



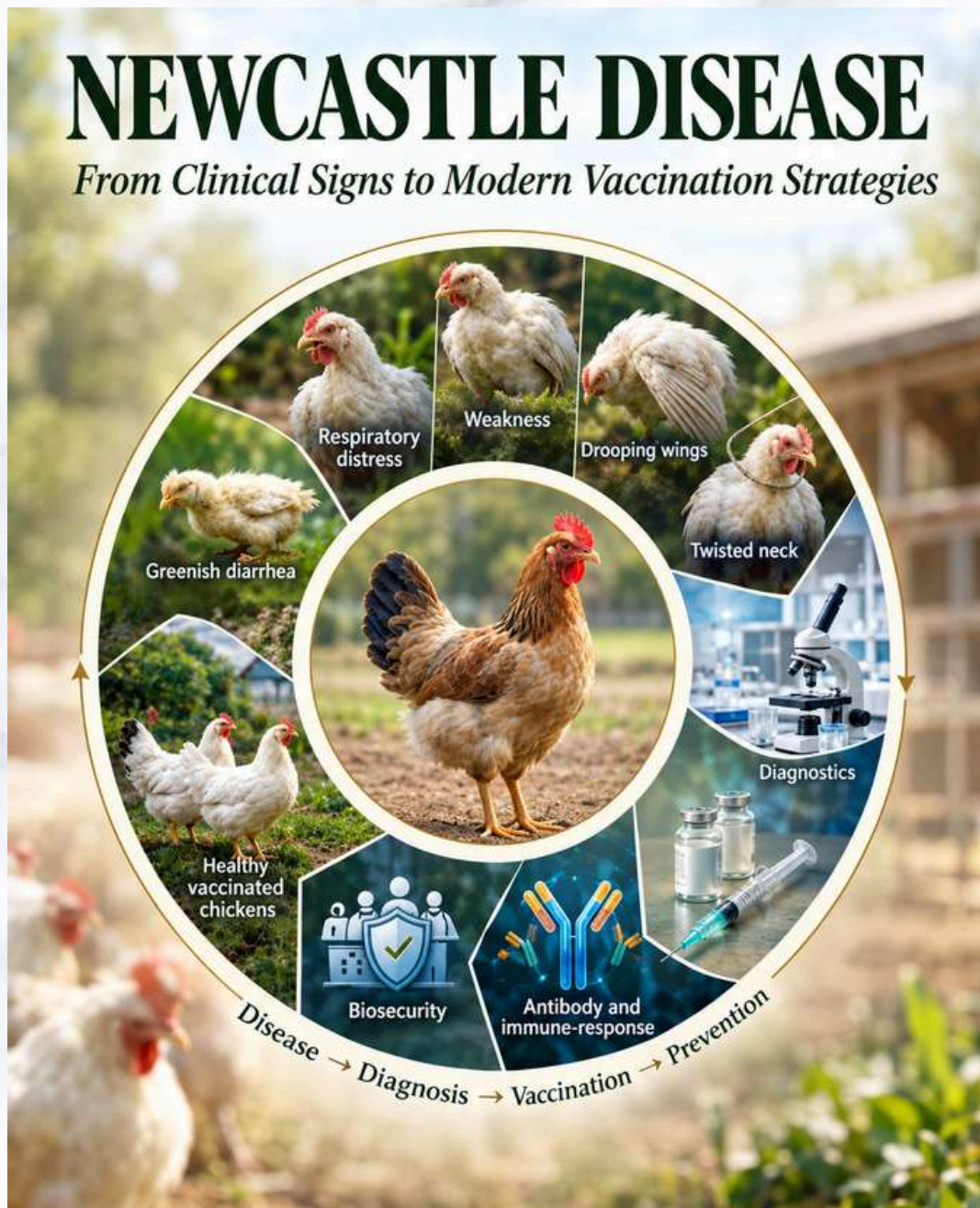
ISSN:2583-9071

VOLUME 4, ISSUE 10 | OCTOBER 2026

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Poultry farming is more than raising birds—it is a continuous commitment to maintaining health, productivity, and biosecurity. Among the diseases that can seriously disrupt poultry production, Newcastle Disease (ND) remains a major concern because of its contagious nature, diverse clinical presentation, and potential to cause substantial economic losses. The disease can affect birds of different ages and production stages, and its signs may range from respiratory distress and depression to neurological manifestations and reduced production. Recognizing these warning signs at an early stage can play a crucial role in initiating timely control measures and protecting the flock.

With this perspective, we bring you “Newcastle Disease: From Clinical Signs to Modern Vaccination Strategies,” an informative article that takes the reader from the first visible signs of disease to contemporary approaches for prevention and control. The article highlights the importance of understanding clinical manifestations, routes of transmission, diagnosis, biosecurity, and flock management while giving particular attention to vaccination as a cornerstone of disease prevention. It also emphasizes that vaccination should not be viewed in isolation; its effectiveness depends on factors such as vaccine selection, timing, administration, flock health, maternal antibodies, and adherence to appropriate vaccination programmes.

As poultry production becomes increasingly intensive and technologically advanced, disease prevention must evolve alongside it. Early recognition, effective biosecurity, scientifically planned vaccination, proper flock management, and continuous monitoring together form the foundation of sustainable Newcastle Disease control. We hope this article will serve as a valuable source of awareness and practical knowledge for poultry farmers, veterinarians, students, researchers, and industry professionals. By strengthening our understanding of Newcastle Disease and embracing modern preventive strategies, we can move towards healthier flocks, reduced production losses, and a more resilient and sustainable poultry sector.

Dr. Deepak Kumar
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EXPLORING KNOWLEDGE & DISCOVERING AGRICULTURE

Respiratory
distress

Weakness

Drooping wings

Twisted neck

Greenish diarrhea

Diagnostics

Healthy
vaccinated
chickens



Biosecurity



Antibody and
immune-response

Disease → Diagnosis → Vaccination → Prevention

AGRI ROOTS E-MAGAZINE

Newcastle Disease: From Clinical Signs to Modern Vaccination Strategies

ARTICLE ID: 0414

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Newcastle disease (ND) is a highly contagious viral disease of poultry and is a notifiable disease under the World Organisation for Animal Health (WOAH) because of its rapid spread and potential to cause severe disease and mortality (Ara et al., 2009). Clinical severity ranges from subclinical infection to severe respiratory and neurological disease, with mortality approaching 100% in susceptible birds. Low-virulence NDV strains may circulate continuously and predispose birds to secondary respiratory infections, thereby reducing productivity and causing economic losses (Brown et al., 1999).

