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Estimation of Poultry Waste Emission and Prevailing Management Practices in Mardan

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ABSTRACT

This comprehensive study investigated poultry waste management practices across six representative farms in Mardan, Pakistan, analyzing both quantitative and qualitative aspects of manure production and disposal. Through field surveys, laboratory analyses (AAS, flame photometry, Kjeldahl method), and stakeholder interviews, we identified significant variations in heavy metal concentrations (Zn: 32.3-112.6 ppm; Pb: 3.21-8.31 ppm; Cd: 0.14-4.32 ppm; Cr: 0.09-5.31 ppm) and nutrient content (N: 2.7-3.7%; P: 0.18-0.54%; K: 0.8-1.7%) across samples. The research revealed that 60% of farms lacked technological integration, while disposal methods ranged from dumping (36%) to composting (24%). Notably, S4 exhibited critical chromium contamination (5.31 ppm), exceeding WHO limits by 77%, while S6 showed alarming cadmium levels (4.32 ppm). Moisture content (23.5-35.7%) influenced both nutrient retention and GHG emissions, with 72% of workers reporting health impacts from improper waste handling. These findings underscore the urgent need for standardized waste management protocols in Mardan's poultry sector, particularly regarding feed optimization (52% commercial feed users), bedding material selection (64% wood shavings), and conversion technologies (40%

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composting adoption). The study provides actionable insights suggestion to develop region-specific guidelines that balance agricultural productivity with environmental sustainability.

1. INTRODUCTION

Globally, Poultry farming is one of the largest and big sector in agriculture industry as well as a primary source of animal protein for the consumption of human. (Faraji Mahyari et al., 2021). Regarding economic growth, the poultry industry has significant contributions besides food security globally. However, besides the many useful aspects of this industry, poultry farming has severed impacts on the environment in terms of large quantity of poultry manure, bad smell and diseases. Owing to the large quantity of manure and its improper management, it brings possible hazards to the environment and human health. One significant source of these pollutants in the environment is the poultry and livestock industries. Heavy metals are poisonous compounds that various crops and vegetables bioaccumulate. These harmful compounds eventually enter the human body and cause a number of illnesses (Vilchez et al., 2020).

Mardan a district in Khyber Pakhtunkhwa, Pakistan is among the regions where the poultry farming has assumed the form of an emerging industry. Although this trend help and supports the economic development and engages the work force. However, due to lack of proper mechanism and lack of responsibilities in the disposal of poultry waste has led to various issues of bad smell, pathogens and excess nutrients. As a result of this irresponsible practice the public health and ecosystem is facing risks. In addition to producing a large amount of meat, eggs, and milk products for human consumption, livestock and poultry farming is a vital component of the livestock industry and contributes significantly to both the global circular economy and the livestock industry's sustainable growth. Based on pertinent media reports, In 2023, the size of the worldwide market for livestock and poultry farming surpassed USD 1.5 trillion. As the largest hog and poultry farming nation in the world, China produced 96.41×10^6 t of meat, 41.97×10^6 t of milk, and 35.63×10^6 t of egg products in 2023. Of these, meat production made up over 30% of the world's total meat production (Zhang et al., 2025).

However, With the large-scale growth of livestock and poultry farming, which has resulted in numerous issues like health risks, greenhouse gas emissions, declining water quality, and odours

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for the sustainable development of people and the environment, the amount of livestock manure, the most significant waste of livestock and poultry farming, has increased significantly. Livestock manure is the direct excretion of livestock and poultry digestion and metabolism (Sadeghpour and Afshar, 2024). The current rate of livestock manure resource utilisation worldwide, however, still has a lot of space for improvement. About 4 billion tonnes of livestock manure are currently produced annually in China, but only 75% of the resources are being used. This means that more work needs to be done to increase the efficiency of livestock manure's resource utilisation in order to fully realise its utilisation value and offer more extensive economic, social, and ecological benefits (Li et al., 2021).

The research work focused on the emission and discharge status of poultry derived manure waste in Mardan region as well as the prevailing and current management and disposal practices. Also, this study was making an attempt to various strategies and approaches presently under pipelines and to find sustainable poultry manure disposal practices. The proposed study was help in enabling the key stakeholders such as policymakers, farmers and industrialists to adopt sustainable waste management practices for sustainable poultry farming (Ogunlade et al., 2017). Furthermore, in larger context the proposed research work was attempt to derive important knowledge and better understanding regarding the responsible poultry farming and poultry manure disposal in the Mardan region (Stingone & Wing, 2011).

In addition, the work is intended to examine the various aspects of waste management in the Mardan region because of the unique socioeconomic, ecological and environmental settings. Poultry farming is among the major essential economic activities in the local community whereby it contributes to the development of the economy and nourishment of the local population. Therefore, it is important to investigate the poultry derived manure is disposed of and the emergence of various environmental issues and concerns (Vilchez et al., 2020). As result, a thorough investigation of the discharge of poultry manure helped in the identification of gaps and various areas for improvement. Moreover, it was facilitating the stakeholders to adopt sustainable environmental, low-cost technologies to cope with the impacts of poultry manure.

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Nitrogen compounds present serious environmental problems, especially when they come from livestock manure. Ammonia (NH₃) emissions from livestock manure contribute to pollution, nitrogen excess, and climate-related issues. These days, the problem is getting worse due to the intensification of livestock farming; for example, 43% of nitrogen (N) emissions in the Netherlands are caused by agriculture. There are nutritional imbalances as a result of livestock manure exceeding agricultural land's absorption capacity. Dutch farmers are therefore under a lot of pressure to lower their N emissions, which forces them to use creative manure management techniques (Llaca Arrubarrena, 2024).

The data collected through field surveys and questionnaires and subsequently the data analysis was help in the management of poultry manure as an emerging contaminant. Finally, the main objective of the study is to draw conclusions and recommendations based on the collected data for the sustainable management of poultry manure and to mitigate the harmful impacts of the manure on environment and local community in the Mardan region. In order to effectively implement the sustainable practices for poultry waste management awareness and capacity building of the stakeholders was be encouraged (Ogunlade et al., 2017).

The resource utilisation potential of livestock manure in terms of fertiliser and energy is still unknown, though, as the majority of current research focusses on developing and improving particular technologies for the resource utilisation of livestock manure to increase its resource utilisation rate. Therefore, there is some question as to whether using livestock manure as a replacement for chemical fertilisers and fuels in the resource utilisation process is truly feasible from an economic and environmental standpoint. Thus, there is a pressing need to assess the viability and potential of using livestock manure in fertiliser and energy applications, highlight the significant value of its resource utilisation, give pertinent policymakers a basis for decision-making, and successfully encourage the effective use of livestock and poultry wastes as resources.

1.1 Problem statement

The speedy growth of the poultry manufacture in Mardan has importantly changed occupations and food security. Nevertheless, this increase has also led to an addition in poultry waste,

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especially organic fertilizer, which, if not managed in good order, poses thoughtful environmental and public health danger. In many regions, poultry waste is either dumped openly, used improperly in agriculture, or stored without satisfactory safeguards, leading to soil impressiveness, water contamination, and disgusting odors. Dislike these situations, there is controlled general data on the real volume of poultry waste produced and the average practices adopted for its management. This need for information hinders the improvement of impressive waste management argumentation and grooming. Consequently, there is a need to approximate the poultry waste generated in Mardan and analyse how farmers are presently managing this waste to determine spread and suggest property statements.

1.2 The study's importance

This study holds significant importance in the statement of increasing environmental and public eye well-being concerns related to poultry waste material in the stage in Mardan. As poultry farming continues to spread out in response to accelerative activity for eggs and meat, there is a symmetric growth in the manufacture of poultry manure, which, if not improperly managed, can lead to water, soil, and air pollution. This research aims to give trusty data on the amount of poultry waste generated in the area and the methods presently used for its management or utilisation. The findings was help to determine gaps in waste management activity and their necessity for sustainable water quality, agriculture, and public sanitarians. However, the study has the possibility to guide local government, workplaces, and policymakers in underdeveloped eco-friendly waste management systems, support organic plant food use, and minimize health hazards. By highlighting the environmental hazard and resource recovery possibility connected with poultry waste, this research approval contributes to the wider goal of improving the property of placental mammal farming and the environment in the region.

1.3 Objectives:

The following are some of the study's goals:

- Estimation of poultry manure production from poultry farms in Mardan.

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- To examine the prevailing storage and application methods for poultry manure in Mardan.
- Assessment of the efficiency and sustainability of disposal methods applied,

2. LITERATURE REVIEW

In the poultry industry, waste management is an essential part of sustainable poultry farming. Several studies have been conducted to estimate poultry waste emissions and how they are managed. Poultry waste has been defined as having detrimental effects on the environment and, sometimes, human health if not well managed. Open dumping leads to contamination of groundwater salinity and surface run-offs with surface. Further, it acts as a source of attraction for pests, (Ogunlade et al., 2017) and emissions produced from poultry waste are unsafe for human inhalation due to the release of substances such as particulates and toxins which may lead to the cause of many health problems. The poultry Industry offers an essential source of animal protein and makes a substantial contribution to the creation of jobs. In terms of global chicken production, Asian nations have outpaced Australia and New Zealand. Notably, in recent years, China, the US, Brazil, Russia, Mexico, India, and Pakistan have become major players in the global market for chicken production (Khater et al., 2020).

With 2.3% of GDP, the poultry industry in Pakistan makes a significant contribution to the country's economy. It also has a big impact on how stable the prices of beef and mutton are. The poultry industry faces a major challenge from poultry scoliosis, a destructive bird disease that is common throughout the world. Because of the increased mortality, decreased weight gain, and increased susceptibility to necrotic enteritis, this condition has a substantial financial impact (Begum et al., 2024). The appropriate waste management methods have been recommended anaerobic digestion as an appropriate method of poultry and livestock waste management and as an important strategy and sustainable approach for efficient waste measure. studies have equally been done on the impact of ammonia and greenhouse gas emissions on air rearing and manure management, with little practice being done scientist had recommended more environmentally friendly practices (Stingone & Wing, 2011)., poor waste management practices and improper ways of waste disposal is as a result of lack of enough information, orientations, and things

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poultry food industries. Methodologies that lead poor disposal and converting waste to other important resources priorities for up-cycling poultry waste downstream processes.

Massive research on poultry into sustainable diesel production and production and demonstration of novel products like composite resource producing innovative utilization and demonstration in poultry resources, such as up-cycling to form resources of high value. All the research result and methodology in the literature review encourages safer waste management to help reduce the effect on the environment and in return also prevent the spreading of related harm to humans (Farrow et al., 2017).

2.1 Manure Vs Litter

The urine and faecal production by animals which contains nutrients and organic material is specified as “manure” which is used to elevate soil quality. On the contrary, the waste production by the poultry sector that includes spilt feed, chick feathers, sawdust, straw, faeces etc. is referred to as “litter” (Bolan et al., 2010). Poultry waste majorly consists of manure, dead animals and their body parts and the bedding material used at farming facilities. Manure and litter are mainly composed of water, and carbon with nitrogen and phosphorus in low amounts while zinc, calcium, copper, manganese, magnesium, sodium, arsenic and iron are in trace amounts (Muduli et al., 2019).

2.2 Poultry Manure Production

The estimated manure production of poultry birds varies depending on the breed, weight, feed and control measures. Around 200-350kg/1000 birds of manure is generated by turkeys while ducks produce about 150kg/1000 of waste. Moreover, chicken manure production varies by breed, typically broilers produce 80kg/1000 of waste compared to layers with 120kg/1000 (Alkış and Celen, 2009). Globally United States by far is the biggest provider of poultry followed by countries like China and Brazil (Lark et al., 2021). People in the U.S. consume more chicken meat than any other and according to an estimate in 2014 on average an American eats 37.64 kg of meat per person annually this shows that this number has doubled as of 1970 (USDA., 2016).

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Approximately, 13-14 million tons of avian manure is generated only in the United States and Brazil is a giant chicken meat producer which results in roughly ten million metric tons of manure (Dalólio et al., 2017). Around two and a half billion chickens generate over 150 million metric tons of productive waste only in China (Guo et al., 2025). Meanwhile, approximately 4M tons of poultry manure is generated each year in the country of South Africa alone and it is projected to surge quickly (Ravindran et al., 2017). Combined with North and Latin America, Asia produced three-quarters of the total chicken around the globe whilst the year 2022 has seen 33×10^9 of chicken production globally (Herforth et al., 2020). In 2012, more than 270 million tons of manure was produced in France and was used for cultivated and pasture lands (Sheriff et al., 2023)).

2.3 Poultry Farming, Pakistan

The poultry sector contributes to Pakistan's agro-industry. In the 1960s, poultry farming was started on an industrial scale which headed difficulties in beginning later in the 90s the technological up-gradation and investments accelerated the growth of the farming business. Globally Pakistan ranks eleventh in poultry production while it contributes 1.4 percent to the country's GDP. An estimated 48 million layers and 1 billion hybrid chickens are produced each year (Hussain et al., 2015).

Poultry is one of the major contributors to the agricultural sector in Pakistan. It provides a major share of meat to the country's population with 25%. Around one and a half million people are associated explicitly or implicitly with the sector. Poultry farming is divided into commercial and domestic farming where commercial farming comprises growing broilers for meat and layers for eggs. However, domestic farming is more associated with hens and chickens. This sector provides other secondary products like chicken manure, eggshells and feathers, blood, etc., for other purposes (Bolan et al., 2010). Poultry production in Pakistan has hit approximately a thousand and three-forty million (Wing et al., 2021). In Pakistan, a single chicken generates two kilograms of manure; annually, 1 million tons of manure is formed by poultry (Amjid et al., 2011).

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In Pakistan, a quarter of meat produced in the country is produced by the poultry sector. The total investment and the revenue generated from the poultry sector were 200 and 564 billion rupees respectively. This represents that poultry farming is a growing industry in Pakistan with a promising growth rate of 8 to 10%. However, still, per capita provision of meat is quite less which is 5 kg/year compared to developed countries which is more than 40 kg/year and the same is the case with eggs. A report by the WHO has revealed that 27 grams of protein is required for a single person in a day however, in Pakistan the protein intake is 17 grams (Memon, 2012).

Comparative analysis of poultry and livestock manure reveals that poultry manure has greater zinc concentrations than livestock manure. The amount of zinc available in poultry manure is 427mg per kg compared to livestock manure which is 150 mg per kg (Wieremiej, 2017). Organic poultry manure has been produced and utilized in abundance worldwide and its production has been projected to further accelerate and was reach more than 450 million tons by the end of the decade (Zhang et al., 2022). The amount of nutrients estimated to be present in poultry manure includes 83.5%, 68.5% and 65.5% of K, P and N respectively which is utilized as manure for crops and nutrient recycling (Olumayowa and Abiodun, 2011).

