Discover Environment

Review

Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review

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Abstract
The surge in Nigeria's population has led to heightened demands for food, clean water, and agricultural products, resulting in a significant increase in waste generation. Nigeria ranks among the top countries globally in terms of waste production, particularly from food, water, and agriculture. Unfortunately, the management of these vast quantities of waste is often inadequate, leading to environmental pollution, disease, and heightened CO_2 emissions. While reducing such waste is important, completely stopping waste generation from food, water, and agriculture is impossible. Therefore, it becomes imperative to adopt eco-friendly and cost-effective approaches to handling this waste, including collection, conversion, treatment, recycling, and reuse. Effectively managing waste can mitigate pollution and its adverse impacts on public health. This review delves into the environmental, economic, and health challenges associated with the generation of waste from food, water, and agriculture in Nigeria. It highlights the importance of implementing sustainable practices for waste treatment, conversion, reuse, and application. By harnessing these waste materials effectively, Nigeria stands to reap significant economic benefits while simultaneously safeguarding the environment from pollution.

Keywords Agricultural waste · Economic impact · Environmental pollution · Food waste · Food insecurity · Wastewater · Waste utilization

1 Introduction

The current world population stands at 8 billion as of 2022 according to the United Nations. Nigeria has an estimated population of 218 million as of 2022 with an increase of 2.41% annually [1]. In an attempt to meet the needs of the rising population in terms of food and clean drinking water, an increase in the production of food, water and agricultural products is ongoing annually. Despite the increase in food production, there are still approximately 700 million people who are hungry [2], while 844 million people lack access to clean drinking water [3]. Nigeria has an estimated population of 25 million people who are hungry [3, 4] and 70 million people lacking clean drinking water [5, 6]. Due to the increase

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in food production, there is also a corresponding increase in the amount of waste generated from households, fast food post and restaurants [7]. The issue of food waste is very challenging, especially for the environment, as it is most often sent to landfills. Food waste generated is usually incinerated or dumped in open areas, and when not properly handled, it leads to emissions of CO_2 gas, health problems, and sanitation issues [8]. Conversion of food waste to value-added products such as phytochemicals, bioactive compounds, food supplements, livestock feed, dietary fibers, bio-pigments and colorants, emulsifiers, edible and essential oils, bio-preservatives, biofertilizers, and biofuels has been carried out due the presence of carbohydrates, proteins, lipids, and inorganic compounds which are biodegradable [7]. In Nigeria, more than 40 per cent of root crops, fruits and vegetables, 20 percent of oil seeds, and 35 per cent of fish are wasted [8, 9]. A survey conducted by the United Nations Environment Programme (UNEP) and Waste and Resources Action Programme (WRAP) indicated that Nigerians are not ready to change their habits of wasting food due their enjoyment lifestyle [9].

Water is a necessary utility of life which humans and animals need to survive; the increasing population is responsible for the increasing volume of wastewater produced annually in the world. The global production, collection, treatment, and re-use of wastewaters is 359.4×10^9, 225.6×10^9, 188.1×10^9, and 40.7×10^9 m^3 $year^{-1}$, respectively [10]. To meet up with the increasing demand of clean water globally, it is necessary to reduce the wastage of water by only using water when it is needed. Also, collection, treatment, and reuse of wastewater is another way to ensure that people can get adequate water for daily use [9]. In Nigeria, wastewater is not properly managed, and this untreated water get to the water bodies causing environmental problems and affecting the aquatic animals. Consequently, this leads to unhealthy practice which is responsible for several water borne related diseases [11]. In several developed countries of the world, wastewater is collected, treated, and reused for different purposes including irrigation, domestic use, laundry services, recreational parks, aquatic farming, industrial purposes, and drinking [12].

Agricultural wastes are often obtained from crop, tuber and root, fruit and vegetable, seed, and animal such as husk, hull, chaff, stalks, skin, peels, fibre, pith, shells, coir, roes, trimmed parts, pincers, blood, fats, hairs, feathers, bones, liver, intestines, wings, trimmed organs, horn, and hides [13, 14]. The global waste from agriculture is enormous and can be converted into several beneficial products. In Nigeria research has been conducted on the use of this enormous agricultural waste by several researchers, but there are little or no practical conversion of this agricultural waste to useful products on a commercial scale [15, 16]. In Nigeria, [17] used boiled rice, boiled cassava products, bread, boiled yam and boiled maize to make fertilizer and sanitary quality of digestate biofertilizer [17]. Biogas was generated from fresh food waste [18]. Wastewater gotten from fish farm was recycled for various purposes excluding drinking water [19]. Adesemoye et al. [20] reported the re-use of treated Abattoir wastewater [20]. Nanoparticle was synthesized from cassava stem waste [21]. Bamboo-Fiber was used to reinforced laterite for building block [22].

Agricultural wastes attracts lot of flies, worms, mosquitoes, microorganisms, and causes environmental pollution when not properly managed, and this can also cause the spread of infectious diseases. In Nigeria, most agricultural waste are often burnt, generating a lot of CO_2 emission and increases the Greenhouse Gas (GHG) emission [23]. In developed countries, agricultural waste are usually converted into value added products which are bio-degradable and cheap such as textile, footwear, reinforcement fibers, bioplastic, additives, and other bio-products that have similar properties with their conventional counterparts [24]. The cost in terms of the waste generated from food, water, and agriculture worth billions of dollars [8]. Since some of the waste is inevitable, the collection, conversion, treatment, recycling, and reuse could generate income which will lessen the loss from the waste.

The conversion, treatment, recycling, and reuse of waste have been proven to solve some of the challenges faced by this enormous waste produced daily [17]. There are also economic benefits from the process of conversion, treatment, recycling, and reuse of these wastes [14]. Some countries have advanced industrial technology processes to handle and convert this waste to useful products and in some cases, there is domestic technology for conversion of waste to biogas or other useful products. However, in Nigeria there is still a lot to be explored from the enormous waste generated daily from food, water, and agriculture. In Nigeria, the common way of handling food waste in the urban areas is by throwing into the bin and get picked up by the waste management organization and taken for landfill, while in the rural areas, the food waste is thrown into the bush, roads, or burnt, causing CO_2 emission and pollution. Wastewater is badly taken care of due to poor channeling facilities; this makes wastewater find way to water bodies causing heavy pollution and contaminating the waters, leading to water borne diseases and killing of aquatic life [24–29]. A lot of research has been carried out on food waste, wastewater, and agricultural waste in developed countries, referring to the challenges, environmental effects, cost, collection, treatment methods, conversion, recycling, and reuse. However, in Nigeria, there is lack of adequate information on the enormous waste from food, water, and agriculture. The management of the waste generated is inadequate. Additionally, the utilization of waste from food, water and agriculture are limited and only few research work has been done relating to this aspect. Thus, there is a need to describe in detail the practice of food waste,

wastewater, and agricultural waste in Nigeria. Therefore, this paper aims to review the current practice relating to waste from food, water, and agriculture in Nigeria and to discuss the challenges, environmental effects, cost, collection, treatment methods, conversion, recycling, reuse, and economic potentials of these enormous waste generated from Nigeria.

2 Overview of waste from food, water, and agriculture around the world: challenges, implication, and application

According to the UN World Food Programme, over 700 million people go to bed without food [2], while 844 million people still lack access to clean drinking water based on UNICEF [3]. Lack of access to food and clean drinking water is a leading cause of poor growth in children [3]. As people from the underdeveloped part of the world lack access to adequate food and clean drinking water, other people from the developed parts of the world have access to abundance of food and clean drinking water, and then eventually waste a lot of food and clean drinking water in their regions. To ensure a reduction in the number of people who lack access to clean drinking water and increase their access to clean drinkable water, waste management is necessary, as suggested by United States Environmental Protection Agency through the waste management hierarchy (see Fig. 1). The global food waste per year is estimated to be 1.3 billion tonnes costing approximately US$1 trillion [2]. While the global wastewater per year is estimated to be 359.4 billion m^3 [10]. On the other hand, the global agricultural waste per year is estimated to be 659 million tonnes [30]. If this enormous waste generated yearly is reduced or recycled, the impact will go a long way in reducing the number of people who lack food and access to clean drinking water. Several countries in the world are working towards reduction of waste from food, water, and agriculture due to the environmental effects, such as increasing CO_2 emissions, health issues and pollution. The waste generated annually from food, water, and agriculture cost billions of dollars [1, 9].

In this context, the following section presents an overview of the environmental effects, cost, food security, access to clean drinking water, water treatments, conversation, and recycling of food waste, wastewater and agricultural waste in countries around the world.

2.1 Food waste

Food waste is a global issue and vary from one region to another, some countries generate more waste from food than others. The enormous food waste are commonly produced either from household or restaurants. Figure 2 shows the global map of food consumption and food waste in different regions. The total global food waste accounts for 17% of the total food produced annually, which is estimated to be 931 million tonnes of food, with 61% from households, 26% from food services (restaurants), and 13% from retail [9]. Figure 3 shows the total food waste per year in millions of tonnes of the 10 top countries in the world. The top four countries with the highest food waste produced annually are China, India, Nigeria, and the United States producing 91,646,213 tonnes, 68,760,163 tonnes, 37,900,000 tonnes, and 19,359,951

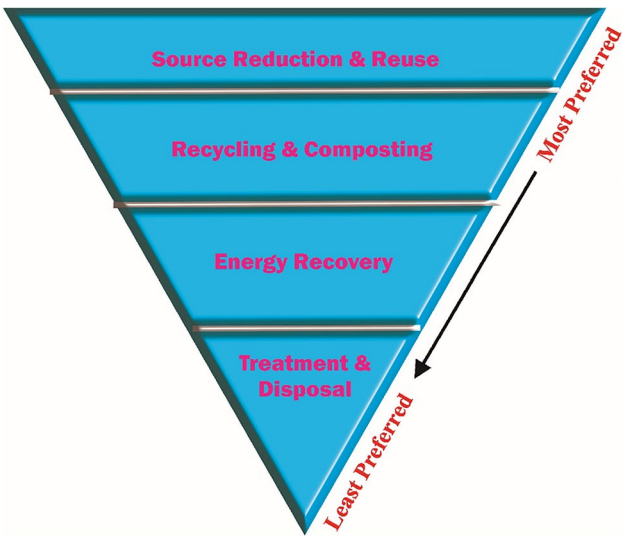

Fig. 1 Waste management hierarchy modified from EPA [31]

