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African Journal of Environmental Science and Technology

Full Length Research Paper

Characterization of the anaerobic digestion of cashew apple pulp from of the casamance

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Anaerobic digestion is considered a good method for processing organic waste. The end result is an almost complete conversion of biodegradable organic matter into finished products like methane, carbon dioxide, hydrogen sulphide, etc. The relative proportions of these gases depend on the nature of the fermented substrates and the fermentation conditions. Moreover, these substrates exist in Senegal with potential not yet fully exploited; as an example, Senegal remains the 15th largest exporter of cashew nuts with an annual production of around 18,000 tons. Kolda, Ziguinchor, Sédhiou and Fatick are the main producers of cashew apples. Thus, each year, after the cashew nut campaign, more than 342,000 tons of cashew apples, pressed or not, are rejected without being valued, and therefore doomed to rot. This work aims to characterize the anaerobic digestion of cashew apples in the presence of inoculum, with a prior pretreatment of the apple. The physico-chemical characterization shows that the cashew apple essentially contains 98.81% organic matter with a C/N ratio equal to 23.27%. The carbon content was determined by an empirical method and that of nitrogen by the Kjeldahl method. The biogas produced is composed of 63.60% methane and 32.71% carbon dioxide.

Key words: Anaerobic digestion, cashew apple pulp, inoculum, biogas.

INTRODUCTION

Climate change is arguably the most imminent environmental threat facing the world today. The rise in global temperature will have some major effects on ecosystems, wildlife, food chains and ultimately human life. There is a general consensus that global warming is due to the large-scale anthropogenic emission of greenhouse gases, which are mainly caused by heat and electricity production. Indeed, much of the world's energy demand is still met through the use of fossil fuels. According to the International Energy Agency (IEA), fossil fuels accounted for up to 81% of the world's primary energy supply in 2007 (Appels et al., 2011), while

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renewable energy sources only contributed 13%. Although much attention is paid to the technical and economic development of the implementation of renewable energy sources, fossil fuels remain the most dominant source of energy in the world, estimated at 77% for the period 2007 to 2030 (International Energy Agency, 2004). This small drop in supply will be more than offset by the 2.5% annual increase in energy demand until 2030. Most of the increase will be achieved by higher consumption of coal, followed by gas and oil (Appels et al., 2011).

It is clear that renewable resources will play a crucial role in current CO_2 mitigation policy. In this respect, energy from biomass is seen as one of the most important renewable energy sources in the future. In addition, solid waste with a high organic content is frequently treated by composting or by anaerobic digestion. Anaerobic digestion is a natural biological process of degradation of organic matter in the absence of oxygen. Degraded organic matter is found mainly in the form of biogas (Fabien Bova et al., 2012). Biogas is an alternative and renewable energy source produced during the anaerobic (oxygen-free) digestion of organic matter. Organic matter is converted into a combustible biogas rich in methane (CH_4) and a liquid effluent called digestate (Jactone et al., 2009). Indeed, at present, there are a large number of biogas plants that process different types of organic waste such as solid waste, the organic fraction separated by solid waste sources, mainly food waste and gardening, manure, sewage sludge and various industrial organic wastes (Ponsá et al., 2011). Applied anaerobic digestion can help reduce the use of fossil fuels and reduce greenhouse gas emissions that can contribute to climate change. Additionally, methane is considered a potent greenhouse gas that can stay in the atmosphere for up to 15 years, and is about 20 times more effective at trapping heat in the Earth's atmosphere than carbon dioxide (Scott and Campbell, 2012; Solomon 2007).

In addition, agricultural residues such as wheat chaff, rice husk and corn stalks are produced in large quantities all over the world every year. Since agricultural waste is an abundant source of organic matter, it can be used as a valuable alternative feedstock for biogas production. Moreover, in Senegal, cashew cultivation, initiated well before independence (1946-1947) by the Water and Forests Service for reforestation and soil conservation purposes, remains today an industrial crop which interests many countries (China and India). It has played three main functions during its development, namely, (i) an environmental management function centered on the protection and conservation of natural resources, (ii) an economic function of creating wealth and jobs, (iii) a function medicinal (treatment of colic, diarrhea, skin infections, bronchitis, diabetes, etc.) (Dieng et al., 2019). Currently, Senegal is the 15th largest exporter of cashew nuts with a production of more than 18,000 tons per year, in 2018, according to the PADEC study (Support Program for the Development of Casamance). Four regions (Kolda, Ziguinchor, Sédhiou and Fatick) are the main producers of cashew apples. In Casamance (Kolda, Ziguinchor, Sédhiou), each year after the cashew nut season, more than 342,000 tons of cashew apples, pressed or not, are rejected without being valued, and therefore doomed to rot (Faye et al., 2020). The purpose of this study is to characterize the production of cashew apple pulp (Photo 1), which is very acidic with a pH that is between (4.2 and 5) which can inhibit the process of anaerobic digestion.

MATERIALS AND METHODS

Preparation of the substrate

In this study, we used cashew apple pulp (Figure 1) from an apple fruit juice processing unit, located near Assane Seck University in Ziguinchor.

The cashew apple, very acidic characteristic with a pH between 4.2 and 5, very fibrous; after collection, has been pretreated to reduce the effects of these two characteristics which are inhibiting factors during its anaerobic digestion (Photo 2). To do this, the cashew apples were ground using a manual grinder, to an average particle size of less than 2 mm. After grinding, the pH of the pulps was adjusted with lime to around neutrality, which is important for a substrate to be methanized, because most methanogens have an optimal pH of between 7 and 8, whereas acid-forming bacteria often have a lower optimum (Angelidaki and Ahring, 1994). If the pH of the waste to be tested is outside the optimal range, and there is not enough buffering capacity, the anaerobic process may be inhibited (Angelidaki, 2004).

After this pretreatment step, the substrate was mixed with inoculum (digested cow dung) before being methanized. Figure 2 describes the cashew apple pulp pretreatment process.

Experimental procedure

The cashew apple pulps and the inoculum were placed in 750 mL capacity bottles for the determination of the production kinetics or the quantitative production of the substrate. A 5 L reactor was used to analyze the composition of the biogas produced under mesophilic conditions at 37°C (Manyi-loh et al., 2013), following a substrate/inoculum ratio of 1/1. The mesophilic inoculum used in this study is taken from a 10 m^3 reactor fed by cow dung and installed on the bioenergy platform of the Assane Seck University of Ziguinchor. The mixtures were prepared homogeneously. During the production of biomethane, there were no added nutrients, including enzymes and chemicals; this in order to assess the quantity and quality of the biogas produced by the apple pulp thus used. To do this, the liquid displacement method (Figure 1) and that of the biogas stock produced (Figure 2) were used. A hat-trick was achieved for the try. The value obtained, expressed as the volume (in mL) of biogas produced per gram of organic matter (OM) added (mLbiogas/g OM), and is the average of the triplet.