Newcastle disease virus (NDV) is a pleomorphic, enveloped virus with a non-segmented, negative-sense, single-stranded RNA genome that replicates in the cytoplasm (Miller et al., 2010). Its genome is approximately 15.2 kb and encodes six major structural proteins: nucleocapsid (N), phosphoprotein (P), matrix (M), fusion (F), haemagglutinin-neuraminidase (HN), and polymerase (L) (Shabbir et al., 2013).

Based on pathogenicity, NDV strains are classified as lentogenic, mesogenic, or velogenic, with increasing severity from mild respiratory infection to severe systemic disease (de Leeuw et al., 2005). Velogenic strains may be further described as viscerotropic or neurotropic according to their predominant pathological effects.

Disease severity is influenced by viral virulence, host susceptibility and immunity, environmental stress, and concurrent infections. The fusion (F) protein cleavage site is a major determinant of NDV virulence. Polybasic cleavage sites facilitate activation by widely distributed host proteases and



support systemic viral replication. However, other viral proteins, including HN and replication-complex proteins, also contribute to pathogenicity. Viral virulence can be assessed using biological tests such as mean death time (MDT), intracerebral pathogenicity index (ICPI), and intravenous pathogenicity index (IVPI) (de Leeuw et al., 2005; Dortmans et al., 2011).

Transmission of Newcastle Disease Virus

Newcastle disease virus (NDV) is mainly transmitted through the respiratory and gastrointestinal routes following inhalation or ingestion of infectious virus. Birds may become infected by inhaling virus-containing droplets or aerosols, while ingestion of virus-contaminated faeces is an important route of bird-to-bird transmission.

Following natural exposure, the incubation period generally ranges from 2 to 15 days, with an average of approximately 5–6 days. The onset and severity of clinical disease depend on several factors, including the virulence of the infecting strain, susceptibility of the host, and prevailing environmental conditions (Kapczynski et al., 2013).

Clinical Signs

The clinical presentation of Newcastle disease varies according to the tissues and organ systems affected, particularly the respiratory, gastrointestinal, and nervous systems. Disease severity and progression are influenced by several factors, including bird species, age, immune status, virulence and dose of the infecting NDV strain, route of infection, environmental stress, and concurrent infections (Merino et al., 2011).

Low-virulence NDV infections commonly produce respiratory signs such as coughing, sneezing,

gasping, and abnormal respiratory sounds (Brown et al., 1999). In neurotropic velogenic infections, neurological manifestations such as tremors, wing and leg paralysis, torticollis, circling, muscle spasms, and complete paralysis may develop, often following the onset of respiratory signs (Wakamatsu et al., 2006; Susta et al., 2011).

Gross and Microscopic Lesions

Gross and microscopic lesions in Newcastle disease vary with the viral pathotype, host susceptibility, and concurrent infections, and lesions may occasionally be absent (Cornax et al., 2012).

Viscerotropic velogenic NDV commonly causes haemorrhagic and necrotic lesions in the proventriculus, intestine, and lymphoid tissues, along with respiratory congestion or haemorrhage (Cattoli et al., 2011). Histologically, severe infections are characterized by lymphoid depletion, necrosis, vascular damage, and respiratory epithelial injury, including oedema, inflammation, and loss of cilia (Brown et al., 1999; Mast et al., 2005).

Neurotropic strains may produce perivascular cuffing, neuronal degeneration, necrosis, and gliosis in the central nervous system (Wakamatsu et al., 2006). Mesogenic strains may cause enteritis and necrotic lesions in visceral organs, whereas lentogenic strains generally produce mild respiratory lesions (Piacenti et al., 2006).

Vaccination and Modern Vaccination Strategies

Vaccination is one of the most important components of Newcastle disease control. Live attenuated vaccines, including LaSota and B1 strains, are widely used because of their safety and immunogenicity. Other

vaccines, including VG/GA and thermostable genotype I strains such as V4 and I-2, may provide respiratory or mucosal protection and are particularly useful in areas where maintenance of the cold chain is challenging (Habibi et al., 2020).

Although conventional vaccines effectively reduce clinical disease and mortality, they may not completely prevent infection, viral replication, or viral shedding when vaccinated birds are exposed to genetically distinct field strains (Hu et al., 2022).

Although NDV is generally considered a single serotype, considerable genetic and antigenic diversity occurs among circulating genotypes, particularly between traditional vaccine strains and genotype VII viruses (Xiao et al., 2012). Genotype-matched vaccines have shown potential to reduce viral shedding more effectively while maintaining protection against clinical disease (Ji et al., 2018).

Continued molecular surveillance of circulating NDV strains is therefore important for

outbreak investigation, epidemiological monitoring, vaccine evaluation, and the development of improved vaccination strategies.

Conclusion

Newcastle disease remains an important poultry disease capable of causing substantial production losses, particularly when highly virulent strains are involved. Effective control requires an integrated approach involving appropriate vaccination, strict biosecurity, sanitation, disease surveillance, and timely diagnosis.

Although vaccination provides strong protection against clinical disease and mortality, vaccinated birds may still become infected and shed genetically different field strains under certain circumstances. Therefore, molecular surveillance and continued development and evaluation of suitable vaccine strategies are important components of modern Newcastle disease control.

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Future of Artificial Intelligence: Its Impact on the Agriculture and Nutrition Sector

ARTICLE ID: 0415

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Artificial Intelligence (AI) is increasingly being adopted across the agriculture and food-nutrition value chain, from the farm to the final consumer. This paper reviews the emerging role of AI technologies such as machine learning, deep learning, computer vision, and the Internet of Things (IoT) in transforming agricultural production and nutritional science. In agriculture, AI-enabled precision farming, crop and soil monitoring, pest and disease detection, smart irrigation, and yield forecasting are helping farmers improve productivity while using natural resources more efficiently. In nutrition and food science, AI is enabling personalized dietary recommendations, automated dietary assessment, food recognition, and improved food safety and quality control. Drawing on recent peer-reviewed literature, this review discusses the concept of AI, its principal applications in agriculture and nutrition, the benefits it

offers to farmers, food producers, dietitians, and consumers, and the challenges—including data quality, cost, infrastructure, and ethical concerns—that continue to limit its wider adoption. The paper



concludes that while AI cannot replace human judgement in either field, it is rapidly becoming an important decision-support tool that, if adopted responsibly,

can strengthen food security and contribute to improved public nutrition outcomes.

