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Safeguarding ecosystems using innovative approaches to manage animal wastes

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Abstract

Animal wastes (AWs) are excreta or discarded materials associated with animal production industries. It could be in solid, liquid, or gaseous form, such as animal dung or droppings, discarded feed, feathers, fur, decayed bodies of dead animals, blood waste, effluent from animal farms, milk wastes, urine, and fart. Animal wastes are generated in high quantity, even beyond the control of animal farmers, due to the increase in animal production globally. These wastes pollute the ecosystem. They release greenhouse gases (GHGs) such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) into the atmosphere through anaerobic fermentation which deplete ozone layer. Nitrogen and phosphorus constituents of Aws alter soil texture and pollute water bodies through run-off and direct disposal into water systems. The resultant effects of the pollution include climate change, degradation of soil and burning of crops, death of aquatic biota, release of offensive odour, especially ammonia (NH_3) and hydrogen sulphide (H_2S), and cause diseases of public health concern to human beings and animals. These consequences are due to the emission of harmful gases and compounds and the presence of pathogens in the waste. Animal wastes are potential sources of income and resources, and their environmental consequences could be reduced if farmers could use innovative approaches such as vermicomposting, production of biogas using wastes, membrane filtration, liquid – solid separation, thermal treatment and chemical treatment approaches to manage animal wastes. Government regulation and policies against indiscriminate disposal and application of animal wastes, coupled with the sensitization of people to the benefits and dangers associated with animal waste, could also prevent environmental challenges.

Keywords: Animal wastes, Characteristics, Benefits, Environmental consequences, Waste management

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INTRODUCTION

The geometrical increase in population has mounted a lot of pressure on available food resources, thereby increasing the level of food insecurity. The challenges of food insecurity and the quest to make adequate and nutritious food available, economic challenges, and unemployment have driven many people into the rearing of animals, which has increased job creation, generation of income, and diversification of agriculture. Nigerians quest to improve consumption of protein has increased production of animals, which directly increases waste generation (Fadairo *et al.,* 2019). Generated wastes harm the ecosystem, and they need to be properly managed in order to reduce their environmental impacts and harness their benefits. After oil, agriculture has been the main source of the Nigerian economy and has, over the years, provided a means of livelihood for many Nigerians. Livestock rearing contributes to Nigeria's gross domestic product. Perhaps this has led the government to support animal farming, which increases animal production in different countries and, in turn, produces a lot of waste, even beyond the level that some farmers can manage or control.

Unfortunately, animal production, especially ruminant animals and other forms of agricultural systems, has negatively impacted the environment. Animal production produces a lot of waste, such as animal dung (faeces), feathers, blood, and discarded cellulose materials (grasses), which undergo both aerobic and anaerobic fermentation. Animal wastes can be classified into two major categories: slurry and solid. Slurry is the liquid or effluent from animal production industries such as urine, waste water, and blood, while solids include those animal wastes in particulate form such as discarded animal feed, bones, horns, feathers, and fur. The problem lies in these wastes, especially coliforms entering food and water bodies (Parihar *et al.,* 2019). Microbial metabolisms that take place during the fermentation processes release greenhouse gases such as CO_2, CH_4, and N_2O. It produces gases with offensive odours such as ammonia (NH_3) and hydrogen sulphide (H_2S) and creates a conducive environment for the growth of pathogenic microorganisms. Moreover, some animal houses are located close to water bodies and residential and industrial buildings, where they easily cause environmental hazards to people and other living organisms. Livestock production influences climate via feed formulation, animal production, manure processing, and transportation. Carbon (iv) oxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are emitted through feed formulation systems and manure generation, which affect climate change (Rojas *et al.,* 2017). Livestock primarily causes GHG emissions in the form of CO_2, CH_4, and N_2O. CH_4 contributes 44% to anthropogenic GHG emissions, which is the highest compared to 29% of N_2O and 27% of CO_2 emissions (Gerber *et al.,* 2013). Livestock contribute 44% of anthropogenic CH_4, 53% of anthropogenic N_2O, and 5% of anthropogenic CO_2 emissions globally and higher concentrations of these greenhouse gases are caused by lower efficiency and productivity of livestock practices, which are attributed to excess losses of organic matter, nutrients, and energy (Gerber *et al.,* 2013). IPCC (2022) is the most commonly used estimating parameter (value) in the literature for greenhouse gas emissions, and it has been reported that the warming potential of CH_4 is 25 CO_2-eq, while that of N_2O is 298 CO_2-eq. Therefore, the livestock sector contributes both directly and indirectly to total greenhouse gas emissions through animal physiology, animal housing, manure storage, manure treatments, land application of animal manure, and chemical fertilisers. Agriculture takes the lead as a source of decreased water quality in lakes and rivers and the third-largest contributor to the degradation of estuarine habitat (U.S. EPA, July 2021). Nutrients, sediments, pesticides, salts, and animal wastes are the contents of agricultural land runoff, which enters water bodies and decrease water quality (Kosimov, 2024). As earlier stated, the livestock sector contributes 14.5% of global GHG emissions and could cause a decrease in biodiversity, increase air and water pollution, and cause land degradation (Singh and Rashid, 2017). It is noteworthy that climate change, on the other hand, affects livestock production through competition for natural resources, quantity, and quality of feeds, causes livestock diseases, heat stress, and loss of biodiversity, yet the demand for livestock and its products is increasing on daily basis globally (Singh and Rashid, 2017).

Despite the negative consequences of animal waste, they have positive consequences (benefits). They have physical, chemical, environmental, economic, and organic benefits. They condition the soil, provide nutrients, and improve the physical properties and microbial activities of the soil. The benefits of animal wastes to soil depend on the quality of the waste added, the quantity applied, and the number of reapplications needed (Burnett, 2019).