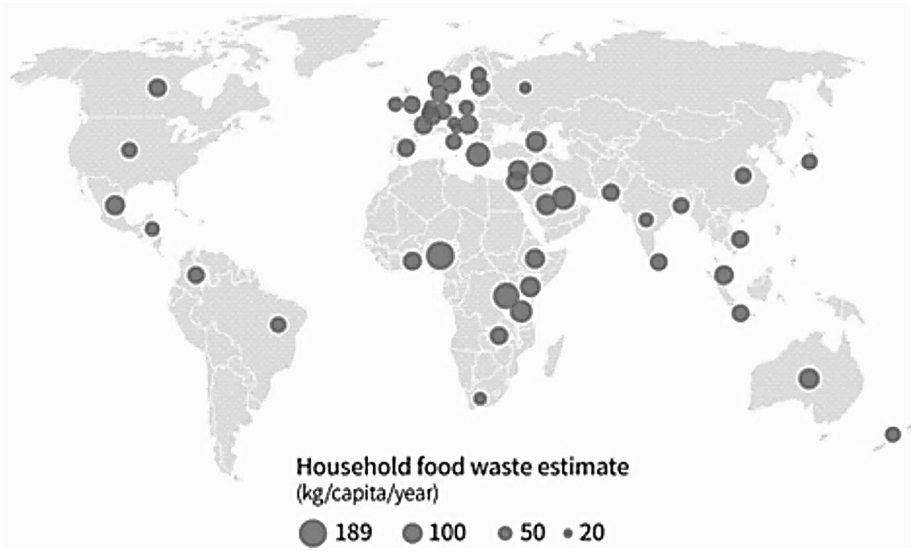

Fig. 2 Food waste worldwide. Source: Authors' modification from UNEP [9]

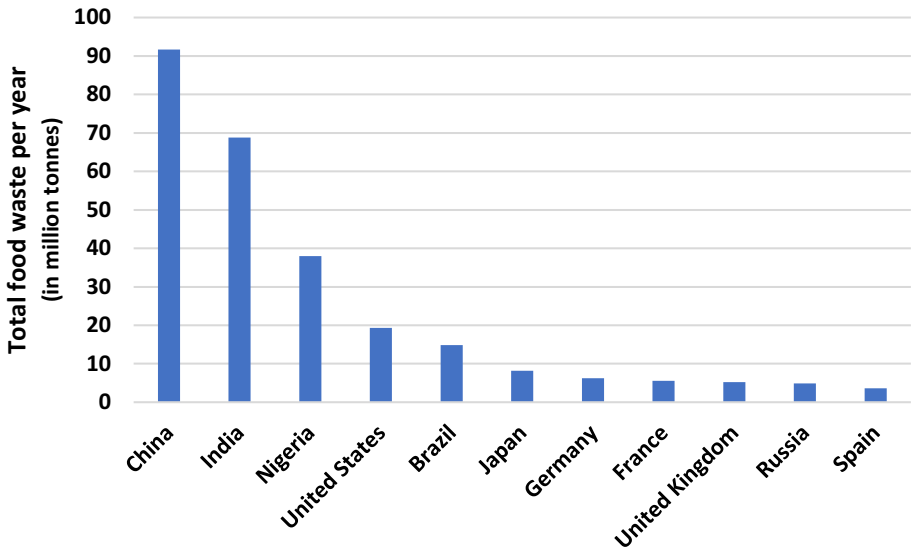

Fig. 3 Total food waste per year (in million tonnes) for top 10 countries in the world [9]

tonnes, respectively [8, 9]. Figure 4 shows the estimated food waste per capita in kilograms of the 10 top countries in the world, with Nigeria, having the highest food waste per capita (kg) which is 189 kg, followed by Greece with 142 kg according UNEP Food Waste Index Report 2021 [8, 9]. The global cost of food waste per year is estimated to be $ 936 billion annually according to the FAO [9]. Food waste in developing countries is mainly from stages of production, storage, and transportation [32]. Food wasted annually is responsible for food insecurity in several parts of the world today, especially in Africa. This is largely responsible for the number of people who go to bed without food daily. Reducing the waste loss from food alone will go a long way to tackling food insecurity globally.

In recent years, the food processing industry has grown rapidly, but this has led to a significant increase in global food waste, valued at around 1 trillion USD, with the United States alone generating 60 million metric tonnes annually [33–36]. Fruit and vegetable waste, rich in beneficial compounds, contributes significantly to this waste [37–43]. Despite their nutritional value, these byproducts are often discarded, leading to economic losses and environmental harm [36, 37]. Major producers include the United States, China, India, and the Philippines [44].

The other issue that arises from food wastes is the environmental issue, because most of the waste generated from food are often not managed properly or burnt, leading to emission of CO_2, littering the environment, attracting insects, flies and other microorganisms which cause several diseases in the environment. Emissions of CO_2 from food waste is one third of the total CO_2 emission [9]. In 2013 the Food and Agriculture Organization of the United Nations (FAO) estimated that 3.3 gigatons of CO_2 was emitted from food waste which is approximately one-third of the global CO_2 emissions in

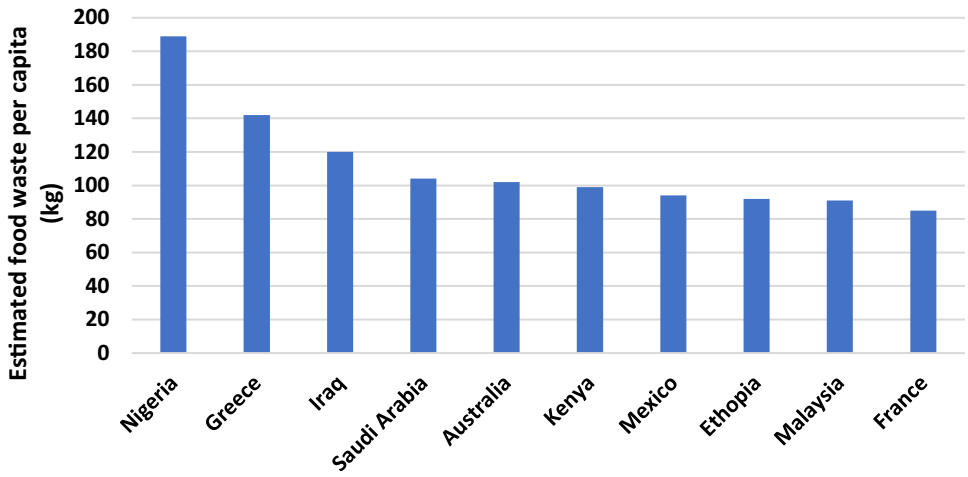

Fig. 4 Estimated food waste per capita (kg) for top 10 countries in the world [9]

2022 [23]. Food waste also has a severe environmental impact, accounting for 8–10% of global greenhouse gas emissions [9]. It has been said that if food waste is a country, it will have been the third highest CO_2 emission country in the world after China and the United States [23, 45].

Reducing food waste saves money, helps other people who are in need, and preserves resources. The United Nations Sustainable Development Goal (SDG) 12.3 has mandated countries around the world to work to reduce food waste per capita by half at the household and retail level by 2030. The United States, China, Australia, and European Union member countries are developing new technologies, strategies, and policies to minimize wastage and to convert wasted food into useful products. Landfill, incineration, recycling, and composting are often used to manage food waste, thereby reducing the pollution in the environment.

2.2 Wastewater

Wastewater, if not carefully managed, can cause lot of damages to the human environment, such as environmental degradation and health risk. The annual global production of wastewater has been reported to be 49 m^3 $year^{-1}$ per capita and 359.4×10^9 m^3 $year^{-1}$ [10]. Figure 5 shows the global production of wastewater in m^3 $year^{-1}$ per capita across different continents, with darker regions having the highest wastewater produced per year. Figure 6 shows the quantity of wastewater generated from eight (8) different regions of the world in m^3 per capita and in million m^3. Wastewaters contain several dirt, heavy metals, acids, chemicals, paints, oils, solvents, hormones, toxic organic compounds, pesticides, herbicides, feces, urine, and all these may end up in water bodies such as rivers, oceans, causing risk to human health, aquatic wildlife, and plant [28, 29].

Fig. 5 Wastewater production (m^3 $year^{-1}$ per capita) [10]

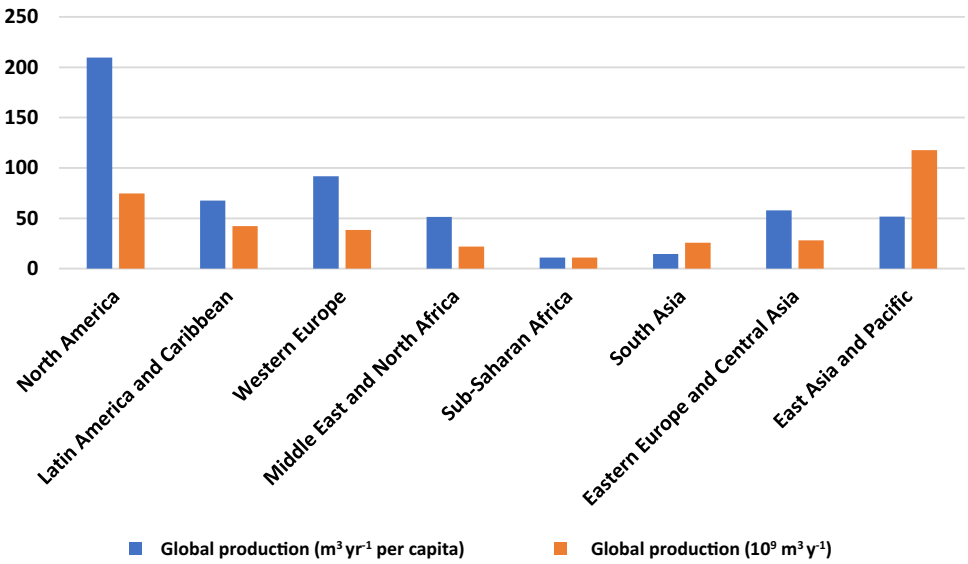

Fig. 6 Geographic region of wastewater production (10^9 m^3 $year^{-1}$) [10]

Sometimes these wastewaters are treated before being discharged into large water bodies, but in the rural areas of some less developed countries where the necessary technology for treatment is not available, the wastewaters go directly into the large water bodies leading to pollution of the water which many dwellers might drink or use for other domestic uses [27–29]. The World Health Organization (WHO) has reported that an estimate of 3.4 million people dies from waterborne disease every year, because wastewater is the most dangerous source of diseases [46]. To safely provide access to clean water for the population of people who currently lack clean drinking water, it is necessary to develop efficient technologies to collect, treat and re-use the wastewater produced yearly.

