainability [111]. While these inputs may boost short-term productivity, their excessive use leads to environmental degradation and rising costs, making it harder for farms to maintain profitability in the long run. This reliance also reduces the farm's resilience to environmental challenges and market fluctuations.

Reduced Viability of Traditional Grazing Systems

The shift toward intensive dairy farming has led to the decline of traditional grazing systems, which are often more environmentally sustainable and less dependent on synthetic inputs [112]. The reduced viability of these systems undermines local agricultural heritage, disrupts pastoral economies, and diminishes the benefits associated with natural grassland ecosystems, such as biodiversity and soil health.

High Costs of Ecological Restoration

Ecological restoration of lands degraded by intensive dairy farming is a costly and time-consuming process. The damage caused by overgrazing, soil compaction, and water pollution often requires significant investments in soil rehabilitation, reforestation, and water quality management [113]. These restoration efforts are financially burdensome for both farmers and governments, especially when resources are limited.

Loss of Ecotourism Opportunities Near Degraded Areas

Ecotourism is often a key economic activity in rural areas, but intensive dairy farming can lead to the degradation of landscapes and natural habitats that attract tourists. Pollution, habitat destruction, and loss of biodiversity can reduce the appeal of these areas, leading to a decline in ecotourism revenue [114]. This loss negatively impacts local communities that depend on sustainable tourism for income generation.

Socioeconomic Disparities Linked to Farm Intensification

Farm intensification tends to widen socioeconomic disparities by favoring wealthier operators who can afford to invest in high-output, resource-intensive practices. This results in a concentration of wealth and land, while smaller, less capitalized farmers face increasing challenges. The unequal distribution of resources deepens the divide between rural communities and urban centers, further exacerbating poverty and inequality in agricultural regions.

Reduction in Agricultural Resilience to Climate Shocks

The focus on intensive dairy farming often reduces the resilience of agricultural systems to climate shocks, such as droughts or extreme weather events [115]. The high-input, high-output model does not

prioritize long-term soil health or water conservation, making farms more vulnerable to the unpredictable effects of climate change. This reduces the ability of farming communities to adapt to changing environmental conditions.

Conflicts Over Shared Water Resources

Intensive dairy farming requires significant water resources for irrigation, livestock, and cleaning, putting pressure on local water supplies. This can lead to conflicts over shared water resources, particularly in areas where water is already scarce [116, 117]. Disputes between farmers, communities, and other stakeholders can arise over water access and distribution, further complicating the social and economic dynamics of rural areas.

Decline in Cultural Landscape Values

Intensive dairy farming can lead to the decline of cultural landscapes that have been shaped by traditional agricultural practices. The conversion of natural landscapes into monoculture pastures or industrial-scale dairy operations can erode the cultural identity and heritage of rural communities [118]. This loss diminishes the aesthetic, historical, and social value of these landscapes for local populations.

Long-term Loss of Natural Capital Impacting Livelihoods

The degradation of natural capital, such as soil fertility, water quality, and biodiversity, due to intensive dairy farming has long-term implications for rural livelihoods [119]. The depletion of these resources affects agricultural productivity, local economies, and food security, ultimately threatening the sustainability of rural communities. The inability to regenerate natural capital limits future economic opportunities and undermines resilience to environmental challenges.

CONCLUSIONS

Intensively managed dairy farms, while essential for global dairy production, pose significant long-term ecological risks. These systems contribute to soil degradation, water pollution, biodiversity loss, and greenhouse gas emissions, which threaten environmental sustainability. Addressing these challenges requires a paradigm shift toward more sustainable practices that minimize ecological footprints while maintaining productivity. This study highlights the need for a holistic approach that integrates ecological health with farming practices, focusing on resource efficiency, waste management, and ecosystem preservation. By adopting more sustainable dairy farming methods, it is possible to mitigate the negative impacts on the environment, ensuring the future viability of dairy production systems while promoting environmental stewardship and resilience.