Therefore, the challenges in animal production include how to maintain a balance between productivity, household food security, and environmental preservation (Wright *et al.,* 2012). Because of adoption of imperfect technologies in managing animal wastes, the increasing animal production would continue to result to environmental pollution. (Kosimov, 2024). So, animal farmers should adopt sustainable animal waste management systems to prevent or reduce its environmental consequences, harness the benefits of animal waste, and generate income from the waste.

REVIEW METHODOLOGY

A literature search was conducted using Google scholar search engine and research gate to download published articles. All the articles used in writing this paper were screened based on the article keywords and title. The string of the keywords was animal wastes, environmental consequences, benefits, innovative approaches to animal wastes management and classification of animal waste management. The search strategy was specific to the search key words.

(A)

(B)

Figure 1: Animal Wastes. **A** is a Donkey wastes dump site located near river at Nkwo market, Izhiangbo, Ohaukwu Local Government Area, Ebonyi State. **B** is cow dung.

Characteristics of animal waste

Animal waste contains many useful and recyclable components. These compounds are beneficial and harmful, depending on their concentration, usage, and management system. These compounds produce other characteristics that are of environmental concern, such as odour, emission of GHGs, supporting the growth of pathogens, and exerting harmful effects. Nitrogen and phosphorus are the most abundant elements in animal waste. The characteristics (physical and chemical) of animal wastes impact their potential as fertilizer. The determinants of the physical and chemical characteristics of animal wastes are the constituents of animal feeds, management, and the digestive tract of those animals. Animal wastes are classified on the basis of their consistency or moisture content; up to 5% of solids are classified as liquid; slurry and semi-solid manure are between 5 and 25% solids content; and solid manure is above 25% solids content (Ogejo, 2015). Table 1 shows the general characteristics of manure generated from typical animal production operations. In consideration of the variability in consistency, physical structure, and chemical composition of animal wastes, preference is given to locally produced animal wastes.

Table 1. Characteristics of farm animal manure (animal unit per day, per 1000kg). Modified from ASABE (2005)

Type of Manure	Category of Animal	Weight (kg)	Moisture (%)	Total Solids (kg)	Volatile Solid (kg)	Biological Oxygen Demand (kg)	Nitrogen (kg)	Phosphorus (kg)	Potassium (kg)
Diary Manure	Lactating cow	44.04 – 59.02	39.50	5.45 – 7.72	4.1768 – 5.902	0.95	0.30	0.05-0.07	0.14 – 0.17
	Calf	37.68	37.68	4.18	3.50	-	0.19	0.02	0.05
	Heifer	25.42	37.68	3.86	3.31	0.54	0.12	0.02	0.05
	Dry cow	23.15	39.50	3.00	2.54	0.38	0.14	0.02	0.05
Beef Manure	Beef cow in confinement	47.22	39.95	5.90	4.99	1.14	0.16	0.04	0.11
	Growing calf in confinement	34.96	39.95	4.18	3.50	0.77	0.20	0.04	0.13
	Finishing cattle	29.51	41.77	2.36	1.95	0.45	0.16 – 0.23	0.02 – 0.03	0.11
Swine Manure	Gestating Sow	11.35	40.86	1.14	1.04	0.38	0.07	0.02	0.05
	Lactating Sow	26.79	40.86	2.68	2.45	0.91	0.20	0.06	0.13
	Boar	8.63	40.86	0.86	0.77	0.30	0.06	0.02	0.04
Poultry Manure	Layer	25.88	34.05	6.81	4.99	1.50	0.50	0.15	0.18
	Broiler	39.95	33.60	9.99	7.72	2.41	0.44	0.13	0.25
	Turkey toms	15.44	33.60	4.00	3.22	1.04	0.24	0.07	0.11
	Turkey hen	21.79	33.60	5.45	4.45	1.36	0.33	0.09	0.14
	Duck	46.31	33.60	12.26	7.26	2.04	0.45	0.16	0.23

Negative environmental consequences of animal wastes

Due to the increase in livestock production globally, animal waste has become a serious environmental hazard. It results in greenhouse gas emissions, land degradation, and other factors capable of causing water scarcity (Espinosa *et al.,* 2022). In the year 2000, contamination of drinking water by animal wastes caused several deaths in Walkerton, Canada (Catelo *et al.,* 2001). Steeg and Tibbo (2012) reported that 59%-63% of world non-carbon dioxide, 54% of methane, and 84% of nitrous oxide global emissions are contributed by agriculture and about 35% of world GHG emissions from agriculture come from livestock production. Consequently, the expansion of livestock production leads to the need to tackle subsequent environmental problems. Some of these environmental issues are summarised in Table 2.

Table 2: Environmental problems of animal wastes

Item	Sources from livestock production	Area of Environmental concern	Reference(s)
Carbon dioxide (CO_2)	Fossil fuel combustion, respiration	Climate change	Giampiero *et al*., 2019
Methane (CH_4)	Enteric fermentation, anaerobically stored manure	Climate change	Giampiero *et al*., 2019
Nitrous oxide (N_2O)	Manure-amended soil	Climate change	Giampiero *et al*., 2019.
Ammonia (NH_3)	Manure	Air quality, eutrophication, odour	Williams *et al*., 2017 Kosimov, 2024
Volatile organic compounds	Fermented feeds, fresh manure	Tropospheric ozone formation	Place and Mitloehner, 2014
Particulate matter	Dry-lot housing for livestock, formation from ammonia	Air quality	Williams *et al*., 2017
Nitrate (NO_3)	Manure-amended soil	Eutrophication	Williams *et al*., 2017
Phosphorous runoff	Manure-amended soil	Eutrophication	Singh and Rashid, 2017
Salts	Manure-amended soil	Soil quality	Williams *et al*., 2017
Bacteria	Manure-amended soil	Soil and water quality	Singh and Rashid, 2017 Kosimov, 2024
Antimicrobials	Manure-amended soil	Soil and water quality	Singh and Rashid, 2017

