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THE CHALLENGES AFFECTING THE GROWTH OF CHARTERED PRIVATE UNIVERSITIES IN GHANA

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Abstract

Purpose – This study examines the key challenges facing chartered private universities in Ghana.

Methods – A sample of 287 academic staff, representing 63% of personnel from selected institutions, was obtained through random and purposive sampling. A sequential mixed-methods approach was applied, integrating quantitative and qualitative strategies. The Relative Importance Index (RII) was used to rank challenges, while thematic analysis interpreted qualitative responses.

Findings – Lack of strong government support emerged as the most pressing challenge. Although private universities expand access to higher education, they perceive neglect in policy incentives, subsidies, and institutional support. Their sustainability and competitiveness are therefore strongly shaped by government policy frameworks. Competition from both public and international universities further affects student choices, as these alternatives are often seen as offering greater affordability, value, or prestige. Interestingly, Ghana Tertiary Education Commission (GTEC) compliance ranked sixth, indicating that private universities regard the regulator as relatively fair and predictable. This differs from other contexts where regulators are often viewed as overly rigid.

Conclusion and Recommendation – Private universities should build on their cordial relationship with GTEC to advocate for stronger financial and policy support. Institutional theory highlights the importance of aligning with regulatory expectations to gain legitimacy, while resource dependency theory underscores the need to diversify revenue. Exploring alternative financing models and income-generating ventures will reduce overreliance on tuition fees, strengthen financial resilience, and promote long-term institutional growth.

Keyword: Chartered Private University

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Introduction

The demand for higher education in Ghana has led to the proliferation of private universities, many of which aspire to attain chartered status. Chartered private universities play a critical role in complementing public universities by expanding access to quality tertiary education. Despite their significant contributions, these institutions face several challenges that hinder their growth and sustainability. Issues such as financial constraints, regulatory burdens, and infrastructure deficits impact their ability to compete with public institutions and international universities. Addressing these challenges is crucial to ensuring their long-term viability and contribution to national development. *Private university governance is strongly influenced by Institutional Theory, Resource Dependency Theory and Stakeholder Theory (Gopalakrishnan & Vikneswary, 2024, Gulden et al., 2020, and Langrafe et al., 2020). Together, these theories provide a holistic framework for understanding private university governance. Institutional Theory explains the mimicking of trusted governance models for legitimacy; Resource Dependency Theory illustrates how governance is crafted to ensure resource stability and minimize vulnerability; and Stakeholder Theory highlights governance as an inclusive mechanism balancing the needs of students, staff, regulators, donors, and the community. Applying these lenses offers a nuanced understanding of how private universities navigate legitimacy, financial sustainability, and stakeholder engagement in complex and dynamic environments.*

Statement of the Problem

Although chartered private universities in Ghana contribute immensely to education and national development, their growth is impeded by numerous challenges. These include limited financial resources, stringent accreditation processes, inadequate faculty development, and competition from well-funded public institutions. Furthermore, sustainability issues such as environmental responsibility, economic viability, and social equity remain pressing concerns. If these challenges are not adequately addressed, the expansion and effectiveness of chartered private universities may be severely hampered, limiting their role in achieving Ghana's higher education and development goals.

Research Objectives

The research objective is:

To examine the financial challenges and analyze the impact of regulatory frameworks on the growth and operational efficiency of chartered private universities in Ghana.

Significance of the Study

First, the findings of this study will be beneficial to chartered private universities in Ghana by shedding light on the key challenges affecting their growth. By identifying these challenges, university administrators and policymakers will be better equipped to develop strategic interventions that enhance institutional sustainability and competitiveness. Second, the study will contribute to academic research by providing empirical evidence on the obstacles facing private higher education in Ghana. Researchers and scholars interested in higher education development can use the findings as a foundation for further studies on private university growth and sustainability. Third, prospective students seeking higher education opportunities will benefit from the study's insights into the private university landscape in Ghana. The findings will help them make informed decisions by understanding the factors influencing the stability and quality of education in chartered private universities. Fourth, the study will offer a framework for understanding the challenges of academic staff retention in private universities. By identifying the key issues affecting faculty

retention, university management can adopt effective policies and strategies to create a conducive work environment and reduce high staff turnover. Fifth, the study will provide practical recommendations to enhance student enrollment and institutional growth. By addressing financial constraints, regulatory hurdles, and operational inefficiencies, the findings will help private universities improve their competitiveness and long-term sustainability. Furthermore, it will contribute to literature on best practices for overcoming growth-related challenges in private higher education in Ghana.

Delimitations

The research for this thesis was restricted to the three fully-fledged private universities in Ghana. The motivation for the selection of the three chartered private universities was the level of competition among them in terms of attracting students, academic staff, collaboration and secular programmes they offer. The main objective was limited to two dimensions:

- Financial Challenges Affecting Growth and Sustainability
- Impact of Regulatory Frameworks on Expansion and Operational Efficiency

Limitations

The Google format had its own challenges, but this was the ideal strategy to avoid COVID-19 infection. The study attracted 86.6% responses from the respondents due to the institution's policies. In particular, the participants were reluctant to give answers to remuneration and promotion items due to the fear of being victimized by their managements. This problem was overcome by assuring the academic staff that the investigator intention was to use the data for academic work alone. The original ethical clearance letter was shown to them to allay their anxiety. The participants were, therefore, guaranteed of confidentiality and ethical handling of the information given out.

Definition of Term

Chartered Private University: A non-profit making university that is autonomous, funded and managed by an individual or group of people.

Review of Related Literature

*Institutional Theory**:** Private university governance is strongly influenced by institutional theory, which emphasizes how organizational structures are shaped by regulatory norms, societal expectations, and peer models. Recent literature on higher education highlights how institutional pressures—including government mandates, accreditation bodies, and sector-wide trends—drive private institutions to adopt formalized governance mechanisms that conform with broader standards, thereby securing institutional legitimacy (Gulden et al., 2020).*

*Resource Dependency Theory**:** It helps explain how private universities, which often rely heavily on tuition and external funding, structure their governance to secure vital resources. For example, empirical studies outside the academic sphere indicate that organizations strategically position themselves within governance networks to manage resource flow and strengthen their survival capacity (Xiong, Whetsell, Zhao, and Cheng, 2020). Although this research focuses on broader organizational governance, the same principle applies to private universities: governing boards and senior leadership are often structured to maximize access to financial and strategic resources—such as partnerships, grants, and donor support.*

*Stakeholder Theory**:** This theory further enriches our understanding by framing governance as a multi-constituent balancing act. A 2020 empirical study of higher education institutions in Brazil finds that stakeholder inclusion—particularly through participation in decision-making, information exchange, trust-building, and strategic planning—significantly enhances organizational value creation (Langrafe et*

al., 2020). Similarly, a conference paper on Malaysia's higher education sector proposes that applying stakeholder theory supports more inclusive, transparent, and accountable governance practices in private institutions (Gopalakrishnan and Vikneswary,2024).

Research on private higher education institutions highlights various challenges affecting their growth. According to Altbach et al. (2019), financial constraints remain a major barrier, as private universities rely heavily on tuition fees without sufficient endowments or government support. In Ghana, private universities struggle with funding for infrastructure, research, and faculty remuneration (Gyimah, 2020). Moreover, regulatory challenges imposed by the Ghana Tertiary Education Commission (GTEC) add layers of bureaucracy that slow down institutional development (Mensah & Adu, 2021).

Sustainability issues also affect the growth of chartered private universities. Ayivor and Wilson (2018) emphasize that sustainability in higher education includes economic stability, social inclusivity, and environmental responsibility. Many private universities in Ghana lack long-term financial sustainability strategies, leading to high student attrition rates and operational inefficiencies. Additionally, limited engagement in research on sustainable development further weakens their competitive standing.

Methodology

The Population of the Study

A population, according to the Australian Bureau of Statistics (2018), is any complete group that shares at least one characteristic. This study's unit of analysis is universities, and the unit of observation is academic staff. Therefore, the study targeted Deans of faculties/schools, Heads of Department (HoDs), Heads of Administration Unit, and lecturers are drawn from *three Chartered private universities in Ghana which have programmes in Science, Business and Liberal Arts. The three private universities have international linkages. Besides, these Chartered private universities have been in existence and mentored by public universities for at least 10 years. Therefore, changes and experiences drawn from their mentors and operating as fully-fledge universities for one year and more will enable the group selected to give rich information needed for this study.*

The three Chartered private universities have an academic staff population of 444 according to National Accreditation Board (NAB) (2020) now Ghana Tertiary Education Commission (GTEC). Deans, Heads of Department and Administrative Units constituted 60 of the total population and 393 being lecturers.

Table 1: Deans, Heads of Department and Administrative Unit Heads

Name of University	Deans	Heads of Department	*Administrative Unit Heads	Total
University Z	1	4	2	**7**
University X	9	17	3	**29**
University Y	6	14	4	**24**
Total	**16**	**35**	**9**	**60**

Source: NAB website (May 10, 2020)
*Administrative staff who also lecture

Table 2: Number of Lecturers and Proportion Selected

Name of University	Number of Lecturers (Not Dean or HoD)	Proportion selected
University Z	60	10
University X	214	117
University Y	119	37
Total	**393**	**164**

Source: NAB Annual Statistics Report 2018/2019

Note: The proportion selected for each university is determine as: the number of lecturers divided by the total lecturers and the quotient is multiplied by the number of lecturers in each university.

Sample and Sampling Procedure

A sample of this study was drawn from statistical population (453) from the three chartered private universities. The sampling procedure is a statistical method for determining the optimum sample size, allowing the researcher to generalize the findings (Kibuacha, 2021).

In determining the sample size for factor analysis, Gorsuch (1983) recommended that the sample size should not be less than 100. This recommendation appears more liberal than the view of Guilford (1954) who asserted that the sample size should be at least 200. Cattell (1978) even proposed a higher minimum sample size of 250 as desirable for factor analysis. To avoid the confusing minima advocated by Gorsuch (1983), Cattell (1978) and Guilford (1954), Yamane's formular for calculating sample size was used.

The sample size calculation formula was adapted from Yamane (1967). $Sample\ Size\ (n) = \frac{N}{1 + N(e)^2}$ where n = sample size, N = populations and e = margin error. In substituting N = 453 and e = 0.05 in the above formula, the least sample size should be approximately two hundred and twelve (212). Therefore, 320 participants in the universities were employed for the study taken 212 as minimum.

Research Objective using the Relative Importance Index and Regression

The research objective adopted the Relative Important Index (RII) and qualitative content analysis. First, the RII is a descriptive statistical method for identifying the most important variables or factors in multivariate data. It is appropriate when a researcher needs to extract or pinpoint important factors from a large population. The relative importance index is helpful, because it considers population size and the relative disadvantages that various groups have. Relative Important Index (RII) was used in the study to rank the selection difficulties faced by chartered private universities. *Though the questionnaire was adapted from previous studies, the items were pulled out from different sections. Therefore, a pre-test study was carried out using 50 senior members at private University 'A' to establish the content validity and reliability of the instrument. The questionnaire was modified based on the feedback from the pre-test. The Cronbach alpha value for the close ended questions was 0.860.* In order to evaluate the questionnaire, respondents were asked to rate these issues on a 5-point Likert scale. In this study, scale 1 represents Strongly Disagree (Very Low) and scale 5 represents Strongly Agree (Very High). The relative importance indices were created by converting the numerical scores of each of the identified challenges in order to determine the relative ranking of the challenges. The greater the RII value, the greater the challenge. The Tholibon et al. (2021) formula was used to convert the scores to importance indices, which were then used to determine the relative ranking of the challenges.

Relative Importance Index

$(RII) = \sum_{k=0}^{n} Wn/A \times N$

Where, $0 \leq RII \leq 1$
W= Weighting given to each challenge
n= frequency of respondents
A= Highest Score i.e. 5 in this case
N= Total No. of participant (277 in this case)

The relative importance index analysis, which is often reported as a percentage, identifies the majority of the important difficulties based on participant replies. It is also handy for ranking indicators using Likert scales.

Second, in the qualitative analysis, inductive techniques were used to code the response excerpts from the study's interview with eight (8) Deans plus two (2) Registrars. Cleaning up the raw data files into a standard format was the first step in the inductive coding process (Bazeley & Jackson, 2013).

The researcher then read the text data from the interviews several times and interpreted it in order to become familiar with the contents and understand the themes while taking into account all the different meanings that could be attached to them (Thomas, 2006).

The text data from the ten (10) interviewees' responses was coded into the appropriate categories after the categories had been created. To achieve this, relevant words, phrases, and paragraphs from the interview texts were assigned to the defined coding units (Zhang & Wildemuth, 2009). Care was taken to define and identify the themes in order to establish categories, get rid of texts that were already in use, and minimize text overlap (Thomas, 2006).

Data Analysis

To examine the financial challenges and analyze the impact of regulatory frameworks on the growth and operational efficiency of chartered private universities in Ghana.

Table 3: Percentage Response on Challenges affecting Private Universities in Ghana

Statements	SA	A	UN	D	SD
Meeting Ghana Tertiary Education Commission (GTEC) requirements	85(30.7%)	140(50.5%)	17(6.1%)	22(7.9%)	13(4.7%)
Use of competitors as GTEC personnel to assess the university for programme renewal	77(27.8%)	92(33.2%)	81(29.2%)	13(4.7%)	14(5.1%)
Increased competition from other universities	153(55.2%)	111(40.1%)	8(2.9%)	5(1.8%)	-
Staff turnover	85(30.7%)	100(36.1%)	65(23.5%)	27(9.7%)	-
Maintaining reasonably low fees	52(18.8%)	100(36.1%)	79(28.5%)	37(13.4%)	9(3.2%)
Copying courses offered by other universities	19(6.9%)	50(18.1%)	95(34.3%)	80(28.9%)	33(11.9%)
Students' inability to differentiate your courses from those offered by other universities	29(10.5%)	64(23.1%)	90(342.5%)	73(26.4%)	21(7.6%)
High fee default rate among students	56(20.2%)	115(41.5%)	87(31.4%)	9(3.2%)	10(3.6%)
Huge financial requirement to run the university	167(60.3%)	77(27.8%)	29(10.5%)	4(1.4%)	-
Lack of government support for private universities	216(78.0%)	35(12.6%)	10(3.6%)	16(5.8%)	-
Maintenance of teaching and learning infrastructure	123(44.4%)	104(37.5%)	18(6.5%)	13(4.7%)	19(6.9%)
Adjust to current trend of teaching and learning	85(30.7%)	139(50.2%)	32(11.6%)	13(4.7%)	8(2.9%)

Source: Author's Field Data, 2022. *SA=Strongly Agree; A=Agree; UN=Undecided; D=Disagree; SD=Strongly Disagree*

Tables 3 and 4 show the percentages of respondents and the rankings of the challenges that private universities face. This provides opportunities for the university's Council or Management to take decisions based on relative importance index (RII). These RII values are essential to identify and enumerate the significant challenges for priority decision making.

From the Table 3, 216 respondents out of 277 representing 78.0% strongly agree that lack of government support for private universities is the biggest challenge. Also, 19 respondents representing 6.9% strongly agree that copying courses offered by other universities constitute the least challenge faced by private universities in Ghana. Further, more than 55% of the respondents agree to the fact that private universities management battle with the challenges identified in the Table 3.

The primary data collected was analyzed through a formula of relative index analysis method from previous related studies. The finding shows that, there are three challenges that rated high important: The first was "Lack of government support for private universities" with (RII 0.931), "Increased competition from other universities" was ranked second with (RII 0.898) and "Huge financial requirement to run the university" was ranked third (RII 0.895). It was revealed that the Lack of government support for private universities should be first priority decision concern of management of private universities in Ghana.