Future Directions

Future research in intensive dairy farming should focus on developing and implementing sustainable practices that minimize environmental degradation while maintaining productivity. One key direction is the exploration of alternative feed sources and technologies that reduce methane emissions and improve feed efficiency. Advancements in precision farming, including the use of sensors and data analytics, could optimize resource use, such as water and fertilizers, reducing waste and pollution. Additionally, investigating the role of agroecological practices, such as integrated pest management and agroforestry, in enhancing soil health and biodiversity within dairy systems is crucial. Long-term studies are needed to assess the effectiveness of regenerative farming techniques, such as rotational grazing and organic manure application, in restoring ecosystems. Furthermore, policies promoting sustainable dairy farming should be developed, incorporating environmental, economic, and social dimensions. Collaborative efforts across research institutions, policymakers, and dairy farmers will be essential to drive meaningful change.

REFERENCES

1. Sakadevan K, Nguyen ML. Livestock production and its impact on nutrient pollution and greenhouse gas emissions. Adv Agron. 2017;141:147–184. doi: 10.1016/bs.agron.2016.10.002.

2. Hooda PS, Edwards AC, Anderson HA, Miller A. A review of water quality concerns in livestock farming areas. Sci Total Environ. 2000;250(1–3):143–167. doi: 10.1016/S0048-9697(00)00373-9.
3. Grandin T. Grazing cattle, sheep, and goats are important parts of a sustainable agricultural future. Animals. 2022;12(16):2092. doi: 10.3390/ani12162092.
4. Borhan MS, Mukhtar S, Capareda S, Rahman S, Rebellon LFM. Greenhouse gas emissions from housing and manure management systems at confined livestock operations. Waste Manag Integr Vision. Rijeka In: Tech. 2012. pp. 259–296.
5. Hafla AN, MacAdam JW, Soder KJ. Sustainability of US organic beef and dairy production systems: Soil, plant and cattle interactions. Sustain. 2013;5(7):3009–3034. doi: 10.3390/su5073009.
6. Lal R. Restoring soil quality to mitigate soil degradation. Sustain. 2015;7(5):5875–5895. doi: 10.3390/su7055875.
7. Gürsoy S. Soil compaction due to increased machinery intensity in agricultural production: Its main causes, effects and management. Technol Agric. 2021:1–18. doi: 10.5772/intechopen.98564.
8. Pan R, Martinez A, Brito T, Seidel E. Processes of soil infiltration and water retention and strategies to increase their capacity. J Exp Agric Int. 2018;20(2):1–14. doi: 10.9734/jeai/2018/39132.