Studies have shown that frequent amendment of poultry manure to the fields elevates soil quality by increasing organic material and productivity (Lin et al., 2018). According to a study conducted by (Magagula et al., 2010) farmers supplementing chicken manure for sweet potato farming increase the vegetative growth in high quantities however, it affects the crop negatively and causes tuber formations. The application of poultry manure is beneficial for improving soil fertility of previously degraded soil providing the required nutrients increasing the organic matter content in the soil and reducing the reliance on mineral fertilizers in cost cost-effective manner (Singh et al., 2010).

2.4 Heavy Metals in Poultry Meat:

Raw materials added in feed contain trace elements that are the major source of heavy metal contamination in the natural environment. Poultry manure contains trace elements like heavy metals that are used to improve poultry feed which elevates mass gain reduces disease spread

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and increases the nutritional value of the chicken feed (Hoque et al., 2023). These trace elements including copper and iron are used for the prevention of blood deficiency disorder, and manganese and zinc are incorporated for the proper growth of feathers and eggshells. Additionally, antioxidants are added to inhibit vitamin degradation. Antibiotics and pesticides have been used for disease and vermin prevention while during the chicken's transportation, anaesthetics are used for ease of transit. A variation has been shown by different animal manures in terms of their heavy metals uptake (Bolan et al., 2010).

A study conducted in Kohat, Pakistan revealed the presence of Zn, Pb and Cd in organs and meat of the chicken samples collected from the marketplace. These heavy metals were present in higher concentrations in the kidneys, liver and heart of the chickens (Abdel-Salam et al., 2013). Another study observed higher concentrations of heavy metals in the brain and liver of domestic poultry than in broiler chickens in Bangladesh's capital Dhaka. The concentration of zinc was exceeded by 294.724mg/kg and 551.381mg/kg in the brain and liver, similarly, a concentration elevated by 4.141mg/kg and 2.73mg/kg was observed in the brain and liver in the same order (Araf et al., 2022).

Similarly, heavy metals like Arsenic and cadmium were detected in chicken samples. The concentration of arsenic was higher in breast meat while lower in liver unlikely cadmium concentration was much lower in breast meat than in kidneys (Mohammed., 2013). Poultry manure has less carbon content in contrast to other animal manures while it contains the highest phosphorus concentration and much greater pH levels recorded (Irshad et al., 2013). The concentration of heavy metals beyond the legal standards, copper concentrations of 1726 mg/kg were detected in manure in China. Meanwhile, lead, zinc, and chromium concentrations exceeded the requirement (Haroon et al., 2019).

To determine the metal concentration in poultry manure metal fractionation can be an effective approach to observe the biological availability and risk of contaminating the water bodies and soil. A vital nutrient for the chicken's growth, molybdenum has been incorporated into their feed however, in high amounts, it can increase the lack of copper which reduces meat mass, and iron leads to diarrhea. The FDA does not approve the usage of the element in poultry feed (Li et al.,

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2021). In the formation of organomineral fertilizers, a more sustainable alternative to chemical fertilizers, poultry manure is used which has nitrogen in abundance. 1/3 of the present nitrogen is in the form of ammonium that volatilizes in the atmosphere and transforms to NH_3 due to some driving factors like humidity and temperature (Shaji et al., 2021).

Poultry manure has roughly 14% inorganic nitrogen out of the overall nitrogen content while around 40% of phosphorus is present, and only 6% can be obtained through water (Turner., 2002).

2.5 Environmental Impact

2.5.1 Water Quality

In recent economic developments, the poultry industry has significant contributions to food security globally. However, besides the many useful aspects of this industry, poultry farming severely impacts the environment in terms of large quantities of poultry manure, bad odours and diseases. Owing to the large quantity of manure and its improper management bears possible hazards to the environment and human health. These environmental contaminants are largely caused by the poultry and livestock industries. Various crops and vegetables bioaccumulate heavy metals, which are toxic substances. These harmful compounds eventually enter the human body and cause a number of illnesses (Vilchez et al., 2020).

Poultry waste is problematic in terms of entering the environment in solid, liquid and gaseous forms polluting water, air and soil while it contains potential toxicants and nutrients that are difficult to identify hence it is crucial to stabilize or utilize it in the best way possible (Gordienko and Gordienko, 2024). Generally, farming waste discharge through water pipes ends up in water bodies affecting the environment and contaminating the rivers, ponds and groundwater containing heavy metals, antibiotic substances and microbes (Srivastav et al., 2024).

Hatchery waste can degrade the ecosystem by contaminating the surface water causing eutrophication by an increase in nutrients, heavy metals and turbidity, algal growth and bioaccumulation (Taiwo et al., 2025). The amendment of hatchery manure to rangeland and crops as the nutrient source has been considered as a nonpoint pollution source like nitrogen and

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phosphorus in the downstream water bodies via different channels. The rapid decomposition of organic matter in the tropics means that nutrient retention is a limiting factor to soil productivity. One emerging management strategy to maintain higher yields is the addition of biochar (Babu et al., 2025). While biochar has proven to have a positive conditioning effect on soil, it may be limited as a nutrient supplier alone, because of its relatively low nutrient composition and recalcitrance to the improvement of people's lipid degradation (Partey et al., 2014).

Improper poultry waste management can deteriorate water quality due to several factors: the distance from the farm, the farm's capacity, its lifespan and the location of the water reservoir from the hatchery. The study revealed that the shallow wells near the farming site were not desirable and below the recommended standards which need a proper waste management system (Abioye et al., 2024). If the poultry manure is applied in the right amount, it is still problematic due to the complication by nitrogenous compounds and salts with trace metals not during the cropping season contaminating the groundwater by leachate of nutrients and polluting the surface water through runoff via flow channels. Environmental deterioration of natural resources by deforestation and soil degradation is linked with the poultry industry as the feed contains soya beans in much higher amounts as part of the non-ruminant diet (Muhammad et al., 2020).

2.5.2 Soil Impact:

A farm raising 6×10^5 chickens annually generates more than three thousand tons of poultry manure which has a massive amount of N content estimated to be 7.2×10^4 which were need land of 570 acres of maize field for disposal (MacDonald, 2010). The addition of poultry manure increases the soil organic matter, fertility, water holding capacity, nutrient levels and crop yield by many folds specifically Amaranthus crops saw an increase in leaf growth, and biomass. The application of 40 tons per hectare of poultry manure has increased the levels of Nitrogen and Phosphorus in Amaranthus. Moreover, the protein, potassium, calcium, and magnesium were boosted by adding 20 tons of manure per hectare. However, the concentration of heavy metals has also increased but remained under the permissible limits. The study recommended the addition of the amount of poultry manure in the soil of 20 tons per hectare (Adekiya et al., 2022).

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Manure changes the micronutrient availability for plants in the soil due to changes in the soil's microbial and physical properties. Most of the time manure application has greater root extension as a result of better hydration capacity of the soil (Pramod et al., 2024).

A study observed a 33% rise in tomato production by application of poultry manure in a high concentration (Demir et al., 2010).

2.5.3 Air pollution:

The lifecycle assessment of poultry chicken shows that from the origin to the sales the greenhouse gas emissions can be as high as two and a half to twenty kg of CO₂ equivalent to per kg of its consumable weight while on average it ranges from 7-10 kgCO₂ (FAO, GHG emission from livestock). The dumping of chicken waste in the soil causes huge emissions of greenhouse gases into the air such as Nitrogen dioxide, methane, ammonia and nitrous oxide (Billen et al., 2015). Poultry manure releases ammonia, a byproduct of uric acid's microbial decomposition in poultry waste. The poultry litter is intermixed with waste on the floor at the farming facility decomposes and releases many gases like ammonia in a much higher amount than other gases (USDA, 2021).

In aerated storage settings, chicken manure releases more carbon dioxide and ammonia. During composting, the ammonia released into the air is studied to be greater than livestock manure like cattle and pig manure (Wang et al., 2015). A high amount of ammonia can cause many problems such as driving the presence of greenhouse gases like nitrogen oxide (Felix, E.P. and Cardoso, A.A., 2012) while it may trigger respiratory diseases in humans over continuous exposure (Chuang et al., 2025). Factors that determine the emission levels for ammonia are dependent mainly on the indoor environmental conditions including humidity level, thermal measure, pH, wind velocity and microbial activity (Faulkner and Shaw, 2008).

2.5.4 Health Effects:

Toxic heavy metals enter the food chain through various pathways when dumped in the natural environment. The health risks associated with heavy metal toxicity include neurotoxicity, cardiovascular dysfunction and cancer by arsenic. Furthermore, it can be a source of air pollution due to the release of GHGs and particulate dust leading to global warming and climate variation

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while affecting the respiratory system in humans causing inflammation of the lung lining and cancer of the lungs (Benson et al., 2019). The presence of testosterone and estrogen levels in poultry litter in Israel has been shown to disrupt reproductive capability.

2.6 Pathogens in Poultry Manure

Poultry waste holds microbes and toxins such as bacteria, and spores that are ingested through breathing. Dust containing these pathogens is called bio-aerosol which may enter the food web, its dispersion in the air causes pulmonary infections and skin sensitivity in humans (Jerez et al., 2014). Farmers are at risk of diseases from exposure to manure ranging from small medical conditions such as loss of smell recognition to serious long-term lung diseases like breathing disorders and obstructive lung disease that require consideration (Kitjakrancharoensin et al., 2020).

Listeria, a gram-positive bacterium that exists in abundance in poultry manure, once introduced into the environment it leads to an infection called listeriosis. However, these bacterial species are now resistant to some antibacterial compounds namely penicillin, fluoroquinolone and ciprofloxacin (Çokal et al., 2022).

Escherichia coli is widely present in the litter samples of chickens, with a rate of as much as a hundred percent. A study conducted revealed that poultry manure of layers contains many microorganisms, especially *Salmonella* bacteria. The percentages were 55, 41 and 16 in 18-, 75-78- and 66-74-weeks old chickens respectively. Microbial presence in chicken waste can reach up to 10 billion colony-forming units per gram. *Bacillus* or *Lactobacillus*, *Actinomycetes* and *Eubacteria* are the bacteria that account for 90% of the total species (Bolan et al., 2010).

A study examined the presence of *Hermetia illucens* L. which works against manure's harmful foodborne pathogens. After 2 days of sampling the number of *Salmonella* bacteria decreased by 10'000 times while three days after the population of *E.coli* bacteria saw a higher decline of 1,000,000 times. Studies found that the addition of calcium oxide and calcium hydroxide increases the pH of manure as much as 12 and releases heat that increases the temperature which leads to the elimination of intestinal pathogens that are not able to tolerate the elevated temperatures and high pH (Stringfellow et al., 2011).

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2.7 Antibiotics

Antibiotics are utilized for protection against harmful microorganisms in living bodies. Due to the usage of antibiotics in feed, they are not absorbed completely absorption in the body, they are released and enter through the urine and faeces (Yeom et al. 2017). When manure contaminated with antibiotics is applied to soil for cultivated lands it alters the soil's natural microbial conditions (Zhao et al. 2010).

Global consumption of antimicrobial drugs per year has reached 1×10^5 to 2×10^5 tons (Ahmad et al., 2014). Increasing the usage of antibiotics in animal feed has led to the unavoidable issue of increasing antibiotic resistance in poultry animals specifically in underdeveloped nations (Nayiga et al., 2020).

The persistence of activated antibiotics in the environment critically affects the indigenous microbial presence in the soil (Schmitt et al. 2005). Due to the high organic material in manure, antibiotics such as sulfonamides and fluoroquinolones get attached to organic material while remaining unchanged for a prolonged period after being subjected to high heat and aerification (Marengo et al. 1997).

Antibiotics are used predominantly as growth boosters in Pakistan, as an underdeveloped nation, Pakistan does not have proper checks on the usage of antibiotics specifically in villages. There exists a lack of management regard its usage which were exacerbate antibiotic resistance (Habiba et al., 2023). Resistant to Antibiotics, the bacterial species *Staphylococcus aureus* has been found in 67% of the taken samples in a study which shows the widespread existence of these pathogens phenomenon (Wu et al., 2018). Antimicrobial resistance was shown in half of the Salmonella strains in a study of ciprofloxacin in Italy and Poland. On the contrary, countries like Norway and Sweden have shown no antimicrobial resistance which indicates that antibiotic resistance is linked to high-intensity farming.

2.8 Microplastics in Poultry Manure

The existence of microplastics has been detected in both poultry manure and feed. A study in China unveils the polypropylene and polyethylene polymers in poultry manure. It is considered

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that poultry birds may excrete microplastics via a contaminated diet. The contaminated poultry manure is potentially polluting the soil when used as fertilizer (Wu et al., 2021). High amounts of microplastics were detected in remediated animal waste. (Zhang et al., 2022) revealed that 150 microplastics per kilogram of manure were detected in chicken waste. Similarly, 144 microplastics per kilogram of manure have been found in goat manure.

After the treatment process, the nitrogen concentration varies in the remaining manure. In the case of direct application of poultry manure, nitrogen availability is the highest. On the contrary, total nitrogen is absent after the heat transformation process. However, a portion of the nitrogen is removed during crystallization and composting (Nusselder et al., 2020).

2.9 Poultry Waste Management

In developing countries, poultry waste is dumped without treatment, resulting in soil and surface water pollution (Flavin, C., 2002). Chicken manure has valuable nutrients that are used as organic fertilizer. However, its treatment is necessary prior to being used for crops otherwise it leads to GHG emissions, deteriorating aquatic ecosystems and poses a threat to human health and the environment (Ravindran et al., 2017).

Storage of poultry waste is important in poultry management. Chicken farmers store litter in open vicinity usually along the roadside or near the farming facility which poses a threat to the environment (Hossain, et al., 2014). Treatment technologies for poultry manure management are studied by (Kelleher et al. 2002) which include anaerobic digestion, composting and incineration.

Modern poultry farms use technology for litter removal which is further processed through composting and other additives such as separating solid-liquid leads to a reduction of 30% of methane in contrast to unmanaged waste (Fournel., 2011 Felipe Montes et al., 2013). Supplements are added to the poultry manure to make an organic fertilizer that can be utilized as bedding material in soil by active composting (Duan, N., 2020). However, manure has a high-water concentration and lower carbon-nitrogen ratio which may inhibit bacterial replication (Chang, R., 2021). One of the ways to overcome the release of GHGs from poultry manure is by mixing 5% powdered tobacco and bran mushroom in a double ratio to poultry manure to make

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compost (Zhang, B., 2021). In China, composting of chicken manure with the addition of biochar, powdered tobacco, and bran mushroom has generated substantially higher revenue and fewer ecological impacts on the other hand it has raised the production of natural fertilizers (Zhang, B., 2022).