Sequential qualitative studies with eight Deans and two Registrars as respondents answered the question '*Does your university receives grants from government and which form does it take?'* The following three (3) interview excerpts summarise the issue of government support in the private universities as given by three participants of the universities.

[…] *Government does not support the university in any way. Some years back we received a bus. That is all I know about Government's support. Considering the fact that we contribute to the manpower development of the nation's youth, government could do more'*. (Participant 4, University Z, 19th August, 2022)

'[…] *No free support from government and agencies. Support from the regulator and other government agencies are fully paid for. Even so, we are not reimbursed for the cost of building roads on our university campuses. The biggest issue we face as a university is this.* (Participant 6, University Z, 19th August, 2022)

[…] *The only government assistance we receive is access to the student loan scheme, which helps some students pay their tuition fee. The government could provide scholarships to private university lecturers for further studies, particularly doctoral degrees to argument staff training in private universities. (Participant 5, University X, 20th August, 2022)*

According to the responses, running a private university is expensive, and government assistance could alleviate some of the difficulties. The provision of library buildings and the stocking of books and other equipment could be of enormous assistance to chartered private universities in their training of scholars.

Another follow up question was posed to the respondents as '*Do you usually advertise your programmes'? Justify your answer*'.

[…]*Yes, we cannot do without it. Now we are heavy on social media as well. When we did not have many competitors, our management was a bit relaxed, but now lack of enrolment has led to the discontinuation of some of the programmes. The university has a policy not to run programmes with a minimum threshold of admission. Also, with low differentiation in the products and services offered by competitors, competition is expected to increase. The market for*

university education is becoming more competitive. This is especially true when universities in the same region offer courses that are similar and identical. The identical courses offered, facilitate substitution by students and enhance competition among private universities. (Participant 1, University Y, 17th August, 2022)

[…] *There was a time when we had a lot of students, however since the public universities began more innovative enrolments, like evening and weekend school, fee-paying, and so on, the competition for students has been high. Another factor is the multiplicity of accredited private universities and foreign universities with campuses in Ghana.* (Participant 2, University Y, 17th August, 2022).

In the excerpts' summary, the feeling is that numerous competitors exist in the higher education space, particularly in areas of Business programmes that are identical and market driven. The competition is compounded, when foreign universities establish their campuses in Ghana.

Table 4: RII on Challenges Facing Private Universities in Ghana

Statements	Mean	Std. D	RII	Rank	RII Index
Meeting Ghana Tertiary Education Commission (GTEC) requirements	3.951	1.053	0.789	6th	Medium Important
Use of personnel to assess the university for Competitors as GTEC programme renewal	3.741	1.072	0.748	8th	Medium Important
Increased competition from other universities	4.490	0.646	0.897	2nd	High Important
Staff turnover.	3.882	0.959	0.775	7th	Medium Important
Maintaining reasonably low fees	3.542	1.044	0.707	10th	Medium Important
Copying courses offered by other universities	2.791	1.087	0.558	12th	Low Important
Students' inability to differentiate your courses from those offered by other universities	3.033	1.105	0.605	11th	Low Important
High fee default rate among students	3.711	0.945	0.742	9th	Medium Important
Huge financial requirement to run the university	4.471	0.740	0.893	3rd	High Important
Lack of government support for private universities	4.630	0.809	0.925	1st	High Important
Maintenance of teaching and learning infrastructure	4.080	1.146	0.815	4th	Medium Important
Adjust to current trend of teaching and learning	4.011	0.934	0.802	5th	Medium Important

Source: Author's Field Data, 2022. *To measure the relative importance of each factor or variable used indices of range 0.85-1.00=High Important; 0.65-0.84=Medium Important; 0.00-0.64=Low Important*
RII means Relative Importance Index

In Table 4, the second priority challenge to private university management is "increased competition from other universities". Private universities compete predominately for potential students for enrolment, quality staff and grants. The number of private universities is on the rise in recent years. By 2018, private tertiary institutions increased to eighty-one (81) accredited private tertiary institutions (Accreditation News, 2018).

Institutions of higher learning are rapidly growing, particularly in the vast majority of developing nations (Mbirithi, 2013). The third out of twelve challenges rated in the analysis is "Huge financial requirement to run the university". Many managers of private universities are businessmen and must raise money resources for infrastructure, research, and training mainly from school fees. Private universities, according to Ajadi (2010), rely heavily on tuition fees and other internally generated revenue from students to cover their expenses. The cost of operating a private university is high, and it takes time for the investment to pay off. Unfortunately, many

owners of private universities in Ghana don't seem to have the resources to support the financial responsibilities of these institutions. The management of Ghana's university system, whether public or private, has identified funding as its biggest challenge, according to various academics and stakeholders (Abiodun-Oyebanji, 2011). Many of these universities have subpar facilities because of a lack of funding and the apparent scarcity of funds available to private universities. Thus, these are the three most important challenges that private universities' management must consider in decision making toward achieving growth in infrastructure, innovation in teaching and learning in higher education.

The other seven of the challenges of private universities with relative important index ranging from RII 0.816 (Maintenance of teaching and learning infrastructure) to RII 0.707 (Maintaining reasonably low fees) recorded Medium Important Index in decreasing magnitude. The 4th and 5th Medium Important indices are challenges regarding maintenance of teaching, methods of teaching and teaching infrastructure that are challenges facing quality teaching and learning. Therefore, this indicator implies private university managements and stakeholders pay more attention to quality teaching and learning.

Table 4 further reveals that two of the challenges were ranked low important. They are 'Copying courses offered by other universities' with (RII 0.609) and 'Students inability to differentiate your courses from those offered by other' with (RII 0.557). These two challenges regarding courses offered in private universities are considered least in decision making to private university management. The implication is that private universities are getting it better relative to courses they offer. Most courses offered at the private universities are flexible and innovative. These results confirm Suleiman et al., (2017); Amponsah & Onuoha (2013) that private universities are more effective at adapting to organizational changes and innovations because of their organizational flexibility in management and administration. This, in turn, enables them to introduce more curricular and programme innovations, better assessment techniques, and cutting-edge teaching methods compared to public institutions.

A follow-up question was posed for participant comments, thus '*How can you describe the relationship between your university and Ghana Tertiary Education Commission (GTEC)?'*

[…] *The relationship between our University and GTEC is cordial, even though sometimes there is the feeling that GTEC is stricter on chartered Private Universities than the public Universities. As the regulator, we have no choice but to submit to their requests.* (Participant 9, University Y, 17th August, 2022)

[…] *The university relationship with GTEC is cordial. However, there are areas of divergence sometimes in areas such as programme accreditation there are undue delays in the delivery of feedback from GTEC after panel assessment of programmes. One challenge is that, GTEC puts undue quotas on our programmes that are usually oversubscribed.* (Participant 8, University Z, 19th August, 2022).

The relationship between chartered private universities and GTEC is friendly. However, participants believe that academic programmes submitted to GTEC for accreditation are being delayed excessively. Furthermore, academic programmes at private universities that attract more students are given quotas. This may result in the private universities running below capacity and therefore increasing the costs of capital.

Conclusions and Recommendations

The integration of quantitative survey results with qualitative interviews confirms that government support to private universities in Ghana is negligible. While statistics demonstrate the overwhelming financial reliance on tuition fees, the qualitative narratives provide context, illustrating institutional frustration and unmet expectations. This triangulation strengthens the conclusion that lack of government support should be a top-priority concern for private university management.

Private universities should capitalize on their cordial relationship with the Ghana Tertiary Education Commission (GTEC) to advocate for increased financial support. Through this partnership, GTEC can play a crucial role in helping private institutions expand their student quotas, particularly for high-demand programmes. Furthermore, GTEC's engagement can assist private universities in developing strategic initiatives that reduce their heavy reliance on tuition fees by facilitating access to alternative funding sources and innovative revenue-generating opportunities.

The evidence shows that securing adequate government support remains the most pressing challenge for private universities. This concern is underscored by the mean score of 4.63 and a relative importance index of 92.5%, reflecting strong consensus among the management of chartered private universities. The findings highlight that tuition fees continue to dominate as the primary source of income, a model that is unsustainable in the long term.

The broader implication is that without meaningful government support and diversified revenue streams, the sustainability of private higher education in Ghana will remain fragile. If unresolved, this dependency threatens not only institutional survival but also national objectives of expanding access to higher education, promoting equity, and producing the skilled workforce needed for socio-economic development. Thus, strengthening partnerships between government agencies such as GTEC and private universities is critical for building a more resilient and sustainable higher education system in Ghana.

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MOHAMED IRFAAN ALI (2025). ACHIEVING GLOBAL FOOD SECURITY. THE CARIBBEAN EXPERIENCE AND BEYOND. SINGAPORE: WORLD SCIENTIFIC PUBLISHING.

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Abstract

Achieving Global Food Security. The Caribbean Experience and Beyond is authored by the President of the Co-operative Republic of Guyana, Dr. Mohamed Irfaan Ali. The book makes a timely and distinctive contribution to intensify efforts towards the "Zero Hunger" United Nations Sustainable Development Goal (SDG) 2 by 2030. This erudite work consisting of six interrelated chapters guides regional and global leaders in harnessing their collaborative potential to make agri-food systems more efficient, inclusive, resilient and sustainable. Chapter One briefly introduces the ordeal of global hunger (pp. 1-2); Chapter Two presents the global food security crisis (pp. 3-9); Chapter Three provides a focused analysis at the regional level (pp. 11- 22) and Chapter 4 deepens the analysis from a country-level perspective (pp. 23-79). Policy recommendations to address the current regional food crisis are underscored in Chapter 5 (pp.81-100). Immediate action is deemed imperative for a Caribbean Community (CARICOM) cross-border agri-food investment Strategy and the establishment of a regional agro-tech campus. Hence, a key recommendation is Research and Development to eliminate knowledge barriers, create new technologies and develop environmentally resilient islands that can withstand challenges of food insecurity across the region. Chapter 6 shares some of the works already in the pipeline in Guyana and the way forward (pp. 101-112). Dr. Ali's book convincingly illustrates that amidst initiatives for national food production, human security and sustainable development, leaders can leverage technology for effective communication and stay connected with each other to end the global hunger crisis.

Keyword: Global food security, Inclusive, Resilient, Sustainable

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Book Review

The United Nations Sustainable Development Goal (SDG) 2 was formulated in 2015 with a focus on policies, legislation and interventions to ensure all people have access to safe, nutritious and sufficient food by 2030. Yet towards the end of the 21st century first quarter, undernourishment continued to increase globally. The annual report (2024) emerging from context of the G20 Global Alliance against Hunger and Poverty Task Force Ministerial Meeting in Brazil, admonished that the world is far behind in achieving SDG 2. According to the Food and Agriculture Organization of the United Nations et al (ibid), globally trends varied considerably: the percentage of the population grappling with hunger increased in Africa (20.4 percent), remained stable in Asia (8.1 percent) but presented a serious challenge as the region accommodates over half of the people facing hunger worldwide —and indicated progress in Latin America (6.2 percent). From 2022 to 2023, hunger intensified in Western Asia, the Caribbean, and most African subregions. Hence, it is imperative to combat stagnation in the progress of global food security.

The book, *Achieving Global Food Security: The Caribbean Experience and Beyond* (2025) authored by the President of the Co-operative Republic of Guyana, His Excellency, Dr. Mohamed Irfaan Ali makes a timely and profound contribution to accelerate the achievement of Zero Hunger, as outlined in (SDG) 2. In the global context of a humanitarian call to action, the book highlights that food insecurity remains a critical challenge to nations of the Global South, including the Caribbean and its many Small Island Developing States (SIDS).

Through a powerful blend of the president's focus on leadership responsibility and practical concerns for human survival, the book commands the attention of world leaders and their governments to transform agri-food systems by making them more efficient, inclusive, resilient and sustainable. Beyond that, the book significantly impacts the social responsibility of diverse professions, including agriculturists, environmentalists, scientists, technologists, small farmers, entrepreneurs, teachers and students, spanning across international organisations to every ordinary citizen around the globe who can play a role in sustainable food production.

A unique feature of scholarly impactful research is the use of statistics to analyse quantitative data and derive meaningful inferences in a precise manner for operative applications (Singh & Jassie, 2023). The book under review presents statistics and current trends at national and regional levels in key areas such as food production imports, investments in agriculture, government debts, and the impacts of the climate crisis on food security vulnerability. The tables, figures, charts, and graphs help readers to understand findings presented in a simple manner. These visual tools engage and sustain their interest in processing contextual information in relation to data analysis. The presentation of quantitative findings enables readers to understand characteristics, distribution, relationships between data and draw inferences to enhance deeper learning and implementation of policy recommendations.

The Introductory chapter of the book briefly contextualizes critical reflections on the following quotation. *War is tipping a fragile world towards mass hunger. Fixing that is everyone's business* (The Economist, 2022). Chapter 2 unfolds with a global perspective of food security in crisis. Chapter 3 moves the discussion to the Caribbean region with a macroeconomic overview of food insecurity amidst a complex system of economic and environmental vulnerabilities. Chapter 4 covers an in-depth analysis from a country-level perspective. Of immense value, Chapter 5 provides

policy recommendations for the current food crisis in the region. In Chapter 6, President Ali presents works already in the pipeline in Guyana and a way forward to join with the Caribbean region to fix the burning issue of mass hunger. The book's development for action and intervention at national and regional levels is meant to have a decisive impact on how countries can come together to achieve global food security and forge ahead with progress already happening.

Against the brief backdrop of increasing global food insecurity and hunger in Chapter 1, the book effectively begins to develop an integrated people-centered approach to eliminate social and economic inequalities. Chapter 2 draws focused attention to the combined and interlinked effects of the Covid-19 pandemic, the Ukraine war, disruptions to global food supply chains, inflation and deepening inequalities. High-risk regions identified were South Asia, Africa, Latin America and the Caribbean. The supply chain turmoil is described as "one of the greatest threats to the growth of companies and countries' economies, even greater than the pandemic, war and labor shortage" (McKinsey survey, 2022 cited in Chapter 2, p.8). The second chapter illustrates extenuating circumstances such as the global energy crisis and climate change which have led to higher inflation and constrained economic growth. Reference to factual information with specific details appeals to everyone's concern about serious consequences that negatively affect vulnerable populations, mainly, poverty, unequal standards of living and malnutrition.

Chapter 3 is titled the Regional Picture which piques the reader's interest. It encapsulates the food security environment within the Caribbean region from a macroeconomic standpoint. It informs readers that Caribbean countries remain volatile in terms of their geographic and demographic characteristics, economic structure, income levels, financial debt and agricultural development. Therefore, high levels of inflation in the Caribbean are likely to prolong as a critical challenge to many countries, particularly SIDS, due to heavy reliance on food imports and inadequate diversification. A key issue is well elucidated in the context of the book's central goal to achieve global food security. Achieving SDG 7- 'to end hunger' is directly correlated to building climate resilience (Tidemann et al., 2022) towards equitable, inclusive and sustainable agriculture. This is clearly understood as a significant development process involving farming communities, households, and individuals in system-wide productivity to prevent, mitigate, or cope with climate and other environmental risks, while adapting to change and recovering from global shocks.

In Chapter 4, in his dual role as President of Guyana and the Caribbean Community (CARICOM) Lead Head of Government with responsibility for agriculture and food (2021- present), Dr. Mohamed Irfaan Ali, provides a cross-cutting perspective of contextual realities across the entire Caribbean and on-the-ground knowledge for achieving food security. Investment in the agricultural sector in the Caribbean has been traditionally low due to a lack of access to affordable capital. The chapter reinforces that initial problems have been compounded by the Covid-19 pandemic. It turned into a severe global economic crisis with inherent vulnerabilities of food security provision and global inflation which increased the food import bill throughout the region. Many countries were affected as follows: Antigua and Barbuda, the Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Haiti, Suriname and Trinidad and Tobago. A unique strength of this book lies in its inclusivity. While all countries have been sensitised to economic conditions and food security, each can now develop a deeper

level of awareness and response to improve and transform food systems regionally.