According to Jones et al. [10] the global production, collection, treatment, and re-use of wastewaters is 359.4, 225.6, 188.1, 40.7 (10^9 m^3 $year^{-1}$), respectively, as shown in Fig. 7. This information shows that only 11.32% of wastewater produced globally is re-used after treatment. Figure 8 shows the global production, collection, treatment, and re-use of wastewater according to the level of income. This indicates that high income countries produce, collect, treat, and re-use the highest amount of wastewater as it clearly shows that the production, collection, treatment, and re-use of wastewater decreases as the level of income decreases. Wastewater treatment is effective but comes at a cost. In 2022, approximately US $ 55.9 billion was spent globally on wastewater treatment services [47]. Nevertheless, no matter the cost, it is necessary to carry out the process of treating wastewater to reduce environmental pollution and the harmful effect on human, plants, and aquatic wildlife. The treatment process of wastewater involves the removal of contaminants

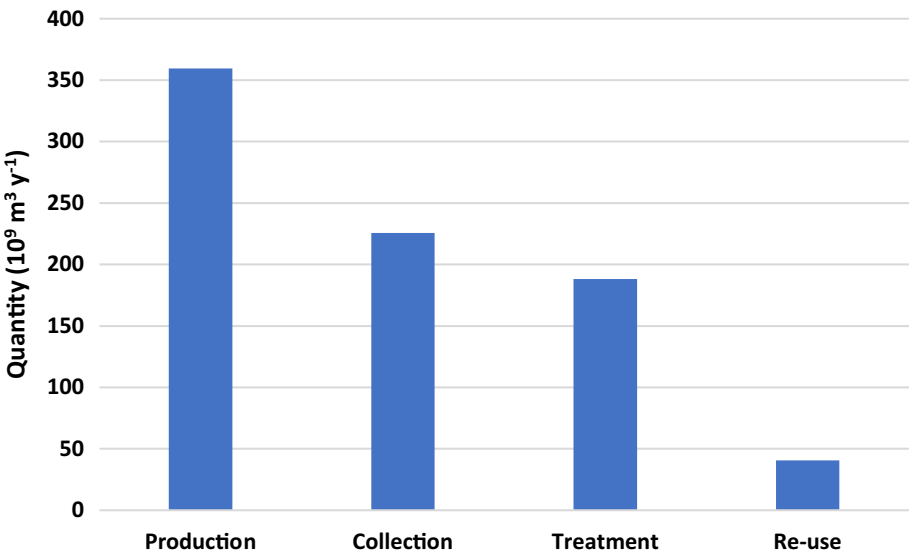

Fig. 7 Global of wastewater production, collection, treatment, and re-use (10^9 m^3 $year^{-1}$) [10]

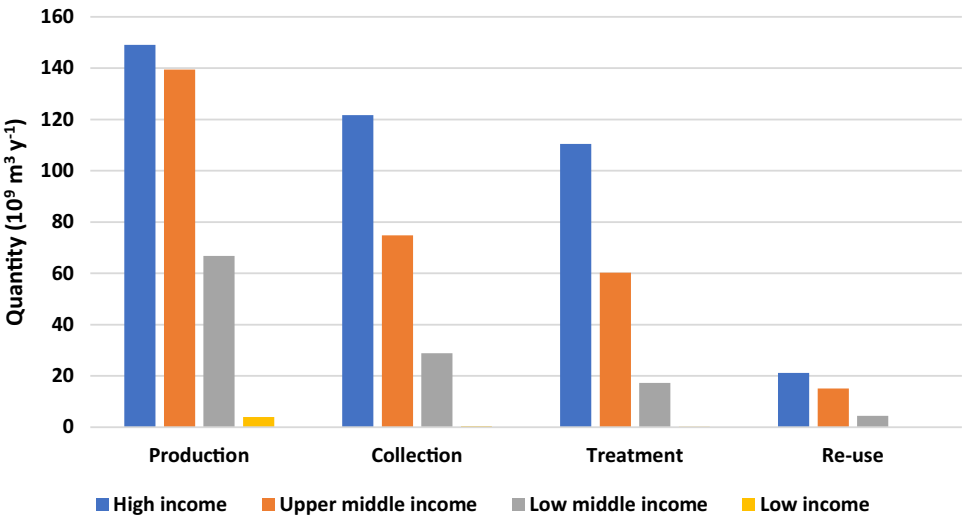

Fig. 8 Global of wastewater production, collection, treatment, and re-use (10^9 m^3 $year^{-1}$) based on income level [10]

and impurities from wastewater and conversion of it into an effluent. Currently, UNICEF is engaging in building access to clean water in support of the sustainable development goal 6 through the targeted water, sanitation, and hygiene (WASH) construction projects [3]. There are currently several technologies used to treat wastewater, so that it can be reused for certain purposes.

Wastewater treatment methods are divided into physical, mechanical, biological, chemical, and advanced techniques [48, 49]. Treated wastewater has been reported to be reused for several purposes [50] including drinking water in some cases after sufficient treatment that ensures the water is safe for drinking water [51]. Figure 9 shows the global reuse of wastewater according to countries per day, with the United States having the highest amount of reused treated wastewater.

2.3 Agricultural waste

Agricultural waste refers to the organic materials produced as by-products from harvesting and processing of agricultural crops such as straw, stem, stalk, leaves, husk, shell, peel, pulp, stubble, etc. which come from cereals (rice, wheat, maize or corn, sorghum, barley, millet), cotton, groundnut, jute, legumes (tomato, bean, soy) coffee, cacao, tea, fruits (banana, mango, coco, cashew) and palm oil [52].

Agricultural waste can be further classified into two (2).

Primary agricultural residues—paddy straw, sugarcane top, maize stalks, coconut empty bunches and frond, palm oil frond and bunches.

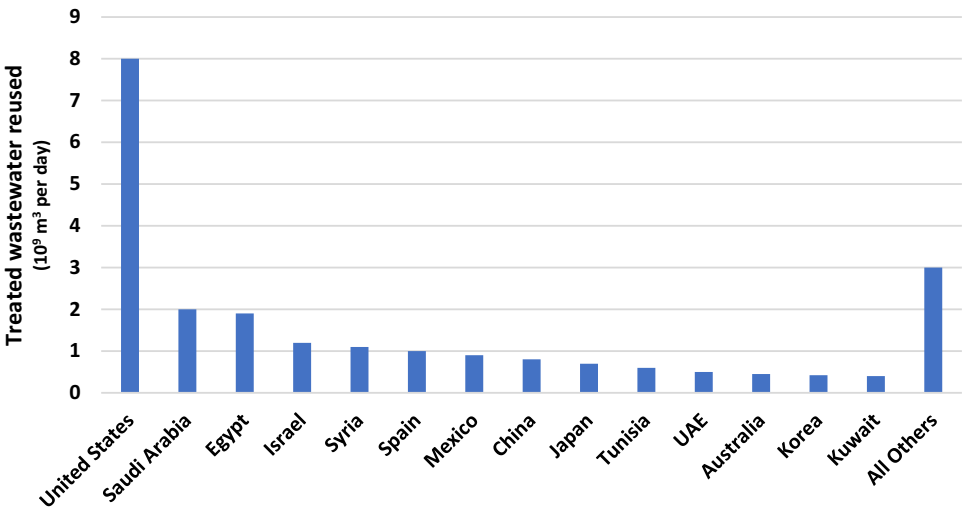

Fig. 9 Global re-use of treated wastewater (10^9 m^3 per day) [10]

Secondary agricultural residues—paddy husk, bagasse, maize cob, coconut shell, coconut husk, coir dust, saw dust, palm oil shell, fiber and empty bunches, wastewater, black liquor.

Agricultural wastes are not limited to agricultural residues from crops, but also those from livestock and fruits are regarded as agricultural waste as illustrated in Fig. 10. Cherubin et al. reported that the total agricultural residue estimated in 2013 was approximately 5 billion tonnes, with Asia continent being the largest producer amounting to 47%, followed by America (29%), Europe (16%), Africa (6%) and Brazil (9%) [53].

2.3.1 Crop residues

Crop residues are wastes from agricultural crops after harvest such as stalks, stems, leaves, seeds pods, etc. Crop residues can be converted into valuable products such as clothes, footwear, household items that have similar properties to conventional products. However, these residues can lead to environmental issues that might affect human health when not properly managed [14]. Root and tuber crop mostly consist of plants that yield starchy roots, tubers, rhizomes, corms, and stems which are majorly divided into edible and non-edible [54, 55]. Examples of edible root and tuber crops are yam, sweet potato, cassava, cocoyam, and potato, which are commonly consumed by humans as food, starch, alcohol, and fermented beverages including beer in Africa, Asia, and South America continents, while the non-edible root and tuber crops are dahlias, daylilies, peonies, cyclamen, and tuberous begonias, which are mostly used as herbs and are mostly found in the North America continent [56–58]. Annually, approximately 836 million tonnes of root and tuber crops are harvested globally in an attempt to meet up with the high demand of food due to a rising population worldwide [55, 58, 59].

2.3.2 Fruit and vegetables waste

In the last decade, the growth in the food processing industry has been tremendous and has been recognized as one of the fastest growing sectors globally. Significant amounts of food waste are produced globally at different phases of food processing, production, marketing, and consumption [60]. According to FAO (2016), the quantity of waste generated on a global scale is one third of total edible food produced globally for human consumption and these wastes have been estimated at 1 trillion USD [34]. Thus, this indicates that 30–50% of food produced worldwide is wasted [60]. Gupta et al. [60] reported that 60 million metric tonnes of food wastes worth of 162 billion USD is produced yearly from United states of America. In comparison with other food processing sector, 25–30% of waste are gotten from fruits and vegetables industries [35]. Therefore, fruit and vegetable wastes cause a lot of economic loss and add to sources of environmental pollution. Fruits and vegetables are horticultural crops that can either be eaten raw, processed, or minimally processed due to their abundance in bioactive compounds that are beneficial to human health [36]. The wastes generated from fruit and vegetables consist of skin, seed, pods, pomace that are abundant in vitamins, oils, polyphenols, enzymes, carotenoids, dietary fibers among others. These natural compounds have several beneficial effects such as antioxidant, anticarcinogenic, antibacterial, with low toxicity, eco-friendly, and biocompatibility over synthetic compounds [37–42].

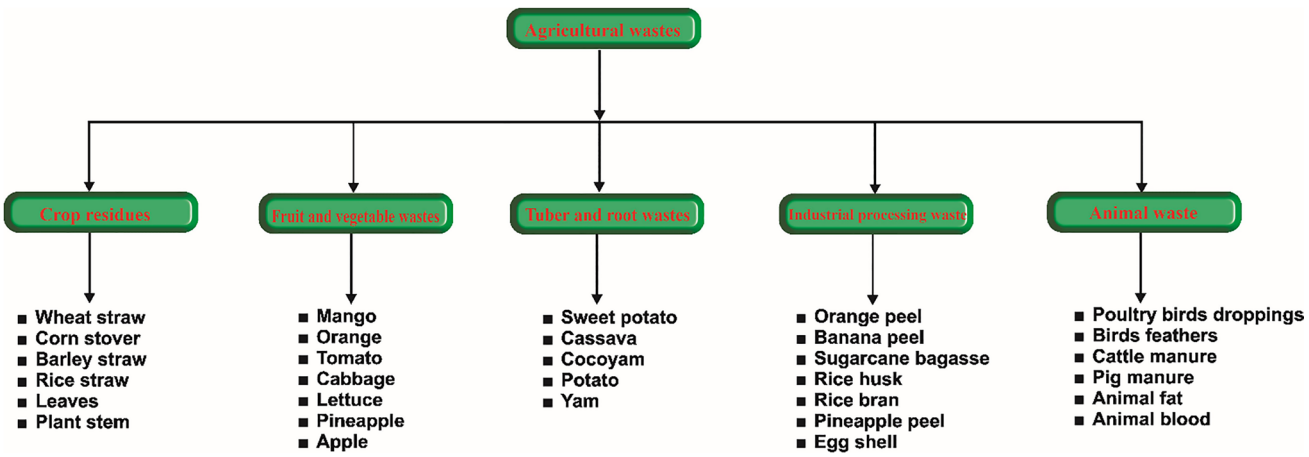

Fig. 10 Classifications of agricultural wastes

It was reported that approximately 55 million metric tons wastes are derived from every processing step which include 5–9 million tons during wine processing, 5.5 million tons from fruits and vegetables processing, 6 million tons during canning and freezing with the largest producers from United States, China, India, and Philippines [44]. Additionally, in trying to meet the growing worldwide demand for food, seed production has increased rapidly, and the generated seed waste are estimated to be 260 million tonnes annually according to FAO [61].