1. Introduction

Agriculture and nutrition are two of the most fundamental pillars of human survival, and both are currently under pressure from a growing global population, climate variability, shrinking arable land, and rising rates of diet-related diseases. Meeting these challenges requires tools capable of processing large amounts of environmental, biological, and behavioural

data and translating them into actionable decisions. Artificial Intelligence (AI)—broadly defined as the capability of machines to perform tasks that normally require human intelligence, such as perception, reasoning, and learning—has emerged as one such tool. Over the past decade, AI has moved beyond research laboratories into agricultural fields and food-related applications, supported by cheaper sensors, satellite imagery, mobile connectivity, and advances in machine learning and deep-learning algorithms [1], [2].

Historically, technological development in agriculture progressed from simple mechanisation to computer-aided record keeping and, more recently, to data-driven precision agriculture. In parallel, nutrition science has progressed from generalized dietary guidelines toward increasing recognition that dietary requirements vary among individuals. AI lies at the intersection of these developments. The same underlying techniques of pattern recognition and predictive modelling that enable a machine-learning model to identify a diseased crop leaf from an image can also be used to identify food items on a plate and estimate their nutritional content [3]. This article reviews the applications of AI across the agriculture–nutrition continuum, the benefits reported in the literature, and the challenges that must be addressed for wider adoption.

2. Artificial Intelligence: Concept and Relevance

Artificial Intelligence is an umbrella term encompassing several sub-fields relevant to agriculture and nutrition. Machine learning (ML) algorithms identify patterns from historical data and use them to make predictions on new datasets, such as forecasting

crop yields using weather and soil information. Deep learning, a subset of ML based on artificial neural networks, is particularly effective for image-based applications such as identifying pests, weeds, crop diseases, or fruit maturity from images captured using drones or smartphones.

The Internet of Things (IoT) refers to interconnected networks of sensors deployed in agricultural fields, storage facilities, food-processing units, or wearable devices. These sensors continuously generate data that can be analysed by AI systems for real-time monitoring and decision-making [1], [5]. Together, these technologies enable a transition from basic automation toward intelligent decision support, where systems can collect data, analyse patterns, recommend actions, and, in some cases, automatically execute operations such as adjusting irrigation or identifying potential nutritional deficiencies.

3. AI Applications in Agriculture

3.1 Precision Farming and Crop Management

Precision agriculture combines AI with satellite and drone imagery, soil sensors, and weather information to tailor agricultural operations to the specific conditions of different areas within a field. Instead of applying inputs uniformly, machine-learning models can analyse historical yield, soil, and climatic data to support decisions regarding the timing and quantity of sowing, fertilization, irrigation, and harvesting [1–3]. AI-based crop-management systems can improve resource-use efficiency and potentially reduce input costs. However, the magnitude of benefits varies

according to crop, location, data quality, technological infrastructure, and management practices.

3.2 Pest and Disease Detection

Convolutional neural networks and other deep-learning models are increasingly being used to analyse images of leaves, stems, fruits, and other plant parts captured using smartphones, drones, or other imaging systems. These technologies can assist in identifying crop diseases and pest infestations at an early stage [1], [3].

Early identification allows farmers to undertake targeted management measures, potentially reducing crop losses and unnecessary pesticide applications.

3.3 Smart Irrigation and Resource Optimization

AI-driven irrigation systems combine soil-moisture measurements, weather forecasts, and crop-growth information to determine appropriate irrigation timing and quantity [5], [6]. Such systems can help conserve water while reducing the risks associated with both water stress and excessive irrigation.

Similar decision-support systems are being developed for fertilizer application, weed management, and pest-control scheduling, contributing to more efficient and environmentally responsible agricultural practices.

3.4 Yield Prediction and Farm-to-Market Logistics

Machine-learning models integrating satellite imagery, soil characteristics, historical climate information, and crop data can assist in predicting crop yields before harvest [2–4]. Such information can support farmers, cooperatives, agribusinesses, and government agencies in planning storage, transportation, processing, and marketing.

AI is also being applied across the wider agrifood supply chain to improve logistics, reduce post-harvest losses, and match agricultural production with market demand [6].

4. AI Applications in Nutrition and Food Science

4.1 Personalized Nutrition

Personalized nutrition aims to move beyond generalized dietary recommendations by considering an individual's genetic profile, metabolic characteristics, lifestyle, dietary habits, and health objectives. AI and machine-learning models can integrate information from wearable devices, electronic health records, dietary logs, and other sources to generate individualized dietary recommendations [7–9].

Applications include dietary management, weight management, chronic-disease support, and sports nutrition. However, many applications remain in the research and early-development stages and require further validation before widespread clinical implementation [7].

4.2 Dietary Assessment and Food Recognition

Traditional dietary assessment methods often rely on food diaries, questionnaires, and dietary-recall interviews. These approaches can be time-consuming and may be affected by inaccurate reporting. AI-based image-recognition systems can identify food items from photographs and estimate portion sizes and nutritional composition, potentially simplifying dietary monitoring [8], [11].

Natural-language-processing tools can also analyse recipes and food-related information to estimate

nutritional and, increasingly, sustainability characteristics.

4.3 Food Safety and Quality Control

AI technologies, including machine learning, computer vision, and sensor-based systems, are increasingly being investigated for real-time food-quality assessment, contamination detection, and shelf-life prediction [5], [10], [12].

AI-enabled traceability systems can also support monitoring of food products across the supply chain. Such systems may help identify the source of contamination more rapidly during food-safety incidents and improve overall quality-management processes.

4.4 Nutrition Education and Public Health

AI-powered chatbots and virtual dietary assistants are being developed to provide nutrition information and behaviour-change support to consumers [7], [12]. These tools can complement, rather than replace, professional guidance from dietitians and nutritionists. At the population level, AI-based analysis of dietary and health data may assist public-health agencies in identifying patterns of malnutrition and diet-related diseases and in developing more targeted interventions.

5. Impact on Farmers, Nutritionists, and Consumers

For farmers, AI-based decision-support systems can reduce uncertainty in day-to-day farm management and provide data-driven recommendations for crop production, irrigation, pest management, and resource allocation [1], [4].

For dietitians and nutritionists, AI tools can automate time-consuming tasks such as dietary-data collection, food recognition, and nutrient estimation, potentially allowing professionals to devote more time to counselling and evidence-based decision-making [7].

For consumers, the integration of AI into agriculture and nutrition has the potential to contribute to more efficient food production, improved food quality, and personalized dietary guidance. However, access to these technologies remains uneven. Regions with stronger digital infrastructure, better connectivity, and greater financial resources generally have greater opportunities for AI adoption than resource-constrained regions [4], [6].