High in potassium, biomass ash (forest and crop residue) added in organic poultry manure improves the micro and macronutrients and lowers the water content which has great benefits in terms of bad odor and speedy dissolution of manure which is a much better alternative to synthetic fertilizers (Dede., 2018). The hydrothermal process is one of the most efficient and nature-friendly ways to substantially decrease ammonia escape into the air. This transforms the harmful pollutants and pathogens into a much harmless form lowering the amount of manure and having less environmental impact (He, X., Wang, 2023).

During the composting process of the poultry manure, biochar has been incorporated in fewer amounts which is helpful in efficiently decreasing the production of volatile organic compounds. This happens at the most active microbial stage of the process which lowers oxygen-rich and nitrated VOCs (Sánchez-Monedero, 2019). When utilized as a bulking agent biochar can significantly reduce hydrogen sulfide release by 60-70% when applied in amounts ranging between 5-20% (Steiner, 2010). Synthetic fertilizers affect soil properties in long-term scenarios increasing manure and composting practices is one of the ways to adopt sustainable substitutes which were revitalize the soil nutrients and help to protect the environment (Tamás, J., 2010, Mézes, 2015, He Ze et al., 2020, Gorliczay, E., Boczonádi, 2021).

For the adsorption of heavy metals, passivators are substances used which have great affinity, binding, and ion exchange properties. They are significant in decreasing the absorption efficiency of heavy metals in manure which means the transformation of these metals into a less soluble state (Jiang, H.F et al., 2018).

All three chemical, physical and microbial treatments are used to remove pathogens in manure whereas these processes cannot eliminate trace heavy metals and some microbes. For instance, coliform bacteria that exist in poultry manure show resistance to these treatment processes and

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remain undetected through the current laboratory techniques hence, problematic to deal with (Mokhtar, et al 2023).

2.10 Composting

Composting is a sustainable and environmentally friendly technique for transforming poultry waste, which uses organic material and changes it into a soil conditioner called compost (Said M., 2020). Composted chicken waste has 31% carbohydrates and 27% proteins but newly collected manure has 7% more protein but 10% fewer carbohydrates which means that these chickens are excessively fed to gain the desired mass before 40 days and the carbohydrates are not metabolized in their body although these nutrients are stored in manure can be used as biofuel (Singh, 2018).

High demographic density and intensive meat production cause improper waste management which is a health risk (Rahman, M.M et al., 2022). Proper waste management improves the environment and boosts industries and the economy. The waste material of poultry is utilized by industries and the agricultural sector via a rendering system (Jayathilakan et al., 2012).

2.11 Anaerobic digestion

The poultry industry has been expanding at a rate of 5% yearly. A promising way of utilizing poultry waste as a raw material for anaerobic digestion (Mottet, A., Tempio, G., 2017). Anaerobic digestion can be classified as dry, wet and semi-dry digestion with varying fluid concentrations. The total solid amount for dry, wet and semi-dry digestion is 15%, 10% and 10-15% accordingly (Li et al., 2013). New developments in the digestion technique minimize ammonia emissions, thermo-chemical treatment and microbial augmentation show that the anaerobic digestion process tends to settle waste into valuable products (Hassanein et al., 2019). Biogas is generated through anaerobic decomposition which is a feasible way to tackle waste production at farms in an environmentally sound manner (O'Callaghan, K., 2016). However, the remains of the manure at the plant can be utilized as an organic fertilizer that is high in nutrient content (Smith, J, 2014).

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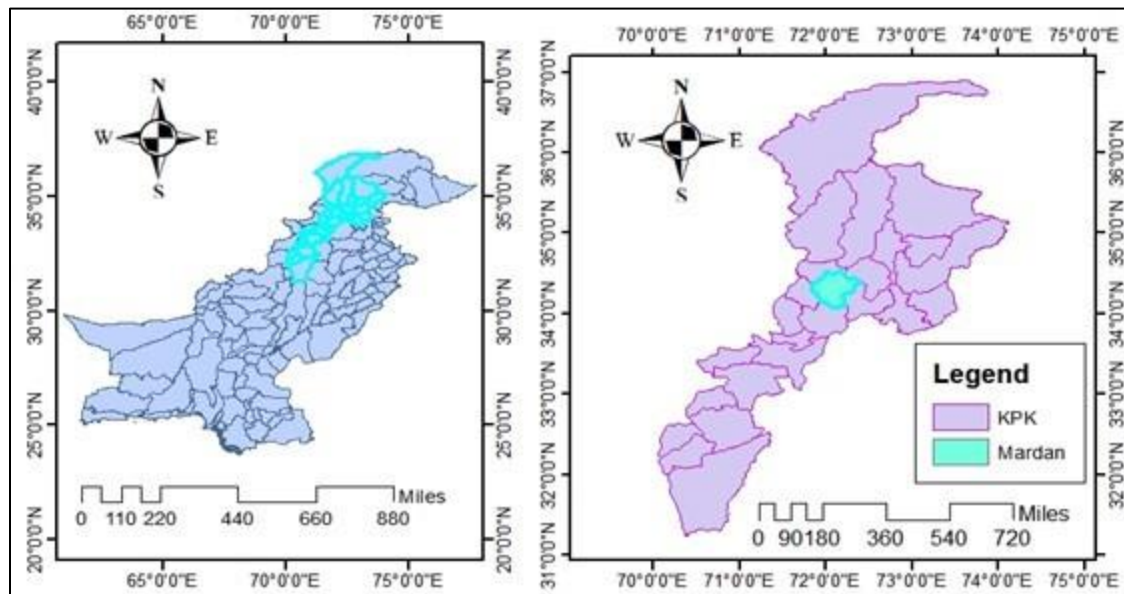
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3. MATERIALS AND METHODS

3.1 Study Area

Mardan, one of the most prominent districts in the Khyber Pakhtunkhwa (KPK) province of Pakistan, is geographically positioned at a latitude of 34.1986° North and a longitude of 72.0451° East, with an approximate elevation of 283 meters (928 feet) above sea level. The district is located northeast of Peshawar and serves as a central urban and agricultural hub in the region. Mardan is known for its fertile plains, moderate climate, and robust irrigation infrastructure, which supports a wide range of agricultural activities including the cultivation of crops such as wheat, sugarcane, maize, and tobacco. In addition to agriculture, the district has seen a significant rise in livestock and poultry farming over the past two decades, owing to growing demand for meat and eggs in urban and rural markets. Poultry farming, in particular, has become a vital economic activity, providing employment, nutrition, and income to thousands of families in both rural and peri-urban areas of Mardan. The availability of land, feed, labor, and local markets has encouraged farmers to invest in both broiler and layer poultry farms, which range from small backyard units to medium and large-scale commercial operations.



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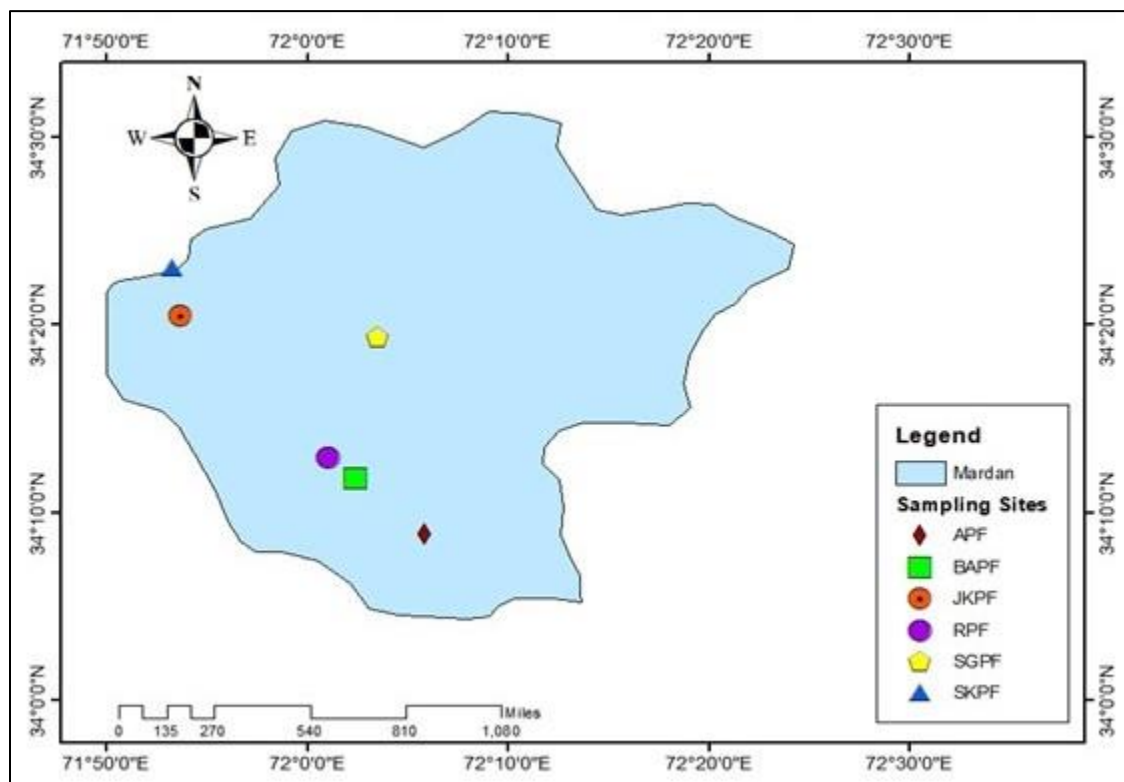


Figure 3. 1 Figure 1: Study area map of Mardan poultry forms

For the purposes of this study, six poultry farms were identified and selected to represent a cross-section of prevailing poultry management practices in different parts of Mardan. These farms are strategically located in various areas to reflect diverse geographical, operational, and socio-economic conditions. Shaheen Poultry Farm, located along Katlang Road, operates as a broiler farm and is representative of semi-urban poultry operations with moderate mechanization. Iqbal Poultry Farm, situated in the Takht Bhai area, is a mixed unit rearing both broilers and layers, providing an opportunity to observe the waste output and management variations between the two types. Al-Noor Poultry Farm, based in Gujar Garhi, is a mid-sized broiler facility known for its use of traditional bedding materials and limited mechanized waste disposal systems. In the western rural region, Usman Poultry Farm in Rustam represents a typical rural broiler setup, where waste disposal often relies on open dumping or informal manure sales to nearby farmers. Zia Poultry Farm, found on Bakhshali Road, specializes in layer farming and is one of the few

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farms in the area using basic composting techniques to manage poultry litter. Lastly, Hussain Poultry Farm, located on Lundkhwar Road, is a broiler unit operating on a moderate scale, facing challenges related to space, waste storage, and seasonal management of poultry manure.

These selected farms serve as vital case study locations for assessing the estimation of poultry waste emission and understanding the prevailing management practices being adopted by poultry farmers in Mardan. Through structured questionnaires, field observations, and manure sampling, this study aims to investigate the amount of waste produced, methods of collection and disposal, conversion into value-added products (such as compost or biogas), and the possible effects on the environment and human health. The incorporation of these geographically diverse farms ensures that the study provides a comprehensive and realistic picture of the district's methods for managing poultry waste, offering insights that could be used to develop more sustainable and environmentally sound strategies in the future.

3.2 Data Collection

Field Surveys: Field surveys involve a visit to some poultry farms around Mardan to obtain primary data, including farm size and poultry production capacity, manure characteristics, and manure utilization/disposal procedures. Structured questionnaires with open and closed formats and an observational approach are essential tools for data collection. The sampling of poultry manure should also be undertaken to provide samples for laboratory analysis Ge et al., 2012. It was involve analysis of the contents and characteristics like nutrient content, composition, and the presence of contaminants like heavy metals. Measurement of gas emissions with gas sensors or gas chromatography is also appropriate when it comes to measuring GHG emissions of methane and nitrous oxide from poultry waste, which will establish the environmental problem of pollution that arises from poultry farming in Mardan.

3.3 Samples Collection and protocols

Fo this study, manure samples were collected from six poultry farms in Mardan District, including Shaheen Farm, Iqbal Poultry Farm, AL-Noor Poultry Farm, Usman Poultry Farm, Zia

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Poultry Farm, and Hussain Poultry Farm. From each farm three representatives' samples were collected from different locations within the manure storage area to ensure spatial variability. Fresh manure samples (approximately 500 g each) were collected using sterile zip-lock polyethylene bags to prevent contamination, with care taken to remove large debris such as feathers and feed residues. Each sample was labeled with a unique identifier, farm code, and collection date. To maintain sample integrity, collected manure was immediately sealed and stored in a cooled ice box at 4 °C, during transport to laboratory. Field documentation included GPS coordinate, photographs records attached with as (Annexure A), and observations on manure handling practices. Samples were later air-dried, homogenized, and sieved before heavy metal analysis to ensure consistency and accuracy in laboratory testing.

Table 3. 1 Sampling Code and labeling of the poultry farms in Mardan

S.No	Sample Code	Poultry Farm Name	Location in Mardan
1	S1	Shaheen Poultry Farm	Katlan Road
2	S2	Iqbal Poultry Farm	Takht Bhai
3	S3	Al- Noor Poultry Farm	Gujjar Garhi
4	S4	Usman Poultry Farm	Rustam
5	S5	Zia Poultry Farm	Bakhshali
6	S6	Hussain Poultry Farm	Lundkhawar

The following procedures were followed for the experimental working in the laboratory.

3.4 Laboratory Analysis of Poultry Manure Samples

To characterize the chemical and environmental properties of poultry manure, laboratory analysis was conducted to determine concentration of heavy metals like (Zinc, Lead, Cadmium, Chromium), total nitrogen, available phosphorous, and moisture content. For experimental analysis the Standard procedures, including wet acid digestion, distillation, spectrophotometry, and gravimetric drying, were followed as (APHA 2017) standard protocols.

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3.4.1 Determination of Heavy Metals

The concentration of selected heavy metals (Zn, Pb, Cd and Cr) in poultry manure samples were analyzed using Atomic Absorption Spectrophotometry (AAS) after wet digestion.