2.3.3 Animal wastes

Animal waste is waste derived from animal excretion, straw, hay, wood shavings or other sources of organic debris usually from leftover feed. Therefore, by way of definition, the term "animal waste" is generally used to imply metabolic wastes such as urine, feces, enzymatic by-products of digestion, urea, or similar substances ejected by animals (livestock, poultry, or fish). "Animal waste" could also be used to connote wastes from animals that is mixed with animal beddings, compost, feed, soil, or like materials. Sources of animal waste include dairy shed effluent (i.e. urine, dung, wash water, residual milk, and feed residues), dairy manure, poultry litter (i.e. manure, water, spilled feed, feathers and bedding materials), renderings, and other wastes from livestock production activities. Animal waste could also be sourced from aquaculture i.e. waste from fish farms. Aquaculture wastes can come from metabolic, chemical, and pathogenic sources. Metabolic wastes can be dissolved (nitrogen- ammonia, nitrite, nitrate; phosphorus and organic matter) or suspended in form (unconsumed feed). Ammonia (excreted from the gills) is the most toxic form of metabolic aquaculture waste. Fish farms can significantly contribute to an increase in potentially pathogenic organisms in the environment [62].

Improper management of animal waste can be detrimental directly or indirectly to human and environmental health. Highly concentrated excreta or high application rates of manure to soils without requisite management usually leads to high salt concentrations in the soil causing adverse effects (pollution) on living organisms or plants resident in the soil [63]. Zoonotic transfer of pathogens from animals to humans via animal wastes is also possible. It is widely reported that animal waste is the most significant source of STEC (Shiga toxin-producing *Escherichia coli*) and Salmonella. This usually occurs sequel to the application of manure or slurry to fruit and vegetable farmlands. The spread of these zoonotic pathogenic organisms can be directly or indirectly through the poor handling/management of contaminated water, tools, workers hands, birds, rodents, insects or other formites [64]. Some plants have also been reported to internalize STEC from highly contaminated soils leading to a significant increase in the survival and spread of these pathogens could also increase the risks of them not being removed from contaminated farm produce during harvesting and cleaning thus finding their way to consumers [64].

2.3.4 Importance of agricultural waste

Natural fibers which are commonly obtained from agricultural products such as abaca, agave fibers, bast fibers, coir fibers, cotton lint, coconut shell fiber, fiber crops, flax fiber and tow, ex scutching mill, hemp tow waste, jute, kenaf, allied fibers, kapok fiber, ramie, sisal, henequen, silk, wool, animal fibers, amount to 32.9 million tonnes annually [65]. The estimated residue produced from cereals legumes, sugar crops, tubers, and roots are presented in Figs. 11, 12, 13, 14, 15, which are usually used for producing value added products.

Agricultural wastes are sometimes dumped on the farmland, surrounding environment, or waterbodies [14, 66]. When these wastes are not properly utilized or managed, they litter the environment, and contaminate water bodies. In some communities, farmers burn the waste obtained from their farms, which in turn increases greenhouse gas emissions [14, 54]. This regular dumping of waste causes health problems through breathing in of populated air, intake of toxic substances by inhaling CO_2 caused by burning of generated wastes [67, 68]. Some of these wastes can block water drainages leading to flooding and other related environmental issues [67]. Others can be blown by wind, dumping them around and making the whole environment very unkempt. Figure 16 shows 10 top CO_2 emitting countries by crop residues, this indicates the contribution of crop residues to the CO_2 generated globally.

Animal waste contamination does not only affect the health of host communities, living creatures and ecosystems, they can also have significant economic impact expressed as lower land values, reduced tourism, wasted resources and attendant high clean-up costs. Animal wastes from agricultural or research activities where a large population of animals are housed together in organized livestock systems are usually managed in two ways:

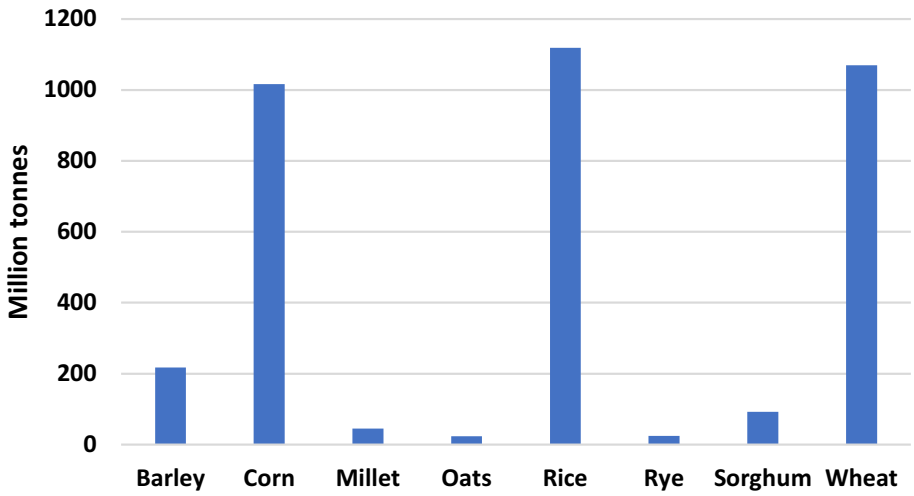

Fig. 11 Estimate of residue produced from cereals [53]

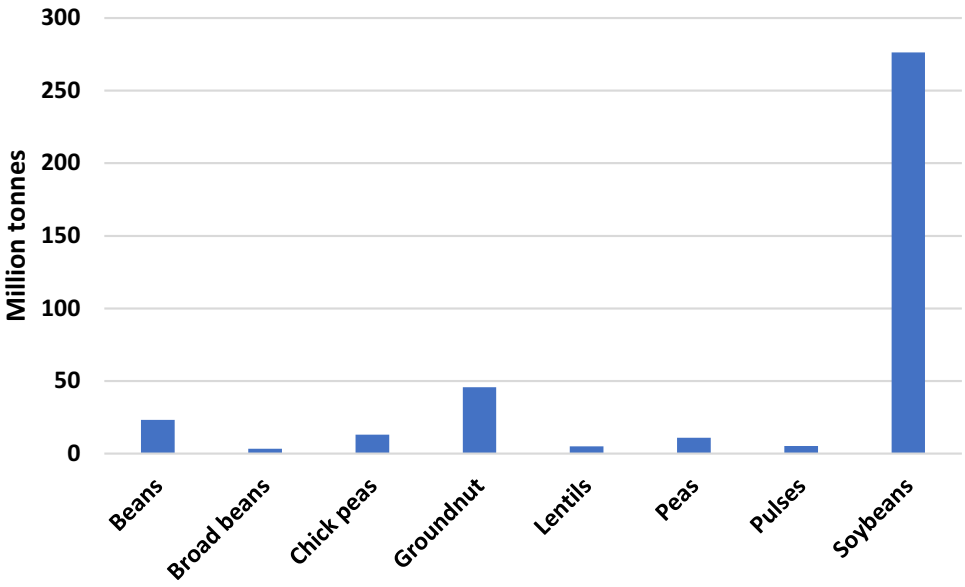

Fig. 12 Estimate of residue produced from legumes [53]

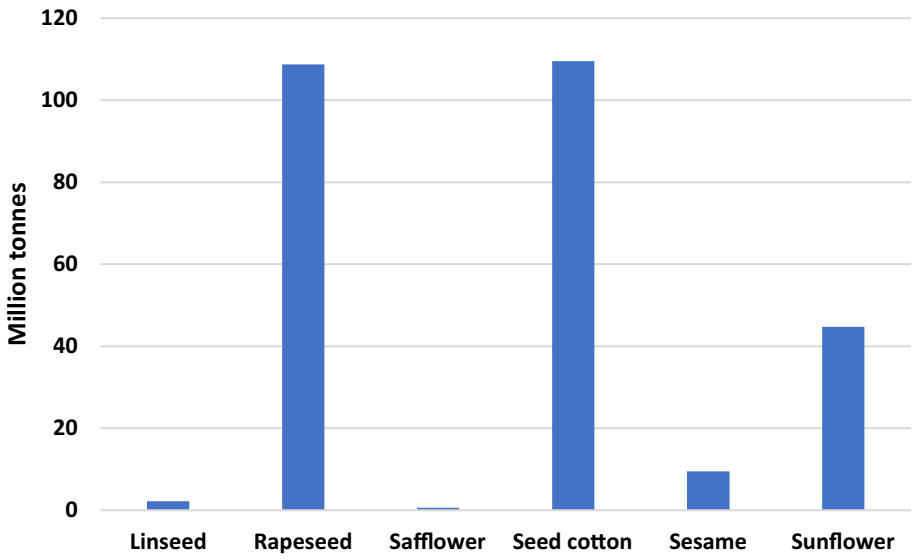

Fig. 13 Estimate of residue produced from oil crop [53]

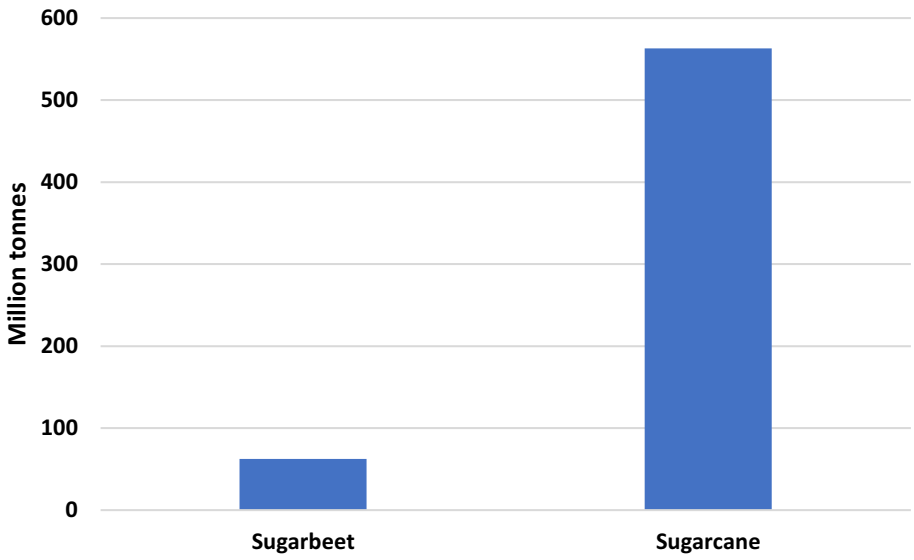

Fig. 14 Estimate of residue produced from sugar crop [53]