9. Bilotta GS, Brazier RE, Haygarth PM. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. Adv. Agron. 2007;94:237–280.
10. Rashmi I, Karthika KS, Roy T, Sinoji KC, Kumawat A, Kala S, et al. Soil erosion and sediments: A source of contamination and impact on agriculture productivity. In: Agrochemicals in Soil and Environment: Impacts and Remediation. Springer; 2022. pp. 313–345. doi: 10.1007/978-981-16-9310-6_14.
11. Pimentel D. Soil erosion and the threat to food security and the environment. Ecosyst Heal. 2000;6(4):221–226.
12. Mohanavelu A, Naganna SR, Al-Ansari N. Irrigation induced salinity and sodicity hazards on soil and groundwater: An overview of its causes, impacts and mitigation strategies. Agric. 2021;11(10):983. doi: 10.3390/agriculture11100983.
13. Singh A. Are nitrogen fertilizers deleterious to soil health? Agronomy. 2018;8(4):48. doi: 10.3390/agronomy8040048.
14. Yadav AS, Jaiswal B, Gautam M, Agrawal M. Soil acidification and its impact on plants. In: Plant Responses to Soil Pollution. 2020:1–26. doi: 10.1007/978-981-15-4964-9_1.
15. Hill A, Morra MJ, Stalder T, Jechalke S, Top E, Pollard AT, et al. Dairy manure as a potential source of crop nutrients and environmental contaminants. J Environ Sci. (China), 2021;100:117–130. doi: 10.1016/j.jes.2020.07.016.
16. Groot MJ, van't Hooft KE. The hidden effects of dairy farming on public and environmental health in the Netherlands, India, Ethiopia, and Uganda, considering the use of antibiotics and other agro-chemicals. Front Public Heal. 2016;4:12. doi: 10.3389/fpubh.2016.00012.
17. Shankar T, Praharaj S, Sahoo U, Maitra S. Intensive farming: It's effect on the environment. Int Bimon. 2021;12:37480–37487.
18. Brussaard L, BehanPelletier VM, Bignell DE, Brown VK, Didden WAM, Folgarait P, et al. Biodiversity and ecosystem functioning in soil. Ambio. 1997;26(8):563–570.
19. Shaheb MR, Venkatesh R, Shearer SA. A review on the effect of soil compaction and its management for sustainable crop production. J. Biosyst Eng. 2021;46(4):417–439. doi: 10.1007/s42853-021-00117-7.
20. Khorrami M, Malekmohammadi B. Effects of excessive water extraction on groundwater ecosystem services: Vulnerability assessments using biophysical approaches. Sci Total Environ. 2021;799:149304. doi: 10.1016/j.scitotenv.2021.149304.
21. Verloop J, Boumans LJM, van Keulen H, Oenema J, Hilhorst GJ, Harts HFM, et al. Reducing nitrate leaching to groundwater in an intensive dairy farming system. Nutr Cycl Agroecosystems. 2006;74(1):59–74. doi: 10.1007/s10705-005-6241-9.
22. Knobeloch L, Salna B, Hogan A, Postle J, Anderson H. Blue babies and nitrate-contaminated well water. Environ Health Perspect. 2000;108(7):675–678. doi: 10.1289/ehp.00108675.