Analytical methods

For determination of percentage dry matter (%DM) and moisture

Photo 1. Pile of cashew apple pulp substrate.

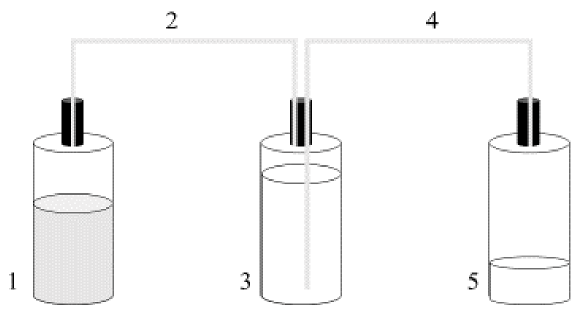

Figure 1. Liquid displacement method. 1: Reactor; 2: Biogas transport pipe; 3: Bottle filled with water; 4: Water transport pipe coming out of the bottle; 5: Graduated bottle for measuring collected water.

content (%H), the substrates were dried in a ventilated oven at 105°C for 24 h (Cheng et al., 2014; Park et al., 2014).

For measuring the organic matter content (% OM) and the percentage of mineral matter (% MM), the substrate sample was dried, then ground and finally calcined at 550°C for 4 h in a muffle furnace (Nikiema et al., 2015; Park et al., 2014).

The percentage of total carbon (%C) is determined by the empirical method (Afilal et al., 2014) using the formula of Equation 1 opposite.

$$\%C = \frac{\%MO}{1{,}724} \quad (1)$$

Nitrogen was assayed by the Kjeldahl method carried out following mineralization with concentrated sulfuric acid and in the presence of a mineralization catalyst (K_2SO_4 and $CuSO_4$), the nitrogenous compounds are mineralized into ammonium sulphate. The ammonia displaced by the soda is entrained by the vapor of the solution and trapped in a boric acid solution to then be dosed with a hydrochloric acid solution (Labconco, 2015; Nikiema et al., 2015). This method gives the percentage of nitrogen (%N) of the sample by calculation from Equation 2.

$$\%N = \frac{V \times T \times M_N}{m \times 1000} \times 100 \quad (2)$$

where V: volume of HCl, T: titration of the HCl solution, M_N : molar mass of nitrogen, and m= mass of the sample.

The composition of the biogas produced will also be evaluated using a biogas analyzer, model Optma7 Biogas.

RESULTS AND DISCUSSION

Physico-chemical characterization of substrates

The study aimed to assess the production of biogas from cashew apple pulp in the presence of inoculum. The process of anaerobic digestion was carried out in the regular state where the temperature of the process takes place in a mesophilic medium (temperature set at 37°C by a water bath) (Manyi-loh et al., 2013; Scully et al., 2005). The physico-chemical characteristics of the cashew apple pulp and the inoculum are shown in Table 1.

Table 1 shows that cashew apple pulps mainly contain organic matter (%OM>98%) with a low content of mineral matter (%MM<2%). This is therefore an interesting result because organic matter (OM) is considered to be the part of the substrate that is likely to transform into biogas, including methane (Cheng et al., 2014).

Furthermore, the volumetric yield of methane can be significantly improved for high organic matter content of

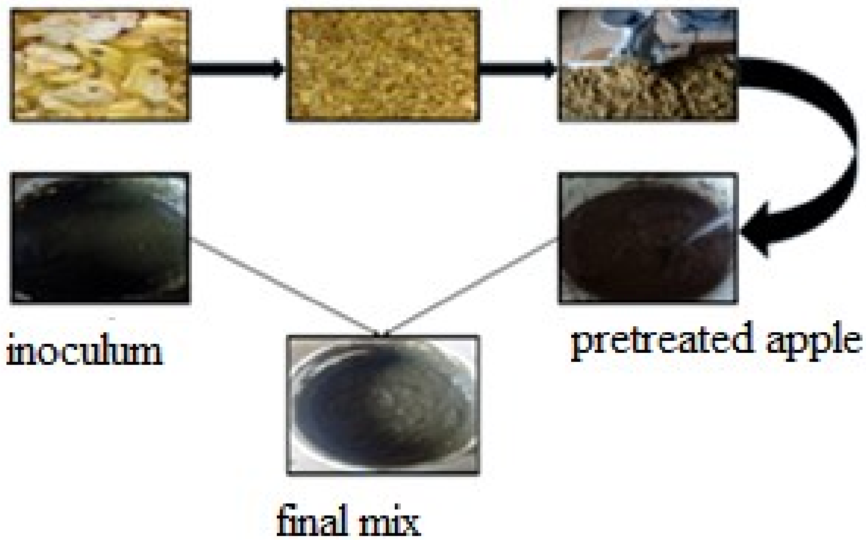

Photo 2. Method of preparation and mixing of the substrate with the inoculum.

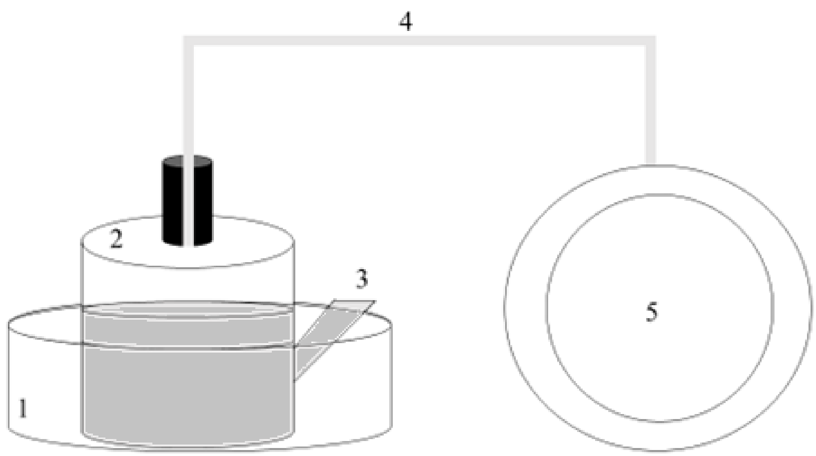

Figure 2. Experimental biogas production device. 1: Water bath at 37°C; 2: 5 L reactor; 3: Sampling nozzle; 4: Pipe for transporting biogas to the air chamber; 5: Air chamber for collecting the gas produced.

Table 1. Physico-chemical characterization of the studied substrates.