6. Challenges and Limitations

Despite its potential, AI adoption in agriculture and nutrition faces several challenges.

Data Quality And Availability: AI systems depend heavily on the quality and representativeness of training data. Agricultural and dietary datasets may be fragmented, inconsistent, incomplete, or unavailable for particular regions and populations [3], [4].

Cost And Infrastructure: Sensors, connectivity, computing resources, software, and technical expertise can involve substantial costs. These factors may restrict access for smallholder farmers and small food businesses [4], [6].

Data Privacy And Ethics: Personalized nutrition may involve sensitive genetic, health, and behavioural information. Ensuring privacy, informed consent, and responsible data management is therefore essential [7], [8].

Algorithmic Bias: AI systems may produce less reliable recommendations when training datasets do not adequately represent different crops, geographical regions, populations, or dietary patterns.

Interpretability: Complex deep-learning models are often described as “black boxes” because their decision-making processes can be difficult to understand. Greater transparency and explainability are important for building confidence among farmers, nutrition professionals, consumers, and regulators [5].

7. Future Directions

The integration of AI with complementary technologies such as IoT, remote sensing, robotics, and blockchain-based traceability may strengthen connectivity across the agriculture-to-nutrition value chain [5], [6], [9]. Data collected from farms could increasingly contribute to improved forecasting, food-quality assessment, supply-chain management, and downstream nutritional applications.

Federated-learning approaches, in which AI models can be trained across multiple institutions without directly sharing raw personal data, are also being explored for applications such as personalized nutrition [8]. Such approaches may help address privacy concerns while allowing researchers to work with larger and more diverse datasets.

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Future progress will require investment in affordable technologies, rural digital infrastructure, capacity building, data standards, and transparent regulatory frameworks. Ensuring that AI technologies remain accessible and inclusive will be important for achieving broad societal benefits.

8. Conclusion

Artificial Intelligence is becoming increasingly important across the agriculture and nutrition sector, from precision farming and crop-health monitoring to personalized dietary recommendations and food-safety management. The available evidence indicates that AI can support improvements in productivity, resource-use efficiency, food-quality assessment, and individualized dietary guidance.

However, wider adoption requires attention to data quality, affordability, digital infrastructure, privacy, algorithmic bias, and transparency. AI should be viewed as a decision-support technology rather than a replacement for the practical knowledge of farmers or the professional judgement of dietitians and nutritionists. When developed and implemented responsibly, AI can contribute to more efficient agricultural systems, stronger food-security strategies, and improved nutrition outcomes.

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Beyond Vaccination: Managing the Continuing Threat of Fowl Pox

ARTICLE ID: 0416

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Fowl pox is a widespread viral disease affecting domestic and wild birds. It is caused by fowlpox virus (FWPV), a double-stranded DNA virus belonging to the genus *Avipoxvirus* of the family *Poxviridae*. The disease occurs worldwide and is particularly common in tropical and subtropical regions, where warm conditions and insect vectors favour transmission.

Fowl pox can cause reduced growth in young birds, decreased egg production in layers and increased mortality in severe cases. Transmission occurs mainly through direct contact, contaminated materials and mechanical vectors such as mosquitoes and other blood-feeding insects. Backyard and free-range poultry are particularly vulnerable because of greater exposure to vectors and limited biosecurity (Giotis et al., 2019; WOA, 2023).

Although vaccination remains the principal preventive measure, outbreaks can occur in vaccinated flocks because of inadequate vaccination, poor vaccine application, insufficient immunity or variation among



field virus strains (Biswas et al., 2011). The disease occurs mainly in two forms: cutaneous (dry) and diphtheritic (wet). The cutaneous form produces lesions on unfeathered skin,

whereas the diphtheritic form affects mucous membranes of the mouth and respiratory tract and may cause severe respiratory distress.

Etiology and Virus Characteristics

Fowl pox is caused by FWPV, a member of the genus *Avipoxvirus*. The mature virus particle is characteristically brick-shaped and contains an outer envelope, a central biconcave core and lateral bodies. Its large linear double-stranded DNA genome is

approximately 288 kb and contains numerous genes involved in viral replication, host interaction and pathogenicity (WOAH, 2023; Minhas et al., 2024).

The virus is relatively resistant to environmental conditions and may persist in contaminated poultry houses, equipment and organic material. Therefore, proper cleaning, disinfection and sanitation are important components of disease prevention.

Epidemiology and Transmission

Fowl pox can affect birds of different ages, breeds and production systems. Transmission occurs primarily through:

- Direct contact between infected and susceptible birds
- Contaminated equipment and materials
- Infected scabs and feather debris
- Skin injuries and mechanical inoculation
- Mosquitoes and other blood-feeding insects

Mosquitoes can act as important mechanical vectors, and detection of FWPV in field-collected mosquitoes supports their role in natural transmission (Yeo et al., 2019).

Backyard and free-range poultry are at increased risk because of greater exposure to insects, environmental contamination and other birds. However, outbreaks may also occur in commercial poultry farms. Infection in vaccinated flocks has been reported, demonstrating that vaccination alone may not completely prevent disease under all field conditions (Matos et al., 2022).

Pathogenesis and Clinical Signs

FWPV is primarily epitheliotropic, producing epithelial hyperplasia, inflammation, degeneration and necrosis at sites of infection.

1. Cutaneous Form

The cutaneous or dry form is characterized by:

- Nodular and wart-like lesions
- Thick scab formation
- Lesions on the comb, wattles, eyelids, legs and other unfeathered areas
- Reduced feeding and general performance

Histologically, lesions may show epidermal hyperplasia, acanthosis, ballooning degeneration, hyperkeratosis and characteristic eosinophilic intracytoplasmic inclusion bodies known as Bollinger bodies (Mohamed et al., 2024).

The cutaneous form is generally less severe but may result in secondary bacterial infections and reduced productivity.

2. Diphtheritic Form

The diphtheritic or wet form affects the mucous membranes of the mouth, pharynx, larynx and sometimes the trachea. Thick proliferative and necrotic membranes may develop and interfere with feeding and respiration.

Severe respiratory obstruction can result in respiratory distress and death due to asphyxiation. The severity of disease depends on the virus strain, age and immune status of the bird and the presence of secondary infections (Surendar et al., 2025).

Both cutaneous and diphtheritic forms may occur simultaneously.

Diagnostic Techniques

Diagnosis is based on clinical signs, characteristic lesions and laboratory confirmation. Important diagnostic approaches include:

Clinical Examination: Identification of typical skin nodules, scabs and diphtheritic lesions.