Chapter 4 further evaluates factors affecting food dependency within the Caribbean region as follows: unavailability of applied technology, limited access to human resources, a lack of market opportunities, and low levels of public investment in critical infrastructure towards mitigating the harmful effects of climate change. The chapter underscored, "Agriculture production has remained volatile due to the frequency of climate related events" (p.77). This speaks to recurrence of hurricanes, drought, floods, and landslides with major setbacks for food production and agricultural exports in several countries, notably Antigua and Barbuda and Jamaica. A core issue of the book for readers to reflect upon, is that increases in debt burden which can arise from a variety of aforementioned factors, could potentially expose countries to elevated levels of food insecurity in the future. Notably, Guyana aims to "utilize the increased fiscal space from a lower debt burden and from oil production and the sale of carbon credits to bolster the resilience of its food production system" (p.49). Readers recognise that only when food systems are resilient, they can then become more equitable, inclusive and sustainable.

The 5th chapter of the book is titled Strategic Policy Recommendations. President Ali made recommendations in support of an actionable, pragmatic and innovative approach to food production in the Caribbean region, namely: a CARICOM Cross-Border Agri-Food Investment Strategy, Acceleration of the Trade Facilitation Reform Process for CARICOM, an Agricultural Catastrophe Fund and an Integrated Water Resources Management for each country. Of strategic value, the book emphasises the role of Research and Development (R&D) as the cornerstone for rapid progress. Accordingly, the President recommended that a Regional Agro-Tech Campus (RATC) will promote translational research and experimental development of agriculture to become the leading institute of technology for food and environmental science.

Chapter 5 creates an enlightening strategic path for regional universities and education systems in R&D to overcome knowledge barriers and offer innovative solutions to complex problems. It aims to enhance a sustainable biological and synthetic system as a means of confronting key challenges in agriculture while ensuring the protection of the environment and innovation for the bioeconomy. Three main areas for capacity-building are focused on development of training programs to support entrepreneurship, expansion of R&D in life science and technologies, and improved quality of education and research in partnering academic institutions. Together, regional universities and the RATC can leverage strategic relationships and close linkages with key international partners to promote innovation across the ecosystem through evidence-based research. What makes the book exceptional is its strategic path with heavy reliance on the higher education sector to revolutionise the Caribbean food and agriculture industry.

Chapter 6 is focused on "Works in the Pipeline and Way Forward: Guyana." President Ali emphasized the book's overarching goal to build a more prosperous future through innovation and transformative investments for the diversification of agricultural productivity. The commitment to self-sufficiency is apparent in following three growing sectors in Guyana: The Corn and Soya Bean Pilot Project; Horticulture and Livestock; and Investment in Agro-Processing Facilities. Guyana's blueprint of an inclusive and sustainable development -The Low Carbon Development Strategy (LCDS) 2030 is comprehensively explained as an essential pathway to preserve the country's forest and simultaneously develop its economy five-

fold over the next 10 years. The LCDS will ensure protection against climate-related events and biodiversity loss through resilient agriculture for sustainability. This intensive task coherently extends to the strengthening of coastal infrastructure, the protection of mangroves and climate risks assessment and insurance. These are insightful proactive measures which the book shares for building resilience to counteract risks and the severity of climate-related shocks to food systems.

This final chapter of the book also reaffirms Guyana's commitment to bilateral partnerships with prime attention directed to investment in a Regional Food Hub, regional aquaculture and agriculture tourism towards a sustainable agri-food system in collaboration with CARICOM member states (CARICOM Vision 25 by 2025 plan).

Achieving Global Food Security. The Caribbean Experience and Beyond (2025) places the onus on Caribbean leaders to explore policy and priority actions aligned with the goal of SDG 2 of Zero Hunger. President Ali, called for regional leaders to act through international cooperation, regional integration, and multi-sectoral actions involving all stakeholders of the Agri -food system. His book makes a compelling call for committed leadership of the region to explore policy options aimed at sustaining the quest for food security. The matter of urgency is for smaller countries of the world to take determined action, if they must eliminate dependence on extra-regional food imports and strengthen food production and nutrition security.

This book is simple but authored from the viewpoint of a regional leader, it has profound impact and lasting significance. It provides a solid foundation to develop healthy food habits essential for success in the production and consumption of food for people from all walks of life. Future researchers in the field of agriculture can use the information presented in each of the country briefs (Chapter 5) to further examine cross-comparative challenges and successes for equity in food security within the Caribbean region.

In summation, President Ali's book presents a decisive new research and policy agenda for inclusivity to end global hunger. He provides implementable options towards resilience, socio-economic progress, sustainable development and food security for the Caribbean Region with lessons for the Global South and the wider global community. *Achieving Global Food Security. The Caribbean Experience and Beyond (2025)* is not only a testimony of a president's unwavering commitment to developing Guyana through food sustainability but his deepening collaborative initiatives to end hunger for human survival beyond.

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Bibliographical note

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TOWARDS A CIRCULAR ECONOMY: COMPARATIVE EVALUATION OF ECO-PAVEMENT AND CONCRETE PAVEMENT BRICKS

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Abstract

The escalating generation of solid waste poses significant threats to human health, biodiversity, and the environment, exacerbated by rapid industrialization, population growth, and economic development. This study investigates the potential of reusing solid waste materials in the production of eco-pavement bricks, comparing their sustainability with traditional concrete pavement bricks. Conducted in Bunso, Ghana, the research involved the development and assessment of eco-pavement bricks alongside commercially acquired concrete pavement bricks. The bricks' physical and mechanical properties, including dimensions, weight, water holding capacity, and compressive strength, were evaluated. Descriptive statistics and Analysis of Variance (ANOVA) were employed to analyze the data. The results indicate that eco-pavement bricks exhibit comparable performance to concrete bricks, with satisfactory water holding capacity, high compressive strength, and economic viability. The findings suggest that eco-pavement bricks are suitable for constructing walkways, pathways, and walls. This study concludes that eco-pavement bricks offer a promising approach to solid waste management, contributing to a circular economy and environmental sustainability. Adopting eco-pavement bricks can be a viable solid waste management strategy.

Keyword: Solid Waste generation; Reusing; waste recycling; Eco-pavement bricks; circular economy; environmental sustainability, biodiversity

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Introduction

Globally, the rate of solid waste generation is increasing as a result of population density, economic growth, urbanization, and industrialization which has resulted in the generation of large quantities of solid waste across various urban and rural areas. Even in Ghana, about 12,710 tons of solid waste is generated daily, with only 10% collected and disposed of at designated dumping sites (Lissah *et al.,* 2021). Pointedly, increased population growth and economic development led to increased volumes of municipal solid waste significantly and its composition (Miezah *et al*., 2015).

Most municipal wastes are usually generated from variable sources where different human activities are encountered (Abdel-Shafy & Mansour, 2018) such as industries, domestic and agricultural activities etc. Assessments conducted by Ghanaian academic institutions suggest that the country generates 0.47 kg municipal solid waste (MSW) per person per day, translating into about 4.6 million tons of MSW per year. According to Markandey (2020), organic waste account for the largest content of MSW with 61%, 14% plastics, 6% inert material, 5% paper, 3% metals, 3% glass, 1% leather and rubber, 1% textiles and 5% miscellaneous. Some of these waste materials are biodegradable hence, can be used or reprocessed into other essential products. Unfortunately, several of these waste materials cannot degrade. Therefore, the longer they persist in the environment, the more their effects accumulate and render adverse effects to human health and the environment as a whole. Subsequently, the effective and efficient management of solid waste is one of the biggest challenges local government authorities face, especially in urban setting (Firdaus & Ahimad, 2010).
Recently, most developing and developed countries are creating ways of mitigating or adapting to the undesirables changes that has occurred as a result of the rate of solid waste generation and establishing measures of reusing and recycling of various solid waste materials for other beneficial products. There is now a shift from traditional linear economy towards circular economy aimed at waste minimisation and effective use of resources. Therefore, the state of the art for sustainable, unconventional, natural, and recycled building materials should be taken into account (Kawereaki & Achal, 2020).

This research seeks to develop and compare the sustainability of pavement bricks made from waste materials against pavement bricks made from concrete. It also aim to ascertain the sustainability of the eco-pavement bricks. Additionally, it seek to reveal and publicize the benefits to the environment such as, mitigating waste build up, creation of employment, protect the environment and ensure the achievement of the Sustainable Development Goals (SDGs) 11, 12 and 13.

According to conclusions by Khan *et al*. (2021), Solid Waste Management (SWM) is a significant challenge for a society that arises local issues with global consequences. In low-income countries, over 90% of waste is often disposed at unregulated dumps or openly burned, creating serious health, safety, and environmental consequences (Solid Waste Management, The World Bank Group, 2022). As the world's population continues to grow, so does the amount of waste being produced. In 2015, the world generated 2 billion metric tons of solid waste. This number is expected to grow to 3.4 billion metric tons by 2050 (Ramakrishna, 2022).
Also, poor municipal solid waste disposal and insufficient collection practices generate serious health related problems to humans and the environment (Loboka *et al*., 2013).

Within this context, this research seeks to develop an eco-pavement brick from waste materials and assess its ability to save cost, protect the environment and ensure the

achievement of environmental sustainability.

Materials and Methods

Study area

The study was carried out at Bunso in the Abuakwa South Municipality, Eastern Region of Ghana (Figure 1). The yearly temperature is ''29.06^{0}C'' (84.31^{o}F) and it is 0.2% higher than Ghana's averages. Bunso lies between longitude 0.56 West and 0.15 West and latitude 6.03 North and 6.35 North and lies in the west semi-equatorial zone. Bunso receives about 117.32 millimetres (4.62 inches) of precipitation and has 242.75 rainy days (66.51%) annually, thus a double rainfall occurring in June and October.

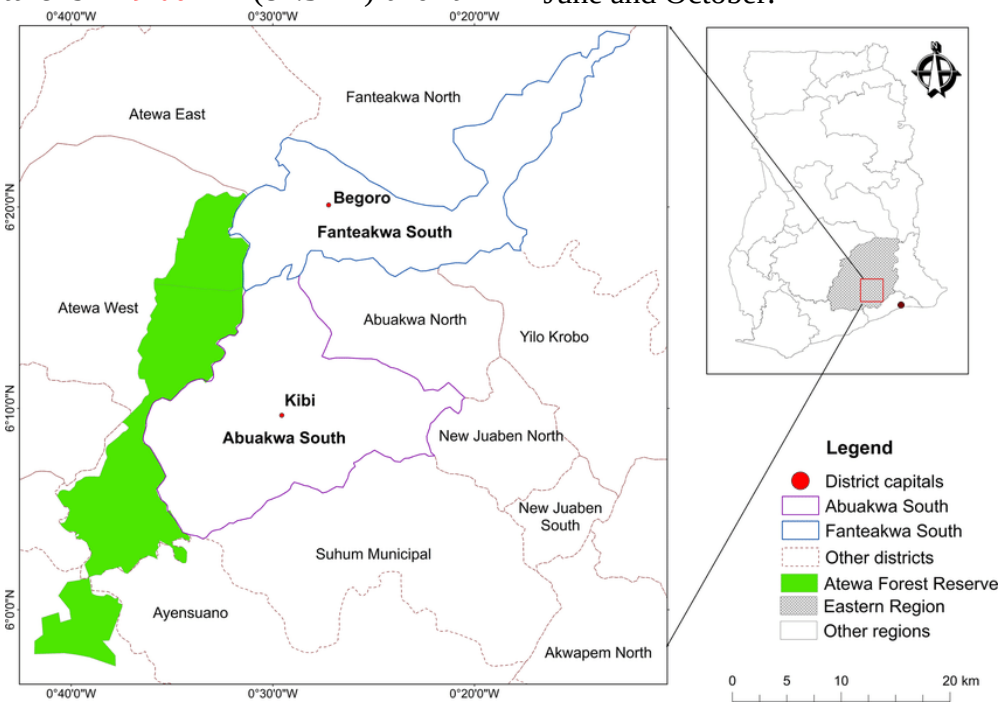

Figure 1: Map of study location (Abuakwa South Municipality of Ghana). *Aggrey et al*. (2021)

Sampling

Survey instrument and justification

Materials and equipment used in the construction of the bricks include, commercial cement, tailings, sand, pavement brick moulder, portable water, powdered coconut husk, shredded plastic, sawdust, quarry dust, Personal Protective Equipment (PPEs), weighing scale, head pan, and loading shovel.

Data collection

Construction and Design of Pavement Bricks

As stated earlier, the study was conducted at Bunso where convenient sampling was employed for the collection of the solid waste. Waste materials were collected from where they were available since due to the improper disposal of the waste materials, they are abundant in the environment everywhere. Each of the waste sample from the source of generation had their individual weights determined and recorded. The plastics were collected, washed, sun-dried and shredded into a required particle sizes. The quantity of plastic waste which was used in developing a brick size of 72cm^2, is 40 pieces of the pure water sachet which also gives a weight of 0.2kg after shredding. During shredding, the size of the plastic is reduced to a range of 2.36–4.75 mm. This process has been shown to improve blending in concrete mixes and to minimize the loss of compressive strength. The coconut shells were collected from the environment, burnt into brickets at a certain level of temperature, watered, dried and grinded in powdered form. The sawdust were acquired from a sawmill in Nsutam, a

town closer to Bunso. A pavement moulder was made according to the measurement of the same mould used in constructing the concrete pavement brick and tailings were collected from Narawa Company Limited, a mining company located in Nsuapemso. The total weight of each of the waste were determined and expressed in kilograms and the percentage of each constituent were calculated (Ansah, 2014). Waste materials were mixed together at their right proportion and with the right amount of water.

Concrete pavement brick (CPB) consisted of two main materials which were cement and quarry dust with the ratios of 1.7: 0.9 respectively. Two kinds of Eco- pavement bricks (EPB 1 and EPB 2) were made. The EPB 1 consisted of Cement, shredded plastic, coconut husk powder, and sawdust, whereas the EPB 2 consisted of tailings, shredded plastics, coconut husk powder, and sawdust. But in all, ten (10) quantities of eco-pavement bricks were constructed, five made with 100% waste materials and the other five made with waste materials and a binding agent (cement). All the concrete mixtures which were prepared, meet the requirements specified in the standards as given by the Ghana Standard Authority (GS 1217:2018), demonstrating that concrete incorporating waste materials can be used as paving bricks and building bricks under limited conditions (Kim & Kim, 2022).

The Eco-pavement bricks made, were compared with acquired concrete bricks using dimensions, weight, cost analysis, compressive test, and water absorption as the parameters. The mechanical tests were done at the Building and Road Research Institute, located in Kumasi, Ghana.

Assessing the sustainability of the pavement bricks

The sustainability of the bricks were compared and determined using water absorption, dimensions, cost analysis, weight, and compressive strength parameters. Gencel et al. (2012) recorded that, the compressive strength is an important parameter in evaluation of paving brick quality.

Dimensions

The dimensions of each brick was determine using a tape measure and a surveying rule to measure the length , width and height of the brick and it was recorded. Length 20cm/200mm, width 10cm/100mm and height 6cm/60mm.

Weight

The weight recorded for the eco- pavement bricks were the same as that of the concrete pavement brick after a 14 day drying period which 2.6kg for all the three kinds of pavement bricks.

Cost Analysis

A cost analysis was evaluated between the cost of a concrete pavement brick and the cost of producing an eco- pavement brick. The transportation cost was used to determine the cost of producing an eco-pavement brick which revealed that, the cost of a concrete brick is 5 Ghana cedi ($0.44) whereas the cost of producing the eco-pavement brick was 2 Ghana cedi 32 pesewas ($0.21) which gives a clear indication that, eco-pavement bricks are economically viable than the concrete pavement brick.