Settings	Substrates	
	Cashew apple	Inoculum
% Dry matter (DM)	14.56	7.51
% Humidity (H)	85.44	92.49
% Organic matter (OM)	98.81	48.30
% Mineral matter (MM)	1.19	51.71
% Volatile matter (VM)	56.78	27.76
% N	2.44	1.46
C/N	23.27	19.05

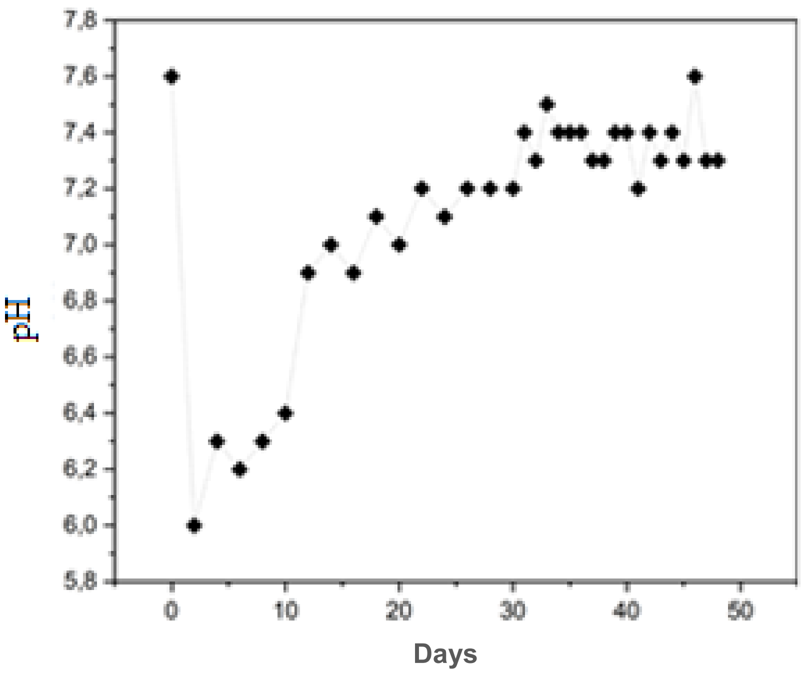

Figure 3. Evolution of pH during digestion of cashew apple pulp with inoculum.

loaded substrates (Asam et al., 2011). It was also found that the carbon content of apple pulp is quite high (56.78%). The nitrogen content is 2.44%. A C/N ratio equal to 23.27 was obtained, ideal for anaerobic digestion with an optimal C/N ratio of between 20 and 30 (Zhang et al., 2008).

The inoculum used, with an OM content of less than 50%, does not in any way increase the yield of the biogas or that of the methane, but it does allow a certain stability of the anaerobic digestion process. In the literature, experimental data have demonstrated that the ultimate methane yield as well as the methane production rates are substrate and inoculum specific (Eskicioglu and Maryam, 2011). Large inoculation volumes ensure microbial activity, low risk of overload and low risk of inhibition (Angelidaki and Wendy, 2004; Cabbai et al., 2013). A study found that inocula applied to the anaerobic digestion process can significantly improve the performance of the process. It is also mentioned that the better performance of digesters with inoculated substrates can be associated with the accelerated reproduction of microorganisms that contribute to the fermentation of organic matter in the digesters (Lopes et al., 2004). Also, another study mentioned that inoculum has an important role in starting the anaerobic digestion process as it is able to balance the populations of certain bacteria which include syntrophobacter which is responsible for the degradation of propionate as well as butyrate and methanogens (Pandey et al., 2011).

Evolution of pH during anaerobic digestion

pH plays a major role in anaerobic digestion. It influences the activity of enzymatic hydrolysis and active micro-organisms. The anaerobic digestion process occurs in the pH interval located from 6.0 to 8.3 and 6.5 to 7.5 (Djaafri et al., 2014). Most methanogens have an optimum pH between 7 and 8. If the pH of the waste to be tested is outside the optimum range, and the memory buffering capacity is not sufficiently present, the anaerobic process may be inhibited (Angelidaki, 2004).

Adjusting the pH can minimize the inhibitory effects of acid build up and accelerate the rate of waste degradation (Vavilin et al., 2003). Anaerobic digestion processes are strongly influenced by pH. In Figure 3, it can be seen that the pH varies during the anaerobic digestion. The pH evolution curve can be divided into three stages described opposite.

The first stage is the hydrolysis and acidogenesis stage which led to a rapid drop in pH from a value of 7.6 to 6 from the first two days. This decrease in pH value is due to the breakdown of substrate polymers into monomers and the production of volatile fatty acids (VFAs), such as acetate, butyrate, propionate or lactate, into other organic acids (lactate) and alcohols using acidogenic microorganisms (Amani et al., 2010).

The second stage begins from the third day until the tenth day, where there is a fluctuation of the pH value between 6 and 6.5. This is the stage of acetogenesis; it is

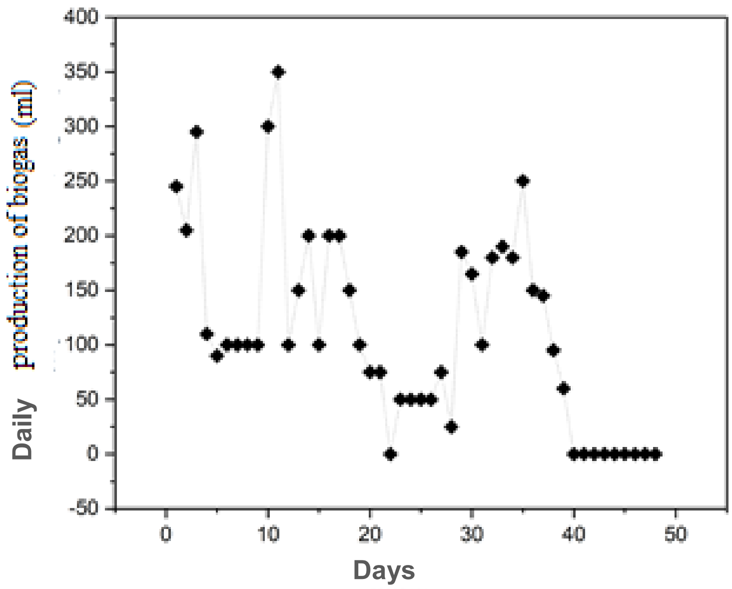

Figure 4. Daily production of biogas from inoculated cashew apple pulp.

due to the formation of acetate from the products of hydrolysis and acidogenesis. This conversion can take place according to two metabolic pathways, thanks to bacteria consuming either VFAs or CO_2 and hydrogen (Batstone et al., 2002). One of the pathways is the second metabolic pathway of acetogenesis, called homoacetogens, the other is hydrogenoclastic methanogenesis. There is therefore an obligatory association between the species producing hydrogen and those which consume it; this is called a syntrophic relationship (Delgenes et al., 2003; Nie et al., 2008; Schink, 1997).

The third stage is methanogenesis, which starts on the eleventh day until the end of the experiment, on the 48th day; signaled by the depletion of organic matter following an inflation of the inner tube. During this step, acetate, H_2 and CO_2 are transformed into CH_4 and CO_2. This reaction is carried out by archaea of several types:

(1) Methanogenic acetoclastic archaea which use acetate as a substrate. This metabolic pathway produces 70% of total CH_4 in anaerobic digestion (Pavlostathis, 2009) and involves different microorganisms such as *Methanosaeta concilii* or *Methanosarcina acetivorans* (Amani et al., 2010).