Soil degradation

Over the years, animal waste has been disposed of in the environment without proper waste and nutrient treatment or management plans. This has led to environmental problems such as over-fertilisation of the soils, toxic runoff, and the leaching of contaminants. Frequent application of manure has led to the provision of nutrients above crop requirements, the accumulation of macronutrients (such as nitrogen, phosphorus, and potassium), and heavy metals such as copper and zinc, which consequently have impacted negatively on animal health through grazing and crop feeding (Maillard *et al.,* 2014). The impact of livestock on the soil can be physical impact and biological impact. Physical impacts occur as a result of prolonged heavy grazing, which puts many edible plant species into extinction, and subsequently, the environment may be dominated by inedible, herbaceous plants or bushes. Degradation of soil occurs as animals search for green pasture to feed on, whereas biological and chemical impact occurs as a result of the incorporation of animal wastes such as faeces and urine into the soil, which causes a lot of microbial and chemical alteration in the soil. Field experiment conducted by Jim *et al*., (2016) provides strong evidence that annual pasture nitrogen uptake is more strongly influenced by high urine nitrogen deposition than pasture nitrogen concentrations. Excess nitrogen and phosphorus cause environmental issues such as surface water contamination and soil erosion because of their low solubility in the soil.

Water pollution

Microorganisms, sediment, nitrogen, and phosphorus are the greatest concerns for water quality assessment parameters. These parameters pollute water bodies. Pollution is a complex process, and animal waste management practices determine the availability and form of the pollutants that are released into the environment. Pollution of both surface and underground water by animal waste occurs through runoff from the soil and direct disposal to water bodies. Animal wastes accumulate in the soil when they are applied in excess of crop requirements. During this saturation point, manure nutrients are lost and flow to both surface and underground water. The two nutrients of greatest agricultural concern are nitrogen and phosphorus, as they cause water pollution. Free NH_3 is toxic to fish compared to NH_4^+ (Wang *et al*., 2017). Singh and Mohd (2017) reported that effluent from animal production contaminate drinking water which causes serious health challenges for people. This shows that nutrients from animal waste can contaminate drinking water. Apart from human infection, leaching of animal wastes into water bodies increases the nutrient (nitrogen and phosphorus) concentration of water, resulting in eutrophication as presented in Figure 2. Eutrophication, which is the massive and fast growth of algae and other aquatic plants, results in algae blooms, reduces the availability of dissolved oxygen in water, and impairs photosynthesis. Consequently, some algae and other aquatic plants die due to the deprivation of sunlight and oxygen. Bacteria decompose the dead aquatic plants. Bacteria, fish, and plants compete for the available dissolved oxygen in water to carry out their metabolic processes. Oxygen and sunlight deprivation and the presence of harmful compounds like NH_3 in water kill aquatic biota, especially fish. This could lead to the extinction of some beneficial aquatic biota. The use of manure should be regulated by the government by enacting laws.