Histopathology: Detection of characteristic Bollinger bodies in affected epithelial cells.

Virus Isolation: FWPV can be isolated using embryonated chicken eggs or suitable avian cell cultures.

PCR And Real-Time PCR: Molecular assays, particularly those targeting conserved genes such as **P4b**, provide rapid and sensitive detection of FWPV.

Serological Tests: Virus neutralization, agar gel immunodiffusion (AGID) and ELISA can be used to assess antibody responses, vaccination status and flock exposure (WOAH, 2023).

Differential Diagnosis

Fowl pox should be differentiated from other diseases producing similar skin, oral or respiratory lesions.

- **Infectious Laryngotracheitis:** Characteristic intranuclear inclusion bodies help distinguish it from fowl pox, which produces cytoplasmic inclusion bodies.
- **Trichomoniasis:** Diphtheritic lesions in pigeons may resemble lesions caused by *Trichomonas gallinae*.
- **Nutritional Deficiencies And Toxin Exposure:** These may produce skin abnormalities resembling pox lesions.

Histopathological examination and appropriate molecular or microbiological tests are useful for confirmation (Tripathy and Reed, 2020).

Control and Prevention

Effective control requires an integrated approach rather than vaccination alone. Important measures include:

1. Effective vaccination using appropriate vaccines and correct administration techniques.
2. Strict biosecurity to minimize introduction and spread of infection.
3. Regular cleaning and disinfection of poultry houses, equipment and contaminated areas.
4. Vector control to reduce mosquito and biting-insect populations.
5. Avoidance of overcrowding and maintenance of good ventilation.
6. Prompt isolation of affected birds to reduce transmission.
7. Monitoring of vaccination success, including proper observation of the vaccine "take."
8. Surveillance and molecular characterization of circulating field strains.

Vaccination

Vaccination is the primary preventive measure against fowl pox. Live attenuated vaccines are commonly produced using chicken embryos or tissue-culture systems. Vaccines are generally administered through the wing-web method, and development of a characteristic local "take" is used as an indication of successful vaccination.

Booster vaccination may be necessary in layers and breeders depending on the production system and disease risk. Vaccine handling, storage, administration and timing are critical for achieving effective immunity.

Recombinant fowl pox viruses are also being investigated and used as vaccine-vector platforms for other poultry diseases, including Newcastle disease,

avian influenza and infectious laryngotracheitis (Giotis et al., 2019; Minhas et al., 2024).

Beyond Vaccination: The Way Forward

The continuing occurrence of fowl pox despite vaccination highlights the need for a multilayered disease-control strategy. Vaccination should be combined with vector management, biosecurity, sanitation, early diagnosis and regular surveillance.

Particular attention is required in backyard and free-range poultry systems, where interaction with wild birds and insect vectors can increase the risk of virus transmission. Molecular surveillance of field strains can also help identify emerging variants and improve understanding of vaccine protection.

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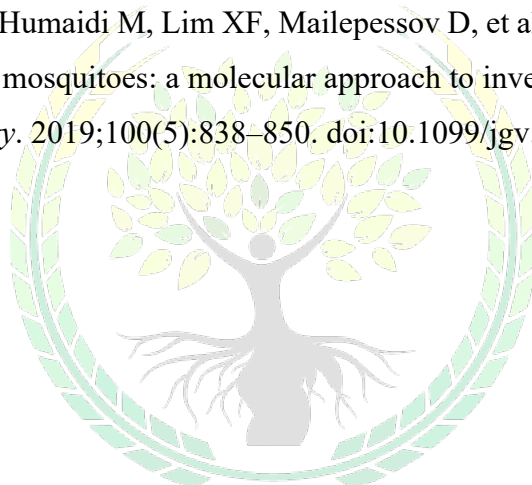
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Conclusion

Fowl pox remains an important viral disease of poultry, particularly in backyard and poorly managed production systems. Its persistence is associated with environmental contamination, mechanical insect vectors and occasional disease occurrence in vaccinated flocks.

Vaccination remains the foundation of prevention, but it should not be considered a stand-alone solution. Effective biosecurity, vector control, sanitation, early diagnosis and continuous surveillance are essential for reducing disease losses. Greater molecular characterization of circulating field strains will further support the development of improved prevention and control strategies.

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Poultry Waste in Aquaculture: Environmental Impacts, Food-Safety Risks, and Regulatory Challenges

ARTICLE ID: 0417

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Poultry-derived wastes, including manure, viscera, offal, feathers, and other slaughterhouse by-products, have potential applications in agriculture and resource recovery. However, the direct use of untreated poultry waste in aquaculture can introduce environmental and food-safety concerns, particularly when waste is contaminated, applied in excessive quantities, or managed without appropriate treatment. Organic loading may increase biochemical oxygen demand, ammonia concentrations, nutrient enrichment, and microbial contamination in culture ponds. Poultry waste may also contain antimicrobial residues, antimicrobial-resistant microorganisms, and potentially toxic elements, although the magnitude of these hazards depends on the waste source, treatment method, application rate, and culture conditions.

This article examines the environmental, microbiological, toxicological, and regulatory

considerations associated with untreated poultry waste in fish culture. It also distinguishes raw manure from processed poultry by-products and discusses safer alternatives, including formulated feeds, properly treated organic fertilizers, composting, and controlled waste-management systems. The article emphasizes



that regulatory restrictions differ among jurisdictions and that risk-based management, scientific monitoring, and compliance with applicable food-safety

and environmental standards are essential for sustainable aquaculture.

1. Introduction

Aquaculture production depends on nutritionally appropriate feed, good water quality, disease prevention, and effective waste management. In some regions, poultry manure and slaughterhouse by-products have been used as organic fertilizers or supplementary feed materials. However, these

materials differ considerably in their composition, treatment requirements, and potential environmental risks.

Poultry manure contains nitrogen, phosphorus, organic matter, and microorganisms. When appropriately treated and applied at controlled rates, it may contribute to nutrient recycling. However, excessive or untreated application can increase organic loading and nutrient concentrations in culture ponds, potentially reducing dissolved oxygen and deteriorating water quality (Edwards, 1980; Boyd & Tucker, 1998).

Poultry slaughterhouse waste, including viscera and offal, is compositionally different from manure. Its high moisture content, protein concentration, and microbial load create specific storage, processing, and feed-safety challenges. Therefore, manure, raw offal, and processed poultry by-products should not be treated as interchangeable materials.

The use of poultry waste in aquaculture should be assessed according to applicable national regulations, waste-treatment standards, species requirements, and food-safety objectives. A general claim that all poultry-derived materials are prohibited worldwide is not scientifically or legally justified.