(2) Hydrogenotrophic methanogenic archaea that produce CH_4 from CO_2 and H_2. This pathway corresponds to 30% of the production of total CH_4 in anaerobic digestion even if this reaction is more energetically efficient (Hattori et al., 2000) and can be carried out by *Methanobacterium bryantii, Methanobrevibacter arboriphilus* (Amani et al., 2010; Faye et al., 2020; Moletta, 2003).

Figure 4 shows the evolution of the daily production of biogas during the anaerobic digestion of inoculated cashew apple pulp.

The daily biogas production kinetics of the pulps lasted 48 days until the production of biogas was no longer observed. Biogas production started immediately from day one and daily biogas production peaks were observed after day one. The highest biogas production rate was obtained on day 11 with a maximum biogas production rate of 350 mL. From the 12th day, the production continued, but the values fluctuated between about 75 and 200 mL. On the 22nd day, the production of biogas from the pulp was zero (0 mL).

This may be due to the formation of crusts on the production surface, which can prevent contact between bacteria and create a production disruption. From the 23rd day, a second phase of production was observed. This production phase extends until reaching a maximum production of 250 mL on the 35th day. And then, a drop in production is observed from the 36th day to the 39th day. Between the 40 and 48th days, no biogas production was observed.

Figure 5 illustrates the cumulative biogas production kinetics of inoculated cashew apple pulps.

The volume of biogas produced is an important parameter for controlling and monitoring the anaerobic digestion process, it also tells us about the production potential of our substrate to ferment. Furthermore, a substantial production of biogas reflects both the stability and the proper functioning of the digester (Zerrouki et al., 2017). Figure 5 shows the cumulative production of

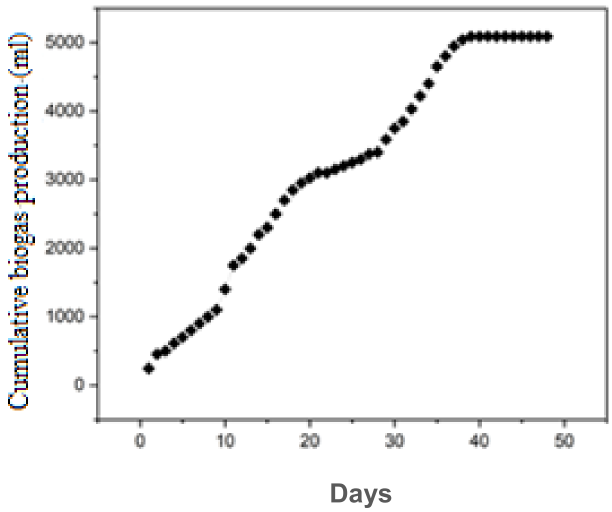

Figure 5. Cumulative production of biogas from inoculated cashew apple pulp.

Table 2. Composition of biogas produced from cashew apple pulp.

Symbol	Unit	Settings
CH_4	%	63.60
H_2S	ppm	6
CO_2	%	32.71
LHV	Kcal/kg	5148
HHV	Kcal/m^3	6582

biogas during the duration of the experiment, which is 48 days. The volume of biogas recovered is 5089 mL and stabilizes after 41 days of anaerobic digestion. The quantity of biogas produced is interesting compared to the organic load introduced into the digester, which is 333 g/L. It was noted that the kinetics of biogas production is subdivided into three main phases.

(1) Slowdown phase: This phase corresponds to the adaptation phase of the free microorganisms contained in the substrate to their environment. The duration of this phase is 10 days. And this is the phase that records the lowest production. This period corresponds to the liquefaction phase during which hydrolysis, acidogenesis and acetogenesis take place.
(2) Exponential phase: During this phase, the multiplication of micro-organisms is maximum, which results in a favorable living environment for bacteria, for good biogas production. This leads to optimal biogas production on the 41st day of fermentation, with biogas production reaching 5089 mL.
(3) Stabilization phase: During this phase, from the 41st day, the production of biogas is stabilized due to the exhaustion of organic matter in the digester. Table 2 gives us the composition of the biogas and the calorific values of the cashew apple pulps studied.

The quality of the biogas produced is essentially assessed by the percentage of methane (CH_4) it contains. A biogas is all the better as its percentage of methane is high (Sadak et al., 2011). According to the results in Table 2, from a qualitative point of view, the cashew apple pulps show good results with a methane percentage of 63.60%. At the exit of the digester, the biogas obtained is difficult to recover in its raw composition. In addition to CH_4 and CO_2, it contains volatile matter, and is saturated with water vapour. Thus, the use of biogas for cooking (combustion) requires a control of the flammability limit of the CH_4 produced. During combustion, the mixture of CH_4 and O_2 burns to give CO_2, H_2O and heat (energy) (Equation 3).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + Energy \quad (3)$$

The biogas-air mixing index for complete combustion for our sample is composed of 63.6% methane and that the air contains 21% oxygen and 79% nitrogen (only O_2 participates in the combustion reaction) is expressed by:

(1) $\alpha = \frac{1}{0.636} = 1.57233$, volume of CH_4 required for complete combustion

(2) $\beta = \frac{2}{0{,}21} = 9.52381$, volume of O_2, necessary for complete combustion

(3) also we noted, $\delta = \frac{\beta}{\alpha} = \frac{9.52381}{1.57233} = 7.057132$ reagent volume,
(4) reagent mixing index $\eta = \frac{1}{1+\delta} = \frac{1}{1+7.057132} = 0.1417$ in % η = 14.17% of biogas in the air (stoichiometric air requirement).

Biogas burns in a narrow range of mixtures from 9 to 17% biogas in the air. So the CH_4 obtained from our sample has complete combustion, because η obtained is included in the 9 to 17% range.

However, in the energy field, the lower heating value (LHV) and higher heating value (HHV) are used as an indicator. The LHV is of paramount importance for the thermal recovery of substrates. It represents the amount of heat released by the complete combustion of the substrate with the formation of water vapor (Moletta and

Cansell, 2003). The results of this study also show us that the biogas from apple production contains a lower calorific value greater than that of cow dung which is equal to 4.330 kcal/kg (Faye et al., 2020). The value of the higher calorific value of the biogas produced by the pulps of the cashew apple is included in the range given by Sadak and Abenm (2014). According to these authors, the calorific value of biogas is proportional to its CH_4 content and it varies between 5000 and 8500 kcal/m³.

Conclusion

This study shows that the adjustment of the pH before the start of the anaerobic digestion process with cashew apples which have a very acidic pH is essential for the optimization of the bio-methanization process.