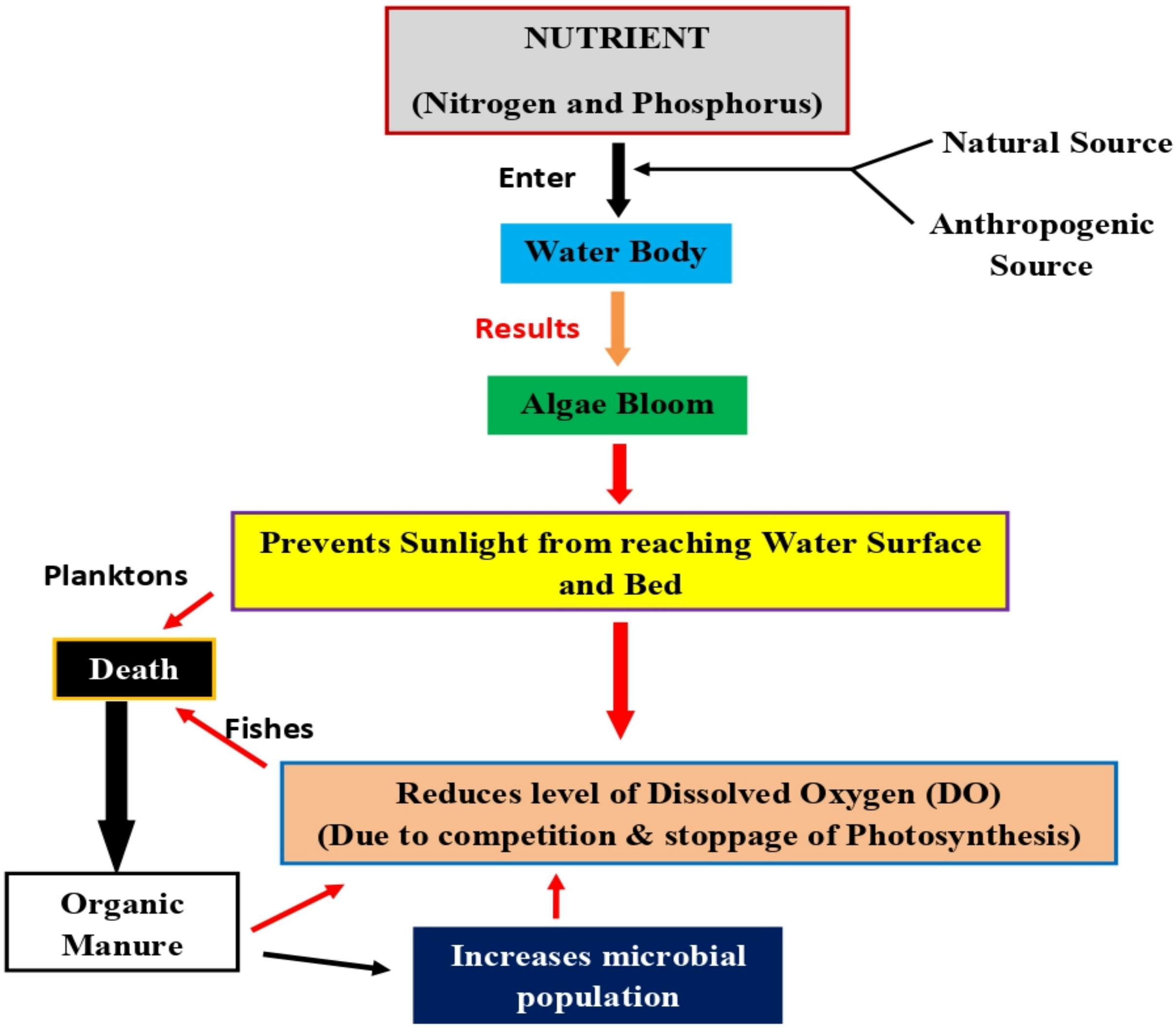

Figure 2: Steps involved in eutrophication and its environmental consequences. The red arrows show the resultant environmental consequences of each of the steps.

Surface water: Animal wastes get into surface water through runoff (Parihar *et al.,* 2019). The impacts of land-applied manure are based on the factors that control or influence runoff and erosion. These factors include soil type, intensity and duration of rainfall, topography, and the nature of the soil surface. When considering the pollution rate and animal waste loading rate, timing and management practices play important roles. The three ways potential pollutants can be transported from the area where they are treated are through solution or suspension, absorption into the soil, and particulate form. Solution/Suspension: Organic nitrogen like uric acid, soluble phosphorus, carbon, nitrates, and ammonium can be transported by this method. Microorganisms can also leach out through this means. Absorption to Soil**:** Microorganisms and other substances such as NH_4+ and P (phosphorus) may be absorbed by soil particles and transported by erosion to water bodies. Particulate Form: Transport in particulate form is possible for forms of organic C, P, and N.

Groundwater Impacts: The quality of groundwater can be impaired by the accumulation of water runoff containing pollutants. Groundwater collects pathogens through runoff from animal wastes (Parihar *et al.,* 2019*)*. Ways by which groundwater pollution occurs include diffusion, sorption, and saturated and unsaturated water flow in sub-processes. Subsurface transport depends on the hydraulic characteristics of soil waste and the form and quantity of potential pollutants available. Soluble forms of nitrogen, such as salt, soluble phosphorus, and nitrous oxide, and microbial contamination of groundwater have received much research attention. Using raw or untreated poultry wastes does not allow uptake of phosphorus because it is mainly inorganic (about 32–4%) and accumulates in the soil and leaches into the water (Kacprzak *et al.,* 2022).

Air Pollution

Greenhouse gases such as methane, nitrous oxide, carbon dioxide, and other potential airborne pollutants capable of destroying the ozone layer and causing diseases are emitted through livestock production practices. The most important greenhouse gases from animal wastes are CH_4 and N_2O, and mitigation strategies should be targeted at reducing their emissions (Giampiero *et al*., 2019). There is a higher content of N_2O and NH_3 in poultry wastes compared to cattle wastes (Kacprzak *et al.,* 2022). Depletion of the ozone layer results in global warming. Many nations depend on the animal nutrition and wealth for survival so, a lot of wastes and gases are generated which are not eco-friendly and causes nuisance especially in urban and industrialized settings (Singh and Mohd, 20017; Younis *et al*., 2023). Large livestock facilities cause the emission of airborne contaminants such as toxic gases and matter such as particulate matter, endotoxins, ammonia, hydrogen sulphide, nitrous oxide, methane, and volatile organic compounds. Most of the gases emitted from animal husbandry come from the fermentation in the digestive tracts of ruminant animals or from anaerobically stored waste. Methanogens are responsible for the fermentation. The daily amount of gases emitted per animal in a day is determined by feed stuff, feed concentration, fat content of the feed, the presence of feed additives, the amount of feed taken by animals, and the digestion strategy of the feed that changes the microbial activities of rumen (Dammgen *et al*., 2012). The calculation of IPCC shows that the warming effect of 1kg of carbon (iv) oxide is less than 63 times the warming effect of 1kg of methane. Nitrous oxide (N_2O) emitted through livestock production comes from the soil fertilised with animal wastes (Junior *et al.,* 2013). Methane and nitrous oxides are the two major gases that cause global warming. They are also associated with the photochemical reaction that leads to ozone layer formation. The single largest source of NH_3 emissions is estimated to be livestock. NH_3 is formed by the combination of urine and faeces and the subsequent hydrolysis of urea by the urease enzyme, which is found in animal waste. Nitrogen excreted from animal wastes is emitted as NH_3. This ammonia causes respiratory problems, eutrophication, odour pollution, formation of acid rain and causes imbalance in the ecosystem through nitrogen deposition, fertilization of vegetation and influencing the reaction of some aerosols which alter radiative balance of the earth's surface. Movement of animals, exhaust used in ventilating animal houses, reactions between particles, and movement of farm equipment result in the release of dust (Cambra *et al.,* 2010). The fermentation of either animal feed or newly produced manure is the main source of volatile organic compounds (VOC). VOC can lead to the oxidation of NO to NO_2, known as NOx, and ozone (O_3) can occur in the presence of sunlight (Ling and Guo, 2014).