Water Absorption

To check the water absorption of the bricks, the weight of three bricks were taken after being dried for 14 days. The brick specimen were then soaked into a head pan of 5 litres of water for 24 hours. After the 24 hours, the weight of the bricks were measured and recorded. The Water absorption (Wa) was calculated using a formula given in the Ghana Standard Authority (GSA) standard for the three brick. $W_a = \frac{m_2 - m_1}{m_1} \times 100$ where m1 refers to the initial weight of the brick in grams before being submerged in water and m2 refers to the weight obtained after 24hours submerging of the brick.

Compressive strength test

Nine specimen of bricks were sent to the Building and Road Research Institute (BRRI- Kumasi) to conduct the compressive strength test of the bricks. Out of the 9, each of the 3 bricks (CPB, EPB 1 and EPB 2) had three replicates which were used to conduct the test by placing the surface area of each brick towards an upward direction to the testing machine. Each brick was tested three times using their replicates, this was done to ensure accuracy. A two – way analysis of variance was used to ascertain the differences between the numbers of times at which each bricks were tested.

Data analysis

The data was analyzed and summarized using Microsoft Excel 2016 package and with descriptive statistics in Statistical Package for the Social Sciences (SPSS). Analysis of Variance (ANOVA) were used to ascertain the significant differences in the different treatments of the brick strengths in SPSS.

Results

Waste generation in Bunso

Composition of Solid Waste in Bunso

The types of solid wastes generated in Bunso during the study include plastic, natural organic material, metals, and glass. Out of the total amount of waste generated over the study period, 75% were plastic waste, 15% were organic waste, 3% were glass; and metals and others were 2% and 5% respectively.

Impacts of improper disposal of solid waste

Ninety-six (96%) of the respondents indicated that they are aware of the effects of the improper disposal of solid waste whereas the remaining 4% said they are not aware of the effects.

According to 38% (57) of the respondents, air pollution is the highest effect of improper disposal of solid waste. 37% also said health impacts followed by 11 % (17) soil degradation, 11% (16) water contamination and the others with 3% (5) (Figure 2).

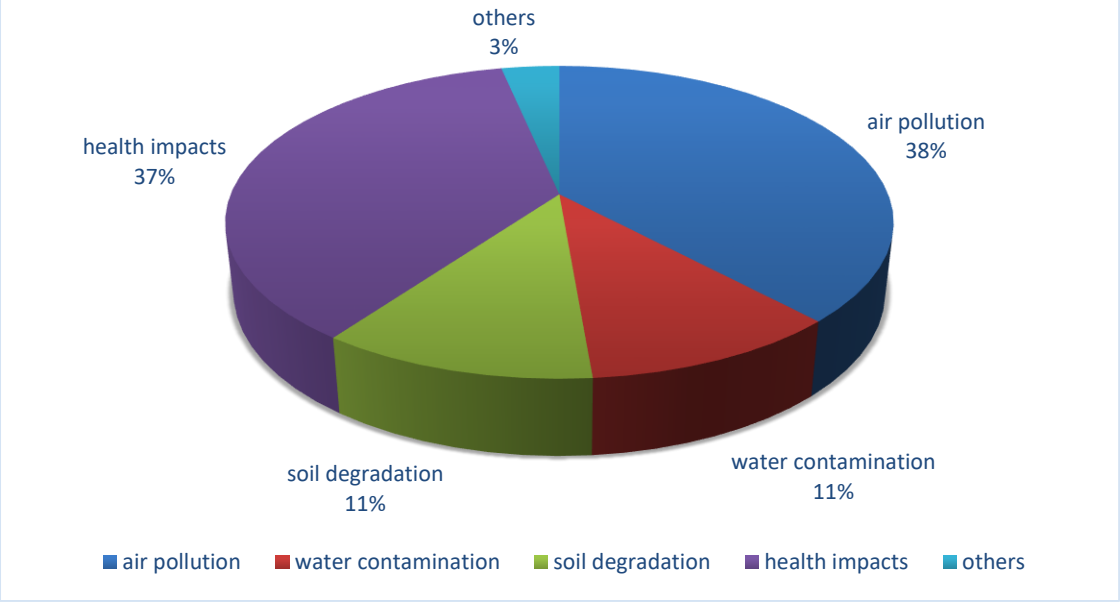

Figure 2: Composition of the effects of improper disposal of solid waste at Bunso

Waste Minimisation

Out of the total responses, 79% of the respondent answered that, they have being provided with and information on solid waste management methods and 21% said otherwise.

According to (66) of the respondents, recycling was indicated as the kind of solid waste management method they have been provided with. Thirty-seven (37) also indicated that, composting is the most known solid waste management method

followed by source reduction and reusing with (27) and (20) respectively.

Constructed and Designed Pavement Bricks

Bricks are a large and important part of the building and construction industry. Bricks have been used as masonry units due to the strength and durability they provide in structural applications. (Murmu and Patel, 2018). According to Al-mansour *et al*., (2019), Concrete bricks are another type of conventional brick made of Ordinary Portland Cement (OPC), water, aggregates and additives. The generation of high volumes of waste is both an environmental and economic challenge. It has become unsustainable to manage this waste. Thus, recycling of waste into valuable products has become part of the sustainable development goals for many countries. (Makgabutlane *et al*., 2022). The utilization of waste in construction materials does not only reduces pollution but also the number of natural aggregates used, which are responsible for environmental degradation and the depletion of natural resources. Zero-cement products known as alkali-activated bricks have been developed as sustainable construction materials. These products utilize waste such as rice husk, fly ash, bottom ash, cement kiln dust, blast furnace slag and mine tailings limited conditions (Kim & Kim, 2022).

At the end of the study, ten (10) eco-pavement bricks were constructed, five made with 100% waste materials which are denoted as Eco-Pavement Brick One (EPB 1) and another five made with waste materials and a binding agent (cement) denoted as Eco-Pavement Brick Two (EPB 2), additional five bricks were acquired which were the concrete bricks, and are denoted as Concrete Pavement Brick (CPB) **(Figure 3)**. Thus, in all fifteen pavement bricks were available for the study. **(Table 1)** gives a summarized information about the characteristics of the pavement bricks. The total waste materials summed up to 2.6kg, 2.6kg and 2.6kg for CPB, EPB 1 and EPB 2 respectively. The composites makes up the total weight of each brick

Figure 3: Constructed eco-pavement bricks and an acquired concrete brick.

Table 1: Summarised characteristics of the pavement bricks.

Specimen type (Prism)	Thickness (mm)	Compressive Strength (MPa)		Brick size(cm^3)	Weight (kg)	Water Absorption (Wa)	Cost of production (GH¢)
CPB	100	19.81	413.30	72	2.6	9	5
EPB 1	100	25.46	531.33	72	2.6	16	2.32
EPB 2	100	22.91	477.99	72	2.6	11	2.32

Sustainability of the pavement bricks

Dimensions

The pavement bricks takes the shape of a prism, and to calculate the brick size with such shape, the surface area is needed which includes the height, width and length. Hence, per the dimensions given the brick size is $72m^3$.

Weight

The calculated weight of the concrete pavement brick (CPB) was 2.6kg (2600.0g). The eco-pavement bricks EPB 1 and EPB 2 had calculated weights same as the CPB of 2.6kg (2600.0g) and 2.6kg (2600.0g) respectively.

Cost analysis

In **(Table 2),** a cost analysis was evaluated between the cost of a concrete pavement brick and the cost of producing an eco-pavement brick. The transportation cost was used to determine the cost of producing an eco-pavement brick which revealed that, the cost of a concrete brick is 5 Ghana cedi ($0.44) whereas the cost of producing the eco- pavement brick was 2 Ghana cedi 32 pesewas ($0.21). Cost of producing one brick= 116 /50 = **GH¢2.32**.

Table 2: Calculations of the cost of producing an Eco-pavement brick.

Materials	Transportation cost (GH¢)	Quantities	Weight (kg)	Number of bricks being estimated
Sawdust	10	$^1/_2$ Sack	6.9	23
Coconut husk powder	10	$^1/_2$ Sack	6.7	23
Plastics	null	500 pieces	2.5	25
Cement	15	I bag of cement	50	30
Tailings	15	1head pan	25	15
Total=50				Total=116

Water Absorption (Wa)

Ghana Standard Authority, (2018) in their pavement standards provide a formula or an equation for calculating the water absorption $W_a = \frac{m_2 - m_1}{m_1} \times 100.$ As stated earlier, before the calculations were done, all the kilogram units were converted into grams.

According to the calculations done and as presented in **(Table 3)**, the water absorption for the three brick specimen were 9%. 16% and 11% for CPB, EPB 1 and EPB 2 respectively. The water absorption of bricks determined in accordance with clause 6.6 in the standard state that, it should not exceed 10%. But EPB 1and EPB 2 failed the test by achieving more than 10% as stated in the standard. Only the CPB gave out a good and accepted results.

The samples in total 3 were submerged in water as required by the Ghana Standard Authority standard in clause 6.6. The specimens were weighed completely dry on the electronic scale with the following absorption percentages: 9% for CPB, 16% for EPB 1 and 11% for EPB 2. According to the aforementioned standard, the absorption percentage should not be greater than 10% for concrete pavers. As the samples are made of waste materials, cement and tailings, these paver did not show excellent results for this variable except CPB.

Table 3: Information on the processes of water absorption for each pavement brick.

Bricks	Drying days	Weight before immersion (kg)	Duration of soaking (hours)	Amount of water used (litres)	Weight after 24hr. of immersion (kg)	Total water holding capacity (%)
CPB	14	2.6	24	5	2.9	9
EPB 1	14	2.6	24	5	3.0	16
EPB 2	14	2.6	24	5	2.7	11

Compressive Strength Test

From the compressive strength test results, EPBI (25.4642MPa) and EPB2 (22.9078MPa) attained the highest compressive strength followed by CPB (19.8075) which served as the control specimen during the study. All the nine bricks had the same thickness of 100mm. The maximum load of the bricks were recorded and an average was calculated which resulted in CPB (413.3029kN), EPB 1 (531.3318kN) and EPB 2 (477.9941kN).the means of the nine bricks were recorded and subjected to Analysis of Variance (ANOVA) to statistically test if there are any significant differences between the means of the bricks. The strength mean levels obtained are presented in the mean table **(Table 4)** and a visual interpretation presented in **(Figure 4).**

Table 4: A mean table showing results from the Analysis of Variance

Category	LS means	Groups
CPB	19.43	A
EPB 2	22.91.	A
EPB 1	25.46	A
LSD	9.79	

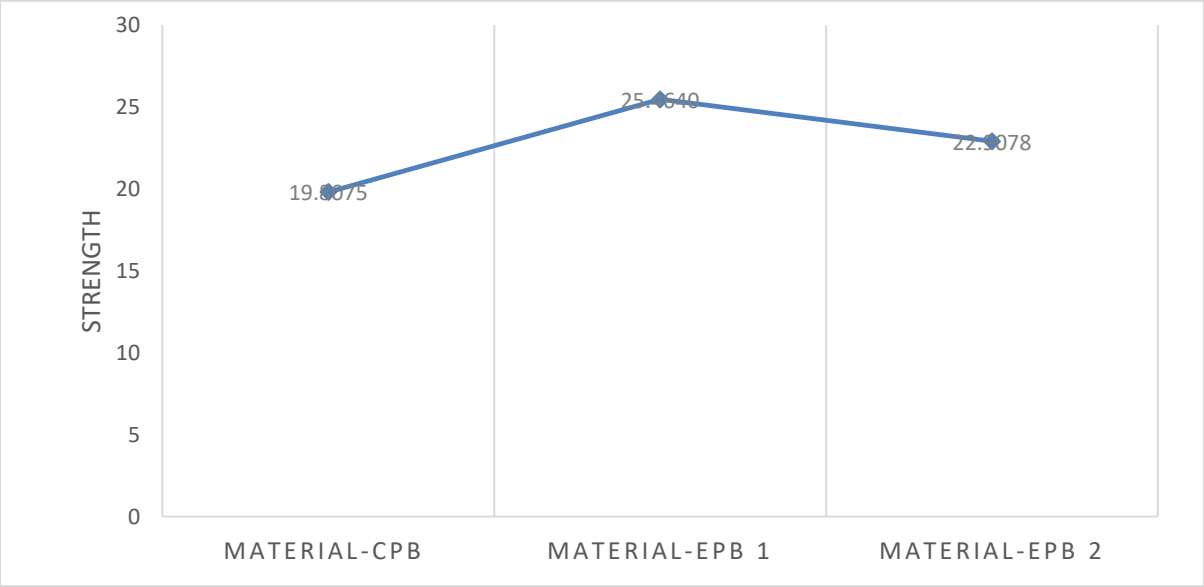

Figure 4: A visual interpretation of the mean table.

Discussion

Solid Waste, disposal, effects and Management

Observations in literature showed that, increased population growth and economic development led to increased volumes of municipal solid waste significantly and its composition (Miezah *et al*., 2015). Organics wastes account for the largest content of MSW with 61%, 14% plastics, 6% inert material, 5% paper, 3% metals, 3% glass, 1% leather and rubber, 1% textiles and 5% miscellaneous. (Markandey, 2020). From the survey it was revealed that solid wastes generated in Bunso were mostly plastics and organic waste. The large volume of plastic wastes implies that there is a strong resource potential for reusing and recycling. The conventional landfill, incineration, composting, and ways of handling solid wastes are common as mature technologies for waste disposal (Hannan *et al*, 2018). Most developing countries that suffer from sever environmental pollution problems are caused by the large quantities of solid waste. (Al-Khatib & Martini, 2010), and from the study air pollution recorded the highest percentage among the effects of improper waste disposal. However, from the study source reduction and reusing are being practiced in the waste management chain likewise the organic wastes which are being used for compost on farmlands of some household heads. Traditionally, the most commonly used technologies for the treatment of the organic fraction of MSW is composting. Solid waste segregation depends mainly on the public awareness and the active participation which attest to the fact from the replies of the study respondents.

Utilization of solid waste as composites for Eco-pavement bricks

The incorporation of waste materials in construction composites can compromise some of the brick properties (Delva *et al*., 2018). The utilization of waste in construction materials do not only reduces pollution but also reduces the rate of exploiting our natural aggregates, which are responsible for environmental degradation and the depletion of natural resources. The study reveals that, the quantity of plastic waste needed as part of the additives to make an eco-pavement brick is 0.2 kg which is equivalent to the waste generation rates across Ghana irrespective of the socioeconomic considerations ranged from 0.2 to 0.8 kg/person/day (UNEP, 2013).

Nationally, waste generation rate was 0.47 kg/person/day a Middle class area and 0.27 kg/person/day for a low class socioeconomic area all in the Kumasi metropolis in Ghana. (Zikali *et al*., 2022). Gaisie & Owusu-Ansah (2022) obtained similar generation rates data among the different socioeconomic class areas in Accra. The average per capita per day generation were 0.29 kg organic, 0.02 kg paper, 0.06 kg plastic and 0.004–0.01 kg for metal, glass, textile or leather and rubber. (Gaisie & Owusu-Ansah, 2022).

More than 50% of the global production of coconut is processed into dried coconuts (Rogers *et al.*, 2012). Coconut shell is one of the most vital natural fillers produced (Leman *et al*., 2017), Coconut shells have shown great potential to be used as admixtures in the production of concrete due to its excellent properties. It has been revealed that the utilization of coconut husk showed considerable enhancement in strength development (Hasan *et al.*, 2016). According to Subramanian *et al*. (2015), several studies have analysed the suitability of wood ash as a partial cement replacement material in the production of structural grade concrete and self-compacting concrete for applications in building construction. Shreekant *et al*. (2016) in his study used cement, jelly dust, baby jelly and iron ore tailings for making blocks. An experimental study carried out by Gayana & Ram Chander (2018) on iron-ore tailing

based interlocking paver blocks, which gives the properties of interlocking concrete block pavers mixed with iron ore tailings as a partial replacement for cement.