23. Shine P, Murphy MD, Upton J. A global review of monitoring, modeling, and analyses of water demand in dairy farming. Sustain. 2020;12(17):7201. doi: 10.3390/su12177201.
24. Le Riche EL, VanderZaag AC, Burtt S, Lapen DR, Gordon R. Water use and conservation on a free-stall dairy farm. Water (Switzerland). 2017;9(12):977. doi: 10.3390/w9120977.
25. Darwall W, Bremerich V, De Wever A, Dell AI, Freyhof J, Gessner MO, et al. The alliance for freshwater life: A global call to unite efforts for freshwater biodiversity science and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems. 2018;28(4):1015–1022.
26. Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, et al. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol Rev Camb Philos Soc. 2019;94(3):849–873. doi: 10.1111/brv.12480.
27. Chen K, Li J, Lin L, Qin W, Gao Y, Hu E, et al. Occurrence, fate and control strategies of heavy metals and antibiotics in livestock manure compost land application: A review. Sci Total Environ. 2024:957:177381. doi: 10.1016/j.scitotenv.2024.177381.
28. Foster SS, Chilton PJ. Groundwater: the processes and global significance of aquifer degradation. Philosophical Transactions of the Royal Society of London. Philos Trans R Soc Lond B Biol Sci. 2003;358(1440):1957–1972. doi: 10.1098/rstb.2003.1380.
29. Biagini D, Lazzaroni C. Eutrophication risk arising from intensive dairy cattle rearing systems and assessment of the potential effect of mitigation strategies. Agric Ecosyst Environ. 2018;266:76–83. doi: 10.1016/j.agee.2018.07.026.
30. Bicudo JR, Goyal SM. Pathogens and manure management systems: A review. Environ Technol. 2003;24(1):115–130. doi: 10.1080/09593330309385542.
31. Delaby L, Finn JA, Grange G, Horan B. Pasture-based dairy systems in temperate lowlands: challenges and opportunities for the future. Front Sustain Food Syst. 2020;4:543587. doi: 10.3389/fsufs.2020.543587.
32. Soder KJ, Rook AJ, Sanderson MA, Goslee SC. Interaction of plant species diversity on grazing behavior and performance of livestock grazing temperate region pastures. Crop Sci. 2007;47(1):416–425. doi: 10.2135/cropsci2006.01.0061.
33. Kremen C, Iles A, Bacon C. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecol Soc. 2012;17(4). doi: 10.5751/ES-05103-170444.
34. Nicholls CI, Altieri MA. Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. Agron Sustain Dev. 2013;33:257–274. doi: 10.1007/s13593-012-0092-y.
35. French NP. Impacts of non-native species on livestock. In: Impact of Biological Invasions on Ecosystem Services. 2017:139–154. doi: 10.1007/978-3-319-45121-3_9.
36. Rojas-Downing MM, Nejadhashemi AP, Harrigan T, Woznicki SA. Climate change and livestock: Impacts, adaptation, and mitigation. Clim Risk Manag. 2017;16:145–163. doi: 10.1016/j.crm.2017.02.001.
37. Cooper CM. Biological effects of agriculturally derived surface water pollutants on aquatic systems —A review. J Environ Qual. 1993;22(3):402–408. doi: 10.2134/jeq1993.00472425002200030003x.
38. Quandahor P, Kim L, Kim M, Lee K, Kusi F, Jeong IH. Effects of agricultural pesticides on decline in insect species and individual numbers. Environ. 2024;11(8):182. doi: 10.3390/environments11080182.
39. Cumby TR, Phillips VR. Environmental impacts of livestock production. BSAP Occas Publ. 2001;28:13–22. doi: 10.1017/s1463981500040930
40. Prasad RJ, Sourie SJ, Cherukuri VR, Fita L, Merera CE. Global warming: Genesis, facts and impacts on livestock farming and mitigation strategies. Int J Agric Innov Res. 2015;3:1473–2319.
41. Džermeikaitė K, Krištolaitytė J, Antanaitis R. Relationship between dairy cow health and intensity of greenhouse gas emissions. Animals. 2024;14(6):829.
42. Petersen SO. Greenhouse gas emissions from liquid dairy manure: Prediction and mitigation. J Dairy Sci. 2018;101(7):6642–6654. doi: 10.3168/jds.2017-13301.