Public health issues

Livestock husbandry produces wastes that support the growth of many microorganisms, such as bacteria, viruses, parasites, and fungi, that pose potential health risks. This health risk may occur during the subsequent spreading of manure on agricultural land. It is worrisome how human waste treatment plants are in place, yet livestock waste treatment plants are not rampant. The worst health challenge associated with concentrated animal feed operations (CAFOs) is the quantity of manure they produce. CAFOs have environmental and human health challenges or consequences. Many microorganisms in animal waste survive in the environment for a long period of time. Zoonotic diseases associated with animal wastes are the most confirmed cases of diseases (Singh and Mohd, 2017). Zoonotic diseases are diseases transmitted from animals to human beings. Such diseases are: *Salmonellosis*, *campylobacteriosis*, leptospirosia, hantavirus pulmonary syndrome and toxoplasmosis. Animal waste and its effluent are the principal vectors of animal diseases when considering outbreaks of diseases among farm animals. This outbreak is worse in the absence of good waste management protocols and could result in an increased rate of disease spread and infection on neighbouring animal farms. Bezanson *et al.* (2014) reported that some cases of food crop contamination by pathogenic microorganisms are caused by treating food crops with animal wastes as fertiliser. Food crops, especially those that are eaten raw, can be contaminated by pathogens such as Salmonella and Campylobacter by applying animal wastes to those crops as either soil amendment or fertiliser. Although the contamination of food crops is relatively minimal, the public still considers it a high risk, which leads to the campaign for restrictions on the use of such animal wastes. There is a high risk of disease contraction by animal farmers, which could be a result of direct infection of internal animal wastes resulting in the inhalation of some gases and dust (Maryam *et al*., 2015). The infection of people outside the farm could be due to runoff and the production of aerosols. The odour produced from this activity is a nuisance. Zoonoses can contaminate food by using water contaminated by animal waste to irrigate food crops. The route of irrigation of vegetables is important, as the water used in washing such vegetables, as well as other foods, can also present a risk (Wang *et al.,* 2015).

Endocrine - disrupting chemicals (EDCs) are another category of pollutants of concern that can be found in animal waste. Examples of EDCs in animal wastes are steroids and arsenic in the form of arsenate (Combalbert *et al.,* 2012). They can come from drugs used in treating animals or animal excreta. EDCs are either organic or inorganic chemicals that exert adverse health effects by interfering with the hormonal signalling pathways of human beings or animals, including their offspring (European Union 2014). EDCs interfere with hormone receptors to alter the outcome of internal signalling events by mimicking the function of estrogenic or androgenic hormones. Even at a minimal level (part per trillion or nanogram per litre), EDCs can still exert their disruptive activity (Combalbert *et al.,* 2012).

Airborne contaminant emissions from manure can include toxic gases and particulates which cause different airway diseases such as asthma, chronic obstructive pulmonary diseases, bronchitis, and irritation of the mucous membrane (Singh and Mohd, 2017). Endotoxins, organic aerosols, and other inflammatory agents are associated with inflammatory diseases especially among swine workers and nearby inhabitants. Some gases' emissions from animal wastes, like NH_3, cause lethal effects in regional places by travelling far beyond the farm location. A study conducted by Tang *et al.* (2015) detected high concentrations of antibiotics in vegetables, especially tetracycline. These antibiotics pose health and environmental issues, depending on their type and quantity. Consumption of vegetables treated with animal waste could result in widespread antibiotic resistance (Wang *et al.,* 2015), which could consequently strengthen pathogenic organisms.

All animal husbandry practices generate odorous compounds as a result of the microbial degradation of organic matter. High concentrations of these odorous compounds, especially ammonia and hydrogen sulphide, pose respiratory problems to both animals and workers when accumulated. Obviously, odour causes ill health.

Heavy metals pollution

A large number of heavy metals, about 90% or more, are excreted through livestock manure (animal waste). According to the study carried out by Delahaye *et al*. (2003) on the heavy metal balances of soil in the Netherlands, such as Zn, Pb, Ni, Cd, Cr, Cu, and Hg, a high number of heavy metals was observed. It was observed that an excess of these heavy metals led to the absorption of the heavy metals in plants, which consequently leaked out into both surface and underground water. Frequent application of swine and poultry wastes leads to the accumulation of heavy metals. This destroys the normal functioning and structure of the soil and, as well, contaminates the crops. Toxic substances such as hormones, antibiotics, and other veterinary medical residues require much attention and concern in environmental analysis of animal waste impacts because they may have negative effects on food quality, human health, and aquatic life.

Positive environmental consequences of animal wastes

Though animal wastes pose a lot of harm to the ecosystem, as discussed earlier, they still have many environmental benefits. Animal wastes are applied to land as fertiliser, which improves soil fertility and sequestration of soil carbon (Qin *et al.,* 2021). These benefits are dependent on management practices and the quantity and quality used. Positive environmental consequences of animal wastes are stated below, as modified from Burton (Burnett, 2019).

Animal manure releases nutrients slower than inorganic fertilisers; therefore, its nutrients last longer in the soil to sustain crops than conventional fertilizers. Manures reduce soil erosion and runoff through soil infiltration and their binding capacity. This reduces the rate of soil degradation compared to inorganic fertilisers. Due to its slower supply of plant nutrients, it provides crops with the needed chemical nutrients over time. The supply of nutrients depends on the materials used as animal feed. Therefore, animal wastes should be subjected to laboratory testing to bring balanced nutrients to our farmland. Organic manure generated from animal wastes adds carbon to the soil. This enhances the activity of soil microbes, resulting in increased soil strength, oxygen peculation, and enzyme activity. Animal wastes improve soil structure, moisture retention, and water infiltration. This physical improvement of soil happens over time; therefore, amendment of soil with animal wastes should be consistent in soil lacking nutrients.

Though the economic nature of animal manure depends on its availability and proximity to farms, it is still cost-effective as it lasts longer in the soil than inorganic fertilisers. Animal wastes are good sources of materials for biogas production. Methane (CH_4) is produced at the end of the anaerobic fermentation of waste in a biodigester. The gas (methyl) can be captured in an airtight cylinder and used as cooking or heating gas in both industries and homes.