The sustainability of Eco-pavement bricks against the Concrete pavement brick

Per this study, pavement bricks with wastes and cement (EPB 1) had the highest water absorption, this depicts that the waste materials create pore spaces within the brick which easily allow the flow of water into it hence, retains more moisture content. The water absorption of quality bricks should be less than 20 % after 24 hr. of immersion in water (Wahid et al, 2015). Thus, in this case all the three bricks pass the test of water absorption as bricks were immersed for 24hours and the results are 9%, 16% and 11%. Nevertheless, per the GSA standard, only the CPB passed the test and gave an excellent results while the other two samples failed the test. As it can be evidenced, the use of this raw material would generate a great benefit for the environment, as well as provide direct and indirect jobs.

Furthermore, after the compressive strength test, the bricks with plastic waste turned out to be the ones with the highest compressive strength. It was then advised that, the eco-pavement bricks can be used for unload bearing structures like; corridor pathway, walkways, walls etc.

Arbili *et al*., (2022) concluded that, the use of iron ore tailing from 5 % to 15 % has shown increase in the compressive strength of the concrete compared to normal concrete. Whereas, addition of iron ore tailings from 15 % to 25 % has resulted in lower compressive strength compared to that of conventional concrete. (Arbili *et al*., 2022). Thus in the case of the study, EPB 1 and EPB 2 had a compressive strength between 20MPa to 23MPa with 14 days curing.

Conclusions and recommendations

It was estimated in the study that solid wastes generated in Bunso were mostly plastics and organic waste which implies that there is a strong resource potential for reusing, recycling and composting. The practice of improper solid waste disposal leads to high levels of air pollution and the most practiced solid waste management methods are recycling and composting. Generally, it is concluded that, Eco-pavement bricks can be made with coconut husk powder, sawdust, cement and plastic waste. It was revealed that, the quantity of plastic waste needed as part of the additives to make an eco-pavement brick is 0.2 kg which is equivalent to the waste generation rates across Ghana irrespective of the socioeconomic considerations ranged from 0.2 to 0.8 kg/person/day (UNEP, 2013). Dimension of the bricks (concrete and eco-pavement) were 20cm×10cm×6cm giving a brick size of $72cm^3$. The Concrete pavement brick and the two eco-pavement bricks had the same weight of 2.6kg, which can be concluded that all the three kinds of bricks had same weight. Per the Ghana Standard Authority, only the concrete pavement brick obtained an acceptable percentage for the water absorption, hence the eco-pavements failed but in some research, these two would have been considered as providing good water absorption level yet in these instances, the pavement bricks can still be used for constructing walkways, corridors and pedestrian pathways.

Moreover, pre the compressive strength test, the category of pavement bricks with plastic waste expressed higher strength levels and maximum load limits whereas the concrete pavements which were the control rather expressed lower compressive strength levels as well as the maximum loading limits. It is concluded that the eco-pavement bricks should be used for unload bearing structures like; corridor pathway, walkways, walls since they have same dimensions, weight, higher compressive and higher water absorption rate. Since the

survey recorded 95% of the total respondents who consider Eco-Pavement brick as an initiative of solid waste management, it can be concluded that individuals are ready to take up this initiative of managing their solid waste.

Further studies should be done to investigate the impacts of using tailings as a binding agent in place of cement. Other factors such as durability, abrasion resistance, tensile and flexile strength tests, etc. should be tested to determine the sustainability of an Eco-pavement brick. This initiative should be practiced by individuals and households to help ensure effective reuse of plastic waste. Further studies should be done to investigate the factors that account for the relatively high strength recorded for the eco-pavement bricks, compared to the concrete pavement brick.

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Compliance with ethical standards

Competing interest statement: authors declare that they have no conflicting interest.

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AN AFRICAN ECOCRITICAL CONSCIOUSNESS: A READING OF AMMA DARKO'S FACELESS

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Abstract

This study explores Amma Darko's novel, Faceless, through an ecocritical lens, situating it within the broader discourse of African environmental literature. Recognising the novel's depiction of human and non-human interactions in a degraded urban Ghanaian setting, the study employs qualitative content analysis to examine themes of displacement, ecocultural conflict, and environmental sensitivity. Findings reveal how Darko constructs ecological consciousness by portraying the interconnectedness of social and environmental degradation, particularly through the experiences of marginalised characters. Faceless contributes to ecological discourse and fosters environmental awareness in African literature. The paper concludes by emphasising the importance of environmental sustainability and the integration of ecocritical thought into Ghanaian cultural consciousness.

Keywords: Amma Darko, ecocriticism, ecoculture, environmental sensitivity, Faceless

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Introduction

> *My dream, began the boy, "is to be able to go home one day to visit my mother and see a look of joy on her face at the sight of me … Whenever I visit her, she does not let me stay long before she asks me politely to leave. She never has a smile for me. She is always in a hurry to see me back… One day she said to me, 'Go. You do not belong here.'… She worries about the food that she has. It is never enough (2).*

Amma Darko employs different approaches to present the relationships between human and nonhuman and their environment. In the respect, we see in *Faceless*, the relationship between humans and the physical environment, emphasising how the novel reflects and influences ecological consciousness. Environmental discourse unveils the relationship between humans and nonhumans and their response to their surroundings. The introduction of the boy's dream in the epigraph serves as a metaphor for the fractured human-nature relationship, highlighting the emotional and ecological disconnect within familial and societal structures. The epigraph presents a graphic picture of a disconnected relationship between mother and child, who are supposed to coexist within the family system, community and the environment as a whole. The unnamed boy's mother despises him and responds negatively to his visits. We see the boy's detachment from family and mother which translates into neglect of the environment and nature. The boy's lifestyle appears fragmented because he is denied the basic necessities and happiness in life which completes human beings.

Within the literary space, the setting of a literary work reveals the situational context where the event took place, and ecocriticism highlights the role and place of nature and the reaction of human or nonhuman to environmental concerns as depicted in literary texts. Environment or nature plays pivotal role in any literary work. Through the interdisciplinary approach, ecocritics uncover the ecological significance of literary works and contribute to environmental discourse by offering a valuable framework for understanding the relationship between literature and the environment (Tajane et al 2024).

Most African writers foreground human experiences as environmental concerns in their writings and literary works. In most literary works, the writers create environmental consciousness to sensitize the African people on how they should relate and embrace environmental issues. The writers present nature, environment and human interactions with the natural world and the need for coexistence. The desire for human beings to be in tune with the world and its elements seems a paradigm shift for most writers to explore pressing issues in the society. The landscape comprises the population of both human and non-human which co-exist in spite of their differences. In *Faceless* (2003), Darko explores the landscape of Ghana paying particular attention to a suburb in Accra where she exposes the interactions and the interconnections between both humans and nonhumans. We see similar representations of human interactions with nature in other works of Darko. In *Beyond the Horizon* (1991), Darko describes the plight of an uneducated girl, Mara, who accepts her father's decision to marry her off to Akobi without her consent. Mara joins her husband in Europe but faces betrayal which exposes her to a different environment initiating her into prostitution and pornography. Similarly, in Darko's *Not Without Flowers* (2007) the narrative shifts in between two worlds: the world where the protagonist, Aggie, is symbolically enveloped with nature, a garden full of lovely flowers of all shades and the other environment where she kills all the lovely plants and flowers as she destroys her enviable marriage. We see how humans and nature play out in both novels.

Faceless (2003) is the novel that made Amma Darko famous. The novel describes the lifestyle of street children of Agbogbloshie in the city of Accra, particularly the child heroine, Fofo, who ends up on the street as a result of an irresponsible mother, Maa Tsuru, who incites her daughters to go in search for greener pastures. Fofo is a fourteen (14) year old girl who has a dream like other street children living in a degraded environment. The same debased environment generates the twist of the narrative where Fofo's dream is realized after the death of her sister, Baby T. In a disguised form at the Agbogbloshie market, Fofo accosts Kabria, a married woman with three children and a worker at MUTE, a non-governmental

organisation, and this meeting begins the turning point in Fofo's life. In the introduction, we have established ecocriticism as the guiding framework for analysing Darko's *Faceless*, setting the stage for a deeper exploration of environmental and cultural dynamics in the subsequent sections.

Defining Ecocriticism: Origin and Debate

The complex relationship between literature and the natural world is the focus of ecocriticism which explores how literature reflects, influences, and responds to ecological concerns. Ecocriticism has its origins in the environmental movements of the 1960s and 1970s, which brought attention to ecological degradation and the effects of human activity on the environment. Glotfelty and Fromm describe ecocriticism as the relationship that exist between literature and the physical environment and literary ecology is the study of the ways that writing both reflects and influences our interactions with the natural world. (Glotfelty, 1996). This relationship is crucial because basic human needs and opportunities for social and economic developments are provided by physical environment, thus, land, water, animals, buildings, other infrastructure and natural resources (Social Report, 2003: Ministry of Social Development). In Bennet's view, "Literature-and-environment studies must develop a 'social ecocriticism' that takes urban and degraded landscapes just as seriously as 'natural' landscapes" (Bennet 2001:32).

Ecocriticism also considers the notion of nature as a cultural creation as Raymond Williams contends in his seminal work The Country and the City (1973). For Williams, cultural and historical backgrounds influence how human beings view the natural world, and how ideas of nature, rurality, and urbanity are constructed and destroyed in literary texts. An important idea in ecocriticism is the criticism of anthropocentrism, which is the idea that people are the most important or central organisms in the universe. The Environmental Imagination (1995), a seminal work by Lawrence Buell, asserts that literature has the power to subvert anthropocentric worldviews and advance an ecocentric viewpoint that values all living things for their own sake. According to Buell, ecologically themed writing has four essential elements: In addition to serving as a framing device, the nonhuman environment implies that human history is intertwined with natural history; that human interest is not the only acceptable interest; that human accountability to the environment is a component of the text's ethical orientation; and that there is a sense in which the environment is a process. A wide variety of theoretical stances and critical techniques are included in ecocriticism. While some researchers use interdisciplinary approaches and concentrate on closely reading literary texts to determine their ecological implications, others draw on knowledge from the fields of ecology, environmental science, and cultural studies. Ecocriticism also incorporates science, ethics, politics, economics and aesthetics across institutional and national boundaries (Clark 2011).

Methodology

The study employs a textual analysis of Darko's *Faceless* to transform the story into real life situation of human and its environment. Through a careful reading of the *Faceless*, we identified the historical, cultural and social context of the narrative that reveal the issue of displacement and the loss of motherhood. Also, an examination of characters' interaction with one another and their environment give insights into the intersection between culture and the environment. The role of the female figure with the employment of the child protagonist culminated into considering the interplay between feminism and the environment. It is therefore, imperative to respond to the questions: to what extent is the loss of home and motherland an environmental issue? How does Darko explore conflict between culture and environment in *Faceless*? What is the correlation between degraded environment and destabilised women in *Faceless*? These questions set the exploration of human and nonhuman interactions that illustrate the ecological complexity of urban Ghana, paving the way for a discussion on critical environmental issues.

Understanding Human Relationships with the Natural World

Both humans and nonhumans respond to the environment/ nature in diverse forms. In order to understand human relationships to the universe, one needs to know his/her environment, the background, the beliefs system, including the social and pollical landscape. Postcolonial Ecocriticism draws

attention to the social and political usefulness of a literary text which takes the form of material transformation of the world. Amma Darko creates ecological consciousness in the way she realistically recounts social, economic, and cultural issues. Darko metaphorically titles this novel *Faceless* to refer to people who wear masks and seem to be blind to the happenings in the environment. These people are unable to see because they live in congenial conditions, lack perception or engage in deception. The story begins with the description of the setting, the Agbogbloshie market in Accra where Darko reveals as the habitats of the suffering characters in the novel. The narrative charts the plight of the child protagonist Fofo and other street children who demonstrate the loss of home and societal neglect of the environment. As it is known, environmental changes may be driven by many factors including economic growth, population growth, urbanisation, etc., with poverty still remaining a problem at the root of several environmental problems. Clearly, it is evident that poverty seems the main motivation or driving force for the mothers of the street children to send their wards to wallow in the streets for survival. These children are displaced as a result of family neglect. Fofo reveals her exposure to adulthood as a result of making her home on the streets of Sodoom and Gomorrah enclave where she usually watches "adult films … and drinking directly from bottles of akpeteshie" (1).

Darko describes the reckless lifestyle of the street children who out of negligence resort to open defecation causing environmental pollution and health problems and diseases. According to the narrator, the street girls and boys with their thick-set leader, Macho, "regularly unloaded the solid waste contents of their bowels onto the rubbish dumps and in the gutters and open drains." (3) Although Sustainable Development Goal Six (SDG 6) is to "ensure availability and sustainable management of water and sanitation for all" targeted for people living in the rural areas by 2030, the people living in the city of Accra persistently defecate openly. Fofo and Odarley describe the struggles/ ordeal people go through in accessing toilet facilities: "[w]ho can walk a long distance to up there when the thing is coming with force? Ask again. And at the long line of people too always there. Ah! Even if you go there at twelve midnight, you will find a queue." (6) This show how difficult it is for the ordinary Ghanaian to access toilet facilities, making them resort to open-defecation. Darko's narrative foregrounds the effects of open defecation as an essential concern for environmental sensitisation. Her portrayal of the decaying cityscape and polluted environments serves as a metaphor for the moral and ecological decay of society.

Fofo and her friend, Odarley, answer nature's call at the dump site "under the scrutinizing eyes of some early rising pigs and vultures" (6). We read that they found a free spot and Odarley raised her dress and pulled down her pants and got straight to business. While Fofo also lifted her dress and squatted. (6) The scenario serves as a microcosm for understanding the complexities and interconnectedness of ecosystem, revealing the coexistence between humans and nonhumans in the environment. In the ecosystem, this relationship between humans and nonhumans is termed symbiotic relationship where the presence of these species together highlights the interconnectedness of the living organisms and their environment. Therefore, the humans, pigs and vultures-relationship promotes biodiversity by allowing different species to coexist and interact. Each species plays a role in the ecosystem, and their coexistence demonstrates a balance. Also, in terms of food dynamics, pigs scavenge food, vultures feed on carrion, and humans dispose of waste. This interaction illustrates the flow of energy and nutrients through the ecosystem. The ability of these species to coexist in a shared environment, despite potential conflicts, showcases their adaptability and resilience. The dump site ecosystem relies on the presence of each species to function. Humans provide waste, pigs help break down organic matter, and vultures aid in cleaning up carcasses. The coexistence of the pigs, vultures and humans at the dump sites represents a balance between species, highlighting the importance of preserving ecological harmony. In the situation where there is loss of ecological harmony, the species suffer displacement underscoring the vulnerability of marginalised groups and their reliance on nature for survival, as the next section will show.

The Concept of displacement as an Environmental Concern

Ecocritics argue that displacement is a symptom of ecological crisis, driven by human exceptionalism and exploitation of natural resources (Buell, 2005). Nature serves as the perfect place for the creative expression of society's marginalised and silenced voices. The postcolonial tranche ecocriticism has emphasised the concerns of starving, dehydrated, banished, homeless, ill, and imprisoned people all across the world (Mabie, 2016). In *Faceless*, poverty is depicted as a form of economic displacement and Fofo personifies poverty as:

> *"Yes I saw it" "Head to toe. It's face; it's ugly square head; it's big fat toes. I know its shape like ..." I know its length and its breadth and its width and its stench." (27)*

Fofo presents a vivid description of poverty as possessing the features of human beings with "face", "square head" "big fat toes" and shape which presupposes that she has had a personal encounter with poverty. Fofo goes to the streets out of desperation and starvation to fend for herself. She leaves home because she had to go out and beg for food "when there is no food, you don't wait to be asked by anyone to go out and beg. Hunger is a foe and it is overpowering. When it pushes you, you go. It was the same with Baby T." (100). Clearly, poverty succeeds in banishing Fofo and Baby T, making them homeless. Initially, the environment becomes the ideal place or home that accommodates Fofo and Baby T, but the aftermath presents a bizarre situation resulting in the death of Baby T.