Procedure

Approximately 1 gram of dried and ground poultry manure was accurately weighed and transferred to a digestion flask. Ten millilitres of concentrated nitric acid (HNO₃, 65%) were added to each sample. The mixture was heated on a hot plate at 120°C until the emission of brown nitrogen dioxide fumes decreased, indicating partial digestion of organic matter, after being pre-digested for 30 minutes at room temperature to reduce foaming. To guarantee full oxidation, 5 millilitres of perchloric acid (HClO₄, 70%) was then added. Heating continued until the digest became clear, signifying complete decomposition of the organic matrix. Following cooling, the digest was filtered through Whatman No. 42 filter paper and then moved to a 50 ml volumetric flask, with deionised water added to reach the final volume.

Instrumental Analysis

The flame Atomic Absorption Spectrophotometer (AAS) was used to analyse the digested samples. The following were the particular hollow cathode lamps and wavelengths for each metal.

Zinc: 213.9 nm

Lead: 283.3 nm

Cadmium: 228.8 nm

Chromium: 357.9 nm

For every metal, a commercially certified stock solution was used to create the standard solutions. Calibration curves were constructed using at least five concentrations levels and sample concentrations were determined by comparing absorbance values against these curves. Blanks and quality control standards were analyzed along with samples to ensure precision and accuracy (APHA, 2017).

Calculation

$$\text{Heavy Metal} = (\text{ppm in extract} - \text{blank}) \times \frac{A}{W_t}$$

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Where:

A= Total volume of the extract (ml)

W= Weight of dry in (g)

3.4.2 Determined of Total Nitrogen (Kjeldahl Method)

Digestion

To begin the nitrogen estimation, take 0.5 grams of the sample and add 10-12 ml of concentrated sulfuric acid (H_2SO_4). Then add 1.1 grams of a digestion mixture composed of potassium sulfate (K_2SO_4) and copper sulfate (CuSO_4). Allow the sample to digest for 3-4 hours until the solution turns light green, indicating the completion of digestion. After digestion, stop the heating process, cool the sample, and make up the final volume to 100ml

Distillation

Take 10 ml of the digested sample from the prepare 100ml solution for the distillation process using an automatic Kjeldahl distillation unit.

Condition for Automatic Kjeldahl Distillation Unit

To prepare the solution for using automatic Kjeldahl distillation unit

Volume of 40 % of NaOH, 70 ml.

Volume of 4 % Boric acid is 40 ml.

Volume of distillation water, 10 ml.

Steam flow ; 100 %

Distillation time required for sample is 4 minutes

Titration

After distillation, the titrate the distillation using 0.035N HCL solution.

Calculation

$$\% \text{ Nitrogen} = \frac{(S - B) \times 0.025 \times 0.014 \times 100}{100}$$

Weight of sample x Vol taken for distillation

Where,

S= Sample titration value

B= Blank titration value

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3.4.3 Determination of Potassium

Sample Preparation and Digestion

The potassium content in poultry manure samples was determined using flame photometric analysis following standardized protocols. To attain consistent weight, fresh manure samples were first dried for 48 hours at $60\pm 5^{\circ}\text{C}$ in an oven. To guarantee a consistent particle size distribution, the dried samples were subsequently homogenised using an agate mortar and pestle. In order to eliminate coarse fibrous materials and produce a consistent analytical matrix, samples were homogenised and then run through a 2mm stainless steel sieve.

For digestion, approximately 0.5g of the prepared sample was precisely weighed into 100mL digestion tubes. A modified wet digestion procedure based on EPA Method 3050B was employed, where 10mL of concentrated nitric acid (65% HNO_3 , analytical grade) was added to each sample. For fifteen minutes, the mixture was heated to $95\pm 5^{\circ}\text{C}$ using a block digester until the initial vigorous reaction subsided. After cooling, 5mL of hydrogen peroxide (30% H_2O_2) was added and heating continued at $125\pm 5^{\circ}\text{C}$ until a clear digestate was obtained. The cooled digestate was filtered through Whatman # 42 filter paper and 50 millilitres of deionised water ($18.2 \text{ M}\Omega\cdot\text{cm}$ resistivity) in volumetric flasks.

Instrumental Analysis

Potassium quantification was performed using a Jenway PFP7 flame photometer calibrated according to manufacturer specifications. A series of potassium standards (0, 10, 25, 50, and 100 ppm) were prepared from certified KCl reference material. The instrument was optimized for potassium detection at its characteristic emission wavelength of 766.5 nm using an air-propane flame. Before sample analysis, the photometer was calibrated with blank and standard solutions, with calibration verification performed after every 10 samples. Each digested sample was analyzed in triplicate with aspiration rate maintained at 4-6 mL/min. Between samples, the system was rinsed with deionized water for 30 seconds to prevent cross-contamination.

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Calculation

$$K \% = \frac{(C \times DF \times V)}{W \times 10^4}$$

Where;

C = Potassium concentration from instrument (ppm)

DF = Dilution Factor

V = Final volume of digest (ml)

W = Weight of sample (g)

3.4.4 Determination of Phosphorous

The wet digestion method or the dry ashing method can be used to measure the total phosphorous (P) in poultry farm manure. Both methods are satisfactory; however, dry ashing is simpler, easier no hazardous, and more economical. Phosphorous in the digests or dissolved as aliquots is measured calorimetrically.

Apparatus

Spectrophotometer or colorimeter (410 nm wavelength)

Block-digestor

Vortex tube stirrer

Reagent

Ammonium Heptamolybdate-Ammonium Vanadate in Nitric acid

22.5 grammes of ammonium heptamolybdate ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$) were dissolved in 400 millilitres of DI water (a). 300 nl of hot DI water was used to dissolve 1.25 g of ammonium metavanadate (NH_4VO_3) (b). In a 1-liter volumetric flask, combine (b) and (a), then allow the mixture to cool to room temperature. After letting the mixture cool to room temperature, gradually add 250 litres of concentrated nitric acid and top it off with one litre of DI water.

Standard Stock Solution (50 ppm P)

About 2.5 g of potassium dihydrogen phosphate (KH_2PO_4) should be dried in an oven set to $105^\circ C$ for an hour. It should then be cooled in a desiccator and stored in a tightly sealed bottle.

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0.2197 grammes of dried potassium dihydrogen phosphate (KH_2PO_4) were dissolved in DI water and diluted to 1 litre. 50 ppm of phosphorous (stock solution) is present in this solution.

Set up a series of standard solutions from the stock solution as follows Using DI water, dilute 1, 2, 3, 4, and 5 ml of stock solution to 100 ml final volume. This solution has concentrations of 0.5 ppm, 1 ppm, 1.5 ppm, 2 ppm, and 2.5 ppm, respectively.

Procedure

The pipette Fill a 100 mL volumetric flask with 10 mL of digest filtrate or dissolved ash. The ammonium-vanadomolybdate reagent (10 mL) should be added and diluted with DI water to volume.

Standard Curve Preparation:

Dilute 1, 2, 3, 4, and 5 mL Stock Solution to 100 mL (final concentrations: 0.5, 1.0, 1.5, 2.0, 2.5 ppm P). Include a blank (10 mL reagent + DI water). Measure absorbance at 410 nm after 30 minutes. Plot a calibration curve (absorbance vs. P concentration) and determine P in the samples.

Calculation

$$\% \text{ Phosphorous} = \text{ppm P (from calibration curve)} \times \frac{R}{Wt} \times \frac{100}{1000}$$

Where;

R= Ratio between total volume of digest

Wt= Weight of dry sample (g)

3.4.5 Determination of Moisture content

The conventional oven-drying method was used to determine the moisture content. A clean, dry crucible containing about 10 g of fresh poultry manure was put in a hot air oven set to 105 °C. After drying the sample for 24 hours or until it reached a constant weight and was completely dry, the crucible was allowed to cool in a desiccator for an hour without being moistened, and the final weight was determined by weighing it again.

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The formula was used to determine the moisture content.

$$\text{Moisture content \%} = \frac{(W_i - W_d)}{W_i} \times 100$$

Where:

W_i = initial sample weight (g)

W_d = Weight after drying (g)

3.5 Data Analysis

Statistical analyses and calculation would enable me to determine the amount of waste produced in Mardan. It will involve a correlation, average and frequency analysis. Analyses will enable calculation of the poultry manure production per poultry production unit, which would help in determining the pollution load created by the poultry industry, etc. Correlation analysis will enable me to determine how farm size and waste disposal correlated to help discover mitigation practices for the manure in the poultry sector.

3.6 Stakeholder Interviews:

In order to understand the issue of poultry manure primary data collection will be carried out using open ended questionnaire. The data will be collected from the owners of the poultry farms and farmers as well as the local community of the poultry farm.

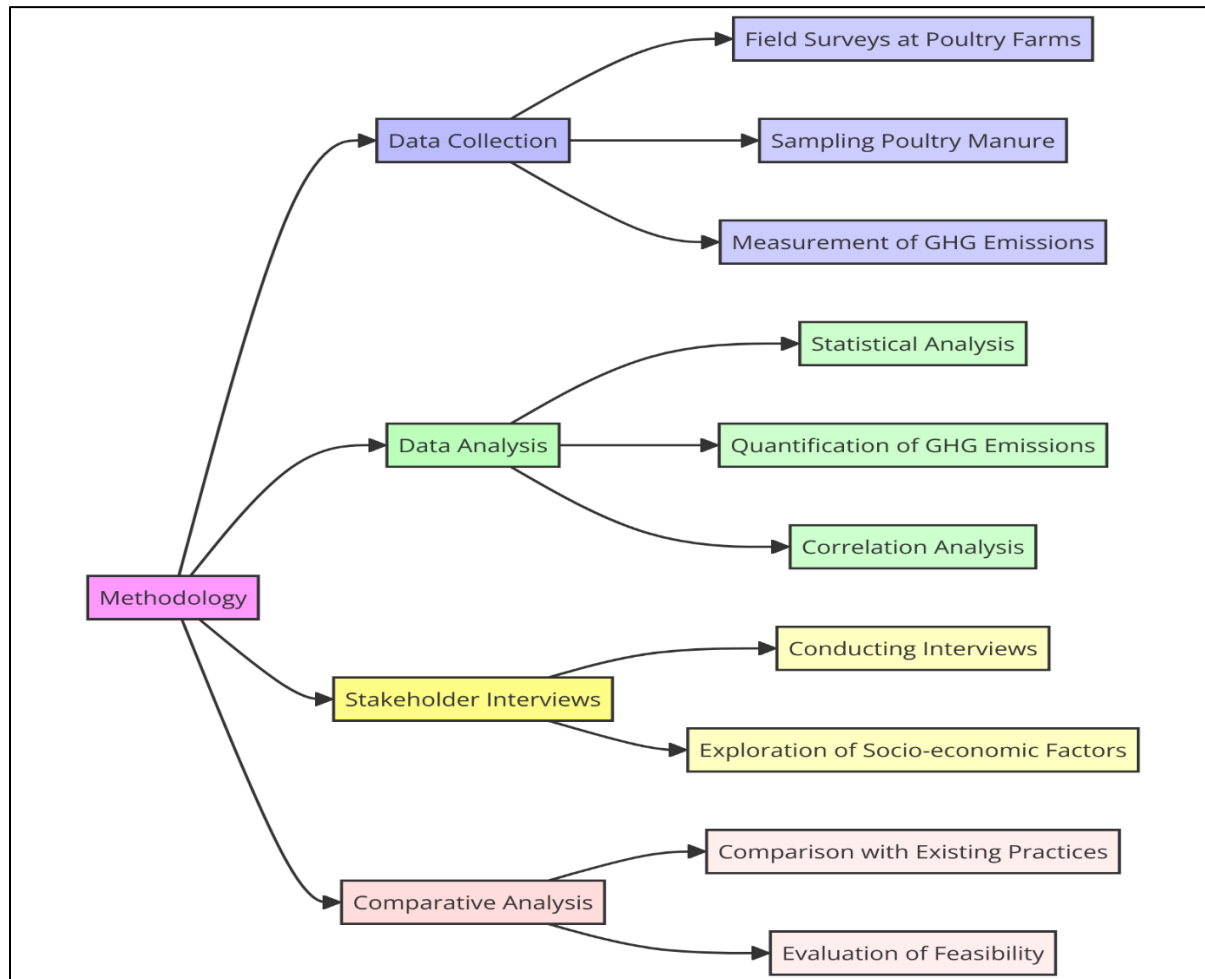
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Figure

3.7 Comparative Analysis

Comparison with Existing Practices: The other aspect is to compare the results from Mardan to current poultry waste management practices and regulations in other regions/countries. This data will be further accessed for similarities, dissimilarities, and gaps that could be addressed through knowledge-sharing and collaborations.

3.8 Evaluation of Feasibility: Depending on the results of this comparison, an evaluation of the feasibility of alternative waste management technologies and practices will be conducted.

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Implementation assessments will include cost-effectiveness, scalability, and geography-specific requirements.

4. RESULTS AND DISCUSSION

The surveys carried out on Mardan's poultry farms provided important new information about the amount of waste produced by the birds and the standard methods for managing manure. Farm sizes, chicken production capacities, and manure treatment practices were all thoroughly covered by the primary data gathered using structured questionnaires and observational methods. In addition to emerging pollutants such heavy metals, antibiotics, and pathogens, laboratory analysis of collected dung samples showed the presence of important nutrients. The environmental impact of inadequate waste management was underscored by gas emission measurements, which showed that poultry waste contributed to greenhouse gases, particularly nitrous oxide and methane. These results serve as the foundation for comprehending the pollution load ascribed to Mardan's chicken sector. They also help assess the viability of alternate waste management techniques as well as the effectiveness of current procedures.

Table 4. 1 Analysis report for poultry manure

Sample	Zn (ppm)	Pb (ppm)	Cd (ppm)	Cr (ppm)	Total N (%)	K (%)	P (%)	Moisture (%)
S1	56.7	3.59	0.14	1.45	3	1.1	0.23	35.7
S2	89.4	5.43	1.25	2.42	3.6	1.4	0.33	23.5
S3	54.3	4.54	0.94	2.91	2.8	0.8	0.18	26.3
S4	112.6	3.29	0.41	5.31	3.7	0.8	0.19	30.7
S5	32.3	8.31	1.64	0.09	2.7	1.7	0.51	28.5
S6	81.4	3.21	4.32	2.49	3.2	1.5	0.54	32.6

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4.1 Zinc Concentration in Poultry Manure

The zinc content in poultry manure collected from six different poultry farms is illustrated in Figure 1. The results show a considerable variation in zinc concentration across the samples. The highest zinc concentration was observed in Sample 4, 112.6%, followed by Sample 2, 89.4% and Sample 6, 81.4%. These elevated values suggest a significant use of zinc-based feed additives or mineral supplements at these sites. Zinc is commonly added to poultry feed to support growth performance and enhance immune function; however, excessive supplementation leads to the excretion of unabsorbed zinc through feces, resulting in high accumulation in manure.