Animal wastes management system/practices

Animal waste management practices involve all the possible methods that are applied in handling waste from animal production. Most farmers in sub-Saharan Africa do not adopt good and recommended animal waste management practices; they do not cover stored manure and floors with water-proof or roofed animal houses, thereby causing greenhouse gas emissions and nutrient loss (Ndambi *et al.,* 2019). In 2012, it was observed that most animal production in China occurred in sub-urban regions, exposing 60% of the population to NH_3 above UN guidelines (Bai *et al.,* 2022). Animal wastes, especially those from slaughterhouses, are produced in large quantities and harbour pathogens, but they could be sources for valuable products if managed effectively (Mozhiarasi and Natarajan, 2022). A common and important goal of livestock waste management is to use environmentally, socially, and economically acceptable ways to derive value from animal wastes (AWs). These could be energy generation from the waste, nutrient recycling, and soil amendment with organic manure. Recycling animal wastes will generate energy and organic fertilisers and minimise pollution problems related to animal wastes (Kasatkin *et al.,* 2022). Traditional or cutting-edge technology may be used in animal waste management systems to disinfect the waste. These methods are discussed in this section. The objectives of manure treatment depend on individual needs and the regulations guiding the management of animal waste in the area. Many available animal waste disposal methods depend on the type of waste, regulations, and capital available. Direct land spreading of animal wastes is the most common method among animal farms (Jiang *et al*., 2015). The main objective of animal waste management is to make use of its nutrients, especially for crop production. The earliest method of manure application was direct spreading on farmland. Due to the increase in environmental pollution and health challenges over the years, animal waste should be handled carefully to minimise any adverse effects on water, soil, and air quality. It is important to know that appropriate storage facilities are needed to help nearby farm from contamination. It is advised not to apply raw manure immediately to crops without proper treatment (Jiang *et al.* 2015).

Objectives of animal wastes management

There are many objectives for adopting a good animal waste management system. They are: manure stabilisation, odour reduction, nutrient management, easy and appropriate storage, reduction of microbial load, reduction in the emission of gases, and reduction of manure ass or biomass.

Manure stabilisation: treatment of animal wastes stabilises the manure and makes its storage and application easy. Odour reduction: The offensive odour caused by the emission of ammonia and hydrogen sulphide can be reduced by treating animal waste before usage or storage. Nutrient management: Different treatment technologies can be used to produce modified manure in which nutrients are in the right agronomic proportions for use as fertiliser. This reduces the risk and chances of nutrient pollution. Easy and appropriate storage: Treating animal wastes before usage reduces the bulky nature and weight of the wastes in a way that they can be stored for a longer time, and transportation is made easier. Reduction of microbial load: It has been established that animal wastes, especially decayed ones, contain numerous microorganisms that cause health challenges. Treating animal waste can reduce the number of pathogens inhabiting the waste. Antibiotics used in treating animals or formulating animal feed can be prevented from leaching into water bodies or being absorbed by crops. Reduction in the emission of gases: proper management of animal wastes reduces the emission of NH_3, H_2S, and greenhouse gases such as CH_4, N_2O, and CO_2. This can be achieved by capturing the gases for more economic and eco-friendly uses. Reduction of manure mass and biomass: proper management of animal wastes results in the availability of a lesser quantity of biomass for transportation.

Classification of animal wastes management system

There are two main classifications of animal waste management systems. There are traditional and modern management systems.

Traditional management system

The traditional management of animal wastes includes spreading (broadcasting), sprinkling, and under-soil surface injection of animal wastes. These are the most common ways of applying animal waste or manure to farmland (Christopher 2015; USDA 2015). Animal waste slurry is injected under the soil surface, while solid wastes are applied to the soil surface by spreading. Solid wastes are mixed and incorporated into the soil by continued tillage. Surface spreading of animal manure or organic waste increases the possibility of zoonotic diseases especially through run-off. Though injecting slurry under soil reduces airborne diseases, it increases the survival rate of pathogens (Jiang *et al*., 2015). Generally, animal waste treatment practices can also be classified as solid, slurry, or lagoon systems. These systems can be combined depending on manure total solids content, means of collection, storage, transportation, and application to the soil. Application of solid wastes to agricultural land could be directly or indirectly (composting) for amending soil (Jiang *et al*., 2015). Animal farm effluent, such as slurry and lagoon, can be recycled to either remove or reduce barns or applied to crops as fertiliser (Jiang *et al*., 2015). In China, 1% of manure is composted, 92% is applied to agricultural land, and 7% is used to produce biogas through anaerobic digestion systems (Chadwick *et al.,* 2015). China is focused on animal farm managers to capture 95% of animal manure by carrying out campaigns that would bring about sustainable and responsible animal manure nutrient use. This approach is insufficient, as over-application of animal wastes as fertiliser results in eutrophication. Jiang *et al.* (2015) advised that animal wastes should be used on farmlands where cereal crops are cultivated because of their high phosphorus demand and to help reduce excess fertilizer. Environmental problems coupled with serious health problems caused by animal wastes are due to bad management and the presence of pathogens, especially food-borne diseases. This occurs due to the direct application of animal wastes to edible crops such as vegetables.

Therefore, there is a need for more environmentally friendly systems to manage animal waste.

Modern management system

Advancement in technology, coupled with awareness of the environmental consequences of animal waste, has led to the development of modern systems for managing animal waste. Traditional methods of animal waste management have challenges associated with the consumption of energy and the quality of nutrients recovered (Dadrasnia *et al.,* 2021), hence modern methods. These modern methods include microbiological, physical, and chemical methods. A lot of environmental and health issues associated with animal waste can be resolved through these methods. Modern methods of animal waste treatment have advantages over traditional methods in the following ways: they produce eco-friendly products such as biogas, generate heat and electricity, reduce microbial load in the waste, reduce emissions of greenhouse gases, are cost-effective, and supply appropriate nutrients to the soil as summarized in Table 3.