The results of the study show that:

(1) apples have a high content of volatile organic matter with a value of 98.81%;
(2) a ratio (C/N) favorable to anaerobic digestion, equal to 23.27%;
(3) the anaerobic digestion of apples gives very interesting concentrations of bio-methane, with a composition of 63.60% methane and 32.71% carbon dioxide;
(4) very high caloric values, 5148 kcal/kg for lower heating value and 6582 kcal/m^3 for higher heating value (HHV), which are higher than those of cow dung produced at the bioenergy platform, which are 4330 kcal/kg for the LHV and 6172 kcal/m^3 for the HHV.

This work thus allows us to conclude that cashew apples are favorable for the start-up of new digesters of different types, for the rural population.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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A review of strategies for resilience of health impacts of climate variability in Guinea

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Climate change presents major health threats in Guinea, a low-income nation in West Africa. Rising temperatures, variable rainfall, floods, droughts and coastal erosion increase climate-sensitive health outcomes, including respiratory infections, diarrheal diseases, malaria, undernutrition and heat-related illness. From 1990 to 2004, there was a notable increase in deaths, starting from approximately 17,815 in 1990 and peaking at about 14,382 in 2004. Following this peak, there was a subsequent decline, albeit with varying rates, settling at around 7860 by 2022. Vulnerable groups like children, the elderly, outdoor laborers, and slum residents are disproportionately impacted. This paper reviews evidence on current and projected disease burdens due to climate change in Guinea. It further discusses strategies to build health resilience using the Building Resilience Against Climate Effects (BRACE) framework including improving infrastructure, disease surveillance, health services delivery, and multi-sectoral coordination. Protecting vulnerable groups and communities through integrated interventions anchored in the local context is emphasized. Guinea requires international support and applied research to inform evidence-based adaptation policies that safeguard population health against escalating climate change threats.

Key words: Guinea, climate change, temperature, rainfall variability, extreme weather, health impacts

INTRODUCTION

Climate change, primarily caused by human activities such as burning fossil fuels and deforestation, leads to increased greenhouse gases in the atmosphere, resulting in global warming (Intergovernmental Panel on Climate Change, 2022). The effects of climate change include rising temperatures, changing precipitation patterns, and more frequent and severe extreme weather events. These changes have significant impacts on human health, particularly in tropical developing nations like Guinea, which are experiencing heightened risks (WHO, 2022). The World Health Organization (WHO) has stated that climate change is humanity's biggest health threat (WHO, 2022).

Transitioning to the specific case of Guinea, this West African nation's vulnerability to climate change is amplified due to several factors. These include its reliance on climate-sensitive sectors, dense urban populations, limited infrastructure, and restricted health systems capabilities. These factors and the broader impacts of climate change pose significant challenges to the

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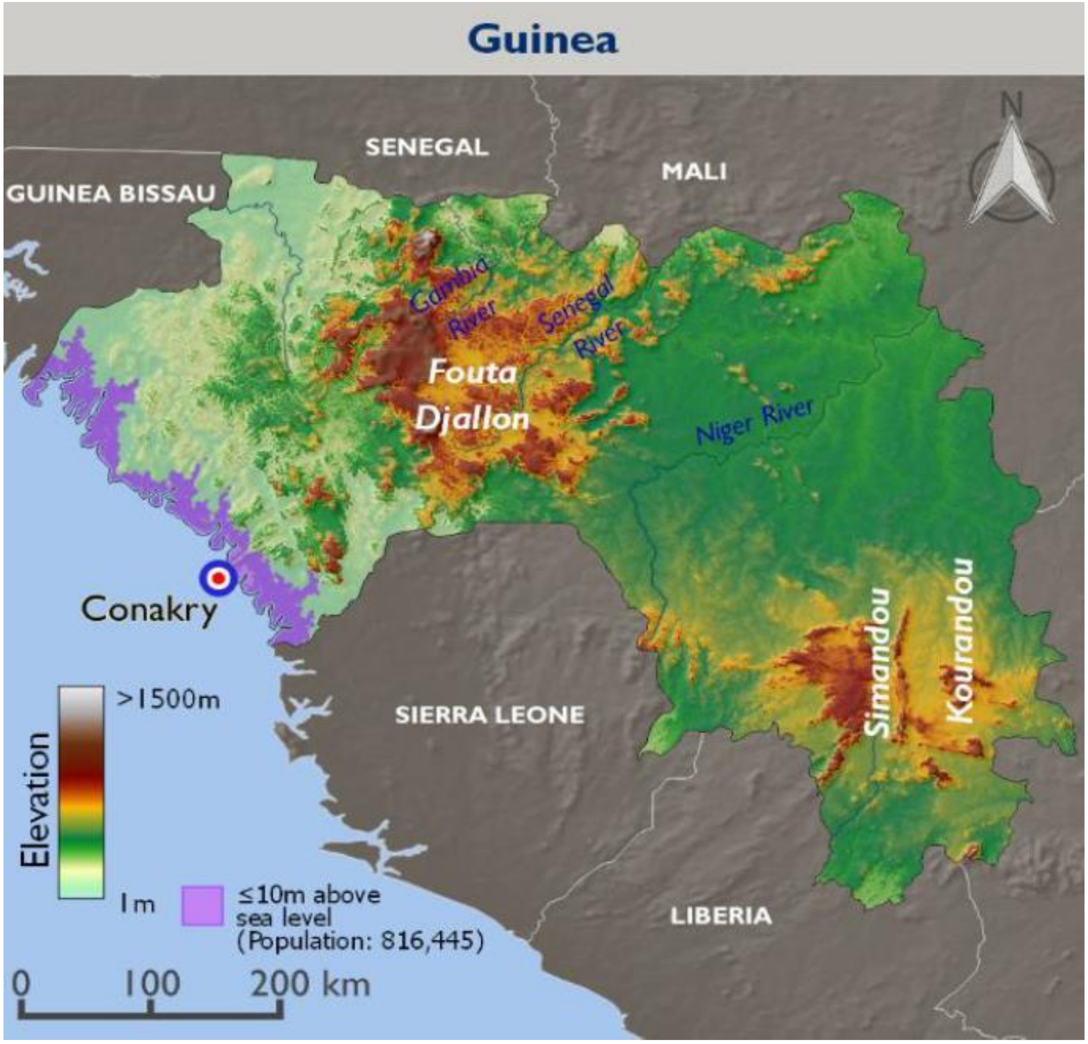

Figure 1. Guinea presentation.
Source: Climate risk profile Guinea, 2018.

country's health and well-being (African Development Bank Group, 2018). A geographical analysis of Guinea reveals distinct topographical features and climatic zones that exacerbate the country's vulnerability to climate-related health issues. Figure 1 illustrates the diverse elevation levels across the country, with a concentration of higher terrains in the Fouta Djallon region and lower elevations towards the coastline where Conakry is located (World Bank, 2017; Climate Risk Profile: Guinea 2018).

Guinea has a tropical climate, with a rainy season from May to October and a dry season from November to April (African Development Bank Group, 2018). Its vast coastline and the country's specific socioeconomic characteristics, such as its reliance on climate-sensitive sectors like agriculture (African Development Bank Group, 2018), make it a critical focal point for understanding the health burdens associated with climate change in Africa.