43. Owen JJ, Silver WL. Greenhouse gas emissions from dairy manure management in a Mediterranean environment. Ecol Appl. 2017;27(2):545–559. doi: 10.1002/eap.1465.
44. Todde G, Murgia L, Caria M, Pazzona A. A comprehensive energy analysis and related carbon footprint of dairy farms, Part 2: Investigation and modeling of indirect energy requirements. Energies. 2018;11(2):451. doi: 10.3390/en11020463.
45. Rotz CA, Montes F, Chianese DS. The carbon footprint of dairy production systems through partial life cycle assessment. J. Dairy Sci. 2010;93(3):1266–1282. doi: 10.3168/jds.2009-2162.
46. Menegat S, Ledo A, Tirado R. Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. Sci. Rep. 2022;12(1):1–13.
47. Brandt P, Hamunyela E, Herold M, de Bruin S, Verbesselt J, Rufino MC. Sustainable intensification of dairy production can reduce forest disturbance in Kenyan montane forests. Agric Ecosyst Environ. 2018;265:307–319. doi: 10.1016/j.agee.2018.06.011.
48. Cramer W, Bondeau A, Schaphoff S, Lucht W, Smith B, Sitch S. Tropical forests and the global carbon cycle: Impacts of atmospheric carbon dioxide, climate change and rate of deforestation. Philos Trans R Soc B Biol Sci. 2004;359(1443):331–343. doi: 10.1098/rstb.2003.1428.
49. Drackley JK, Reynolds CK. The impact of improving feed efficiency on the environmental impact of livestock production. In: Reducing Greenhouse Gas Emissions from Livestock Production. Burleigh Dodds Science Publishing; 2021. pp. 187–208. doi: 10.19103/as.2020.0077.10.
50. Parihar SS, Saini KPS, Lakhani GP, Jain A, Roy B, Ghosh S, et al. "Livestock waste management: A review. J Entomol Zool Stud. 2019;7(3):384–393.
51. Jayasundara S, Appuhamy JADRN, Kebreab E, Wagner-Riddle C. Methane and nitrous oxide emissions from Canadian dairy farms and mitigation options: An updated review. Can J Anim Sci. 2016;96(3):306–331. doi: 10.1139/cjas-2015-0111.
52. Ulrich R, Thoma G, Nutter D, Wilson J. Tailpipe greenhouse gas emissions from tank trucks transporting raw milk from farms to processing plants. Int Dairy J. 2013;31(1):S50–S56. doi: 10.1016/j.idairyj.2012.09.009.
53. Nutter DW, Kim DS, Ulrich R, Thoma G. Greenhouse gas emission analysis for USA fluid milk processing plants: Processing, packaging, and distribution. Int Dairy J. 2013;31:S57–S64.
54. Bhuvaneshwari S, Hettiarachchi H, Meegoda JN. Crop residue burning in India: Policy challenges and potential solutions. Int J Environ Res Public Health. 2019;16(5). doi: 10.3390/ijerph16050832.
55. Ilyas HMA, Safa M, Bailey A, Rauf S, Pangborn M. The carbon footprint of energy consumption in pastoral and barn dairy farming systems: A case study from Canterbury, New Zealand. Sustain. 2019;11(17). doi: 10.3390/su11174809.
56. Chel A, Kaushik G. Renewable energy for sustainable agriculture. Agron Sustain Dev. 2011;31(1):91–118. doi: 10.1051/agro/2010029.
57. Meisinger JJ, Jokela WE. Ammonia volatilization from dairy and poultry manure. Manag Nutr Pathog Anim Agric NRAES-130 Nat Resour Agric Eng Serv. Ithaca. 2000:334–354.
58. Holly MA, Larson RA, Powell JM, Ruark MD, Aguirre-Villegas H. Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application. Agric Ecosyst Environ. 2017;239:410–419.
59. Guthrie S, Dunkerley F, Tabaqchali H, Harshfield A, Ioppolo B, Manville C. Impact of ammonia emissions from agriculture on biodiversity: An evidence synthesis. Impact Ammon Emiss Agric Biodivers An Evid Synth. 2018. doi: 10.7249/rr2695.
60. Zhang XL, Yan S, Tyagi RD, Surampalli RY. Odor control in lagoons. J Environ Manag. 2013;124:62–71.
61. Grout L, Baker MG, French N, Hales S. A review of potential public health impacts associated with the global dairy sector. GeoHealth. 2020;4(2):2019GH000213. doi: 10.1029/2019GH000213.
62. Ibáñez J, Martínez J, Schnabel S. Desertification due to overgrazing in a dynamic commercial livestock-grass-soil system. Ecol Modell. 2007;205(3–4):277–288. doi: 10.1016/j.ecolmodel.2007.02.024.