Table 3. Innovative Approaches to manage Animal Wastes

Classes of Innovative Approaches	Particular Treatment Method	Advantages	Disadvantages	Reference
Microbiological Approaches	Vermi - compos ting	It is eco-friendly. It is safe to health. It serves as bio-indicator for pollution. It is economical in managing wastes. It adds fertility to the soil. Low capital is required. It treats large quantity of wastes. Not affected by cold weather.	It is slow and takes time. It requires high maintenance. Produces offensive odour. There is tendency to lose greenhouse and nutrients.	Younis *et al .,* 2023 Matthew *et al.,* 2023
	Production of Bi ogas using Wastes	It is environmentally friendly. Less greenhouse gas emission. Waste reduction. Flexible and efficient use of biogas. Digestive serve as bio-fertilizer.	There is tendency to release greenhouse gas. The gas still contains impurities.	Khayal, 2019

Table 3 continued

		Reduced odour and infection spread. Source of income.		
Physical Approaches	Membrane Filtration method	It has high filtration rate compared to other methods. It is easy to use. It is environment friendly.	Incomplete elimination of pollutants Very expensive. High demand of energy. Membrane fouling.	Sukanyah *et al*., 2023
	Liquid – Solid Separation	It has high efficiency of separation. It does not pose further environmental problems.	It is stressful.	Sujata and Bhaskar, 2011
	Thermal Treatment	It reduces the waste quantity. Production of heat and energy. Reduction of pollution.	Releases gas to the atmosphere Causes health challenges.	Maryam *et al*., 2015
Chemical Approach	Chemical Treatment Method	It is cheap. It is easy to implement.	It demands a lot of manual labour. Requires high maintenance. It leaves residual chemical that also causes pollution.	He *et al*., 2019

It is indeed crucial to treat animal waste before applying it to the soil. Modern management systems are discussed as follows:

Microbiological treatment method

This involves using living organisms to degrade or reduce the toxic effects of animal waste. It includes the use of microorganisms, insects (worms), and plants. As earlier stated, anaerobic bio-digester is the most widely used manure treatment method. Microbiological management systems include vermicomposting (the use of worms from insects) and the use of microbes to produce biogas from animal waste.

Vermicomposting: This treatment approach involves the use of earthworms to convert the waste from one form to another. It involves growing worms on animal waste, which borrows and converts animal waste into compost manure, which has a lesser environmental effect compared to fresh or untreated animal waste. Younis *et al*., (2023) reported that the safest method for managing organic waste is vermicomposting. *Hermetia illucens* larvae of black soldier fly are used for bioconversion of organic wastes (Wang and Shelomi, 2017). The end product of this bioconversion is mainly insect biomass and waste residue (frass). Zhu *et al.,* (2012) reported promising results from treating swine manure with housefly maggots and black soldier flies, respectively. Using 0.5% weight of maggot inoculum reduced manure moisture content to less than 60% and produced a large amount of maggot that was served as fish meal in one week. They reported that Black Soldier Fly larvae reduced 55 kg of fresh manure dry matter to 24 kg of digested manure dry matter in two weeks. The biomass produced during the conversion process is further degraded by natural occurring earthworms (vermiculture), bacteria, insects, and fungi into less toxic residue by utilising the nutrients in the wastes for their metabolic activities. This conversion is a good treatment method for animal waste because it reduces the nutrient contents and emissions of gases and makes it eco-friendly. Biogas production from animal wastes using microbes: Manure can be fed into bio-digesters and decomposed by microorganisms to produce methane gas (CH_4), carbon (II) oxide, and water (H_2O). See figure 3 for steps involved in biogas production. CH_4 is captured and used to produce electricity and ethanol (Jiang *et al.,* 2015). Once these wastes are fermented into gases under anaerobic conditions, the gases produced are not released into the ecosystem but captured in an airtight cylinder for the generation of heat, electricity, and other purposes. This method is environmentally friendly as it reduces animal waste biomass, nutrients, microbial load, and odour, and the digestate can be used as fertilizer. There are four main stages of biogas production: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis involves breaking down complex compounds into soluble components. Fermentation (acidogenesis and acetogenesis) is the anaerobic degradation of the waste by microorganisms. Acidogenic and acetogenic bacteria are responsible for this conversion, which yields alcohols, acetic acid, other volatile fatty acids, and gases such as carbon dioxide and hydrogen. These are intermediate products that are used to metabolise methane at 60–70% and carbon dioxide at 30–40% (Dolores *et al.,* 2016). Liquid can be separated from solid digestate and used as fertiliser (Dolores *et al.,* 2016). There is a two-phase anaerobic digestion system for generating energy from animal waste. This two-phase digestion allows the selection and enrichment of different bacteria in each digester. The first phase involves the degradation of complex compounds into volatile fatty acids by acidogenic bacteria, which are subsequently converted to CH_4 and CO_2 by acetogenic and methanogenic bacteria. The latter happens in the second phase. The first stage acts as a metabolic buffer, which helps prevent pH shock to the methanogens. Low pH, a high organic loading rate, and a short hydraulic retention time (HRT) are all factors that favour the establishment of the acidogenic phase and preclude the establishment of methanogens (Hidalgo *et al*., 2014). Methanogenesis involves production of methane from the intermediates (acetic acid and CO_2) by methanogenic bacteria.