2. Environmental Impacts of Untreated Poultry Waste

2.1 Organic Loading and Dissolved Oxygen Depletion

Untreated poultry waste contains biodegradable organic matter. When large quantities enter a fish pond, microbial decomposition can increase biochemical oxygen demand (BOD) and reduce dissolved oxygen,

particularly during warm weather or periods of limited water exchange.

Low dissolved oxygen may cause stress, reduced feeding, impaired growth, and fish mortality. The severity of the impact depends on the quantity and composition of waste, pond volume, aeration, temperature, and existing organic loading (Boyd & Tucker, 1998).

2.2 Nutrient Enrichment and Eutrophication

Poultry manure contains nitrogen and phosphorus. Excessive application can stimulate phytoplankton and aquatic plant growth, resulting in eutrophication. Dense algal populations may cause fluctuations in dissolved oxygen and pH, while decomposition of algal biomass can further increase oxygen demand.

Some cyanobacterial species may produce toxins; however, the presence of poultry waste does not automatically result in toxic algal blooms. Cyanobacterial development depends on nutrient availability, temperature, light, water-column conditions, and species composition.

2.3 Ammonia and Nitrogen Transformation

Nitrogenous compounds in poultry waste can be converted into ammonia and other nitrogen forms during decomposition. The proportion of toxic unionized ammonia depends primarily on total ammonia concentration, water temperature, and pH.

Elevated ammonia can damage fish gill tissues, impair physiological functions, and reduce survival. Regular monitoring of total ammonia nitrogen, pH, temperature, and dissolved oxygen is therefore necessary where organic fertilizers are used.

2.4 Sediment and Habitat Effects

Repeated application of excessive poultry waste may increase organic matter accumulation in pond sediments. This can contribute to oxygen depletion near the sediment–water interface, unpleasant odours, and changes in microbial processes.

Appropriate application rates, periodic sediment assessment, water exchange, and aeration can reduce these risks. Environmental effects should be evaluated using actual pond measurements rather than assumed solely from the presence of poultry waste.

3. Microbiological and Toxicological Concerns

3.1 Pathogenic Microorganisms

Poultry waste may contain microorganisms of animal and public-health significance, including *Salmonella*, pathogenic *Escherichia coli*, and other enteric organisms. Their occurrence and concentration depend on poultry health, waste handling, storage, treatment, and environmental conditions.

The direct use of untreated waste in fish culture can increase the possibility of microbial contamination of pond water, equipment, workers, and harvested fish.

Appropriate treatment and hygienic handling are therefore important components of aquaculture biosecurity.

The presence of a pathogen in poultry waste does not establish that it will survive, multiply, or infect humans through fish consumption. Such conclusions require evidence concerning pathogen survival, transfer pathways, fish contamination, and exposure conditions.

3.2 Antimicrobial Resistance

Poultry production may involve antimicrobial use, and poultry manure can contain antimicrobial-resistant bacteria, resistance genes, and, depending on the compound and management system, antimicrobial residues. The environmental dissemination of these materials is a One Health concern.

However, untreated poultry waste should not automatically be described as producing direct transfer of resistance genes into fish tissues. The potential pathway is more accurately described as environmental exposure involving water, sediments, microorganisms, and farm workers. The magnitude of risk requires site-specific microbiological and molecular investigation.

Important management measures include:

- Responsible antimicrobial use in poultry production
- Appropriate waste treatment
- Prevention of uncontrolled discharge
- Monitoring of resistant bacteria and resistance genes
- Improved aquaculture biosecurity

3.3 Potentially Toxic Elements

Poultry manure and slaughterhouse by-products may contain potentially toxic elements, including copper, zinc, arsenic, cadmium, and lead, depending on feed ingredients, supplements, environmental exposure, and waste sources.

Copper and zinc are essential elements at appropriate concentrations but may become toxic at elevated levels. Cadmium and lead have no established beneficial physiological role in humans and require particular monitoring.

Metal accumulation in fish depends on water and sediment chemistry, exposure duration, species, age, tissue type, and bioavailability. Therefore, it is not scientifically accurate to state that poultry waste always causes high concentrations of metals in fish muscle or produces chronic poisoning in consumers. Laboratory analysis should be used to assess contamination, and results should be compared with applicable food-safety limits.

3.4 Antibiotic Residues and Other Chemical Contaminants

Poultry waste may contain residues of veterinary medicines or other chemical contaminants, but their presence and concentration cannot be assumed without analytical testing. Potential risks depend on the chemical properties of the compound, degradation during treatment, exposure conditions, and fish uptake. A comprehensive assessment should include:

- Feed and waste-source documentation
- Chemical residue testing
- Water and sediment analysis
- Fish-tissue monitoring
- Compliance with applicable maximum residue limits

4. Distinction Between Poultry Waste Categories

Waste Category	Main Characteristics	Key Concerns	Management Approach
Raw poultry manure	Fecal material, bedding, nutrients, microorganisms	Nutrient loading, pathogens, ammonia, oxygen depletion	Treatment and controlled application

Poultry viscera and offal	High-moisture, protein-rich slaughterhouse by-products	Rapid decomposition, microbial contamination, oxygen demand	Approved processing or authorized disposal
Feathers	Keratin-rich material with slow decomposition	Low digestibility, contamination if poorly handled	Appropriate processing or managed disposal
Processed poultry by-products	Rendered or otherwise treated materials	Processing quality, contaminants, nutritional balance	Use only under applicable feed-safety standards
Compost or treated manure	Stabilized organic material	Incomplete treatment, nutrient overapplication	Verify treatment quality and application rate

5. Regulatory Framework and Enforcement Considerations

5.1 Regulatory Restrictions

Regulations governing poultry waste use in aquaculture vary by country, state, waste category, and intended use. Some jurisdictions restrict the direct application of untreated animal waste, while others permit controlled use of treated manure under environmental and agricultural regulations. In India, regulatory requirements may involve fisheries departments, pollution-control authorities, local government bodies, animal by-product management rules, and food-safety regulations. The precise legal position should be established using the applicable

notification, government order, or statutory instrument for the relevant state and activity.

5.2 Waste Disposal and Traceability

Effective poultry waste management should include:

- Segregation of manure and slaughterhouse by-products
- Safe storage and transportation
- Authorized processing or disposal
- Documentation of waste origin
- Monitoring of treatment quality
- Prevention of discharge into public water bodies
- Inspection of commercial fish farms where required

Enforcement should be based on documented violations and applicable legal provisions. Newspaper reports can provide evidence of individual enforcement events, but they should not be used alone to establish a nationwide legal prohibition.