Environmental changes may be driven by many factors including economic growth, population growth, urbanisation with poverty as the problem at the root. Fofo and Baby T are pushed into the homelessness situation because of irresponsible parenting on the part of their mother, Maa Tsuru's relationship with several partners. Maa Tsuru, in turn, blames the situation on her partners: "Not one cedi I get from the man who fathered my little girl … (61) and accepts it as a curse on her: "You too were cursed with an irresponsible man?" (62). She justifies irresponsible parenting as an act leading to homelessness "… the act of irresponsible parents which results in children leaving home to live on the streets…" (66). Fofo is pushed out of her home by her mother who chooses a manipulative man (husband) over her children.

The loss of home is equivalent to the loss of motherhood as well as the peace and tranquility that nature alone may provide. For Morton (2013), displacement is not just a human issue, but an ecological one involving the disruption of habitats and ecosystem (Morton, 2013). Most of the children claim to have lost touch with their homes because their mothers make their stay in the house uncomfortable and unsafe to accommodate them. A case in point is Odarley who was sacked from home by her mother claiming that: "Odarley was troublesome. That Odarley was stealing her money. She didn't want Odarley around after Odarley's father left her for another woman and she too found another man". (103). Marital/spousal separation/ broken home is presented as a form of displacement for the children. The peace and serenity of the environment depends largely on the individuals who dwell in it. Fofo confirms same treatment from her mother, Maa Tsuru: "Go away, Fofo, … Go!. Fofo's face clouded fiercely. Is history repeating itself here? Are you sacking me, mother? Because of him?" (21) The street children are exposed to nature/ environment which offer them sense of belonging, emotional healing and shelter. Other children on the streets were subjected to begging instead of going to school. A case in point is the young girl who accompanies the mother to beg on the street: "A girl of about eight, holding the hand of a blind woman" (37), and the mother blaming others for her inability to send the girl to school: "If people like you won't give me money, how can I send her to school …" (37).

Clearly, there is an irony of some mothers finding excuses to disown and displace their children, and pushing them onto the streets to fend for themselves, while others lose their marriages because of barrenness. We read that Dina's marriage with her campus boyfriend was abortive/ failed after "four turbulent years of childlessness" (38). However, Dina is represented as the ideal mother that the street children dream of having. She accepts Fofo in her home because she considers her home as the safest place for Fofo in spite of the fact that Fofo refuses to open up to her initially: "Fofo's presence in my home disorganizes no one" (95) Dina's readiness to accept Fofo in her home

presents the case of unconditional love and care for the poor girl, notwithstanding the challenges involved as she admonishes Kabria: "Attending to Fofo requires extra energy." (95), implying that Fofo needs a conducive environment to make her comfortable and acceptable.

Environmental Imaginations in Faceless

In exploring the complex intersections of nature, culture and human identity (Buell, 2005), Darko presents ecocultural representations which seek to identify the places the characters belong to and the attachment of the place and the environment or features of nature. The narrative raises important questions about the preservation of ecological and cultural heritage. We read about the Sodom and Gomorrah Culture where the location can be alluded to from the biblical perspective. The Bible reveals Sodom and Gomorrah as a place where sodomy (copulation between two men whether consensual or forced) appear to be common, so the wrath of God befell them, and He "rained down burning sulfur on Sodom and Gomorrah" (Gen 19:24). The Bible describes the city of Sodom and Gomorrah as a place where all the evil deeds/ acts take place. In juxtaposing the biblical description with Darko's representation of Sodom and Gomorrah culture in *Faceless*, the narrator describes the place as "the disheartening name of Sodom and Gomorrah" (65) while the characters describe the place as a trouble zone where all kinds of acts take place: "And what trouble here at Sodom and Gomorrah isn't big? I tell you how we boozed yesterday! That one was big trouble" (6). Others describe it as a place where there is drug trafficking: "Drugs after all, flew freely at Sodom and Gomorrah" (27). Also, the text describes Sodom and Gomorrah as a place where killings/ murderer take place frequently: "Aren't bodies always being found there like the aborted fetuses at Sodom and Gomorrah?" (23). Sodom and Gomorrah is a place where migrants from the north and elsewhere in the country in search of greener pastures, "coupled with the consequences of the acts of some irresponsible parents which results in children leaving home to live on the streets, the vices of Sodom and Gomorrah gained momentum" (66) "Who went at life alone at Sodom and Gomorrah" (27) The "filth and sin" which happen in Sodom and Gomorrah lead to environmental pollution. The Sodom and Gomorrah culture influences the street lifestyle where there is superstructure, those with "[b]ig muscles, tiny brains. Can we normal ones ever understand these street people? Normal people?" Street people? (43). We read about street warlords, Poison and Macho who wield power over the other street children living at Sodom and Gomorrah.

Darko also offers contrasting depictions of rural and urban spaces, highlighting the environmental and social impacts of urbanization. The narrative of *Faceless* raises important questions about sustainable development and the preservation of ecological and cultural heritage in the way Darko highlights omen/taboo/curses as symbol of Ghanaian culture. In African traditional societies, curses are believed to be a form of punishment from the gods or ancestors for wrongdoing or disobedience (Mbiti 1969). Curses are often seen as a means of supernatural retribution, where the offender is punished for their actions (Evans-Pritchard, 1937). For Fortes, curses serve as a means of social control, where individuals are deterred from committing wrongdoing due to fear of being cursed (Fortes, 1945). There is the representation of ancestral curse and its effect on the victims. From the narrative, Naa Yomo recounts the circumstances leading to the pronouncement of the curse from a mother to her descendants. According to her, during the birth of Maa Tsuru, her mother pronounced a curse out of pain "the cord was still uncut when she yelled that may her lover and his descendants after him, suffer in more ways and in more forms than he had made her suffer" (93). Maa Tsuru's partner, Kwei suffers as a result of his relationship with Maa Tsuru. Kwei's mother warns him about getting involve with a cursed woman and especially warns him to go on exile fearing for the doom that will befall their family "I shall not sit down idly and watch you go on to make a fifth child with her. I shall not allow you to bring calamity to bear on this family. So go away… A cursed woman and the number five?" (126) So the suffering of Maa Tusru and her children and the aftermath of Baby T's death is characterized with African/ traditional belief in superstitions, mysticism, magic etc. Baby T's dead is perceived as resulting from a curse on the family "a girl carrying a curse upon her head …" (119); therefore, "her ghost will not rest. It will hover among the living until the right thing is done." (43) and to pacify the gods and her soul, "[a] white foul … to appease the girl's soul." (42)., .

Gyekye (1996) emphasizes that ritual sacrifices serve to neutralize social tensions, appease angry spirits and symbolically restore balance after transgressions, thus restoring order and peace. It is important to consider the environmental implications of animal sacrifice in the sense that it can be considered as inhumane treatment to sacrifice an animal to appease the soul of the dead. This involves killing the animal, but the improper disposal of animal remains can lead to pollution of soil, water and air. Darko creates ecological consciousness on some cultural practices that are detrimental to nonhuman species, and the recognition of the need for environmentally conscious practices.

Understanding Degraded Environment and Destabilized Women

This section demonstrates environmental degradation highlighting pollution and patriarchal oppression reinforcing the need for ecofeminist perspectives. Darko presents environmental pollution with the description of Kabria's Creamy car. Kabria ironically nicknames her 1975 VW Beetle "Creamy"; however, "the car had been in and out of every kind of workshop from Abeka to Zongo so many times and undergone all kinds of clinical and plastic surgeries, that it seemed to have grown immune to both". (15) Kabria creates both sound and air pollutions with her car. The narrator describes the movement of the car with its onomatopoeic sound, the "tu-tu-tu-tu-tu fashion". This is because the "[t]u-tu-tu-tu-tu… Creamy's furious engine and exhaust heralded its tattooed arrival. …" (15). To the extent that Kabria's husband feels embarrassed "[w]hen Adade saw his wife and her car, he prayed desperately for the earth to open up and swallow him whole." (15).

There are several effects of both air and sound pollution. Poor quality air is caused mainly by emissions from industries, vehicle fumes, and smoke from the usage of fossil fuels, which fosters the building up of noxious chemicals in the air (Manisalidis et al., 2020). With air pollution from cars, the emissions can exacerbate respiratory conditions like asthma, lung cancer, heart attacks, strokes etc. Air pollution from cars can cause neurological (cognitive impairment) and environmental damages (climate change). Traffic noise induces acute elevations in blood pressure and heart rate and, over time, promotes hypertension, coronary artery disease, heart attack, stroke, and other cardiovascular conditions (Munzel et al., 2014). Generally, air and sound pollutions have a range of potentially devastating effects on the environment and wildlife. The symbolic and literal degradation of urban spaces, lead to how environmental decay disproportionately affects women.

Ecofeminism is a feminist movement that examines parallels between the oppression of nature and women; feminism and environmentalism. It is a philosophical and activist movement that combines ecological and feminist perspectives to challenge the interconnected forms of oppression that harm both women and the natural world. Ecofeminism recognizes the interconnectedness of all living beings and the natural world (Merchant, 1980, p. 12). In Faceless, Darko highlights the disconnection between human beings in the way she presents the relationship between men and women, women and girls, boys and girls etc. Women exploiting their fellow women. We see this in the way Fofo recounts her ordeal in the hands of a woman: "I was living with a woman who tried to sell me to a man. I was given to this woman by a relative of my mother who brought me from the village" (103). In the same way, Maa Tsuru and Kwei's relationship creates an environmentally unfriendly/ non-ecofriendly context for their children: It exposes Fofo to "street lords" described as "animals" with no mercy. It leads Baby T into child prostitution "street worker" (42). It leads to the death of Baby T: "Her face was mutilated … and her head … ah! That too was completely shaven… In fact, all the hair on every part of her body ... (42). Baby T suffers molestation from different men who take advantage of her because of neglect from parents. Women/girls who live in degraded environments are exposed to all kinds of attacks from their male counterparts.

It is worthy of note that patriarchy is partially responsible for the destruction/disturbance of the environment: A case in point is the project on mentally ill pregnant woman "… wee smokers take turns with her when they are high." (39). Ecofeminism critiques the patriarchal systems that perpetuate the domination and exploitation of both women and the natural world (Daly, 1978, p. 23). We read

about the patriarchal system that empowers the male counterpart to exploit the female characters in the novel. Maa Tsuru suffers exploitation from her male partners. Her relationship with Kwei creates tenson when she conceives the third child, he "banned her from stepping anywhere near his doorsteps …" and accused her of "being a bad luck woman and of having a bad worm" (121). Kwei nearly terminated Maa Tsuru's pregnancy "he pounced Maa Tsuru with his fists, landing the blows anywhere and everywhere and on every part of her pregnant body… She began to bleed." (124), such maltreatment or inhumane treatment from Kwei to Maa Tsuru is suggestive of male dominance and exploitation of the marginalized voice. Kwei'a inability to coexist with Maa Tsuru and their children, and his neglect of the family results in a degraded environment. The environment is degraded when the women are destabilized. Similarly, individuals such as Poison, the street warlords also wield power over the street children by extorting money from them: "Poison is feared. He is very elusive. But he has many people working for him. They beat me up and sent me to him. He gave me one vicious slap and warned me to never utter a word to anyone that I knew the dead girl. Let alone that she was my sister." (104). Poison intimates the street children, subject them to beating and collects money from them. Poison show little concern about the children working for him. Although ecofeminism emphasizes the importance of care, reciprocity, and mutualism in human relationships with the natural world (Ruether, 1992, p. 34), it is clear that the dominant species within the Abogloshie, Sodom and Gomorrah environment molest the weaker ones and oppress them leading to deterioration of the environment through depletion of resources, destruction of ecosystems and disturbance to the environment

Conclusion

This study set out to examine Darko's *Faceless* through an ecocritical lens, guided by three key research questions: the extent to which the loss of home and motherland constitutes an environmental issue; how Darko explores the conflict between culture and environment; and the correlation between degraded environments and destabilised women. The findings reveal that displacement—whether economic, familial, or cultural—forces individuals into degraded urban spaces where nature becomes both refuge and threat. This aligns with ecocritical theory's emphasis on the interconnectedness of human and nonhuman elements and the ethical implications of environmental degradation.

Darko's portrayal of urban decay, open defecation, and polluted landscapes reflects the notion of the nonhuman environment as a framing device that intertwines human and natural histories. The depiction of street children coexisting with pigs and vultures exemplifies the ecological symbiosis central to ecocritical thought. Furthermore, the narrative's exploration of curses, taboos, and animal sacrifice underscores the cultural construction of nature, echoing the socio-historical shaping of environmental imaginaries.

The study also demonstrates how ecofeminism—an offshoot of ecocriticism—illuminates the parallel oppressions of women and nature. The destabilization of female characters in *Faceless* is directly linked to environmental degradation, reinforcing the ecofeminist critique of patriarchal systems that exploit both women and the natural world.

In conclusion, the findings affirm that ecocritical theory provides a robust framework for analysing African literature's engagement with environmental issues. Darko's *Faceless* not only reflects ecological concerns but also advocates for environmental consciousness as integral to Ghanaian societal transformation. Promoting sustainability, responsible consumption, and harmonious coexistence with nature emerges as both a literary and ethical imperative.

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RECYCLABILITY OF WASTE PRINTED CIRCUIT BOARDS AND WASTE PLASTIC HOUSINGS FROM ELECTRONIC WASTE MATERIALS IN GHANA

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Abstract

This study examined the content of risk elements, including those controlled by restriction of hazardous substances (RoHS) and total threshold limit concentration (TTLC) regulatory standards, in waste printed circuit boards (WPCBs) and waste plastic housings (WPHs) of common e-waste materials in Ghana and assessed their recycling potential. Twenty-four WPCBs and 47 WPHs were collected from individuals, e-waste recycling sites, and electrical and electronic repairers' workshops in the Greater Accra Region. Each of these samples was analysed for 30 risk elements at SGS Laboratory, Ghana, using inductively coupled plasma atomic emission spectrometry. Results revealed that all analysed elements were present in nearly all samples, except Se, which was below the detection limit (<0.01 mg/kg) in all WPCBs. Arsenic (As), Se, Sb, and Sn were absent in some WPHs. Levels of Cu in all the WPCBs exceeded the TTLC limit of 2500 mg/kg. Similarly, levels of Pb in some WPCBs were more than the RoHS limit of 1000 mg/kg. However, none of the WPHs had concentrations of risk elements to be more than the regulatory standards. The elevated Cu and Pb levels in the boards make them to be hazardous, thereby necessitating strict handling under hazardous waste management protocols. Overall, the diverse and significant concentrations of valuable risk elements in WPCBs and WPHs could be potential secondary raw materials for electronics industry. Therefore, it is necessary to develop suitable and sustainable technologies for their recovery through effective recycling.