63. Shaw SL, Mitloehner FM, Jackson W, Depeters EJ, Fadel JG, Robinson PH, et al. Volatile organic compound emissions from dairy cows and their waste as measured by proton-transfer-reaction mass spectrometry. Environ Sci Technol. 2007;41(4):1310–1316. doi: 10.1021/es061475e.
64. Yuan B, Coggon MM, Koss AR, Warneke C, Eilerman S, Peischl J, et al. Emissions of volatile organic compounds (VOCs) from concentrated animal feeding operations (CAFOs): Chemical compositions and separation of sources. Atmos Chem Phys. 2017;17(8):4945–4956. doi: 10.5194/acp-17-4945-2017.
65. Rivera JE, Chará J. CH4 and N2O emissions from cattle excreta: A review of main drivers and mitigation strategies in grazing systems. Front Sustain Food Syst. 2021;5:657936. doi: 10.3389/fsufs.2021.657936.
66. Ussiri D, Lal R. The role of nitrous oxide on climate change. In: Soil Emission of Nitrous Oxide and its Mitigation. 2013. pp. 1–28. doi: 10.1007/978-94-007-5364-8_1.
67. Zhao Y, Aarnink AJA, De Jong MCM, Koerkamp PWGG. Airborne microorganisms from livestock production systems and their relation to dust. Crit Rev Environ Sci Technol. 2014;44(10):1071–1128. doi: 10.1080/10643389.2012.746064.
68. Place SE, Mitloehner FM. Invited review: Contemporary environmental issues: A review of the dairy industry's role in climate change and air quality and the potential of mitigation through improved production efficiency. J. Dairy Sci. 2010;93(8):3407–3416.
69. Gaffney JS, Streit GE, Hall JH, Spall WD. Beyond acid rain do Soluble oxidants and organic toxins interact with SO2 and NOX to increase ecosystm effects?. Environ Sci Technol. 1987;21(6):519–524. doi: 10.1021/es00160a001.
70. Cambra-López M, Aarnink AJA, Zhao Y, Calvet S, Torres AG. Airborne particulate matter from livestock production systems: A review of an air pollution problem. Environ Pollut. 2010;158(1):1–17. doi: 10.1016/j.envpol.2009.07.011.
71. Stigter TY, Miller J, Chen J, Re V. Groundwater and climate change: threats and opportunities. Hydrogeology Journal. 2023;31(1):7–10.
72. Sharma R, Kumar R, Agrawal PR, Ittishree, Chankit, Gupta G. Groundwater extractions and climate change. In: Water Conservation in the Era of Global Climate Change. Elsevier; 2021. pp. 23–45. doi: 10.1016/B978-0-12-820200-5.00016-6.
73. Yousaf A, Khalid N, Aqeel M, Noman A, Naeem N, Sarfraz U, et al. Nitrogen dynamics in wetland systems and its impact on biodiversity. Nitrogen. 2021;2(2):196–217. doi: 10.3390/nitrogen2020013.
74. Wilcock RJ, Monaghan RM, Quinn JM, Campbell AM, Thorrold BS, Duncan MJ, et al. Land-use impacts and water quality targets in the intensive dairying catchment of the Toenepi Stream, New Zealand. New Zeal J Mar Freshw Res. 2006;40(1):123–140. doi: 10.1080/00288330.2006.9517407.
75. Aarts HFM, Van Keulen H. Groundwater recharge through optimized intensive dairy farms. IAHS-AISH Publ. 2002;29(273):35–40. doi: 10.2134/jeq2000.00472425002900030008x.
76. Scanlon BR, Fakhreddine S, Rateb A, de Graaf I, Famiglietti J, Gleeson T, et al. Global water resources and the role of groundwater in a resilient water future. Nat Rev Earth Environ. 2023;4(2):87–101. doi: 10.1038/s43017-022-00378-6.
77. Cannell MGR. Environmental impacts of forest monocultures: Water use, acidification, wildlife conservation, and carbon storage. New For. 1999;17(1–3):239–262. doi: 10.1023/a:1006551018221.
78. Haq Z, Irshad S, Khan AA, Ahmad SM, Muzamil S. Advances in managing nitrogen and phosphorus emissions in ruminants: A holistic approach. In: Latest Scientific Findings in Ruminant Nutrition-Research for Practical Implementation. Intech Open; 2024.
79. Wiley DY, McPherson RA. The role of climate change in the proliferation of freshwater harmful algal blooms in inland water bodies of the United States. Earth Interact. 2024;28(1):e230008. doi: 10.1175/EI-D-23-0008.1.
80. Scarsbrook MR, Melland AR. Dairying and water-quality issues in Australia and New Zealand. Anim Prod Sci. 2015;55(7):856–868. doi: 10.1071/AN14878.