6. Sustainable Alternatives to Untreated Poultry Waste

6.1 Formulated Aquaculture Feeds

Commercially formulated feeds provide more controlled nutrient composition and can be manufactured according to species-specific nutritional requirements. Feed selection should consider protein quality, digestibility, feed conversion, affordability, and environmental impacts.

6.2 Treated Organic Fertilizers

Properly treated poultry manure may be used as an organic fertilizer in systems where its use is legally permitted and ecologically appropriate. Application rates should be based on nutrient content, pond productivity, water quality, and the requirements of the cultured species.

6.3 Processed Poultry By-Products

Processed poultry by-products may have value as feed ingredients when they comply with relevant feed-safety standards. Processing should be validated for pathogen control and should include appropriate quality assurance for contaminants and nutritional composition.

Raw poultry offal should not be assumed to be safe merely because it is a protein-rich material.

6.4 Integrated Waste-Management Systems

Integrated systems may combine poultry production, composting, biogas generation, crop production, and aquaculture. Such systems require nutrient budgeting, pathogen control, water-quality monitoring, and appropriate separation between waste-treatment areas and fish-production units.

7. Research Gaps and Future Directions

Further research is required to establish:

1. The survival of poultry-associated pathogens under different waste-treatment conditions.
2. The occurrence and persistence of antimicrobial-resistant bacteria and resistance genes.
3. The bioavailability of potentially toxic elements in aquaculture ponds.
4. The effects of poultry waste application rates on dissolved oxygen, ammonia, and phytoplankton.
5. The food-safety implications of different poultry by-product processing methods.
6. The economic feasibility of safe waste-treatment systems.
7. Regulatory differences between raw manure, offal, rendered products, and composted materials.

Future studies should use controlled experimental designs, validated laboratory methods, and risk assessments that consider environmental, animal, and human health together.

8. Conclusion

The use of untreated poultry waste in fish culture can create environmental and food-safety concerns when it results in excessive organic loading, nutrient enrichment, microbial contamination, or exposure to chemical contaminants. However, the severity of these risks depends on waste composition, treatment, application rate, culture conditions, and regulatory context.

Raw poultry manure, slaughterhouse offal, and processed poultry by-products should be assessed

separately because they have different nutritional characteristics, contamination pathways, and management requirements. The presence of poultry waste does not automatically establish toxic metal accumulation, antimicrobial resistance transmission, or consumer illness; such claims require specific scientific evidence.

Sustainable aquaculture should prioritize safe feed inputs, appropriate waste treatment, water-quality monitoring, disease prevention, and compliance with applicable regulations. A risk-based approach, supported by laboratory testing and effective enforcement, can help protect aquatic ecosystems, cultured fish, farmers, and consumers.

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Impact of Climate Change on Groundwater Degradation and Pathways to Sustainable Agriculture

ARTICLE ID: 0418

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Climate change has emerged as one of the most pressing environmental challenges affecting global water resources and the sustainability of agriculture. Groundwater, a vital source of freshwater for irrigation, domestic use, and industrial activities, is increasingly threatened by climate-related changes such as rising temperatures, erratic rainfall patterns, prolonged droughts, floods, and sea-level rise. These climatic

shifts have altered groundwater recharge processes, resulting in accelerated aquifer depletion and deterioration of groundwater quality in many regions worldwide. In arid and semi-arid areas, farmers are increasingly dependent on groundwater for irrigation as rainfall becomes less reliable. This often leads to over-extraction that exceeds the natural recharge capacity of aquifers. Consequently, problems such as declining water tables, salinization, nitrate contamination, and seawater intrusion pose serious threats to agricultural productivity and food security.

Furthermore, unsustainable agricultural practices, including excessive fertilizer use, inefficient irrigation, and poor land management, further intensify groundwater degradation. Groundwater scarcity driven

by climate change adversely affects crop growth, soil health, nutrient availability, and the overall resilience of agricultural systems, threatening the livelihoods of millions



of farming households worldwide. Addressing these challenges requires the adoption of sustainable agricultural practices that conserve groundwater resources while enhancing resilience to climate change. Strategies such as climate-smart agriculture, agroforestry, conservation agriculture, efficient irrigation technologies, and managed aquifer recharge have considerable potential to reduce groundwater degradation and promote agricultural sustainability. Agroforestry systems can contribute to groundwater recharge, improve soil structure, reduce erosion, and

enhance carbon sequestration. Similarly, precision irrigation technologies can minimize water losses and improve water-use efficiency. Integrating these approaches with effective policies and institutional mechanisms can contribute significantly to sustainable groundwater management and climate-resilient agriculture.

Climate change is one of the most pressing environmental challenges of the twenty-first century. Rising global temperatures, unpredictable rainfall patterns, prolonged droughts, floods, and increasing greenhouse gas emissions are placing considerable pressure on natural ecosystems and agricultural productivity worldwide. Groundwater is one of the resources particularly vulnerable to these changes. It is a vital source of freshwater for irrigation, industrial activities, and domestic use and plays a crucial role in supporting global food security, particularly in arid and semi-arid regions where rainfall is limited and highly variable (Swain et al., 2022).

The combined effects of climate change and unsustainable agricultural practices are accelerating groundwater depletion and degradation. Changes in precipitation patterns, increasing evapotranspiration, prolonged droughts, and extreme weather events can alter groundwater recharge and availability. At the same time, increasing dependence on groundwater for irrigation may result in extraction rates exceeding natural recharge. Therefore, sustainable groundwater management has become essential for maintaining agricultural productivity, environmental sustainability, and long-term water security.

Climate Change and Groundwater Degradation

Climate change directly affects groundwater systems by altering precipitation patterns, evapotranspiration rates, recharge processes, and the frequency and intensity of extreme weather events. Rising temperatures increase evaporation from soil and surface water bodies, thereby reducing the amount of water available for infiltration and groundwater recharge. In many regions, prolonged droughts have resulted in declining groundwater levels, particularly where groundwater extraction for irrigation remains high (Stigter et al., 2023).

Groundwater recharge depends largely on the infiltration of precipitation through the soil profile. However, changes in rainfall intensity and distribution associated with climate change can reduce effective infiltration and increase surface runoff. Heavy rainfall events may produce rapid runoff rather than gradual infiltration, whereas prolonged dry periods can reduce soil moisture and groundwater recharge. These changes can disturb the natural balance between groundwater withdrawal and recharge, increasing the risk of aquifer depletion (Swain et al., 2022).