Keyword: Waste printed circuit boards, waste plastic housings, risk elements, recycling potential, Ghana

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Introduction

The electronics industry is the world's most significant, fastest-growing manufacturing sector (Liyakat & Liyakat, 2023). Rising demand for newer and innovative technological products, coupled with their high rate of obsolescence, can account for this remarkable growth. Consequently, large quantities of e-waste from computers, mobile phones, television sets (TVs), etc., are produced globally (Forti et al., 2020). It is estimated that 53.6 million metric tons (Mt) of electrical and electronic waste (e-waste) were generated in the year 2019 alone, with an estimated yearly increment of 2 Mt (Forti et al., 2020). This phenomenon has compelled the need to recycle and reuse obsolete products (or e-waste). For instance, the European Union's Waste Electrical and Electronics Equipment (EU-WEEE) Directive 2012/2019 sets mandatory targets for the collection, recovery, and recycling of end-of-life (EoL) electrical and electronic equipment (EEE) (Penttilä, 2020). This will minimise environmental impact of e-waste and resource depletion associated with the electronic industry (Penttilä, 2020). According to Wäger et al. (2011), recycling plastics, instead of using raw materials, causes a decline in their harmful environmental impact. Moreover, in case of recycling e-waste, it will meet the global demand for metal production, because e-waste materials destined to be disposed of in landfills will be turned into reusable form (Kumar et al., 2017).

Nonetheless, various regulatory standards are in place to ensure that the recycling of e-waste does not have adverse effects on human health and the environment, despite the presence of toxic substances in them (Maphosa & Mashau, 2020). Such standards include the EU's Restriction of Hazardous Substances (RoHs) Directive 2011/65/EU and California's Total Threshold Limit Concentration (TTLC) limits. The EU-RoHS directive regulates certain hazardous substances in EEE; it specifies the maximum limits for concentrations of ten regulated materials, which include three risk elements: lead (Pb), mercury (Hg), and cadmium (Cd) (EU, 2011). The TTLC limits determine whether solid waste can be considered as hazardous, based on specified concentration thresholds, with elements such as copper (Cu), barium (Ba) and molybdenum (Mo) contents (DTSC, 2005a).

E-waste contains both plastics and printed circuit boards (PrCBs). Plastic polymers are used as insulators and/or lightweight parts in EEE. Their composition in WEEE ranges from 2.8 % to 72.3 %, depending on the type of EEE (Lahtela et al., 2022). Elements such as Pb, Cd, chromium (Cr), Hg, bromine (Br) and tin (Sn) are often added to plastic polymers as pigments, fillers, ultraviolet (UV) stabilizers and/or flame retardants. Usually, these materials are added as compounds that often do not chemically bond with molecules of plastics. Rather, they create a suspension in the solid plastic polymer (Nnorom & Osibanjo, 2009). On the other hand, PrCB, which is the most precious component of EEE, accounts for 3 to 6 wt% of the total e-waste (Wang et al., 2020). These materials contain about 60 elements, which are categorised into metals, non-metals and organics (Force, 2009; Szałatkiewicz, 2014). The metal components largely include iron (Fe), silver (Ag), nickel (Ni), antimony (Sb) and bismuth (Bi) (Goosey & Kellner, 2003).

In Ghana, both waste plastic housings (WPHs) and waste printed circuit boards (WPCBs) (sometimes after partial metal recovery, mainly copper) become unessential. They are either stored or scattered in the environment, although these materials are vital sources of Cu and other elements (Maphosa & Mashau, 2023) for recovery and utilisation as raw materials by various industries, including the electronics manufacturing sector. Unfortunately, these waste materials, whether left in the environment or stored, pose a threat to the economy, environment, and human health

(Manikkampatt Palanisamy et al., 2022). It has been projected that a metric ton (1,000 kg) of WPCB alone contains recoverable metals valued at about US$ 92,000 (Suponik, 2025). Thus, failing to recycle them results in direct economic losses. In addition, risk elements such as Pb and Cd, among others, in these waste materials can be released into the environment, where they are easily converted and transmitted to be parts of foodstuffs and drinks (Bortey-Sam et al., 2015; Lente et al., 2022; Osei-Owusu et al., 2023; Donkor et al., 2017). If these toxic substances are consumed in food and drinks, they cause various human health-related problems in vital organs of babies, children and adults (Zeng et al., 2017; Donzelli et al., 2019; Singh et al., 2021; Abubarkar et al., 2022; Dutta et al., 2022). This study, therefore, aims to: (i) examine levels of some risk elements in common e-waste materials in Ghana and (ii) suggest some potential opportunities for recycling.

Materials and Methods

Sample collection and preparation

A total of twenty-four WPCBs and 47 WPHs of different WEEE (mobile phones, television sets, desktop computer monitors, laptop monitors, printer cartridges, calculators and radio sets) were collected between October and November 2015 from individuals, EEE repairers' workshops and e-waste recycling sites in the Greater Accra Region of Ghana. The samples were placed in Ziploc bags and transported to the University of Ghana Chemistry laboratory. The product brand name, origin, and release date were recorded if available. Each WPCB and WPH sample was covered with a clean white cloth to protect and avoid cross-contamination, then crushed using a hammer. The sample size was further reduced to less than 2 mm using a ceramic-coated cutting mill.

Sample analysis

An amount of 0.5 g of each WPCB and WPH sample was digested in polypropylene containers with 10 ml aqua regia (3HCl: 1 HNO_3) solution. Triplicate samples of both the WPCBs and the WPHs fractions were digested. The solutions were heated continuously for 6 hours at 120 °C to near dryness. The digest was re-solubilized with 10 mL volume of deionized water and then filtered and brought to 50 mL and analysed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) (PerkinElmer Optima 5300 DV), and levels were obtained in triplicate analysis. In all, a total of thirty risk elements (Cu, Bi, Sn, Ca, Ni, Al, Ti, B, Mg, Na, Zn, Si, Pb, K, Mn, Sr, As, Zr, Be, Co, Cr, Ag, Li, Ba, V, Mo, P, Cd, Sb, and Se) were analysed. The detection limit were as follows: 0.02 mg/kg - Ag, Al, Cr, Sb, Sn; 0.01 mg/kg - As, B, Ba, Be, Bi, Cd, Co, Cu, Hg, Li, Mo, Ni P, Pb, Se, Sr, Ti, V, Y, Zn, Zr; 1.00 mg/kg - Ca, K, Na; 0.1 mg/kg - Si.

Quality Assurance

Quality control/assurance measures were carried out to ensure the reliability of results. All glassware was thoroughly cleaned and soaked in 5% nitric acid (HNO_3) overnight, then rinsed with de-ionized water before use (Ishak et al., 2015). To avoid cross-contamination, sample preparation tools were cleaned after each sample was prepared. Analytical-grade reagents and sample blanks were used. All samples were analysed in triplicates.

Data Analysis

The experimental data obtained were evaluated by descriptive statistics, analysis of variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) statistical tests using the statistical tool package in Microsoft® Excel® for Microsoft 365 MSO (Version 2405 Build 16.0.17628.20006) 64-bit.

Results and Discussion

Risk Elements in Waste Printed Circuit Boards (WPCBs)

Thirty (30) different risk elements (Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, K, Li,

Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Si, Sn, Sr, Ti, V, Zn, and Zr) were analysed in this study. Table 1 shows the average concentrations from WPCBs of television sets (TVs), radio sets, mobile phones, laptops, and desktop computer monitors. Generally, of the thirty elements analysed, only Se was below the 0.01 mg/kg detection limit in all the samples. The results reflect the wide range of elements found in WPCBs (Van et al., 2021; Vidyadhar, 2016; Szałatkiewicz, 2014). However, there were variations in the concentrations of risk elements observed in the different boards due to factors such as their nature (whether electric or electronic), the type of device, year of manufacture (Szałatkiewicz, 2014; Anić-Vučinić et al., 2020) and the extent to which the recovery of essential component was done (for those that various components have been retrieved and are scattered in the environment). In the current study, the TV boards (TVB), laptop monitor boards (LMB), and mobile phone boards (MPB) exhibited relatively pronounced concentrations of risk elements. In contrast, radio boards (RB) showed the lowest levels for most elements (Al, B, Ba, Co, Cr, Li, Mo, Ni, Si, Sn, Sr, Ti, Zn and Zr). This low concentration observed in the RB results from their very nature, which is generally not as complicated as others. It is worth noting that PrCBs serve as the platform upon which components, such as semiconductor chips and capacitors, are mounted, providing electrical connections between these components. Elements such as Al, Cu, and Bi were much higher than those of Cd, Mo, and vanadium (V) (Table 1). The high levels of these elements suggest that these e-waste materials can serve as a source of raw materials for the electronics industry if proper techniques are employed to recover them. Various recovery technologies such as pyrometallurgy, hydrometallurgy, electrometallurgy, and biometallurgy have been discussed in literature (Dutta et al., 2023; Rene et al., 2021; Kaya, 2019Hadi et al., 2015).

Comparing the results with the TTLC limits, at least Cu and Pb can be a considerable concern in terms of human health and the environment. The average concentration of Cu in all the WPCBs exceeded the TTLC limit of 2500 mg/kg (DTSC, 2005a). Similar trend was observed for Pb, except in LMB. Priya & Haiti (2017) also reported concentrations of Cu to be (201300 ±400 mg/kg) in LMB, whereas that of Pb was 22600±800 mg/kg in TVBs. Thus, levels of both Cu and Pb were above the TTLC limits (DTSC, 2005a). Additionally, Cu levels in DCMB (i.e., 6505.6 mg/kg) observed in this study were lower, when compared to those ranging from 142000 to 25014 mg/kg in reports (Yamane et al., 2011; Kolias et al., 2014; Bizzo et al., 2014). Conversely, Nnorom et al. (2010) reported a lower concentration of 877 mg/kg. Furthermore, the concentration of Pb in the WPCBs exceeded the RoHS limit in all cases except for LMB. According to Anić-Vučinić et al. (2020), Cu is one of the significant components of bare boards of WPCBs. Sources of Pb in PrCBs include Pb soldering (Jha et al., 2012).

In fact, levels of Cu in TVB, MPB, DCB and LMB were significantly ($p<0.05$) different. However, levels of Pb in TVB, MPB, DCB and LMB were not significantly ($p>0.05$) different. Thus, a significant variation in Cu concentrations among the four WPCBs, unlike Pb concentrations in similar e-waste materials. Furthermore, a Tukey's HSD post-hoc analysis for Cu showed that MPBs contained significantly higher Cu levels than all other groups, followed by the LMB. The concentration of Cu in the TVB and DCB showed minimal difference.

Table 1: Average risk element concentrations (mg/kg) in printed circuit boards

RE	MPB *n=11*	*Std.*	TVB *n= 7*	*Std.*	DCMB *n=2*	*Std.*	RB *n=1*	LMB *n=3*	*Std.*	TTLC limit	RoHS limit
Ag	122.80	104.46	38.48	24.79	32.20	5.06	29.62	127.97	7.59	500	-
Al	57508.55	27624.43	4530.45	8898.75	46785.50	8573.67	1329.6	1024.12	105.24	-	-
As	101.83	160.27	4.96	7.13	6.83	3.48	2.48	11.28	1.91	50	-
B	16000.48	7995.31	1059.70	2103.16	14024.00	5704.94	178.44	27474.33	2548.76	-	-
Ba	135.10	122.08	38.61	44.34	54.31	49.64	18.77	339.99	361.56	10000	-
Be	32.06	65.2	nd	-	nd	-	0.007	nd	-	75	-
Bi	16907.64	2548.23	5869.00	8264.39	6262.00	2315.07	4352.5	14334.00	2064.91	-	-
Ca	124771.45	55311.24	18764.86	20289.16	1163.25	466.34	11006	240456.67	29129.71	-	-
Cd	0.02	0.06	9.07	18.14	2.60	2.75	4.72	nd	-	100	100
Co	53.97	69.55	12.94	15.83	19.65	23.87	1.47	36.67	40.01	8000	-
Cr	69.42	49.61	109.77	134.24	14.32	8.49	1.581	98.51	10.26	2500	1000
Cu	17479.36	2655.11	2782.71	1297.09	6505.60	2408.41	4598.9	14879.67	1850.46	2500	-
K	2050.36	785.47	1363.39	1199.62	1752.50	259.51	2116.1	1593.33	404.93	-	-
Li	65.85	25.02	7.09	9.31	33.23	11.69	4.51	55.76	19.29	-	-
Mg	5355.73	1275.63	4212.71	807.29	105.37	149.01	3389	6923.00	1373.91	-	-
Mn	236.89	479.28	593.61	1340.45	59.88	13.72	16.77	99.18	32.00	-	-
Mo	13.21	13.65	0.63	1.10	12.00	15.03	nd	1.44	1.25	3500	-
Na	4811.91	1803.00	3147.00	722.00	5083.00	562.86	7867	6857.33	997.57	-	-

RE: Risk element, MPB: Mobile phone board, TVB: Television board, DCMB: Desktop computer monitor board, LMB: Laptop monitor board, RB: Radio board, TTLC: Total Threshold Limit Concentration, RoHS: Restriction of hazardous substances, n: number of samples and nd: not detected, std: standard deviation.

Table 1 (continued): Average risk element concentrations (mg/kg) in printed circuit boards

RE	MPB *n=11*	*Std.*	TVB *n= 7*	*Std.*	DCMB *n=2*	*Std.*	RB *n=1*	LMB *n=3*	*Std.*	TTLC limit	RoHS limit
Ni	41932.82	23563.37	7117.62	10425.01	22.59	16.82	17.56	15390.00	11682.01	2000	-
P	nd	-	3373.43	8147.00	nd	-	nd	nd	-	-	-
Pb	2168.73	726.29	4720.71	4044.04	2406.00	813.17	3189	983.38	144.71	1000	1000
Sb	0.99	3.28	74.36	192.85	193.67	222.71	17.91	0.84	1.45	500	-
Se	nd	-	nd	-	nd	-	nd	nd	-	100	-
Si	3630.91	1309.76	528.41	917.58	4864.50	1028.84	137.01	3782.40	783.69	-	-
Sn	72643.45	52721.04	34224.86	47477.99	10565.50	7397.04	1020.81	15366.00	14159.71	-	-
Sr	883.84	552.64	128.77	148.01	843.73	563.24	71.88	418.19	53.75	-	-
Ti	6567.76	7287.20	665.26	848.22	728.36	101.44	50.04	6384.00	4280.05	-	-
V	48.09	27.77	13.61	25.86	10.56	0.52	1.10	77.81	13.71	2400	-
Zn	1595.61	916.57	343.41	306.85	309.30	204.50	189.81	527.11	301.85	5000	-
Zr	173.06	196.51	4723.00	12495.88	68.56	26.35	2.29	286.21	95.23	-	-

RE: Risk element, MPB: Mobile phone board, TVB: Television board, DCMB: Desktop computer monitor board, LMB: Laptop monitor board, RB: Radio board, TTLC: Total Threshold Limit Concentration, RoHS: Restriction of hazardous substances, n: number of samples and nd: not detected, std: standard deviation.

Risk Elements Concentrations in Plastics Housing (PH)

The average concentrations of risk elements in eight different WPH samples of e-waste are shown in Table 2. All thirty elements analysed were detectable in all the WPHs, except As, Be, B, Se, and Sn. However, unlike the WPCBs, the concentrations of the various elements analysed in the WPHs were relatively lower. A similar trend was observed by Kolias et al. (2014). In general, aluminium (Al), calcium (Ca), Cu, magnesium (Mg), sodium (Na), and phosphorus (P) concentrations were comparatively higher than those of the remaining analysed elements. Ca had the highest mean element concentration (Table 2). This could be due to their use as fillers to enhance the material's properties (Ahmad Fauzi et al., 2022). Al is also used as a coating on plastics to improve their mechanical properties (Irawan, 2018). In effect, concentrations of Ca in this study ranged from 93.91 mg/kg to 21,192.00 mg/kg, whereas those of Al ranged from 6.71 mg/kg to 2249.30 mg/kg (Table 2). Comparing the levels of metals in the various WPHs, the mean values of their concentrations in the TV plastic housing (TVH) were the highest, followed by those in desktop computer housing (DCH). However, calculator housing (CH) had the lowest.