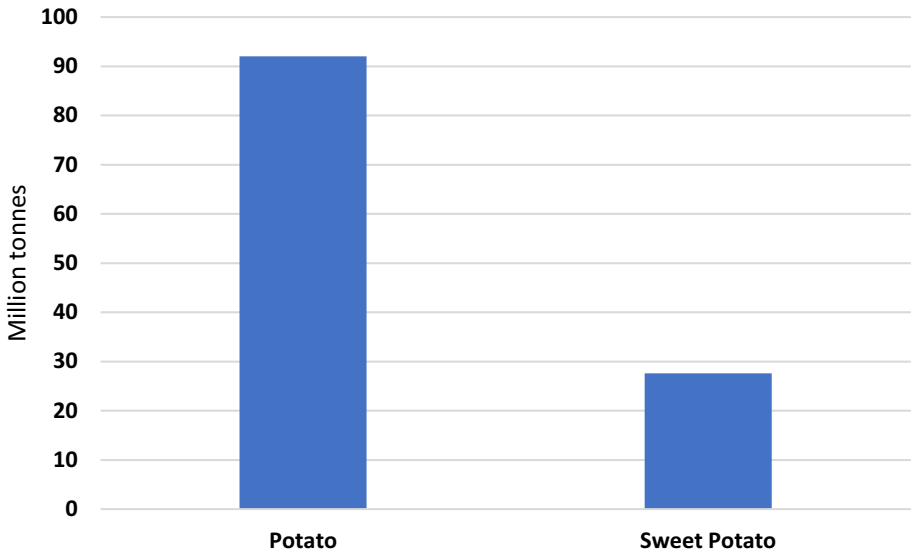

Fig. 15 Estimate of residue produced from tuber and roots [53]

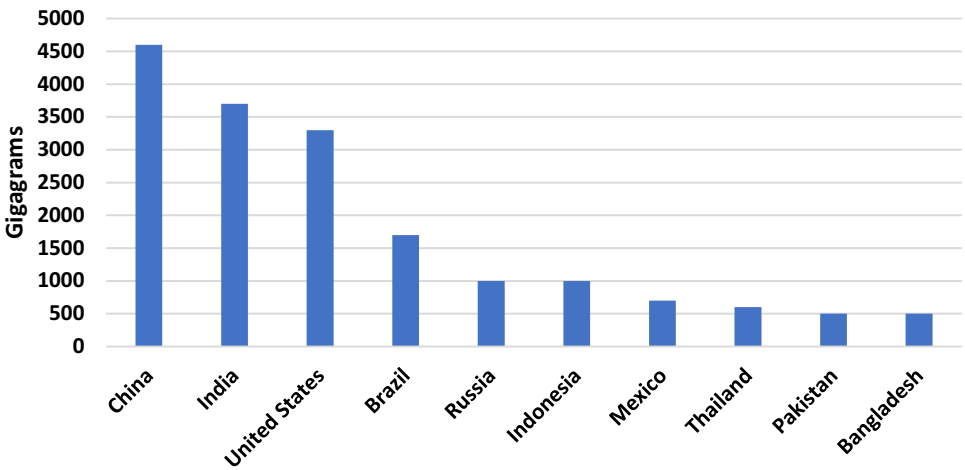

Fig. 16: 10 top CO_2 emitting countries by crop residues (2010–2017) [69]

- Feces and urine can be washed off with water into large anaerobic pools before land application. This set up utilizes anaerobic bacteria fermentation process to breakdown feces and subsequently release methane and ammonia [70].
- Piling up manure in heaps or pits before subsequent application to the soil (i.e. dairy cattle, beef cattle, poultry, or pig manure). Poultry for meat consumption is however frequently reared on deep litter (wood shavings). These are then applied to the land [70].

The waste produced from root and tuber crops amounts to millions of tonnes, and effectively utilizing it would offer a dual solution to the waste issue. Firstly, it would yield cost-effective and environmentally friendly commodities. Secondly, it would aid in environmental cleanup by reducing waste accumulation that contributes to pollution, hazards, and health concerns [14, 66]. This waste can be repurposed in various applications, including the production of nanoparticles for industrial use [68, 71, 72], formulation of anti-corrosion paints [21, 52, 71, 72], utilization as animal feedstock [73, 74], creation of biofuels for alternative energy [56, 75], and development of medicinal drugs [56, 75]. Additionally, even non-edible root and tuber crop waste, often overlooked for its economic potential, can find applications such as herbal uses and other purposes [74]. By enhancing the value of such abundant waste, economic activities can be stimulated in areas where these waste materials are collected.

When animal waste is properly managed, manure can be a valuable resource on the farm (it can be a source of nutrients for crop production and the improvement of soil quality). The main aim of animal waste management is to make the best use of nutrients present in these wastes while protecting the host environment. However, insufficient land mass to utilize the quantity of manure produced or improper handling of manure can pose great risks to water supplies and the environment as concentrated forms of excreta or high application rates to soils without proper management may cause the accumulation of some salts in the soil and cause serious chemical imbalance that could adversely affect life in the host environment [63].

This enhances the moisture retention capacity of such soil, the soil tilth also improves, and some plant nutrients are made more available for subsequent crop uptake [76]. Animal waste has been a major resource in traditional farming and remains a relatively large source of recyclable phosphorus in modern agriculture [63, 76]. All animals and plants need nitrogen and phosphorus, livestock and poultry farmers must maintain a balance between the nitrogen and phosphorus arriving and leaving the farm. These nutrients are contained in the feed and synthetic or organic fertilizers. Nitrogen and phosphorus leave the farm as a part of the animals, animal products, crops, and animal wastes. Whenever more nitrogen and phosphorus arrive on the farm than they are being disposed of, these nutrients then accumulate in the soil [77].

3 Study location: Nigeria: challenges, implication, and applications.

Nigeria currently has a population size of 224,485,149, ranked as the 6th most populated country in the world and 1st most populated country in Africa. The map of Nigeria showing its different states is presented in Fig. 17. In 2022, Nigeria ranked 103rd out of 121 countries in the Global Hunger Index, with a score of 27.3, which indicates that the hunger level in Nigeria is serious [4]. About 70 million Nigerians in 2022, lack access to basic drinking water according to World Bank [6]. Since millions of tonnes of waste from food, water and agriculture products are generated daily in Nigeria, it is necessary to look at ways to reduce such waste or recycle them into more valuable products. In the following section the enormous waste from food, water, and agriculture will be discussed, alongside with the environmental effects, cost, food security, access to clean drinking water, water treatments, conversion and recycling of food waste, water waste and agricultural waste in Nigeria.

3.1 Food waste in Nigeria

In 2021, the United Nation revealed that each year 37.9 million tonnes of food were wasted in Nigeria, which was estimated as 189 kg of food per capita wasted [9]. Nigeria loses and wastes 40% of her total food production, which is equivalent to 31% of her total land use [5]. The Food and Agriculture Organization (FAO) has projected over the years, that Nigeria on average loses $9 billion annually to post-harvest waste, which is approximately a quarter of the yearly budget for the entire country [9]. The grains, vegetables, tubers, and fruits which are being wasted are usually tomatoes, oranges, cashew, onions, beans, wheat, cassava, potato, and yam. According to the National Bureau of Statistics (NBS) more than 82 million Nigerians live on less than $1 daily base on Nigeria's ranking in the UN food wastage index [8].

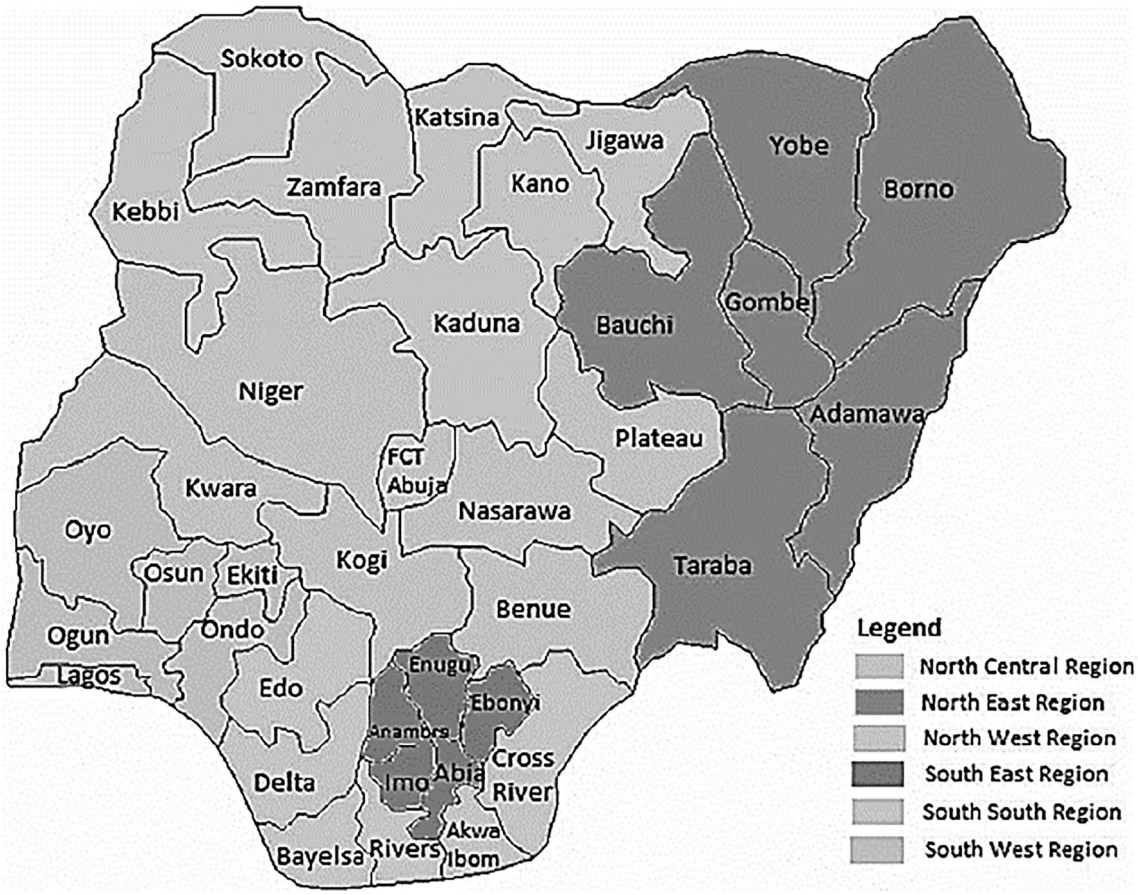

Fig. 17 Map of Nigeria. Source: Vanguard

3.1.1 Causes of food wastage

Poor storage facilities: A significant amount of farm product is lost by majority of commercial farmers in Nigeria because there is a lack of adequate storage facilities.