81. Gerssen-Gondelach SJ, Lauwerijssen RBG, Havlík P, Herrero M, Valin H, Faaij APC, et al. Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change. Agric Ecosyst Environ. 2017;240:135–147. doi: 10.1016/j.agee.2017.02.012.
82. Kraham SJ. Environmental impacts of industrial livestock production. In: International Farm Animal, Wildlife and Food Safety Law. 2017:3–40.
83. Ganguly K, Shabnam S, Das S, Mitran T. Assessment of urban sprawl impact on agricultural land use using geospatial techniques. Geospatial Technol Crop Soils. 2021:489–521.
84. Bolo P, Sommer R, Kihara J, Kinyua M, Nyawira S, Notenbaert A. Rangeland Degradation: Causes, Consequences, Monitoring Techniques and Remedies. CGIAR Work Pap. 2019;23.
85. Aarons SR, Gourley CJP. The role of riparian buffer management in reducing off-site impacts from grazed dairy systems. Renew Agric Food Syst. 2013;28(1):1–16.
86. Mosley JC, Cook PS, Griffis AJ, O'Laughlin J. Guidelines for managing cattle grazing in riparian areas to protect water quality: Review of research and best management practices policy. Idaho Forest, Wildlife and Range Policy Analysis Group, Idaho; 1997.
87. López-Carr D. A review of small farmer land use and deforestation in tropical forest frontiers: Implications for conservation and sustainable livelihoods. Land. 2021;10(11):1113. doi: 10.3390/land10111113.
88. Samanta S, Maji A, Sutradhar B, Banerjee S, Shelar VB, Khaire PB, et al. "Impact of pesticides on beneficial insects in various agroecosystem: A review. Int J Environ Clim Chang. 2023;13(8):1928–1936. doi: 10.9734/ijecc/2023/v13i82149.
89. Marutescu LG, Jaga M, Postolache C, Barbuceanu F, Milita FM, Romascu LM, et al. Insights into the impact of manure on the environmental antibiotic residues and resistance pool. Front Microbiol. 2022:13:965132. doi: 10.3389/fmicb.2022.965132.
90. Reid RS, Bedelian C, Said MY, Kruska RL, Mauricio R, Castel V, et al. Global livestock impacts on biodiversity. In: Steinfeld, H. Mooney, HA, Schneider, F. Neville, LE, editors. Livest. A Chang. Landscape. Drivers, Consequences, Responses. 2010. pp. 111–138.
91. Bouwman L, Goldewijk KK, Van Der Hoek KW, Beusen AHW, Van Vuuren DP, Willems J, et al. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900-2050 period. Proc Natl Acad Sci U S A. 2013;110(52):20882–20887. doi: 10.1073/pnas.1012878108.
92. Tiwari AK, Pal DB. Nutrients contamination and eutrophication in the river ecosystem. In: Ecological Significance of River Ecosystems: Challenges and Management Strategies. Elsevier; 2022. pp. 203–216. doi: 10.1016/B978-0-323-85045-2.00001-7.
93. Khmaissa M, Zouari-Mechichi H, Sciara G, Record E, Mechichi T. Pollution from livestock farming antibiotics an emerging environmental and human health concern: A Review." J Hazard Mater Adv. 2024:100410.
94. Tian M, He X, Feng Y, Wang W, Chen H, Gong M, et al. Pollution by antibiotics and antimicrobial resistance in live stock and poultry manure in china, and countermeasures. Antibiotics (Basel). 2021;10(5):539. doi: 10.3390/antibiotics10050539.
95. Thornton PK, Herrero M. The inter-linkages between rapid growth in livestock production, climate change, and the impacts on water resources, land use, and deforestation. World Dev. 2010;(January):84.
96. Bashir MT, Ali S, Ghauri M, Adris A, Harun R. Impact of excessive nitrogen fertilizers on the environment and associated mitigation strategies. Asian J Microbiol Biotechnol Environ Sci. 2013;15(2):213–221.
97. Jarvis SC. Nitrogen cycling and losses from dairy farms. Soil Use Manag. 1993;9(3):99–104.
98. Sharma C, Rokana N, Chandra M, Singh BP, Gulhane RD, Gill JP, et al. Antimicrobial resistance: its surveillance, impact, and alternative management strategies in dairy animals. Front Vet Sci. 2018;4:237.
99. Zalewska M, Błażejewska A, Czapko A, Popowska M. Antibiotics and antibiotic resistance genes in animal manure–consequences of its application in agriculture. Front Microbiol. 2021;12:610656.