In agricultural regions, declining groundwater levels can increase the cost of irrigation as farmers are required to pump water from greater depths. This may also increase energy consumption and production costs, creating additional economic pressure on farming communities.

Groundwater Quality Deterioration under Climate Change

Groundwater degradation involves not only depletion but also deterioration in water quality. Climate change

can influence the chemical and biological characteristics of groundwater systems by altering temperature, recharge patterns, contaminant transport, and microbial activity. Increasing concentrations of nitrates, pesticides, heavy metals, and dissolved salts have been reported as important groundwater-quality concerns in vulnerable regions (Pham et al., 2024).

Coastal groundwater systems are particularly vulnerable to climate change because of sea-level rise and changes in freshwater recharge. Seawater intrusion can occur when saline water moves into freshwater aquifers, increasing groundwater salinity and reducing its suitability for irrigation and drinking purposes (Richardson et al., 2024). Irrigation with saline water can adversely affect crop growth, soil structure, soil fertility, and agricultural productivity.

Extreme weather events can also contribute to groundwater contamination. Flooding may transport agricultural chemicals, nutrients, pathogens, and other pollutants into aquifer systems. In agricultural areas, excessive fertilizer and pesticide use combined with changing climatic conditions can further increase the risk of groundwater contamination (Ravindiran et al., 2023).

Impacts on Agricultural Production

Groundwater is a critical component of agricultural production, particularly in regions where surface-water availability is limited or unreliable. Declining groundwater levels can reduce irrigation reliability and increase the energy and financial costs associated with pumping. Water scarcity can adversely affect crop establishment, growth, yield, and quality.

The quality of irrigation water is equally important. Salinity, nitrate contamination, and other pollutants can affect crop growth and soil health. Excessive use of nitrogen fertilizers can result in nitrate leaching into groundwater, while inappropriate pesticide application can contribute to chemical contamination (Ravindiran et al., 2023).

Unsustainable agricultural practices can therefore create a feedback loop in which declining groundwater availability encourages greater groundwater extraction, while intensive agricultural production contributes to further groundwater contamination. Sustainable water and land management practices are consequently essential for maintaining agricultural productivity and protecting groundwater resources.

Pathways to Sustainable Agriculture

Climate-Smart Agriculture

Climate-smart agriculture (CSA) provides an integrated approach to improving agricultural productivity while increasing resilience to climate change and reducing environmental impacts. CSA includes practices that improve water-use efficiency, conserve soil moisture, reduce greenhouse gas emissions, and enhance the capacity of agricultural systems to adapt to changing climatic conditions.

Conservation practices such as minimum tillage, mulching, crop rotation, and cover cropping can improve soil structure, increase infiltration, reduce evaporation losses, and enhance soil organic matter. Improved soil structure and infiltration can contribute to groundwater recharge while increasing the availability of soil moisture for crops (Swain et al., 2022).

Agroforestry and Conservation Agriculture

Agroforestry combines trees with crops and/or livestock and can provide multiple environmental and agricultural benefits. Tree-based systems can improve soil structure, reduce erosion, enhance carbon sequestration, and contribute to improved water infiltration. In suitable environments, agroforestry can therefore support groundwater recharge and improve the resilience of agricultural landscapes.

Conservation agriculture, based on minimum soil disturbance, permanent soil cover, and crop diversification, can also improve soil-water relationships and reduce water losses. These practices are particularly important in regions experiencing increasing rainfall variability and water scarcity.

Efficient Irrigation Technologies

Sustainable groundwater management depends heavily on efficient irrigation systems such as drip and sprinkler irrigation. These technologies enable more precise application of water and can reduce unnecessary losses through evaporation, runoff, and deep percolation. Drip irrigation supplies water directly to the crop root zone, while sprinkler systems can provide more uniform water distribution compared with conventional surface irrigation.

Precision agriculture technologies, including remote sensing, artificial intelligence, soil-moisture sensors, and geographic information systems (GIS), are increasingly being used to monitor crop water requirements and optimize irrigation scheduling. These technologies can improve water-use efficiency, reduce unnecessary groundwater extraction, and enhance agricultural water productivity.

Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) is a water-management approach that involves the intentional replenishment of groundwater aquifers using available water sources such as surplus surface water, stormwater, treated wastewater, or floodwater. MAR has attracted increasing attention as a potential strategy for addressing groundwater depletion and improving water security under changing climatic conditions.

Agricultural Managed Aquifer Recharge (Ag-MAR) is particularly relevant in agricultural regions where excessive groundwater extraction for irrigation has resulted in declining water tables. By enhancing aquifer recharge during periods of water availability, MAR can contribute to restoring groundwater storage and improving long-term groundwater sustainability (Levintal et al., 2022).

Policy and Institutional Approaches

Effective policies and strong institutional frameworks are essential for addressing groundwater degradation and promoting sustainable agriculture under changing climatic conditions. Governments and environmental agencies can play an important role in regulating groundwater extraction, improving water-use efficiency, promoting sustainable land management, and supporting groundwater-recharge initiatives.

Integrated Water Resources Management (IWRM) provides a framework for coordinated management of water, land, and related resources. It aims to balance economic and social development with the protection and sustainability of ecosystems (Stigter et al., 2023).

Policies supporting climate-smart agriculture, efficient irrigation systems, groundwater monitoring,

managed aquifer recharge, rainwater harvesting, and sustainable fertilizer management can help reduce pressure on groundwater resources. Strong institutional coordination, farmer participation, scientific monitoring, and awareness programmes are also important for successful implementation.

Conclusion

Climate change is intensifying the challenges associated with groundwater depletion and deterioration, with significant implications for agricultural productivity, food security, and rural livelihoods. Rising temperatures, changing rainfall patterns, prolonged droughts, extreme weather events, and sea-level rise can alter groundwater recharge and quality. At the same time, excessive groundwater extraction, inefficient irrigation, and inappropriate use of agricultural inputs can further accelerate groundwater degradation.

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A transition towards sustainable and climate-resilient agriculture requires an integrated approach. Climate-smart agriculture, conservation agriculture, agroforestry, efficient irrigation, precision agriculture, and managed aquifer recharge can contribute to improved water-use efficiency and groundwater conservation. In addition, effective policies, institutional coordination, groundwater monitoring, and farmer participation are essential for achieving long-term sustainability.

Protecting groundwater is therefore not only a water-management challenge but also an essential component of sustainable agricultural development. Coordinated efforts among farmers, researchers, policymakers, institutions, and other stakeholders can help ensure that groundwater resources remain available for present and future generations.

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