Poor transportation: The epileptic transportation system in Nigeria is also a cause of food waste. Bad roads make transportation of farm products difficult, resulting in damage of perishable foods before reaching the market for sale.

Inadequate electricity: Electricity is needed for refrigeration effectively and efficiently preserve food.

Insufficient knowledge of food preservation methods: Lack of basic knowledge of food preservation methods makes a lot of food get spoilt within a short time. Canning, drying, curing, and smoking are excellent methods that require less skill and energy.

Excessive purchasing: Purchasing more than is needed from the grocery store for a specific period.

Excess cooking: In some households, food is prepared more than the required quantity for consumption. The leftover might not be properly preserved, and get spoilt, especially due to unstable electricity.

Most often the waste from food is dumped on the road, bush, or water body, this attracts flies, mosquitoes, worms, microorganisms, and other infectious insects which may transmit disease from one person to another [9]. Sometimes this wasted food is burnt alongside other wastes, which pollutes the environment. In Nigeria food waste is estimated to produce 5% of the country's GHG emissions [5].

3.2 Wastewater in Nigeria

In Nigeria wastewater comes mostly from toilets, showers, baths, kitchen sinks, laundries and industrial processes which contain hazardous materials and requires special treatment or disposal.

Sustainable waste management practices include reuse, recycle, recovery and treatment [26]. Most domestic households produce an average of 200–300L of wastewater per person daily [26]. All wastewaters can only be reused after treatment. Urban areas usually generate more wastewater in volume compared to rural areas. Mainly because in the urban areas the presence of residential, commercial, industrial, institutional, and other structures with each generating its own peculiar type of waste [78]. Uwadiegwu et al. in a study reported that the amount of wastewater generated is dependent upon the living standard of the residents, urbanization, and industrialization. Wastewater must be treated, or contaminants removed before it can be discharged to water bodies. Wastewater can be managed effectively by avoiding generation of unnecessary wastewater, minimizing the amount of water used by minimizing the strength of contaminants, by treating and re-use of wastewater, and treating wastewater before discharge to waterbodies [79].

To ensure that treated wastewater is safe for reuse, it is necessary to perform tests such as temperature, pH, dissolved oxygen, oils, heavy metals, and pesticides [80]. Poor waste management including sewage treatment in Nigeria, specifically in mega cities such as Lagos and other major Nigerian cities which are linked with economic development, population growth and the inability of municipal councils to manage the resulting rise in industrial and domestic waste [80]. This waste management problem is also attributable to unsustainable environmental management lifestyles for example Kubwa community in the Federal Capital Territory, where there are habits of indiscriminate disposal of waste, dumping of waste along or into the canals, sewerage systems that are channels for water flows, and other poor practices. Haphazard industrial planning, increased urbanization, poverty, and lack of competence of the municipal government are seen as the major reasons for high levels of waste pollution in major cities of the country. Some of the solutions have been disastrous to the environment, resulting in untreated waste being dumped in places where it can pollute waterways and groundwater [80]. As wastewater, which is channeled through open drains daily, causes an increase in dysentery, diarrhea, and cholera, mostly among children. This wastewater should not be disposed to the surrounding, but instead should be channeled through closed drainages to wastewater treatment plants. Currently, most of the wastewater treatment plants built by the federal government or state government are totally or partially not working [80]. Therefore, making wastewater treatment very difficult.

According to Mansoor et al. proper waste disposal is an important component of environmental sanitation and sustainability. A sustainable environment and improved waste management offer opportunities for income generation, health improvements and reduced vulnerability [81]. This could hardly be attained in some of the developing countries, most especially in Nigeria because of non-readiness, uncoordinated and laissez faire attitude toward better ways of waste disposal methods despite their high rate of urbanization and growth in commercial and industrial activities [82]. Idris-Nda stated that wastewater management in Nigeria, is currently poor or non-existent. The quality of domestic wastewater effluents is one of the main causes of degradation of receiving water bodies such as rivers, lakes, and streams [83]. Nigeria has a component of the National integrated water resources management, where wastewater reuse will form an important part of water sources in addition to surface and groundwater sources, which will also eliminate pollution effects of indiscriminate disposal into sensitive ecosystems [84].

3.2.1 Wastewater treatments in Nigeria

The wastewater treatment in Nigeria is divided into conventional or traditional [85].

i. Conventional methods used are as follows;
- *Preliminary treatment*: Removal of large visible objects such as sticks, rags grit plastics, concrete, wood, and debris using screens, grit removal, oil–water separators, and flow equalization.
- *Primary treatment*: Removal of suspended solids and settleable organic solids such as grease are physically separated using gravity settling tanks, which successfully removes about 60% total suspended solid (TSS) and 35% biochemical oxygen demand (BOD) from wastewater.
- *Secondary treatment*: Removal of colloidal and soluble organic matter using biological treatment, which successfully removes about 85% BOD.
- *Tertiary treatment*: Removal of trace organics (BOD), colour, solids, nitrogen, and phosphorus. Advanced treatment removes more than 95% of BOD, solids, nitrogen, and phosphorus from wastewater using a combined physical, chemical, or biological treatment to treat wastewater before finally discharging into water bodies.

ii. Traditional methods used are as follows;
- *Boiling and sieving*: Water from rivers, wells or other groundwater sources is boiled to about 100 °C, allowed to cool down and then sieved.

- *ALUM addition*: Addition of aluminum sulfate which commonly called ALUM in Nigeria, it is non-toxic and purifies water for drinking.
- *Use of WaterGuard*: Which is dilute sodium hypochlorite solution treats household water for drinking.
- *Ceramic filter*: This is a porous ceramic (fired clay) medium used to filter microbes or other contaminants from water [86].

3.3 Agricultural waste

3.3.1 Crop residues

In Nigeria, an estimated average of 74.53 million tonnes of crops residues were generated from cassava, cowpea, groundnut, maize, oil palm, plantain, and sorghum in 2014 [27, 87]. These enormous crop residues generated in Nigeria are commonly not utilized efficiently to produce value added products or properly managed to keep the environment clean. It is well known that in Nigeria the usual practice is to abandon the crop residue to decompose or burn them on the farmlands [27, 87]. The decomposition or burning leads to emission of Green House Gases, which pollutes the environment, posing hazards to both humans and the animals [28, 88].

3.3.2 Seeds waste

Most of these underutilized seeds are discarded as waste with no specific use. Finding application for these rich resources places Nigeria at an advantage of making use of this biomass for biofuel purpose [89]. Nigeria is endowed with several seeds such as citrus seeds, sesame seeds, mango seeds, watermelon seeds, flax seeds, pumpkin seeds, grape seeds, guava seeds, sunflower seeds, and musk melon seeds [90–92]. Waste from these seeds can degrade the environment when dumped without use or treatment. Most times dangerous flies, worms and other harmful insects surround them [90–92].

3.3.3 Tuber and roots waste

A lot of waste is generated annually during and after the harvest period, during the harvest periods the stems, shoots, leaves are usually cut down taking only the food product from the farm. After the harvest period, the peels of the root and tuber crops are removed and become waste. Both wastes obtained during and after harvesting of root and tuber crops are enormous, and are mostly dumped as refuse, serving as waste, which cause several nuisances in the environment [66]. Nigeria is a country which heavily relies on root and tuber crops to provide food for its over 220 million population [9]. Approximately, 121 million tonnes of root and tuber crops are produced and consumed either as processed or unprocessed food [54]. Additionally, other wastes from root and tuber crops can occur when they perish on farms, because of lack of adequate transportation means to commercial centers or when attacked by insects.

3.3.4 Fruit and vegetables waste

The major fruits produced in Nigeria include mango, pineapple, plantain/banana, citrus, guava, pawpaw, while vegetables include onion, tomato, okra, pepper, amaranthus, carrot, melon, Corchorus olitorus (ewedu), Hibiscus sabdariffa (sobo), Adansonia digtata (baobab leaves) [93]. Approximately 60 million tonnes of fruits and vegetables are produced yearly. Enormous waste is generated from the fruit and vegetables annually leaving their peels and seeds behind. In developing countries including Nigeria, food wastes are mostly discarded on landfills as an easy option due to insufficient resources, budget, and infrastructure [94, 95]. Inappropriate disposing of organic waste on landfill has shown detrimental effect on environment and public health [94]. Toxic leachates and infectious microorganisms get to water sources and agricultural soil causing waterborne pollutants, odours, greenhouse gas emissions, waste leachate, and contamination of groundwater, air, and soil [96, 97]. Therefore, a sustainable approach towards collection, processing, transportation, control, and disposal of fruit and vegetable waste is required to reduce waste on landfill coupled with recycling [97].

Fermentation, composting, recycling, incineration, landfills, and animal feed production are convectional and ecofriendly management strategies which are in accordance with global sustainable development goals used for processing organic waste at different levels of effectiveness and technological advancement into value added products [96, 98]. Fermentation is used for different purposes including lipid production from fruit wastes [98]. Undoubtedly, composting has also been used to transform fruit and vegetable wastes into fertilizer [96]. Eriksson and Spångberg reported

incineration as a great waste management strategy for reducing greenhouse gas emission. Therefore, it is necessary to convert fruit and vegetable wastes into value added products, for example footwear, clothes, and ropes in order to reduce environmental and public health issues [99].

3.3.5 Animal waste

Animal waste is mostly from cattle, sheep, goat, rabbit, pig, and poultry birds [100]. Almost every day in all the urban and rural markets in Nigeria, animals are slaughtered, and the meat sold to the public for consumption. Meat wastes originate from killing; hide removal or dehairing, paunch handling, rendering, trimming, processing, and clean-up operations [101]. Therefore, abattoir wastes often contain blood, fat, bedding/litter, animal carcasses, damaged feeders, and water-trough, organic and inorganic solids, and salts and chemicals added during processing operations [102]. Poultry waste also produces a lot of solid waste from the poultry birds which continue to pass out solid excrete, polluting the environment [101].

4 Economic opportunities of wastes from food, water, and agriculture in Nigeria

Due to the over 25 million Nigerians who go to bed without food daily and enormous individual who lack access to clean drinking water in Nigeria, it is necessary for government, policy makers, non-governmental organizations, economist, companies, industries, and small businesses to look for ways to collectively reduces the waste that is generated from food, water, and agriculture, which will ensure more people get food and access to clean drinking water. Nevertheless, some waste from food, water, and agriculture are inevitable, and therefore should be converted, treated, or recycled into valuable added products, which will eventually become a source of income for several individuals who lack jobs in Nigeria. The conversion, treatment, or recycling of waste from food, water and agriculture helps to provide sustainable management solutions to the immediate environment, by reducing CO_2 emissions, diseases, health issues, and toxic substances in the atmosphere. In this context, the economic benefits of the waste generated from food, water, and agriculture will be discussed in this section. Discussing previous research work on food waste, wastewaters, and agricultural waste in Nigeria, while also assessing their economic prospects, will furnish researchers in the corresponding field with vital insights.