100. Rahman MT, Sobur MA, Islam MS, Ievy S, Hossain MJ, El Zowalaty ME, et al. Zoonotic diseases: Etiology, impact, and control. Microorganisms. 2020;8(9):1405. doi: 10.3390/microorganisms8091405.
101. Al Noman Z, Tasnim S, Masud RI, Anika TT, Islam MS, Rahman MT. A systematic review on reverse-zoonosis: Global impact and changes in transmission patterns. J Adv Vet Anim Res. 2024;11(3):601.
102. Alengebawy A, Abdelkhalek ST, Qureshi SR, Wang MQ. Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. Toxics. 2021;9(3):1–34. doi: 10.3390/toxics9030042.
103. Sahoo PK, Kim K, Powell MA. Managing groundwater nitrate contamination from livestock farms: Implication for nitrate management guidelines. Curr Pollut Reports. 2016;2(3):178–187. doi: 10.1007/s40726-016-0033-5.
104. Brender JD. Human health effects of exposure to nitrate, nitrite, and nitrogen dioxide. Just enough nitrogen Perspect. How to get there Reg. with too much too little nitrogen. 2020:283–294.
105. Nimmermark S. Odour influence on well-being and health with specific focus on animal production emissions. Ann Agric Environ Med. 2004;11(2):163–173.
106. Seidel J, Magzamen S, Wang YH, Neujahr V, Schaeffer JW. Lessons from dairy farmers for occupational allergy and respiratory disease. Curr Allergy Asthma Rep. 2023;23(6):325–339. doi: 10.1007/s11882-023-01081-2.
107. Reynolds SJ, Nonnenmann MW, Basinas I, Davidson M, Elfman L, Gordon J, et al. Systematic review of respiratory health among dairy workers. J Agromedicine. 2013;18(3):219–243. doi: 10.1080/1059924X.2013.797374.
108. Alegbeleye OO, Sant'Ana AS. Manure-borne pathogens as an important source of water contamination: An update on the dynamics of pathogen survival/transport as well as practical risk mitigation strategies. Int J Hyg Environ Health. 2020;227:113524. doi: 10.1016/j.ijheh.2020.113524.
109. Qaid MM, Abdoun KA. Safety and concerns of hormonal application in farm animal production: A review. J Appl Anim Res. 2022;50(1):426–439. doi: 10.1080/09712119.2022.2089149.
110. Baden S, Harvey C, Wilson D, Wilson K. Small farmers big change: Scaling up impact in smallholder agriculture. Practical Action Publishing; 2011.
111. Zain NR, Tounchibine O, Lechheb H. Sustainable agriculture and Islamic finance: Cultivating prosperity and values. In: The Future of Islamic Finance. Emerald Publishing Limited; 2024. pp. 155–173.
112. Joubran AM, Pierce KM, Garvey N, Shalloo L, O'Callaghan TF. Invited review: A 2020 perspective on pasture-based dairy systems and products. J Dairy Sci. 2021;104(7):7364–7382.
113. Zhang J. Soil environmental deterioration and ecological rehabilitation. In: Study of Ecological Engineering of Human Settlements. 2020:41–82. doi: 10.1007/978-981-15-1373-2_2.
114. Goodwin H. In pursuit of ecotourism. Biodivers Conserv. 1996;5(3):277–291. doi: 10.1007/bf00051774.
115. Chang-Fung-Martel J, Harrison MT, Rawnsley R, Smith AP, Meinke H. The impact of extreme climatic events on pasture-based dairy systems: A review. Crop Pasture Sci. 2017;68(12):1158–1169. doi: 10.1071/CP16394.
116. Hoekstra AY. The hidden water resource use behind meat and dairy. Anim Front. 2012;2(2):3–8.
117. Palhares JCP, Pezzopane JRM. Water footprint accounting and scarcity indicators of conventional and organic dairy production systems. J Clean Prod. 2015;93:299–307.
118. Lin BB, Johnson-Chappell MJ, Vandermeer J, Smith G, Quintero E, Kerr RB, et al. Effects of industrial agriculture on climate change and the mitigation potential of small-scale agro-ecological farms. Cabi Rev. 2011;2011;6(020):1–18. doi: 10.1079/PAVSNNR20116020.
119. Tesfa A, Mekuriaw S. The effect of land degradation on farm size dynamics and crop-livestock farming system in Ethiopia: A review. Open J Soil Sci. 2014;04(01):1–5. doi: 10.4236/ojss.2014.41001.