Despite the significant impacts of climate change on health outcomes, including infectious diseases, mortality, and respiratory, cardiovascular or neurological outcomes (Rocque et al., 2021), there is a noticeable lack of comprehensive systematic reviews that address the complex interplay between climate change and health in Africa. This represents a significant gap in our knowledge and understanding of the health impacts of climate change in Guinea and similar contexts (Rocque et al., 2021).

This systematic review aims to bridge this gap by amalgamating insights on climate change's present and anticipated effects on Guinea's health landscape. It offers a granular examination of a particularly susceptible yet largely overlooked West African country, and broaches potential strategies anchored in the Building Resilience Against Climate Effects (BRACE) framework to bolster health resilience (Centers for Disease Control and

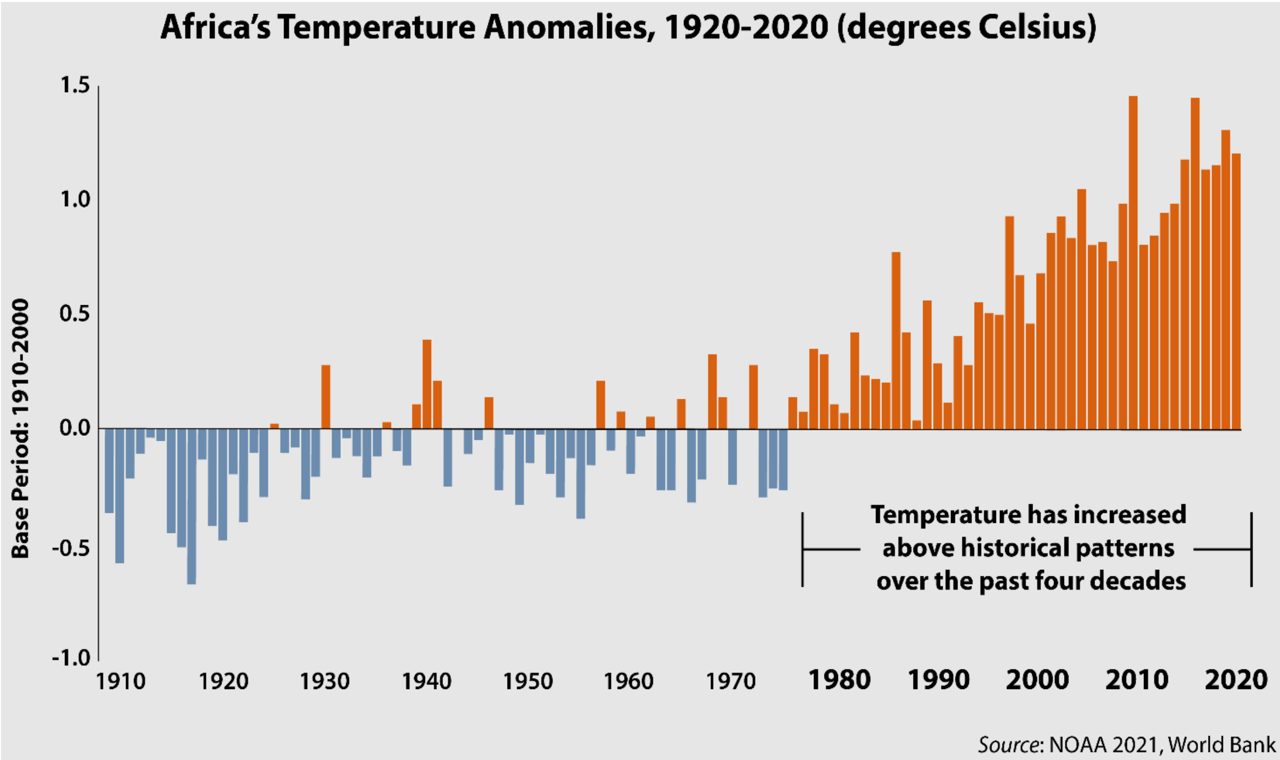

Figure 2. Africa temperature change since 1910.
Source: Africa Center for Strategic Studies (2021).

Prevention, 2022). The CDC BRACE framework provides public health professionals with a useful roadmap to build climate resilience by (1) anticipating climate impacts and assessing vulnerabilities, (2) projecting disease burden, (3) assessing interventions, (4) developing and implementing adaptation plans, and (5) evaluating impacts (Centers for Disease Control and Prevention, 2022).

METHODOLOGY

To unravel the intricate interplay between climate change and health in Guinea, we embarked on a rigorous systematic review encompassing a diverse array of 55 sources, including scholarly articles, government reports, and NGO publications. This expansive review was steered by meticulously crafted inclusion and exclusion criteria, ensuring the capture of both macro-level insights and grassroots nuances to present a multifaceted depiction of the climate-health nexus in Guinea.

Search strategy and source selection

The search was primarily focused on a prominent database, PubMed, Scopus, and Web of Science. Employing a strategic combination of keywords, we sifted through vast information repositories. The keywords encompassed terms like "Guinea", "Climate change", "Temperature rise", "Rainfall variability", "Extreme weather", and "health impacts" (Jalloh et al., 2013) (Figure 2).

Inclusion criteria

1. Peer-reviewed journal articles elucidating the ramifications of climate change on health outcomes in Guinea, including the effects of temperature variations, extreme weather phenomena, and the proliferation of infectious diseases (Rocque et al., 2021).
2. Authoritative reports from globally recognized entities such as WHO. World Bank, IPCC, USAID, and CDC spotlight the interrelation between climate change and health within the African continent, particularly in Guinea.
3. Official publications from the Guinean government detailing climate forecasts, health repercussions, and systemic vulnerabilities.
4. Scholarly books and chapters underscoring the health implications of climate-induced changes (Carlton et al., 2016).

Exclusion criteria

1. Articles from news outlets, opinionated pieces, and general magazine articles were omitted to maintain academic rigor.
2. Investigations narrowly focusing on environmental or health issues without any direct linkages to climate change were sidelined (Cheng et al., 2008).
3. Literature focused on climate change or public health but lacking a targeted focus on Guinea or the broader African region was excluded.

The selection process for sources was rigorously conducted, adhering to predetermined inclusion and exclusion criteria, to ensure a thorough representation of the climate-health nexus within Guinea. Following a meticulous screening procedure, a total of 49 publications were deemed suitable for inclusion in the review.