4.1 Food waste

Since it is obvious that some food wastes are inevitable but can be reduced to some extent, sustainable management of the food waste generated is very important, to provide a safe and clean environment and to impact the economy positively by converting or recycling food waste into valuable products. Since, Nigeria generates 189 kg per capita of food waste based on UNEP Food Waste Index Report 2021 [9], it's crucial to explore methods for diminishing this substantial food waste and simultaneously maximizing the economic advantages derived from it.

4.1.1 Reducing food waste in Nigeria

Most of the food waste in Nigeria occur during these different stages, farming, harvesting, transportation, food production, sales, food preparation, consumption, storage, and finally disposal. Food waste in Nigeria can be reduced through sustainable food management, which requires careful planning between food production, transportation, storage, processing, retailing, and consumption. The United Nations Sustainable Development Goal is working to reduce the per capita global food waste by half at the retail and consumer level by 2030 [30, 89, 103]. This concept will help improve supply chains, reduce chronic poverty, and reduce greenhouse gases emission especially in Nigeria. The Federal Ministry of Environment and Federal Ministry of Agriculture & Rural Development in Nigeria can collaborate to derive a workable plan, to ensure that food waste is properly managed.

4.1.2 Benefits of reducing food waste in Nigeria

Saves money: Purchasing the precise amount of food necessary can decrease food expenses. Furthermore, reducing food waste would lead to lower waste fees paid to waste collection organizations.

Donate food to non-profit charity organizations: Individuals experiencing food insecurity and facing daily hunger can derive benefit from these foods rather than discarding them as waste.

Source of employment for the community: The creation of employment opportunities in converting or recycling food waste into compost and sorting salvageable food is significant.

Preservation of resources: Many resources are invested in food production, including water, gas, fertilizer, pesticides, transportation costs, farming equipment, and more. Reducing food waste helps conserve these resources [89, 103].

4.1.3 Value addition to food waste

In Nigeria, food waste is often converted into composted topsoil or biogas, although the conversion into biogas in Nigeria is very low, compared to many other developed countries like U.S, Brazil, European Union countries and Asia [104]. Ayodele et al. carried out a study to estimate the electricity generation and environmental potentials of hydrogen produced from biogas in food waste generated in the southwestern region of Nigeria. It was estimated that the total amount of hydrogen gas produced from food waste could generate approximately 19.46 million kWh of electricity per annum [104].

Kassim et al. carried out a critical review on the integrated conversion technologies of sustainable agri-food waste valorization, mentioning that Nigeria has an annual agri-food waste (AFW) estimates of 65 Mt and underexploited bioenergy potentials of 1.74 EJ [94]. Orhorhoro et al. in their study stated that food waste generated in Nigeria can be composted through anaerobic digestion process rather than disposed of, which has a negative impact on the environment [105]. Olujobi et al. explored the potential of Nigeria for the conversion of organic wastes into electricity, their findings showed that Nigeria has the potential to generate electricity from it's organic waste [106]. Aderoju, et al. performed an optimization study of the different solid waste in the municipal, include food waste in Abuja, Nigeria for electrical power generation [107]. Ugwu et al. in the study on the utilization of waste on Nigerian University campuses mentioned that compost, energy, and livestock feed can be obtained from leftover food, soups, sauces, meat and cheese, bread, cakes, uneaten sandwiches, peels and leaves from fruits and vegetable, and eggs [108]. Gbolagade et al. discussed the reduction food waste through entrepreneurial action: a tool for food security in Dutsin-Ma Local Government Area, Katsina State, Nigeria [109]. Kolawole et al. in their study used Lean Six Sigma and Double-Loop Learning to address food waste and loss in Nigerian food supply chain [110]. The utilization of various food waste in Nigeria is summarized in Table 1.

4.2 Wastewater

In Nigeria, there are regulatory bodies such as the National Water Resources Institute (NWRI), the River Basin Development Authorities (RBDA), the Federal Ministry of Water Resources (FMWR), the Federal Environmental Protection Agency (FEPA), and the National Environmental Standards and Regulations Enforcement Agency (NESREA), National Environmental (Sanitation and Waste Control) Regulations, 2009, National Environmental (Textile/Wearing Apparel, Footwear, and Leather Industries) Regulations, 2009, National Environmental (Chemical, Pharmaceuticals, Soap, and Detergent Industries) Regulations, 2009, National Environmental (Domestic and Industrial Plastic, Foam, and Rubber Industries) Regulations, 2011, National Environmental (Surface and Ground Water Quality Control) Regulations, 2011 [116]. National Water Policy, National Health Development Plan, National Strategy for Wastewater Sanitation in Urban Areas are policies and regulations regarding sanitation [80]. Generation of wastewater cannot be avoided, however, the wastewater generated can be used and well managed by collection, treatment, and reuse of the wastewater, to avoid pollution of small or large water bodies.

4.2.1 Treatment and recycling of wastewater in Nigeria

In Nigeria, the Federal Ministry of Water Resources is responsible for water management, however, such responsibility has not been effectively performed by the Ministry, therefore leaving most individuals no choice than to generate their own water themselves [80]. Similarly, this also goes for wastewater management (WWM) in the country, most house owners are responsible for having drainages that channel wastewater away from the house to other sources. But the government is usually responsible for drainage on the highway or major roads, that channel wastewater to treatment plants. Collection, treatment, and reuse of wastewater can create an economic cycle that will create jobs, income, and provide clean water for irrigation, domestic uses and in some cases drinking water. Water preservation is crucial in our daily routines, and the utilization of treated wastewater is increasingly vital, particularly given the present scarcity of clean water in certain regions of Nigeria.

Table 1 Summary table for utilization of food waste in Nigeria

S/no	Feedstock	Class	Source	Properties	Utilization	Refs.
1	boiled rice, boiled cassava products, bread, boiled yam and boiled maize	Carbohydrate	Household	pH—4.5, organic carbon—78.3%, Total solids (TS)—6.6%, Nitrogen—0.6%, Phosphate—0.73%, Ash content—1.6%, biochemical oxygen demand (BOD)—2589.0 mg/L and chemical oxygen demand (COD)—1294.2 mg/L	Fertilizer and sanitary quality of digestate biofertilizer	[17]
2	Fresh food waste	–	Restaurant	TS—26.53%, Volatile solids (VS)—86.83%, ash content—13.49%, moisture content—73.47%, pH—4.12, C—45.5, H—6.20, O—44.50, N—2.90, S, 0.90 and COD—13,073.30 Mg/L	Biogas production	[18]
3	Cooked maize	Carbohydrate	Restaurant	–	Ethanol production	[111]
4	All food waste	–	Household & Restaurant	–	Electricity prospective from Biogas	[104]
5	All food waste	All	All source	–	Biomass resources and bioenergy potentials	[112]
6	Vegetable waste, moi-moi (beans loaf) waste, plantain peel, yam peel, beans waste, rice waste, fish waste and meat waste	All	Household	–	Biogas	[113]
7	Boiled yam, breadcrumbs, boiled maize, boiled rice and boiled cassava products	All	Cafeteria	Organic carbon—76.75%, pH—4.52, TS—6.57, nitrogen—0.55, ash content—1.56, BOD—2590 mg/L and COD—12,986 mg/L	Biogas production	[17]
8	Yam, cassava, and cocoyam are known as yam peel, cassava peel and cocoyam peel	Mixed	–	–	Nutrient characterisation and bioenergy potential	[114]
9	All	All	Canteens and restaurants	Organic carbon—2.04%, pH—5.37 and Organic matter—3.58%	Organic fertilizer	[115]

4.2.2 Valuable use of treated wastewater

Irrigation: watering farmlands for agricultural purposes to grow crops and watering of backyard garden.

Domestic use: vehicle washing, toilet flushing, air conditioners, dust control, and cleaning of the environment.

Outdoor cleaning: public parks, sporting facilities, roadsides, street cleaning, and fire protection systems.

Industrial use: cooling water, recirculating cooling towers, washdown water, washing aggregate, making concrete, soil compaction.

Drinking water: sachet or bottled water for consumption.

Agricultural use: food crops commercially processed, pasture for milking animals, fodder, fiber, seed crops, wildlife habitat, orchards, and aquaculture.

Reduction in environmental pollution: reduction of CO_2 gas emission, contamination of water bodies, good healthy life for human and animals [80].

A study conducted by Kayode et al. focused on proposing management recommendations to enhance decentralized wastewater treatment within the food and beverage industry in Nigeria [116]. Idris-Nda et al. studied the challenges of domestic wastewater management in Nigeria using Minna as a case study [83]. Yorkor and Momoh reviewed an anoxic wastewater treatment in Nigeria [85]. The utilization of treated wastewater in Nigeria is summarized in Table 2.

4.3 Agricultural waste

Agricultural waste has found wide application in several industries which are very economical and enables the production of very cheap alternative products which are biodegradable and environmentally friendly compared to several conventional products in the market today [14, 52]. Although limited applications have been made in Nigeria, research on these studies has been carried out.

4.3.1 Crop residue and seed waste

Natural fibers which can be obtained from crop residues and seeds are used in various applications such as building materials [121, 122], composite [65, 123], particle boards [124], insulation boards [124], textile and footwear [125–127], automobile application [128–130], sporting goods [130], packaging [130], human food and animal feed [91, 124], biomass and biofuel [92, 131], cosmetics [68], medicine [90, 91, 130] and for other biopolymers and fine chemicals [14].

4.3.2 Fruit and vegetables waste

Fermentation, composting, recycling, incineration, landfills, and animal feed production are convectional and eco-friendly management strategy which is in accordance with global sustainable development goals used for processing organic waste at different levels of effectiveness and technological advancement into value added products [96, 98, 103].

4.3.3 Roots and tubers

The waste generated from root and tuber crops often amounts to millions of tonnes. Utilizing them effectively offers a dual solution: firstly, providing affordable and environmentally friendly commodities, and secondly, mitigating environmental pollution, hazards, and health issues caused by waste littering the environment [14, 66]. The waste can be used in several areas of applications such as nanoparticles for industrial applications [68, 71, 72], development of anti-corrosion paints [21, 52, 71, 72], feedstock for animals [73, 74], production of biofuel for alternative fuel, drugs for medication [56, 75]. Moreover, non-edible root and tuber crops, often overlooked for their economic potential, can also be utilized for herbal purposes [74] and other applications. Adding value to such waste of large quantity can boost economic activities in regions where these wastes are collected.