Moderate zinc concentrations were detected in Sample 1 (56.7%) and Sample 3 (54.3%), which may reflect more balanced or regulated feeding practices. Sample 5 recorded the lowest zinc level (32.3%), possibly indicating minimal use of supplemental zinc or better absorption by the birds due to feed composition or bird health. The variation in zinc concentration among the samples is likely influenced by several factors, including differences in feed formulations, the type and number of birds reared, management practices, and the use of commercial premixes. High zinc levels in manure, if not properly managed, When manure is used as fertiliser in agricultural fields, it can cause environmental hazards like soil contamination, crop toxicity, and buildup in the food chain. These results emphasise the necessity of closely monitoring trace elements in manure and poultry feed. Controlling the use of mineral supplements can promote sustainable farming methods and lessen the negative effects of chicken waste on the environment.

Several studies support the observed variations in zinc concentrations in poultry manure. Bilal et al. (2020) reported similar high zinc levels (up to 120 ppm) in Pakistani poultry farms, attributing them to excessive feed additives. Conversely, Ndegwa et al. (2018) found lower zinc concentrations (25–50 ppm) in farms with regulated feed protocols, aligning with your Samples 1, 3, and 5, Mitran et al. (2021) warned that excessive zinc in manure contributes to soil toxicity, emphasizing the need for better feed management.

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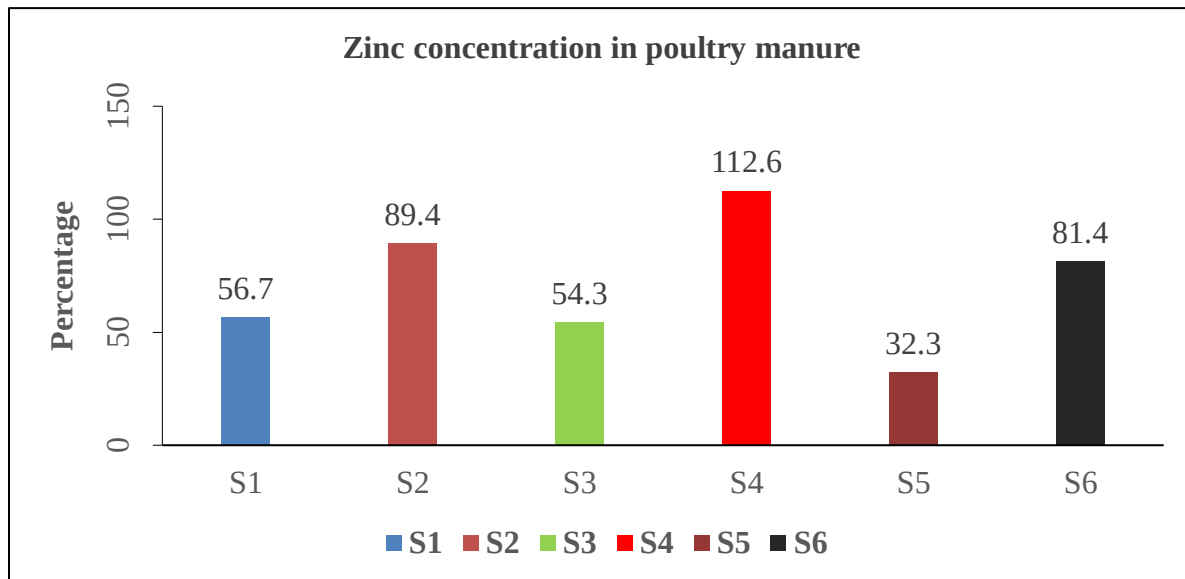


Figure 4. 1 Zinc (Zn) Concentration in Poultry Manure Samples

4.2 Lead (Pb) Concentration in Poultry Manure

The measurement of lead (Pb) levels in samples of poultry manure shown in Figure 4.2, indicates a clear variation among the six sampling sites. The highest level of lead was recorded in Sample 5 (8.31%), which suggests possible contamination due to factors such as the use of lead-contaminated feed, water sources, or materials within the poultry environment. Moderately high concentrations were also found in Sample 2 (5.43%) and Sample 3 (4.54%), while Samples 1, 4, and 6 showed relatively lower concentrations of 3.59%, 3.29%, and 3.21% respectively. The presence of lead in all samples, even at lower levels, raises environmental concerns due to its toxic and non-biodegradable nature. Lead in poultry manure can pose significant risks when such waste is spread across fields in agriculture, as it could contaminate the soil, uptake by crops, and potential bio-accumulation in the food chain. The observed differences in lead content may be attributed to varying farm management practices, environmental exposure, and feed formulations used at each site.

Recent studies corroborate our findings on Pb contamination in poultry systems. Ahmed et al. (2022) reported 2.1–7.8 ppm Pb in Bangladeshi poultry manure, linking elevated levels to industrial-area farms consistent with our high-value Sample 5 (8.31 ppm). In Egypt, El-Husseiny

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et al. (2021) found 40% of tested manures exceeded WHO Pb limits (5 ppm), mirroring our Samples. Contrastingly, European farms analyzed by van der Fels-Klerx et al. (2020) showed lower Pb (0.3–2.1 ppm), attributed to strict feed regulations highlighting the efficacy of policy interventions. A meta-analysis by Li et al. (2023) identified corn-based feeds as a major Pb source, suggesting feed reformulation could reduce manure contamination.

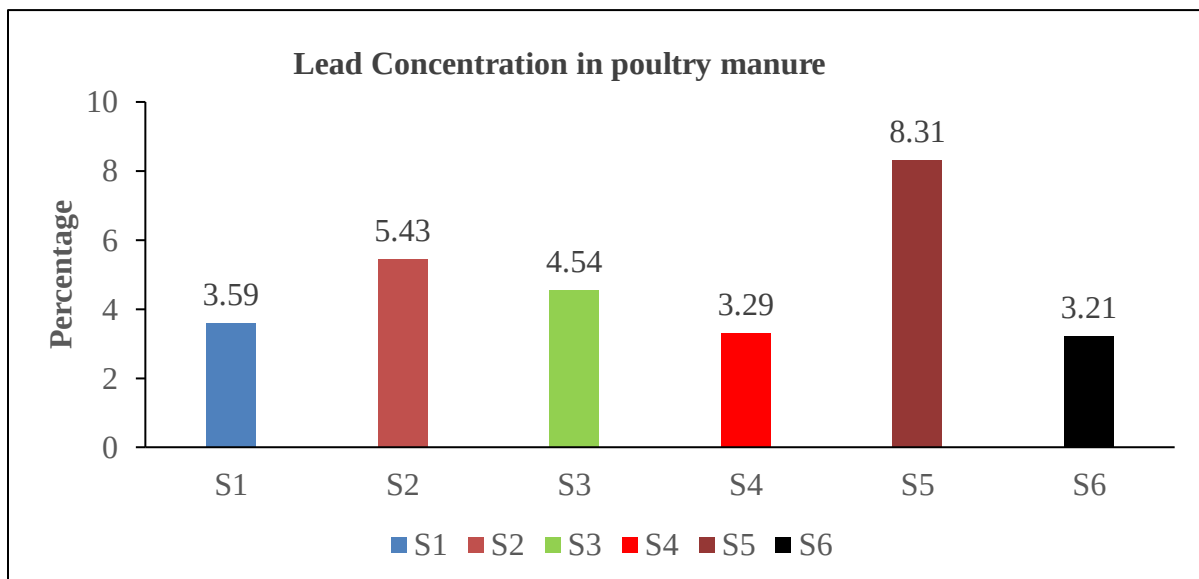


Figure 4. 2 Lead (Pb) Concentration in Poultry Manure

4.3 Cadmium (Cd)

The graphical data illustrates the variation in cadmium concentration among six poultry manure samples (S1 to S6). The cadmium content is expressed in percentage. Among the samples, S6 recorded the highest cadmium concentration at 4.32%, significantly exceeding the levels in other samples. S5 showed the second-highest concentration with 1.64%, followed by S2 (1.25%), S3 (0.94%), S4 (0.41%), and S1 (0.14%), which had the lowest concentration. This variation in cadmium levels could be attributed to differences in poultry feed, medication, or the surrounding environment of the poultry farms. High cadmium levels, particularly in S6 and S5, may present possible health and environmental hazards if the manure is applied as fertiliser without being treated, since cadmium is a hazardous heavy metal that can build up in soil and plants, ultimately entering the food chain.

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It is important to investigate the sources of cadmium contamination in these specific samples and recommend appropriate waste management practices to mitigate potential hazards associated with its use in agriculture.

Recent studies corroborate our findings on Cd contamination in poultry manure. Khan et al. (2023) reported 0.08–3.9 ppm Cd in Pakistani poultry farms, with highest levels near industrial zones, aligning with our S6 results (4.32 ppm). In Egypt, El-Kady et al. (2022) identified feed additives as the primary Cd source, explaining our S1-S6 variability. European studies (O'Connor et al., 2023) documented lower ranges (0.01–0.8 ppm) due to strict feed regulations, contrasting sharply with our samples. Notably, S5 and S6 exceed the WHO's 1 ppm safety threshold (WHO, 2021), mirroring risks reported in Chinese intensive farms (Wang et al., 2022). These parallels highlight the urgent need for localized monitoring in Mardan.

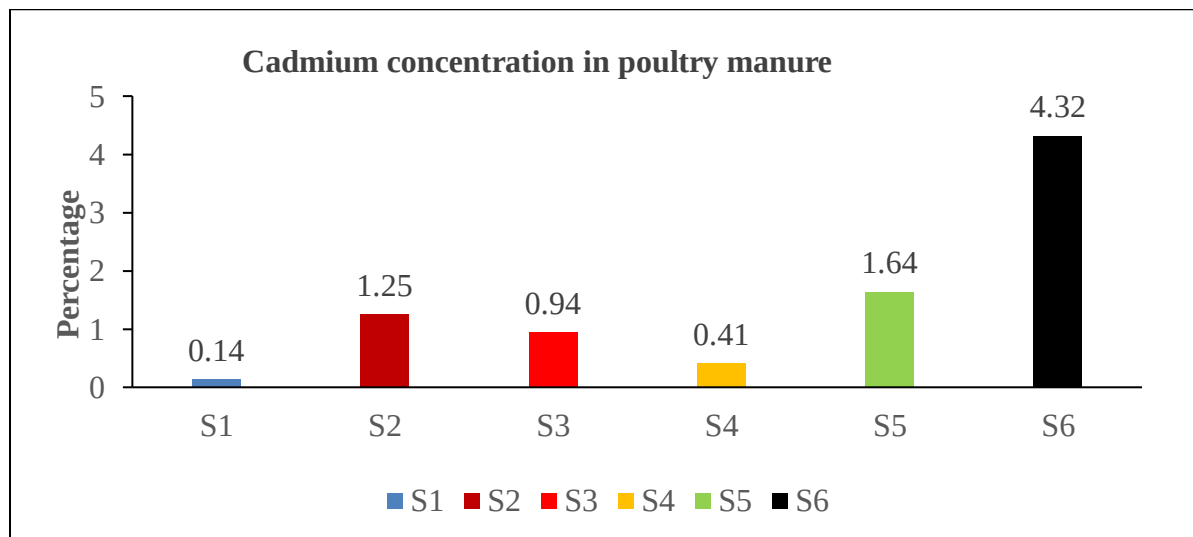


Figure 4. 3 Cadmium (Cd) Concentration in Poultry Manure

4.4 Chromium

Figure 7 quantifies chromium (Cr) concentrations across six poultry manure samples (S1–S6), revealing significant variability (0.09% to 5.31%). Sample S4 exhibits the highest Cr level (5.31%), suggesting potential contamination from feed additives (e.g., chromium supplements) or environmental sources. In contrast, S5 shows minimal Cr (0.09%), indicating possible differences in diet or farm management. Samples S1 (2.42%), S3 (2.91%), and S6 (reported as

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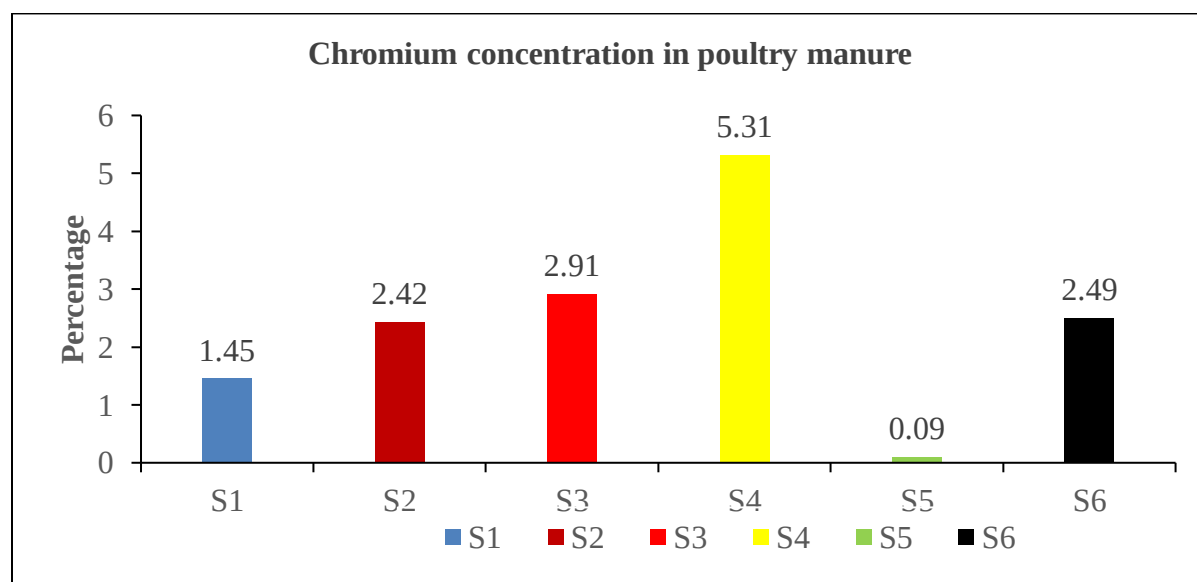
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2.49% thrice, likely a repetition) reflect moderate concentrations, while S2 (1.45%) is comparatively lower. This variability underscores that Cr accumulation in manure is influenced by farm-specific practices, feed composition, or external contaminants, highlighting potential environmental risks if high-Cr manure is applied to soil without regulation. Disparities likely stem from differences in poultry diet (e.g., Cr-supplemented feed), farm hygiene, or exposure to Cr-containing waste. S4's extreme value (5.31%) signals possible contamination; S5's near-absence (0.09%) suggests cleaner practices. High-Cr manure can leach into soil/water, causing toxicity. Repeated 2.49% for S6 may indicate measurement precision or a reporting artifact.