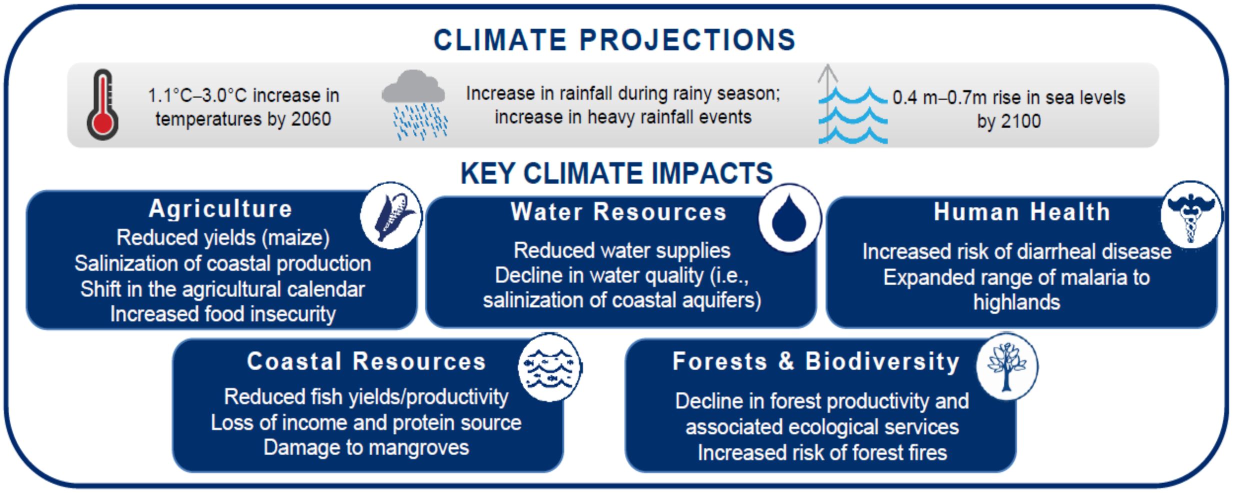

Figure 3. Guinea climate change projection.
Source: Climate risk profile Guinea, 2018.

RESULTS

Current Impacts

Recent observations and projections illuminate the multifaceted impacts of climate change in Guinea, revealing a complex interplay between environmental shifts and public health challenges (Figure 3). Historical climate trends from 1960 to 2016 show a significant increase in average annual temperatures by approximately 0.21°C per year and a decrease in annual rainfall by about 8.14 mm per year since the late 1960s (Loua et al., 2019). This period also saw an increase in the frequency of very hot days and tropical nights, emphasizing Guinea's vulnerability to climate-induced hazards such as floods, storms, and landslides (Byrne, 2021).

Guinea's Second National Communication to the UNFCCC projected further warming between 0.2 and 3.9°C across various regions by 2050, alongside up to a 30% decline in annual rainfall. These climatic changes are poised to exacerbate climate-sensitive health outcomes, including respiratory infections, diarrheal diseases, and malaria, as rising temperatures and fluctuating precipitation patterns create conducive environments for pathogens and vectors (Guinea, 2018; Sylla et al., 2015).

Respiratory infections

Flooding from heavy rainfall promotes mold growth in homes, subsequently increasing asthma symptoms and respiratory infections (Cheng et al., 2008). Drought conditions have been associated with increased airborne dust. This can exacerbate respiratory diseases (Centers for Disease Control and Prevention, 2020). Studies in sub-Saharan Africa following extreme weather events such as floods and droughts have indicated an increase in acute respiratory infections, particularly in children (Tesema et al., 2022). Additionally, it is well-documented that extreme weather events like floods can significantly impact health, increasing respiratory infections (Rha et al., 2020). Despite the lack of reliable data, it is plausible that similar trends could be observed in Guinea.

Diarrheal diseases

Contaminated food or water sources, often resulting from climate-related events such as floods or droughts, significantly elevate the risk of diarrheal diseases (Grist, 2022). Specifically, cholera outbreaks have been frequently linked to heavy rainfall events, which can lead to the contamination of water supplies with sewage, thereby facilitating the initiation of cholera transmission cycles (AP News, 2022). Research has shown that climate variability is expected to increase the risk of diarrheal diseases, a leading cause of child mortality and morbidity in sub-Saharan Africa (SSA), especially when populations have poor access to improved water and sanitation (Levy et al., 2016). This evidence underscores the necessity for ongoing Water, Sanitation, and Hygiene (WASH) interventions, complemented by climate-informed strategies, to mitigate the heightened risk of diarrheal diseases in such climatically vulnerable regions.

Malaria

Guinea faces significant health challenges due to malaria, which accounts for a considerable proportion of outpatient consultations in the country (President's

Malaria Initiative, 2022). While strides in malaria control have led to reduced morbidity, the interplay between climatic variables and malaria transmission is complex, warranting close attention (Beloconi et al., 2023). Studies predict that climate change could lead to shifts in malaria's geographical distribution within Guinea, potentially increasing its prevalence in the country's forested highlands and decreasing it in savanna lowlands (Tonnang et al., 2010). However, model uncertainties call for improved surveillance and adaptable control strategies.

Recent research conducted in Northern Benin, a region with climatic conditions akin to those in Guinea, offers insightful findings relevant to Guinea's context. Gbaguidi et al. (2024a) identified a significant positive correlation between malaria incidence and climatic variables such as temperature, rainfall, and relative humidity in Northern Benin. The study delineates optimal conditions for malaria transmission, suggesting that precipitation ranging from 80 to 220 mm, temperatures of 25 to 35°C, relative humidity of 55 to 85%, and wind speeds of 1.6 to 2.7 m/s are conducive to malaria proliferation. Notably, the maximal temperature and relative humidity were found to substantially influence malaria's spread in the region. These insights could inform the development of a malaria early warning system, potentially applicable in Guinea.

Further advancing the utility of climate data for malaria prediction, another study by Gbaguidi et al. (2024b) introduced an intelligent malaria outbreak warning model using machine learning techniques to forecast malaria prevalence in Northern Benin. Employing algorithms such as linear regression, support vector machine, and negative binomial regression, the model notably achieved an 82% accuracy in predicting malaria incidence with the support vector machine regression emerging as the most effective. This model's projections under climate change scenarios RCP4.5 and RCP8.5 suggest an increase in malaria incidence, underscoring the critical need for climate-informed malaria surveillance and response strategies in Guinea.

Undernutrition

Child undernutrition remains prevalent in Guinea (SPRING/USAID, 2015). Climate extremes like floods or droughts that damage crop yields and incomes worsen food insecurity and malnutrition risk (Phalkey et al., 2015). The study of Headey et al. (2020) found that seasonal rainfall variability contributed to stunting in young Guinean children by reducing household food access. Social protection programs that expand during climate shocks could safeguard nutrition.