4.3.4 Animal wastes

In Nigeria, animal wastes can be effectively utilized through the proper application. Animal wastes have been a major resource in traditional farming and remain a relatively large source of recyclable phosphorus in modern agriculture [63, 76]. Developing an animal waste management plan is an essential aspect that needs attention in any animal facility. It

Table 2 Summary table for utilization of wastewater in Nigeria

S/no	Source	Properties	Treatment	Utilization	Refs.
1	Paint industries	pH—4–12.2, Total suspended solids (TSS)—0–2470 mg/L, TS—1920–6510 mg/L, chloride—63.8–733.8 mg/L, dissolved oxygen (DO)—0–6.7 mg/L, oil and grease (OG)—44–100 mg/L, BOD—162.8–974.7 mg/L, COD—543–1231 mg/L, nitrates—12.89–211.2 mg/L, phosphate—0.02 mg/L, sulphate—195–1434 mg/L, nickel –1.9 mg/L	–	Not good for domestic use	[117]
2	Fish farm	pH—6.58, TDS—45.48 mg/L, total alkalinity—24.85 mg/L, total hardness—48.95, ammonia—0.17 mg/L, Ca^{2+}—7.67 mg/L, Mg^{2+} -2.44 mg/L, Na^{+}—5.25 mg/L, K^{+}—2.74 mg/L, Cl^{-}—5.54 mg/L, SO_4^{2-}—2.26 mg/L, $HCO3^{-}$—29.9 mg/L, PO_4^{3-}—1.57 mg/L, NO^{3-} 0.09 mg/L, NO_2^{-}—0.34 mg/L, Hg^{2+}—0.03 mg/L, Mn^{2+}—1.39 mg/L, Fe^{2+}—1.87 mg/L, Cu^{2+}—0.054 mg/L and Zn^{2+}—0.147 mg/L	–	Discharged	[19]
3	Pharmaceutical, textile and dye industries	pH—12.02, conductivity—24,500 m scm-1, DO—10 mg/L, TSS—7100 mg/L, TDS—12.500 mg/L, COD—290 mg/L, BOD—150 mg/L, Cadmium—0.337 mg/L, Nickel—0.04 mg/L, and Zinc—0.139 mg/L	Microbes treatment	Not re-used	[118]
4	–	pH—5.52, TDS—441 mg/dm^3, alkalinity—154 mg/dm^3, hardness—36.0 mg/dm^3, TS—561 mg/dm^3, COD—544 mg/dm^3, BOD—79 mg/dm^3, SO_4^{2-}—70.1 mg/dm^3, NO_3-—3.5 mg/dm^3, Cl^{-}—531 mg/dm^3, Pb—0.01 mg/dm^3, Fe—0.92 mg/dm^3, Zn—1.88 mg/dm^3, Cu—0.3 mg/dm^3, Cr—0.25 mg/dm^3 and As—bdl	Carbonization and activation	Re-useable including drinking	[119]
5	Domestic	pH—5.63, Salinity—0.064%, Turbidity—12 FTU, Conductivity—0.12 ms/cm, DO—5.3 mg/L, PO_4—0.04 mg/L, NO_3—2.6 mg/L, and NH_3—0.16 mg/L	Bioremediation using bacteria petroleum hydrocarbon	Re-useable for some purposes, but not drinking	[120]
6	Abattoir	pH—4.6, conductivity—34 µS/cm, turbidity—7.6 NTU, TSS—1800 mg/L, TDS—630 mg/L, BOD—35 mg/L and COD—142 mg/L	N.A	Not re-used	[20]

should prepare for the management of manure, its storage, and utilization. Manure to be applied on any defined land should be spread according to the uptake rate of the various crops or grasses to be cultivated on the land. The remaining manure can be disposed of appropriately [77]. Conventional vegetable and fruit production set ups do not use animal waste-based fertilizers to avoid direct contamination [77]. Correct compost formulation in conjunction with adequate time allowance between application of compost to the soil and crop production will help to prevent direct contamination in organic farming. For example, United States Department of Agriculture (USDA) require 120 days between manure application and product harvesting if parts to be consumed are in contact with the soil and 90 days if there is no direct contact [77]. Contaminated irrigation water is also a very important source of indirect contamination of farm produce. Heavy rainfall or flooding is often associated with the leaching of animal wastes into both surface and ground water tables causing bacterial pathogens such as Shiga toxin-producing *Escherichia coli* and Salmonella to be transported by run-off water over long distances and can be subsequently used to irrigate crops. It is also worthy of note that the closer the time the contaminated irrigation water is applied to harvest, the greater the risk of human illness from the consumption of such contaminated crops [64].

In Nigeria, researchers have investigated various agricultural wastes, including those from crops, fruits, vegetables, tubers, roots, and animals, to assess their potential for use as fertilizers and animal feeds [132], bio-fuel [66, 133, 134], bio-energy [135, 136], biodiesel [89, 137], bio-gas [138] and bioethanol [89]. An overview of the sources, structure, applications, and biodegradability of agricultural wastes was carried out [14]. Several other uses have been reported such as green nanomaterials and their anti-corrosive properties [52], polymeric nanocomposite for artificial implants [68], green corrosion inhibitory potentials of cassava plant (Manihot esculenta Crantz) extract nanoparticles (CPENPs) in coatings for oil and gas pipeline [71]. The utilization of various agricultural waste in Nigeria is summarized in Table 3.

5 Future considerations for waste from food, water, and agriculture in Nigeria

The frequent occurrence of food waste in Nigeria can be attributed to the government's inability to adequately address farmers' essential requirements for successful farming, harvesting, storage, preservation, and transportation of agricultural products to markets. Additionally, untreated wastewater generated is inadequately managed, leading to increased contamination of large water bodies. The waste management agency responsible for preventing agricultural waste from littering the environment lacks modern technology to maintain cleanliness in the surroundings. Furthermore, there is insufficient government encouragement for individuals, companies, or organizations to develop affordable and environmentally friendly products from this waste, which could be exported to other countries as a source of foreign revenue for the country.

The ways waste can be minimized and converted to useful products:

- Improvement of road leading to farmlands to transport harvested products to markets
- Provision of storage facilities for preservation of farm products
- Availability of electricity to storage facilities
- Government can provide loans to farmer to purchase mechanized equipment that can help in rapid harvesting of farm products before they begin to perish
- To effectively put this waste into use that will enhance the Nigeria economy, it is necessary for several steps to be taken to ensure successful conversion, treatment, recycling, or reuse of the waste produced from food, water, and agriculture.
- Government should encourage policies that will ensure citizens can convert their domestic generated food waste into biogas, biodiesel, and biofuel.
- The use of manual or automated composting machine, this will reduce the effect of landfill.
- Incineration facilities should be built by companies and organizations to enable conversion of food waste and agricultural waste into energy, using gasification, pyrolysis, and anaerobic digestion.
- Waste from food and agriculture should be converted into phytochemicals, bioactive compounds, food supplements, livestock feed, dietary fibers, bio-pigments and colorants, emulsifiers, edible and essential oils, bio-preservatives, and biofertilizers.
- Wastewater should be collected through standard drainages built by government and treated at wastewater plants (WWP) before discharging them into water bodies.

Table 3 Summary table for utilization of agricultural waste in Nigeria

S/no	Feedstock	Waste type	Source	Properties	Utilization	Refs.
1	Crops and animals' wastes	Farm waste	Farm	–	integrated multigeneration thermal power plant	[139]
2	Peels from banana, cucumber, orange, pineapple and watermelon	Fruit waste	Household	Moisture—83.11%, Ash—2.09%, Crude fibre—6.88%, Protein—1.49%, Lipid—1.92% and Carbohydrate—3.25%	Single cell protein	[140]
3	Cassava stem	Tuber waste	Farm	–	Nanoparticle synthesis	[21]
4	Bamboo		Farm	biomass	Biobutanol	[22]
5	Coconut Shell		Market	Biomass	Coconut Shell Nanoparticles synthesis	[128]
6	Agricultural waste	Not specified	Farm	–	Fertilizer	[141]
7	Agricultural waste	Not specified	Farm	Biomass	Compost	[142]
8	Dried pods of cocoa, kola, and coconut husk	–	Farm	Biomass	activated carbon production	[143]
9	Palm Kernel Oil, Banana Peel, Cocoa Pod Husk	Crop waste	Farm	Biomass	Biodiesel	[144]
10	Cassava leaf	Tuber waste	Farm	Biomass	Nanoparticles synthesis	[72]
11	Bamboo	Farm waste	Farm	Biomass	Bamboo-Fiber Reinforced Laterite for building block	[121]
12	Coconut Shell	Fruit waste	Market	Biomass	Carbonized Coconut Shell Nanoparticles synthesis	[145]
13	Cassava bark (peel)	Tuber waste	Farm	Biomass	Nanoparticles synthesis	[71]
14	Sugarcane Bagasse, Cassava Periderm and Maize Stalk	Farm waste	Market	Biomass	Silica extraction	[146]

- Wastewater should be treated and reused for domestic purposes, such as cleaning, flushing of toilets, irrigation, garden, and in recreational parks.
- Companies should be encouraged to start up wastewater treatment for the purpose of packaging it as portable drinking water for financial profits.
- Agricultural waste holds potential for creating innovative engineering materials that can serve as alternatives to conventional materials. These include composites, fiber reinforcements, bioproducts, footwear, textiles, anti-corrosion inhibitors, as well as metallic and non-metallic nanoparticles for various applications.
- Biomass from agricultural waste should be used for bioenergy, etc.
- Government should reward citizens or companies who develop technologies that can handle waste management
- Transforming waste from food, water, and agriculture into value-added products will decrease greenhouse gas emissions while offering inexpensive, efficient, and environmentally and economically friendly products.
- Government should also develop policies that will help the exportation of products made from waste, which will serve as a means of foreign exchange for Nigeria.

6 Conclusions and recommendations

6.1 Conclusions

In Nigeria, food waste, wastewater, and agricultural waste pose significant threats to the immediate environment, health, and economy. However, with proper management, it is feasible to reduce the waste generated from food, water, and agriculture. Given the inevitability of these wastes, it is crucial to establish eco-friendly and cost-effective applications for them. Options include converting food waste into biofuels, biogas, or compost, treating and reusing wastewater for domestic or industrial purposes, and in some cases, producing safe portable drinking water, thereby reducing pollution in contaminated water bodies. Agricultural waste has the potential to drive industrial innovation by facilitating the development of affordable eco-friendly products such as footwear, textiles, engineering materials, polymers, composites, nanoparticles, coatings, corrosion inhibitors, paint additives, fibers, and bioplastics. Utilizing waste from food, water, and agriculture can contribute to a less polluted environment and create numerous job opportunities, as individuals are needed to source, gather, convert, treat, and recycle this waste due to its widespread presence in the environment. However, effective wastewater collection requires the Nigerian government to ensure proper drainage and channeling systems. This review discusses the environmental challenges, costs, health implications, treatment methods, conversion processes, reuse possibilities, and applications of waste generated from food, water, and agriculture, both globally and within Nigeria.

6.2 Recommendations

Studies should be conducted on the cost assessment of waste management and conversion in Nigeria. Nigerian government, policy makers, non-governmental organizations, economist, companies, industries, and small businesses should formulate strategies to facilitate the efficient collection and conversion of waste from food, water, and agriculture into valuable resources. There is a need to incentivize households to responsibly collect, sell, or convert their waste into useful products by monetizing household waste. Additionally, research on the outcomes of waste conversion from food, water, and agriculture is crucial to understand how waste is managed by Nigerians and to gather insights for improvement.

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Data availability All data supporting the findings of this study are available within the paper.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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