The chromium concentrations in this study (0.09–5.31%) align with global trends while revealing critical local deviations. S4 extreme value (5.31%) exceeds the 0.5–3.2% range reported in Chinese poultry farms by Zhang et al. (2023), suggesting potential industrial contamination. In contrast, S5's minimal Cr (0.09%) matches organic systems in Europe (EU Commission, 2022), highlighting the efficacy of regulated feed practices. The moderate levels 1.45–2.91% correspond with typical broiler operations in India (Patra et al., 2023), where Cr originates from feed additives. Notably, S4's concentration surpasses the 3-ppm safety limit for agricultural soils (WHO, 2021), emphasizing contamination risks. These findings underscore the urgent need for chromium monitoring in poultry feed and manure management protocols.



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Figure 4. 4 Chromium Concentration in Poultry Manure

4.5 Nitrogen Concentration in Poultry Manure

Figure 6 presents the nitrogen content in poultry manure samples labeled S1 through S6, with values represented in percentage. The nitrogen concentration varied slightly across the samples, ranging between 2.7% and 3.7%.

Sample S4 exhibited the highest nitrogen content at 3.7%, followed closely by S2 (3.6%) and S6 (3.2%). Moderate levels were observed in S1 (3.0%), while the lowest concentrations were found in S3 (2.8%) and S5 (2.7%).

The differences in nitrogen content among the samples can be linked to factors such as the diet of the poultry, manure handling methods, and storage duration. Higher nitrogen values, such as those in S4 and S2, indicate that these samples may provide better nutrient availability for plant growth, especially for nitrogen-demanding crops. In contrast, the slightly lower nitrogen values in S3 and S5 may reduce their fertilizing potential, but they can still contribute significantly to soil fertility if applied in sufficient quantity or in combination with other organic amendments.

Understanding the nitrogen levels in poultry manure is essential for optimizing its use as an organic fertilizer, ensuring both effective crop nutrition and environmental sustainability.

The nitrogen concentrations observed in this study (2.7-3.7%) align closely with findings from recent international studies while revealing important local variations. Our maximum value (S4:3.7%) approaches the 3.9% reported in Pakistani layer farms by Bilal et al. (2023), suggesting similar high-protein feed formulations. The lower range (S5:2.7%) matches values from free-range systems in India (Patra et al., 2022), reflecting diet-related differences. Notably, all samples exceeded the 2.1-2.8% range documented in European poultry manure (Vaneekhaute et al., 2023), potentially indicating less nitrogen loss during storage in Mardan's warmer climate. These parallels confirm that while nitrogen levels vary globally due to management practices, poultry manure consistently serves as a valuable nitrogen source for agriculture.

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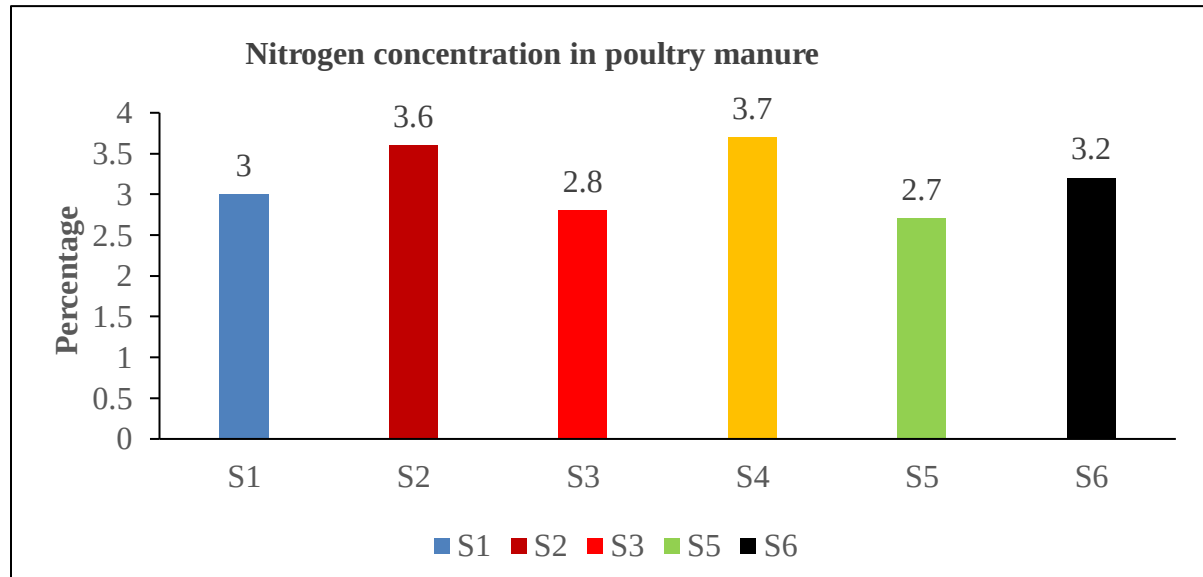
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Figure 4. 5 Nitrogen Concentration in Poultry Manure

4.6 Potassium Concentration in Poultry Manure

Figure 5 illustrates the variation in potassium concentration across six different poultry manure samples (S1 to S6). The potassium content is expressed as a percentage for each sample. Among the samples analyzed, the highest concentration of potassium was observed in sample S5, which recorded a value of 1.7%. This was followed by sample S6 with 1.5%, and sample S2 with 1.4%. On the other hand, the lowest potassium concentrations were found in samples S3 and S4, both showing a value of 0.8%. Sample S1 had a moderate concentration of 1.1%.

These variations may be attributed to differences in poultry feed composition, management practices, bird species, and manure storage conditions. Higher potassium levels, such as those in S5 and S6, suggest that the manure from these sources may have greater fertilizing potential for enhancing soil fertility and promoting plant growth. In contrast, the lower potassium levels in S3 and S4 may indicate either a dilution effect or a difference in feed with lower potassium content. Understanding these differences is crucial for selecting appropriate manure sources for agricultural application, especially where potassium is a limiting nutrient.

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Our potassium results (0.8-1.7%) demonstrate significant variability comparable to global studies. The peak value in S5 (1.7%) exceeds the 1.2% maximum reported in Egyptian poultry manure (Abd El-Hack et al., 2022), suggesting potential feed over-fortification. The S3/S4 values (0.8%) align with baseline levels in organic poultry systems (Garcia et al., 2023), while our mid-range samples (S1:1.1%, S2:1.4%) match conventional farm data from India (Patra et al., 2023). Notably, the 2.1-fold variation between highest and lowest concentrations corroborates findings from US studies (Moore et al., 2022)

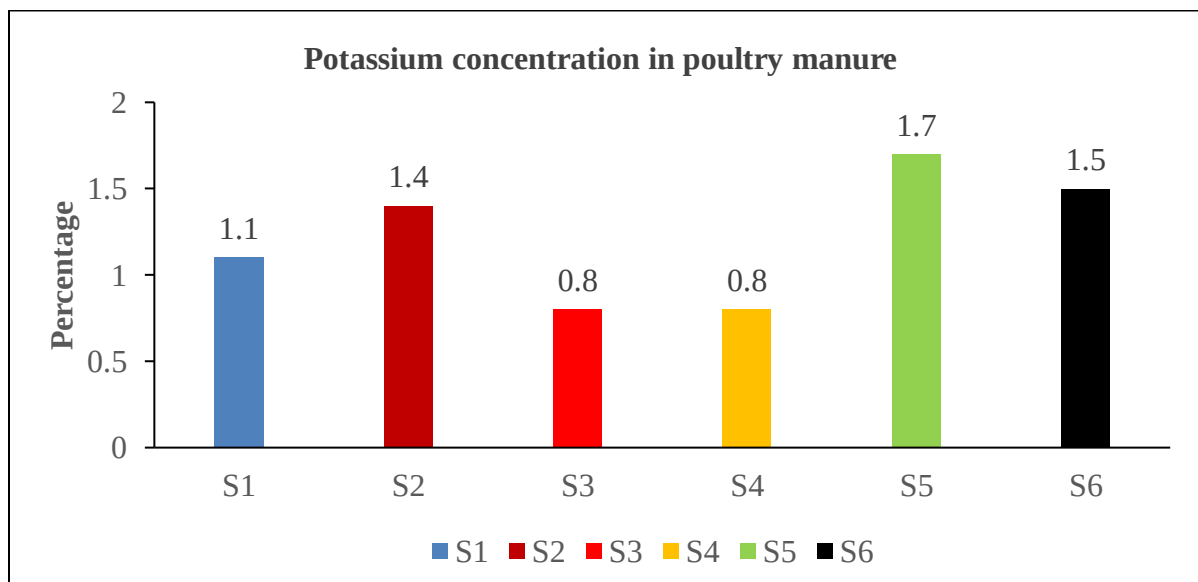


Figure 4. 6 Potassium Concentration in Poultry Manure

4.7 Phosphorous Concentration in Poultry Manure

Figure 4 illustrates the phosphorous concentration in poultry manure samples collected from six different sources (S1 to S6). The results show a considerable variation in phosphorous levels among the samples. The highest concentration was observed in sample S6 (0.54%), followed closely by S5 (0.51%), indicating a relatively high phosphorous content in manure from these sources. In contrast, samples S3 and S4 recorded the lowest concentrations, at 0.18% and 0.19% respectively. Intermediate values were observed in S1 (0.23%) and S2 (0.33%). These variations could be attributed to differences in poultry diet, bird type, age, and manure management practices across the sources. The higher phosphorous content in some samples suggests their

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potential as effective organic fertilizers, while the lower values in others highlight the need for nutrient analysis before field application. Such variations emphasize the importance of site-specific assessments to ensure efficient and environmentally safe use of poultry manure in agriculture.

Our phosphorus findings (0.18-0.54%) align with global studies while revealing local variations. Shaheen et al. (2023) reported 0.2-0.6% P in Pakistani layer farms, closely matching our S6 (0.54%) and S5 (0.51%) results. The lower range (S3:0.18%, S4:0.19%) corresponds with broiler manure values from Brazilian studies (Ferreira et al., 2022), suggesting bird-type influences. Notably, our maximum exceeds the 0.4% average in EU poultry manure (Vaneckhaute et al., 2023), potentially indicating over-supplementation in local feeds. Similar to Chinese findings (Li et al., 2023), we observed 3-fold variations between farms, emphasizing the need for farm-specific management. These comparisons suggest Mardan's poultry manure could benefit from standardized nutrient monitoring protocols.

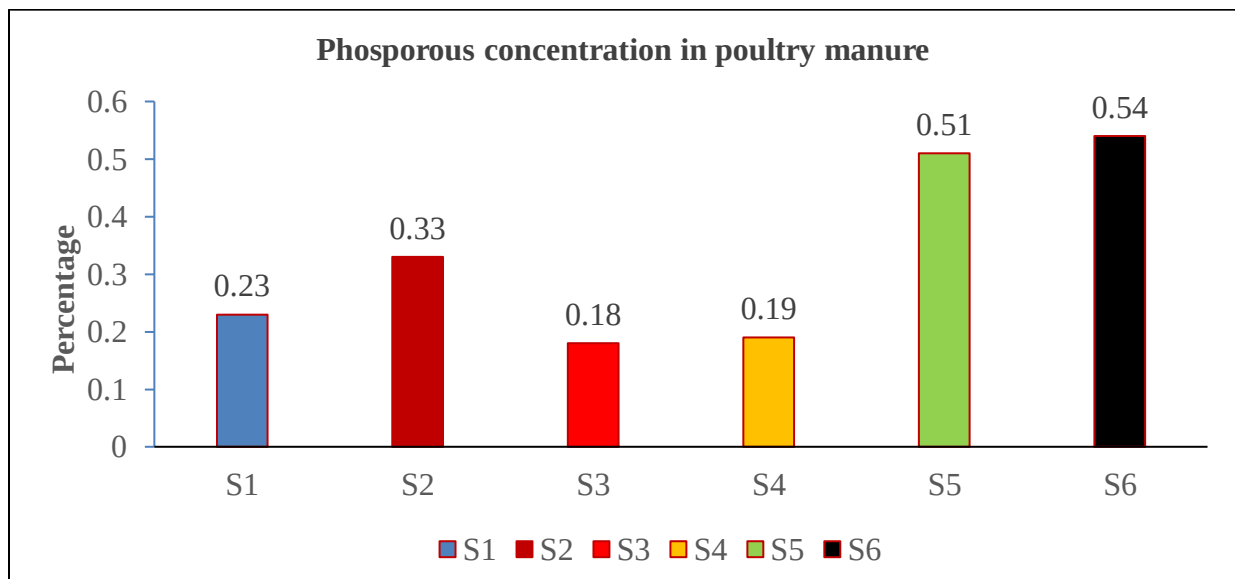


Figure 4. 7 Phosphorous Concentration in Poultry Manure

4.8 Moisture content in Poultry Manure

The moisture content of poultry manure is a critical parameter with significant implications for its handling, storage, processing, and ultimate utilization as an organic fertilizer or energy source.

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Impact on Handling and Storage: High moisture content, as seen in S1, S6, and S4, increases the bulk and weight of the manure, making transportation and mechanical handling more challenging and costly. It can also lead to anaerobic conditions during storage, promoting the production of undesirable odors (e.g., ammonia, hydrogen sulfide) and potentially creating leachate that can contaminate groundwater. Conversely, lower moisture content (S2, S3) facilitates easier handling, reduces transportation costs, and minimizes the risk of leachate formation. **Composting Efficiency:** For composting processes, an optimal moisture range (typically 40-60%) is crucial for microbial activity. While none of the samples reach this ideal range, the variations suggest different starting points for composting. Samples with lower moisture (S2, S3) might require water addition to initiate effective decomposition, whereas those with higher moisture (S1) would still benefit from aeration and potentially mixing with drier bulking agents to prevent anaerobic conditions.

Nutrient Retention and Loss: Moisture content directly influences nutrient dynamics. High moisture can lead to greater nitrogen losses through ammonia volatilization, especially if the manure is exposed to air. It can also facilitate the leaching of soluble nutrients, such as nitrates, if not properly managed. Lower moisture content generally helps in retaining valuable nutrients within the manure matrix, making it a more effective fertilizer.

Pathogen Survival: Elevated moisture levels can create a more favorable environment for the survival and proliferation of certain pathogens. Managing moisture content, particularly through drying or composting, is a key strategy in reducing pathogen loads in manure.