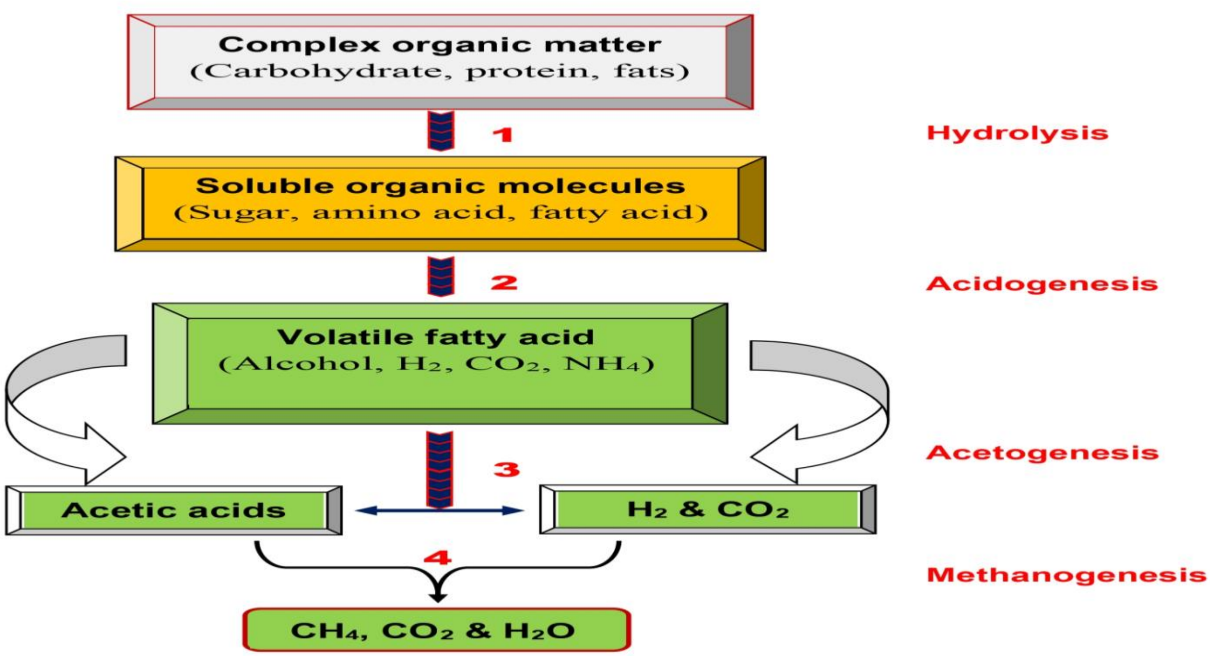

Figure 3: Processes involved in biogas production

Physical treatment method

This is the physical method used to treat animal waste. It includes liquid-solid separation techniques and thermal treatment. Liquid-Solid Separation: This is the separation of animal wastes into their liquid and solid components. This process increases the quality of the fertiliser and reduces the cost of transportation. Separation reduces manure odour and produces biomass that can be used to produce biogas. Nutrients can be removed from manure when this separation process is combined with chemical treatment. Liquid-solid separation by sedimentation or mechanical methods such as the use of screens, centrifuges, or belt presses is imperative because, in a multistep advanced treatment system, it prevents manure particles from overloading subsequent chemical or biological processes (Riano *et al.,* 2014). Mechanical separators are used for the removal of dry matter and phosphorus. This process involves centrifugation, sedimentation, non-pressurised filtration, and pressurised filtration. For flocculated slurry, the best mechanical separation techniques are through the use of screens or filter belts but the additives used to optimise the separation of slurry may cause environmental problems (Guerdat *et al.,* 2013). Microfiltration and ultrafiltration membranes are efficient in solid-liquid separators that can isolate nutrients associated with particles such as phosphorus. Ammonia and potassium retention require nanofiltration or reverse osmosis (Masse *et al.,* 2013). Thermal Treatments**:** This is the use of high temperatures to physically break the bonds between organic matter, resulting in the generation of intermediates such as gas, charcoal residue, and hydrocarbon fuel. Biological-based conversion processes require a longer reaction time. Examples of thermal conversion processes include pyrolysis, gasification, and liquefaction. This process is applied to reducing odour, weight, pollution, and energy from waste. Thermal treatments are heat-intensive, so to make this process energy-feasible, heat recovery should be taken care of. Though combustion converts manure's energy into heat, the method does not provide an efficient means of storing the energy. Another challenge is that the ash product from combustion has yet to find a suitable recycling use (Younis *et al*., 2023). Pyrolysis converts manure organic compounds to char and volatile gases using heat and a non-oxygen atmosphere, containing both non-condensable vapours and condensable tars. Production of char under slow pyrolysis provides farmers with energy and carbon credits for economic purposes. Char can be used as a feedstock, such as "green coal," for existing coal combustion and gasification industries.

Chemical treatment method

Chemical treatment of animal wastes is the use of chemical processes such as chemical coagulation, chemical precipitation, chemical disinfection, chemical oxidation, chemical neutralisation, chemical stabilisation, and ion exchange to reduce the risks associated with animal wastes. A combination of chemicals and physical treatments can be used to remove and recover nitrogen, phosphorus, and heavy metals. Chelme *et al. (*2011) used methods such as precipitation, flocculation, and coagulation help in solid-liquid separation. This physicochemical treatment removed suspended solids (32%), total organic carbon (78%), and nutrients (82% N and 50% P), and there was a reduction of total coliforms. Limewash, acetic acid, calcium cyanide, caustic soda, and others can be used to disinfect manure. This type of treatment is not applied in routine treatment but in cases of epidemic. For chemical disinfection to be effective and successful, the slurry must be mixed before adding chemicals and subsequently stirred.

Conclusion

Animal wastes are not only causing diseases of public health concern to people, including farmers, but also causing a lot of harm to the environment. This is because the majority of animal farmers do not adopt appropriate animal waste management systems. Animal wastes pollute water, air, degrade land, and moreover, alter the earth's radiative balance. These are as a result of nutrients run-offs and emission of harmful and greenhouse gases. Farmers should adhere to regulations guiding the use, management, and discharge of animal waste. Furthermore, people should adopt current animal waste management systems and refrain from building animal houses near residential houses and water bodies. These could help reduce the environmental consequences associated with animal waste. This review focused on animal waste, its environmental consequences, and innovative management approaches but could not take into consideration some other waste management methods.

Conflict of interest

The authors have no conflict of interest to declare.

Author contribution

OFO suggested the title, reviewed literature, and drafted the manuscript and figures. AAI modified the topic and linked it to animal waste. NFN improved/proof-read the manuscript. OAO formatted the references and citations, ICC and OCE cross-checked and assessed the manuscript in line with the journal guideline. All the authors read and approved the final draft of the manuscript.

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