Heat stress

The emergence of escalated heat stress risk in the cities of Guinea is noted with a recorded rise in mean temperatures (Guinea Country Program, 2017). Urban dwellers, especially those without amenities like air-conditioning, are particularly vulnerable to heat (Planning for Urban Heat Resilience). Urban heat islands, especially dangerous and exacerbated by glass, steel, asphalt, and concrete structures, further elevate the heat stress risks. Those in underserved communities, which often lack vegetative cover to mitigate these effects, are disproportionately impacted (Dirt, 2021). The dilemma is particularly acute for lower-income demographics, and outdoor workers entrapped by soaring temperatures who find even mild physical activities potentially fatal (Scopeblog, 2022). Elderly individuals, who typically do not adapt well to abrupt shifts in temperature and may have chronic conditions or medications altering their physiological response to heat, also find themselves notably susceptible to heat-induced health issues (National Institute on Aging [NIA], 2022). Consequently, ageing outdoor workers may choose between premature retirement and risking their lives under severe meteorological conditions. Heat effects can span from exhaustion and renal dysfunction to cardiovascular issues (Harvard Health Publishing, 2022; The Lancet, 2021), though data specifically elucidating heat health burdens in Guinea are currently absent.

Coastal erosion

Guinea has approximately 320 km of coastline (Central Intelligence Agency, 2022), and the country faces escalating sea-level rise and coastal erosion threats. By 2100, up to 37% of coastal rice-farming areas may be lost to rising seas (Guinea, 2018). This would severely impact local agriculture, food security, ecosystems, settlements, and livelihoods. Strengthened planning, early warning systems, and climate-resilient infrastructure are needed to protect coastal populations (Magnan et al., 2016).

Projected health impacts

The financial repercussions of health issues influenced by climate are considerable. The immediate medical care expenses and secondary costs like decreased work efficiency could burden Guinea's delicate economic structure. Exposure-response relationships will determine Guinea's future disease burdens under climate change, its future socioeconomic development pathways, and adaptation efforts (Intergovernmental Panel on Climate Change, 2014).

Key projections from regional models

The projections include:

1. The shifting geographic risk for malaria transmission in Africa due to climate change is a significant concern. The worst-case regional scenario of climate change predicted an additional 75.9 million people at risk from endemic exposure to malaria transmission in Eastern and Southern Africa by the year 2080. Despite a predominance of reduction in season length, a net gain of 51.3 million additional people is predicted to be put at some level of risk in Western Africa by midcentury according to a study by Ryan et al., (2020).
2. Over 20 additional days exceeding heat thresholds in Guinean cities by 2050; up to 5-10% labor productivity declines on hot days (Guinea Country Program, 2017; Sylla et al., 2015).
3. Increased child malnutrition following extreme weather shocks to agriculture and food systems. Early studies project a 2-6% rise in wasting among Guinean children by 2050 (Phalkey et al., 2015; Lloyd et al., 2011).
4. More frequent cholera and other diarrheal disease outbreaks with heavy rainfall and flooding (Carlton et al., 2016).
5. Worsened asthma and respiratory infections from flooding, droughts, and expanding airborne allergens based on exposure-response relationships (Cheng et al., 2008; Asthma and Allergy Foundation of America [AAFA], n.d; National Institute of Environmental Health Sciences [NIEHS], 2022).
6. Growing risks of illnesses and deaths from heatwaves, especially among the elderly and vulnerable groups.
7. 17-37% loss of coastal rice-growing areas by 2100, impacting livelihoods and food security without coastal zone enhancements (Guinea, 2018).
8. Increased population displacement from coastal zone degradation (Magnan et al., 2016). Guinea has approximately 320 km of coastline (Central Intelligence Agency, 2022) facing escalating sea-level rise and coastal erosion threats.

DISCUSSION

Applying the Building Resilience Against Climate Effects (BRACE) framework, the discussion of Guinea's strategies for mitigating climate change's health impacts will focus on assessing interventions, adaptation planning and implementation, and impact evaluation.

Assessing interventions of public health adaptation strategies

1. Heat warning systems and infrastructure upgrades to reduce heat exposure through cool roofs, green spaces, resilient housing, and air conditioning (Knowlton et al., 2014).
2. Disease surveillance and control programs sensitive to climate fluctuations through enhanced epidemiological modeling, forecasting, and preparedness (Lowe et al., 2017).
3. Disaster preparedness and response capacity for extreme weather events through early warning systems, stockpiles of medicines/supplies, and emergency infrastructure (Maxwell et al., 2020).
4. Social protection and nutrition supplementation to buffer food security shocks through cash transfers, food banks/kitchens, and nutritional support (Asfaw et al., 2014).
5. Ecosystem conservation to increase coastal resilience through mangrove restoration and sustainable fisheries (International Union for Conservation of Nature [IUCN], 2022).
6. Strengthened coastal zone management and land use planning through setback zones and climate-informed infrastructure (Magnan et al., 2016).
7. Improved meteorological monitoring and climate risk forecasting to guide health adaptation efforts (McSweeney et al., 2015).

Adaptation planning and implementation

A comprehensive national adaptation strategy for health requires:

1. Considering climate change in all national policy development and budgeting.
2. Developing/upgrading sanitation facilities and transport infrastructures.
3. Integrating climate information into disease control and food security early warning systems (Lowe et al., 2017; Kadi et al., 2015).
4. Fostering partnerships across meteorology, environment, agriculture, nutrition, and emergency response agencies.

Impact evaluation key indicators to track adaptation progress

1. Disease rates following climate hazards and early warning triggers.
2. Temperature and extreme weather-related morbidity and mortality.
3. Child nutrition status trends during/after climate shocks.
4. Mental health following extreme events, communities' adoption of adaptation technologies.

Conclusion

Climate change threatens to undermine Guinea's development through adverse health impacts among vulnerable groups. Strategic adaptation guided by the BRACE framework can build resilience and safeguard population health through integrated investments, policies, partnerships, and research (Centers for Disease Control and Prevention, 2022).

Strengthening Guinea's research capacity is critical for developing localized solutions to climate change-related health issues. Establishing research centers focused on climate and health and facilitating collaboration with international institutes can enhance knowledge sharing.

Regional and global cooperation is needed to provide Guinea with technical expertise and funding that enables locally tailored climate change resilience planning and interventions. With support, Guinea can transit towards a climate-resilient future, protecting its citizens' health against escalating climate threats.

Limitations

During the study, the following are challenges and limitations important to acknowledge.

Data availability

There is a lack of localized data and projections specifically for Guinea. Many studies rely on regional climate models or data from neighboring countries, which may not fully capture Guinea's unique context. More granular data on Guinea disease rates, vulnerabilities, etc., is needed.

Surveillance systems

Gaps in surveillance systems and health data reporting in Guinea constrain efforts to quantify current and projected disease burdens. Improved monitoring and data collection would allow more robust analysis.

Future uncertainty

Uncertainty in future socioeconomic pathways and adaptation efforts makes it difficult to project health impacts precisely. Scenario analysis considering different development pathways could improve projections.

Scope of health outcomes

The review did not consider impacts on all health outcomes that could be climate-sensitive (e.g., injuries, poisonings, and mental health). A more comprehensive scope could reveal further risks.

Complex interactions

Interactions between climate factors and health are complex. The review simplifies connections between climate variables and specific health endpoints that may not fully capture real-world dynamics.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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