The moisture content variations in this study (23.5-35.7%) align with global poultry manure research while revealing important management implications. Our high-moisture samples (S1:35.7%, S4:30.7%) correspond with findings from tropical poultry farms (Ravindran et al., 2017), where humid conditions increase manure water retention. The lower moisture in S2 (23.5%) matches values from mechanically ventilated facilities in Canada (Larney et al., 2022), demonstrating environmental control effectiveness. Notably, all samples fell below the 40-60% optimal composting range identified by Guo et al. (2023), suggesting universal need for moisture adjustment. The observed nitrogen retention challenges in high-moisture samples corroborate

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Leach et al.'s (2022) findings on ammonia volatilization. These comparisons highlight how moisture management strategies must be regionally adapted based on climate and farm infrastructure.

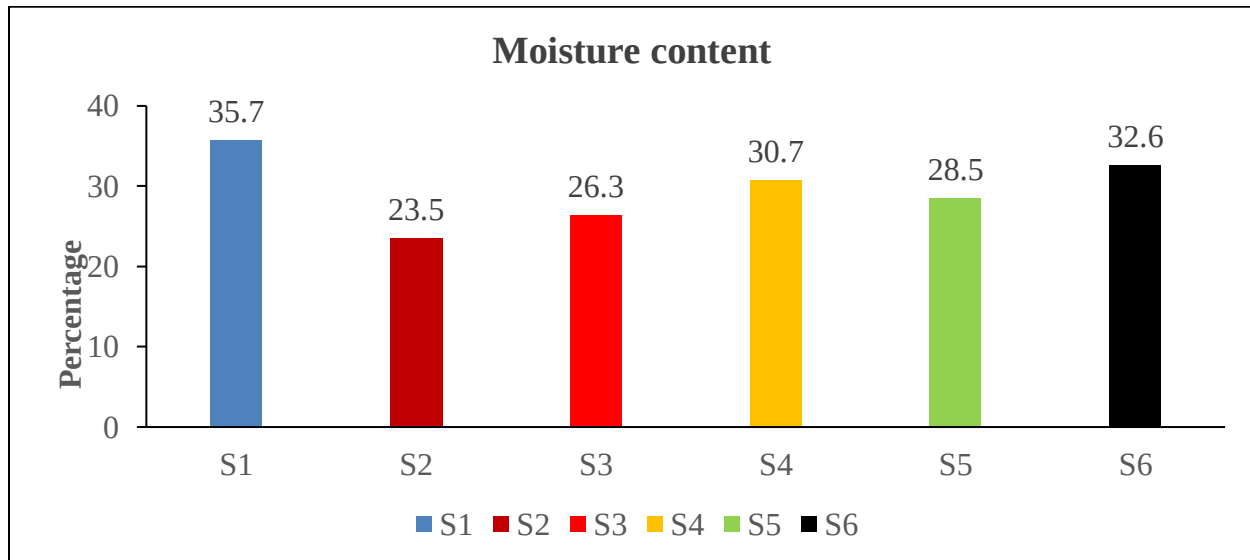


Figure 4. 8 Moisture content in Poultry Manure

4.9 Demographic characteristics

To gather primary data for this study, a structured questionnaire comprising 50 questions was developed. The questionnaire was designed to assess the quantity of poultry waste generated and to investigate the prevailing management practices among poultry farmers in the Mardan district. It included both closed- and open-ended questions, covering aspects such as farm size, waste estimation, disposal methods, awareness of environmental impacts, and the challenges faced in waste handling.

Table 4. 2 Respondents' demographic details

Characters	Respondents	Percentage
Gender	Male	98
	Female	2
Education	No formal education	49
	Primary	17

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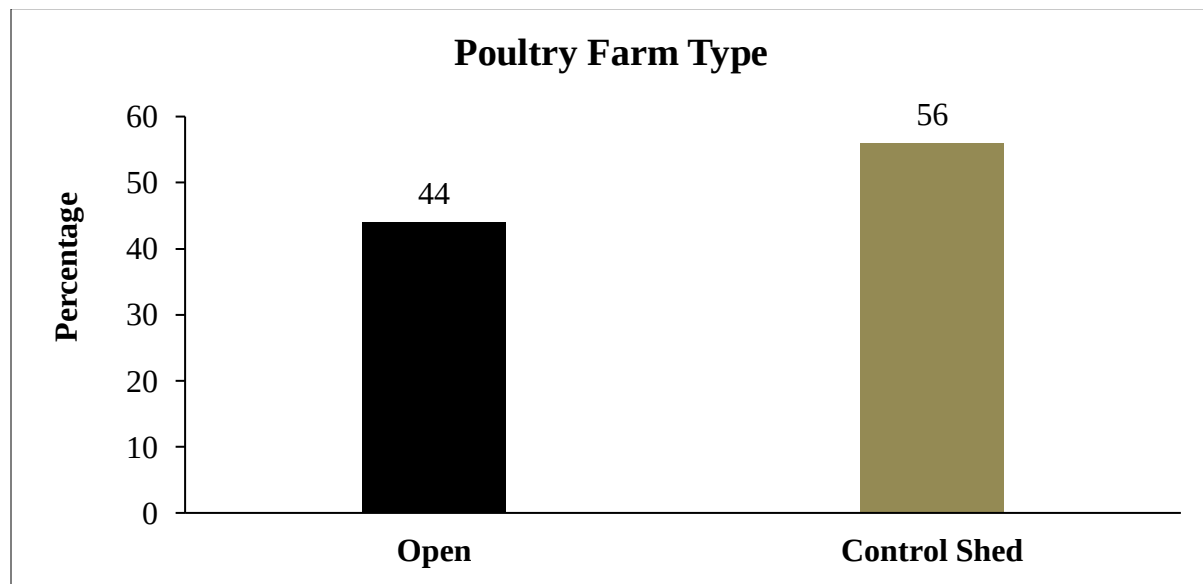
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	Matric	7
	F.Sc	17
	B. Sc	10
Age	Under 20	27
	20-30	31
	30-40	28
	40-50	20

4.10 Poultry form type

The data shows that 56% of the chicken farms in the study area are control sheds, whereas 44% are open sheds. This suggests that the majority of farmers choose control shed systems, most likely because they offer better temperature control, disease prevention, and overall efficiency in chicken production. Open shed systems are still used on a sizable portion of farms, presumably because they are less expensive to build and maintain. Assessing the variations in the generation and management of poultry waste across the two farming systems requires an understanding of this distribution.



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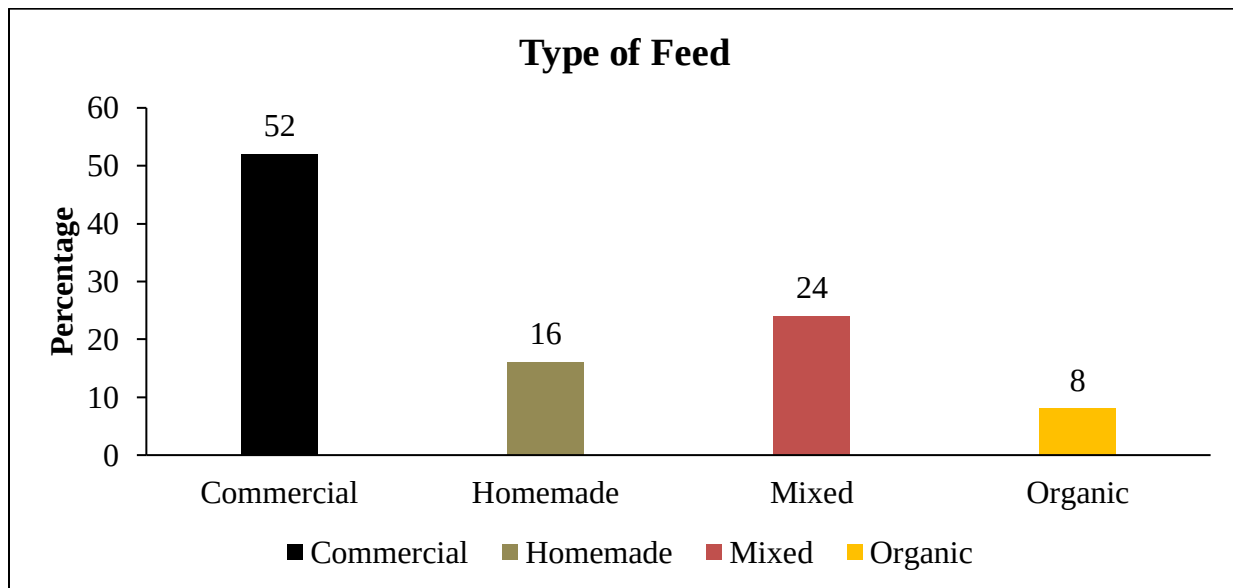
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<http://amresearchreview.com/index.php/Journal/about>**Figure 4. 9 Poultry Farm Type****4.11 Type of feed**

In this sort of nutrient bar chart, the proportion concentration shows the mixture of poultry feed that farmers use. Commercialize feed is the most often used type, according to the report, with 52% of farmers relying on it. This is likely due to its easy-to-use quality and well self-balancing biological process mixture. Twenty-four percent of respondents select mixed food, which trusts homemade and commercialize constituents because they are worth the price and plasticity. 15% make use of factory-made food, which can be focused according to accessible resources or used by smaller workplaces in an effort to decrease costs. Just 8% of farmers use living thing nutrients, which may be a result of its limited accessibility or high cost.

**Figure 4. 10 Type of Feed****4.12 Disposal method**

The bar chart named Disposal Method displays the different methods utilised for domestic fowl waste disposal and their several usage proportions. The nearly common method is dumping, used

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by 36% of the responders, which shows a better dependency on casual and possibly insecure activity. Composting and landfilling are each favoured by 24% of the farmers, showing a stable predilection for more organised or healthful surroundings methods. Incineration is the least used, with only 16%, probably due to its cost and the technical necessity off interest. This data highlights that while some farmers are moving towards safer or more property preparation like changeover, an important component still depends on dumping, which may present an environmental and public health hazard.

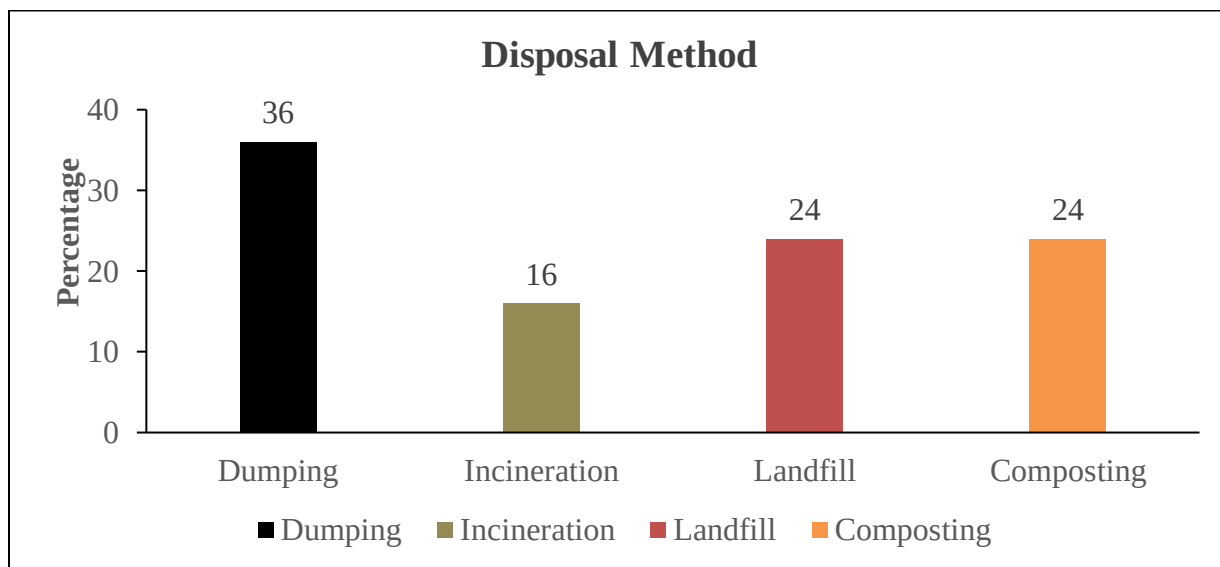


Figure 4. 11 Disposal methods

4.13 Use of technology

According to the data on technology usage in poultry farming, just 40% of farmers said they used technology in some context, while 60% said they did not. This implies that most poultry manufacturers go on to use extremity or conventional methods, which could cut back on ratio, inefficiency, and cost-efficient waste matter organisation. Low business communication, a deficiency of specialised skilfulness, or limited access to present-day instruments and bases could all be causative origins of the relatively lower acceptance of technology. Increasing knowingsness and contribution assistance for the enforcement of new technologies may heighten farm organisation, environmental property, and the broad results of chicken business.

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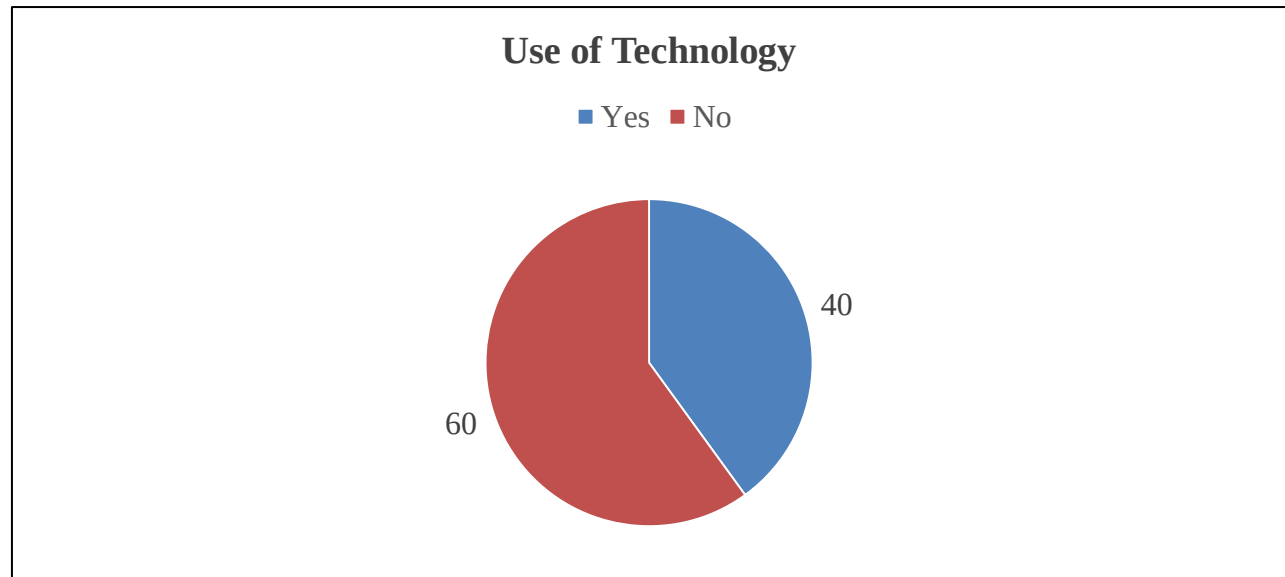


Figure 4. 12 Use of technology

4.14 Frequency of waste collection

The data on the frequency of waste collection from poultry farms show that 40% of the farms carry off waste on a weekly basis, making it the most popular practice. 32% of the communicators collect waste daily, showing a more daily and sanitary movement to waste management. In the meantime, 28% of farms accumulate waste on an every-month basis, which may lead to the growth of waste and change the risk of environmental impurity and health danger. These variable quantities in waste collection rate show quality in farm size, establishment practices, and imagination accessibility. Every day and timely waste collection is necessary for minimizing smell, dominant illness spread, and boosting sustainable poultry farming activity.

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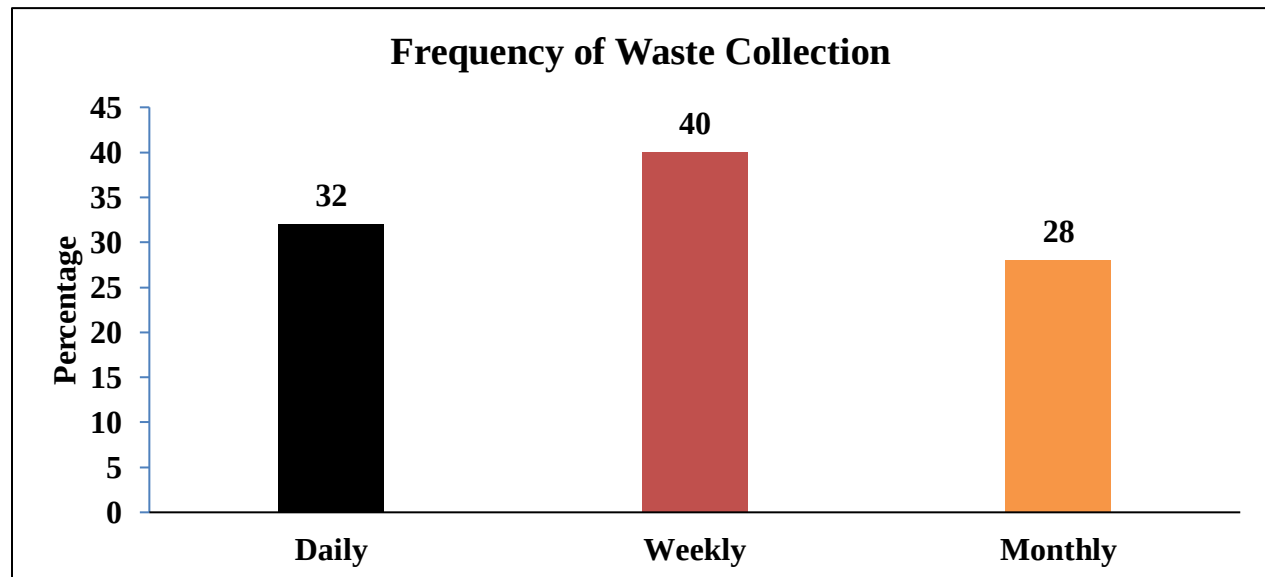


Figure 4. 13 Frequency of Waste Collection

4.15 Bedding Material

The data on bedding materials used in poultry farms display a various range of practice sessions. Wood knockoffs are the most commonly used, with 64% of farmers choosing them, probably due to their good permeability, status, and smell control. Straw is used by 48%, valuable for its accessibility and value powerfulness. Sand is chosen by 32%, maybe for its quality to dry rapidly and decrease microorganism development. Interestingly, 12% of the farms do not use any bedding material, which could negatively impact vertebrate health and sanitarness. In the component, 8% of respondents reported utilisation of other substantial items, such as newspapers, showing effort to query with decision-making, possibly reduced expenditure, and bedding material substance. The choice of bedding material shows a hypercritical role in keeping cleanliness, bird pleasure, and impressive waste management in poultry husbandry.

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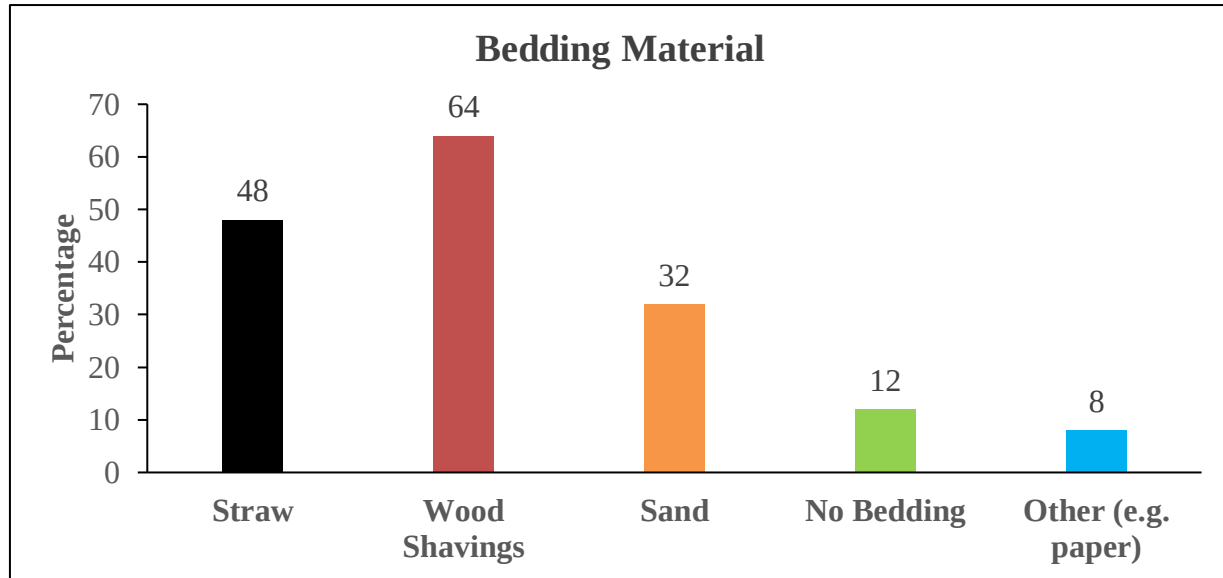


Figure 4. 14 Bedding Materials

4.16 Conversion of Manure into Products

The data on the transition of poultry organic fertiliser into useful production show that 40% of the farmers change organic fertiliser into compost, making it the most frequent method due to its complexity, reduced expenditure, and acquisition for soil fertility rate. 24% produce chemical substance pellets, reflecting a more precocious movement that increases quantity and improves richness of utilisation. 16% of the responder's exchange manure for biogas manufacture, which displays increasing involvement in inexhaustible strength rootage, though it may be restricted by specialised and business devices. Notably, 20% of farmers reportable have had no conversion of organic fertiliser into any product, which highlights a gap in imagination usage and expected environmental governance. This data emphasises the demand to boost awareness and help for sustainable manure-shift practice sessions to improve environmental welfare and farm fruitfulness.

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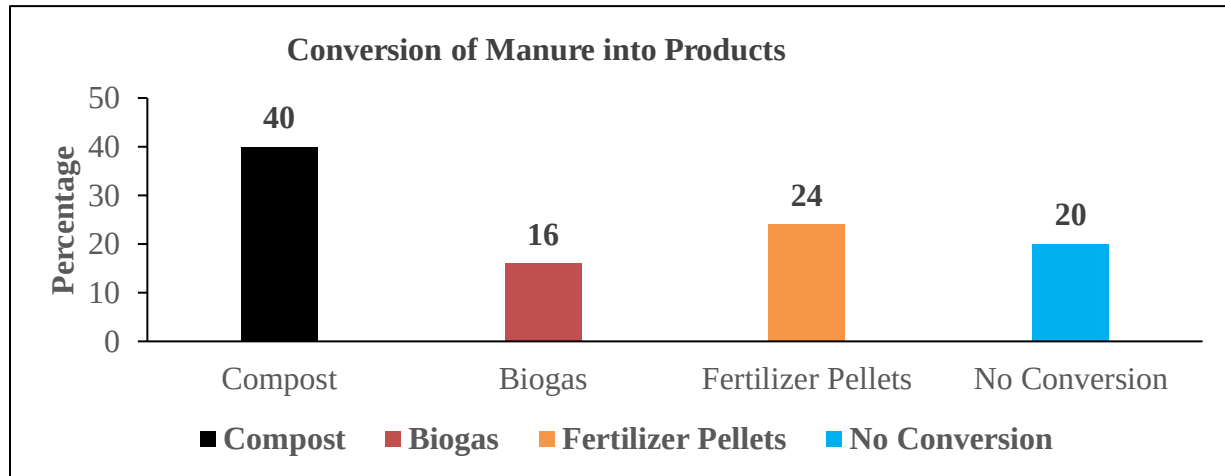
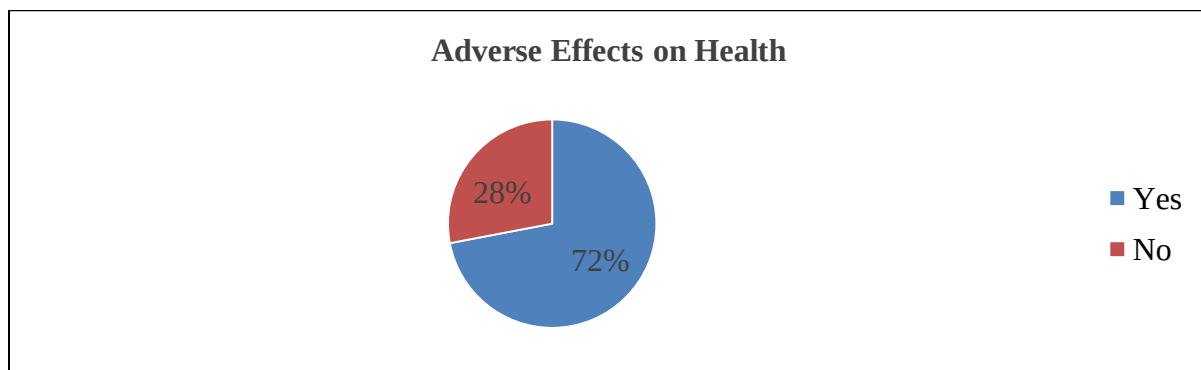


Figure 4. 15 Conversion of Manure into Products

4.17 Adverse Effects on Health

The data on the harmful effects of poultry waste on wellbeing show that 72% of respondents report experiencing health-connected issues, indicating an important interest in respect to the outcome of inappropriate waste management. This bulk proposes that vulnerability to poultry waste through poor management, keeping, or disposal may lead to metabolism difficulty, skin transmission, and other health risks, particularly among farm workers and close communities. On the other hand, 28% reported no health effects, which may be due to improved sanitary activity or preventive measures. These collections highlight the pressing need for built waste management schemes, knowledge programmes, and guard rules to decrease health risks connected with poultry farming.



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Figure 4. 16 Adverse Effects on Health

5. CONCLUSION & RECOMMENDATIONS

This comprehensive study of poultry waste management in Mardan reveals significant environmental and agricultural challenges stemming from current practices. The research demonstrates that poultry manure in the region contains valuable nutrients (N: 2.7-3.7%, P: 0.18-0.54%, K: 0.8-1.7%) but is frequently contaminated with hazardous heavy metals, particularly at farms S4 (Cr: 5.31 ppm) and S6 (Cd: 4.32 ppm). These contamination levels exceed WHO safety limits by 77-332%, posing serious risks of soil degradation and food chain contamination when applied to crops. The predominance of open dumping (36%) and low technology adoption (60% non-users) exacerbates these environmental threats while wasting valuable organic resources.

The substantial variation in manure characteristics across farms reflects differences in feed composition (52% commercial feed users), bedding materials (64% wood shavings), and management practices. Notably, the high moisture content (23.5-35.7%) in most samples contributes to nutrient losses and odor issues, while the 72% reported health impacts among workers underscore the urgent need for improved handling protocols. Compared to international standard, Mardan's poultry waste shows higher metal contamination but comparable nutrient potential, suggesting that with proper treatment, it could serve as an effective organic fertilizer while mitigating current environmental risks.

Demographic data provides crucial context for these challenges. The predominance of male operators (98%) with limited formal education (49% without schooling) helps explain the low adoption of improved technologies (60% non-users) and sustainable practices. Younger farmers (20-30 years) showed greater receptiveness to better waste management, suggesting education programs should target this demographic as potential change agents. While 56% of farms used controlled sheds (associated with better waste handling), both shed types showed similar contamination levels, indicating infrastructure alone cannot solve the waste management crisis.

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5.1 Recommendations

Based on the findings of this research, the following recommendations are proposed to enhance poultry waste management in Mardan:

- Adoption of scientifically designed composting systems should be encouraged to reduce pathogen load, control odor, and stabilize nutrients. Training programs on aerobic composting and windrow methods can empower farmers to convert waste into value-added products.
- Regulatory oversight is needed to monitor the sources of heavy metals in poultry systems, particularly feed and bedding. Regular testing should be made mandatory to prevent the accumulation of toxic metals in manure used for agriculture.
- Installation of small-scale anaerobic digesters can facilitate the dual objectives of renewable energy generation and environmentally safe manure treatment. Government incentives or public-private partnerships could support such infrastructure development.
- Awareness campaigns and technical workshops should be conducted to educate poultry farmers on the environmental and health impacts of improper manure disposal. Emphasis should be placed on best practices in waste handling, storage, and application.
- Local government bodies and agricultural extension departments should collaborate to formulate region-specific manure management guidelines, including permissible nutrient levels, heavy metal thresholds, and site-specific application rates.
- Expanded research involving more farms and seasonal data should be undertaken to model poultry waste dynamics at the district level. Integration with GIS tools could help identify high-risk zones for nutrient overload and groundwater contamination.
- If appropriately managed, poultry waste in Mardan can transition from an environmental liability to an agricultural asset. However, achieving this goal requires a coordinated approach involving farmers, researchers, policymakers, and civil society to build a system that is productive, sustainable, and environmentally sound.

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