Moreover, the mean concentrations of risk elements for all the WPHs were below the RoHS and TTLC regulatory limits. Similar trends were observed by Stenvall et al. (2013) and Singh et al. (2020), corroborating findings in this study.

Implications for recycling

WPCBs and WPHs contain high levels of valuable elements. Hence, these elements make e-waste to be re-utilisable (Cayumil et al., 2014; Sahajwalla & Gaikwad, 2018). The valuable risk elements observed in this study support this fact. However, the recovery rate often depends on the extraction method (Dutta et al., 2018; Sahajwalla & Gaikwad, 2018). The traditional processing of metal extraction across Ghana, involves manual dismantling by opening burning of WPCBs to recover Cu. In fact, these recovery methods are insufficient in retrieving all functional components. Many risk elements left behind after the traditional recovery approaches are employed, thereby requiring effective recycling to be done. This is because environmental problems are apparently associated with the traditional recovery method, which leave traceable risk elements e-waste debris behind in the environment. Hence, the elements in these materials can be leached out into soil to cause pollution (Donkor et al., 2017; Sepúlveda et al., 2010). According to Mao et al. (2020), the migration rate of risk elements such as Cu and Pb in plastics accelerates over time. Therefore, there is a need to develop suitable and sustainable technologies for their recovery through effective recycling.

However, when recovering these essential elements, it is necessary to determine whether the recovery approaches comply with regulatory measures such as the TTLC and RoHS limits. This is because the WPCBs and the WPHs in this study had concentrations of Cu being above the TTLC, whereas concentrations of Pb in all the WPCBs exceeded the RoHS limit, except in the LMB. Regarding these regulatory limits, once a particular substance fails, the entire material is considered hazardous (Okenwa-Ani et al., 2019), which disqualifies it from unrestricted recycling, thereby meriting mandatory hazardous waste handling protocols. Each country's laws and regulations typically establish these protocols. Ghana's compulsory hazardous waste management protocols are detailed in the Hazardous and Electronic Waste Control and Management Act, 2016 (Act 917), along with its associated regulations. These protocols specify that hazardous waste must only be handled by authorised collectors, treatment, storage, and disposal facilities (EPA, 2018).

The types of risk elements and their concentrations directly affect the suitable technology for their recovery. For instance, the level of Pb complicates both mechanical and thermal recycling (Li et al., 2024; Zhou & Qiu, 2010). According to Zhou & Qiu (2010), mechanical processes such as crushing and separation can result in the release of Pb into the environment. Additionally, high levels of Pb increase the risk of Pb vapour emissions during smelting, requiring strict emission controls and strong worker protection measures (Li et al., 2024; Song & Li, 2014).

The current study revealed that MPBs contain significantly more Cu than that in all the other "boards". They represent the most valuable source for Cu recovery. Hence, they should be prioritised in recycling efforts or targeted with more efficient recovery technologies. The LMB can be regarded as a secondary priority for Cu recovery. For Pb, the lack of significant differences indicates that all WPCB types

offer similar lead recovery potential, so no specific board type has a clear economic advantage for Pb recovery. Consequently, Pb recovery can be approached uniformly across all board types without the need for separation based on Pb content.

Table 2: Average concentrations of risk elements (mg/kg) in e-waste plastic housings

RE	TVH n=15	Std.	RH n=5	Std	DCH n=8	Std.	MPH n=11	Std.	TTLC limit	RoHS limit
Ag	5.23	11.38	0.25	0.22	0.51	0.38	13.84	35.57	500	-
Al	1233.25	1325.37	720.65	488.93	407.74	261.35	2116.07	1797.09	-	-
As	9.16	17.85	1.12	2.02	3.59	7.09	2.81	3.55	50	-
B	114.33	106.59	43.43	8.33	47.44	34.33	24.30	6.49	-	-
Ba	85.78	68.45	183.41	73.40	119.42	143.44	150.98	283.15	10000	-
Be	0.03	0.06	0.16	0.09	0.19	0.19	0.04	0.10	75	-
Bi	1197.70	1590.15	53.95	22.52	81.57	125.12	69.36	33.55	-	-
Ca	17871.60	11280.25	21192.00	5214.39	4401.81	2478.50	3655.00	1825.30	-	-
Cd	0.98	0.70	0.88	1.71	4.10	11.23	1.50	3.50	100	100
Co	1.96	4.07	0.65	0.52	51.65	143.00	1.12	1.14	8000	-
Cr	301.28	397.13	271.02	112.75	255.93	150.16	122.78	28.63	2500	1000
Cu	722.17	1089.53	54.41	23.81	41.73	27.50	169.89	268.51	2500	-
K	758.40	177.73	624.85	198.25	658.68	196.74	730.14	280.37	-	-
Li	11.83	7.04	10.20	4.02	5.81	9.08	3.86	4.32	-	-
Mg	7736.06	11949.79	6101.04	1323.89	2154.31	2352.41	621.63	418.08	-	-
Mn	243.12	202.87	84.18	39.16	42.40	14.63	22.45	4.94	-	-
Mo	63.57	31.84	55.25	22.94	17.49	9.71	6.05	3.32	3500	-
Na	3142.60	1114.60	3319.98	709.27	921.44	364.13	916.02	446.82	-	-
Ni	87.83	80.67	87.20	6.52	81.83	32.36	225.27	436.20	2000	-
P	1318.83	4930.80	543.61	1006.60	540.08	370.37	384.92	456.44	-	-
Pb	217.91	655.05	32.68	35.29	17.17	6.81	30.77	20.07	1000	1000
Sb	124.58	385.09	4.30	3.14	397.05	108.25	16.26	33.36	500	-
Se	94.62	135.03	nd	-	57.09	73.22	0.79	1.92	100	-
Si	361.06	479.56	73.20	17.77	136.35	155.91	47.70	18.87	-	-
Sn	80.83	115.34	9.32	18.63	2.97	7.14	3.12	6.17	-	-
Sr	109.09	45.89	128.52	21.11	41.21	63.00	6.61	6.12	-	-
Ti	1178.74	3475.26	196.66	166.71	151.53	108.87	521.89	832.14	-	-
V	4.80	3.68	1.84	0.65	3.01	3.96	1.77	0.71	2400	-
Zn	1301.47	990.67	565.07	255.40	161.22	85.29	179.78	182.93	5000	-
Zr	4.25	4.22	1.87	0.76	3.86	3.99	82.85	65.01	-	-

TVH-television housing, RH-radio housing, DCH- Desktop computer housing, MPH-mobile phone housing, PrCH-printer cartridge housing, CH-calculator housing, LBH-laptop battery housing, TTLC: Total Threshold Limit Concentration, RoHS: Restriction of hazardous substances, n: number of samples and nd: not detected, std: standard deviation.

Table 2 (continued): Average concentrations of risk elements (mg/kg) in e-waste plastic housings

RE	PrCH n=5	Std.	LBH n=1	CH n=1	FH n=1	TTLC limit	RoHS limit
Ag	0.04	0.63	2.21	0.47	0.47	500	-
Al	6.72	2.82	294.60	0.41	1327.13	-	-
As	0.34	0.42	nd	nd	nd	50	-
B	0.37	0.08	14.48	nd	105.71	-	-
Ba	2.63	3.96	12.31	37.45	1234.24	10000	-
Be	nd	-	0.25	1884.31	0.2	75	-
Bi	0.71	0.51	134.53	0.40	132.58	-	-
Ca	186.98	232.21	3960.81	93.91	11207.02	-	-
Cd	0.28	0.35	12.40	12.36	2.19	100	100
Co	0.05	0.08	0.93	0.821	27.13	8000	-
Cr	1.32	0.32	96.92	0.53	139.81	2500	1000
Cu	0.66	0.48	124.01	221.44	124.06	2500	-
K	4.43	0.89	577.21	5686.80	417.82	-	-
Li	0.04	0.04	1.42	664.31	3.71	-	-
Mg	23.72	15.45	396.00	10.81	1085.53	-	-
Mn	0.36	0.20	13.61	5102.05	105.12	-	-
Mo	0.02	0.01	6.35	65.06	9.21	3500	-
Na	9.62	3.16	737.20	52.52	859.27	-	-
Ni	0.57	0.32	74.21	2947.1	110.12	2000	-
P	7.35	9.73	293.91	82.63	7702.14	-	-
Pb	0.14	0.19	11.20	440.08	128.84	1000	1000
Sb	10.65	6.26	nd	14.13	59.81	500	-
Se	0.11	0.13	nd	10.59	nd	100	-
Si	2.23	0.82	16.40	nd	118.73	-	-
Sn	nd	-	nd	129.81	nd	-	-
Sr	0.54	0.35	4.11	nd	24.84	-	-
Ti	0.11	0.06	54.08	147.24	8.21	-	-
V	0.01	0.00	1.13	87.37	1.70	2400	-
Zn	5253.59	10463.71	82.90	2.23	896.91	5000	-
Zr	0.01	0.00	0.82	359.31	0.21	-	-

TVH: Television housing, RH-radio housing, DCH- Desktop computer housing, MPH-mobile phone housing, PrCH-printer cartridge housing, CH-calculator housing, LBH – laptop battery housing, TTLC: Total Threshold Limit Concentration, RoHS: Restriction of hazardous substances, n: number of samples and nd: not detected, std: standard deviation.

Conclusion

Generally, WPCBs had higher concentrations of risk elements than WPH had. Levels of Cu in all the studied WPCBs exceeded 2500 mg/kg, which is the TTLC limit. Similar trends were observed for Pb regarding TTLC and RoHS limits (1000 mg/kg), except in the LMB. Regarding the RoHS and TTLC regulatory limits, all the WPCBs were considered hazardous and should therefore be managed under strict hazardous waste protocols. Among the WPCBs, MPBs contain a considerable amount of Cu, which should be the primary focus for recovery. Further research is necessary to determine the levels of risk elements in other components of e-waste, as well as in other types of WEEE not covered in this study. Additionally, it is crucial to investigate the presence of other toxic substances, such as BFRs, phthalates, and other organic toxicants, in WPHs and WPCBs, especially those classified as POPS under the Stockholm Convention. Moreover, further studies are needed to assess the economic viability of metal recovery from WPCBs and WPH using various extraction techniques, such as hydrometallurgical, pyrometallurgical, or

bioleaching methods, along with life-cycle assessments.

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INCORPORATING PALM KERNEL MEAL, COWPEA HUSK AND SOYBEAN HUSK AS PROTEIN SOURCES IN CATFISH DIETS: EFFECTS ON GROWTH, HEMATOLOGY AND INTESTINAL HISTOLOGY

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Abstract

This study examined the effects of replacing fish meal (FM) with soybean husk (SBH), palm kernel meal (PKM), and cowpea husk (CPH) on growth performance, feed utilization, and intestinal histology of catfish. Four experimental diets were formulated with different proportions of PKM, CPH, and SBH to partially replace fish meal. Juvenile catfish (Clarias gariepinus) were fed these diets for ten weeks. The results indicated that inclusion of these alternative protein sources had significant effects on growth performance and feed utilization compared to FM diet. The weight gain recorded in this study was as follows: SBH (119.5±68.02) > CPH (113.2±53.14) > FM (104.3±56.82) > PKM (86.73±31.51). Feed conversion ratio ranged from 1.25±0.57 (SBH) to 1.52±0.56 (PKM). C. gariepinus fed the diet PKM had the lowest protein efficiency ratio (2.09±0.76), followed by those fed the FM (2.57±1.40) and the CPH diet (2.74±1.28). To a larger extent, the dietary protein sources significantly influenced serum hematology parameters. C. gariepinus fed the FM diet had the highest white blood cells count (133.0±2.51), which was significantly higher than all other groups ($p < 0.0001$). The range of red blood cell values observed in this study was 2.08±0.13 to 2.62±0.13. Histological examination indicated modifications in intestinal morphology, suggesting possible metabolic adjustments to the experimental diets. Fish fed the FM had the highest villus height (441.2±22.6), followed by SBH (398.3±7.51), PKM (279.2±15.65), and CPH (142.3±10.84). Villus width and muscular thickness also followed this pattern, with fish fed the FM diet having the largest villus width (153.7±9.06), significantly greater than all other groups ($p<0.0001$). Overall, incorporating CPH, and SBH into catfish diets appears to be a viable replacement for conventional fishmeal-based diets; however, further studies are required to determine optimal inclusion levels for achieving maximum growth and well-being

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Introduction

Total fisheries and aquaculture production (excluding algae) has significantly expanded in the past seven decades going from 19 million tons (live weight equivalent) in 1950 to an all-time record of about 179 million tons in 2018, with an annual growth rate of 3.3 percent (FAO, 2022). *Projections of about 96 million metric tons of fish were raised in aquaculture in 2023, compared to 90.6 million metric tons that were (fishing) captured same year (Dauda et al., 2023). Feed is necessary in aquaculture, just like in animal husbandry, to guarantee good production, particularly in intensive culture systems that demand a lot of input (Boyd,* 2020).

One of the most significant species of cultured fish and one of the most commonly used fish products is *Clarias gariepinus* (Kari et al., 2021). Farmers are aligning themselves with the culture of catfish farming, which is growing in importance and is catching up to tilapia production (Mbokane et al., 2022). This is because catfish farming provides low-cholesterol animal protein which lowers food insecurity and creates jobs (Montgomery et al., 2022). Fish farming intensified to meet the rising demand for fish has resulted in high stress levels, low wellbeing, and delayed growth performance of aquaculture species (Nasr et al., 2021).

Since feed makes up over 50% of the entire production expenses in the aquaculture business, feed is a crucial component (Mzengereza et al., 2014). The costliest feed ingredient in aquafeeds is the source of protein (Lim et al., 2023). Fishmeal is considered the gold standard protein due to its balanced amino acid content, which is perfect for the healthy growth and development of fish (Perez-Velazquez et al., 2019). Fish by-products and wild-caught fish are used to make fish-meal, an industrial product (Wan, 2015).

Fishmeal is a major source of aquafeed worldwide. However, the rising demand for fish and fish products has caused its price to continuously rise, greatly affecting the market price (Jannathulla et al., 2019). To cut feed costs, several plant-based proteins are now utilized in place of fish-meal, either totally or partially (Jannathulla et al., 2019). Aquafeeds with plant-based protein diets have long been known to perform worse than those with fish-meal (Egerton et al., 2023) due to an inadequate amino acid profile, decreased palatability, and the existence of anti-nutritional factors (ANFs) that have an impact on the performance of farmed fish as a whole (Maundu, 2020). The main objective of using plant-based proteins is to offer fish-meal as a more affordable substitute. Finding a less expensive option isn't the only factor, though (Gutasi, 2021). Moreover, the production of these plant-based proteins needs to be sustainable without affecting the health and growth of fish (Magbanua and Ragaza, 2024). Conventional methods for assessing the general health of fish and their reaction to various proteins and diets include hematological and histopathological studies (Docan et al., 2018). A few of the plant-based protein sources that are used are soybean husk, cowpea husk, and palm kernel meal (Senthilkumaran et al., 2022). These plant sources are more broadly and cheaply accessible worldwide than fish-meal (Senthilkumaran et al., 2022). An agricultural by-product of the oil palm (Elaeis guineensis Jacq) industry, palm kernel meal (PKM) is regarded as an agro-industrial waste (Ng and Chong, 2002; Sangavi et al., 2020). The crude protein content of PKM ranges from 12 to 21%. In addition, PKM is said to be widely available and reasonably priced in many tropical nations (Botello-León et al., 2022). One ingredient that can be purchased in huge quantities for incredibly low costs is soybean husks (Shuaib et al., 2023). Numerous fish species' dietary protein requirements can be covered and met by these plant-based protein sources (Jia et al.,

2022). While lysine and methionine are typically absent from plant-based proteins (Gorissen et al., 2018), this is somewhat compensated for by minuscule amounts of crystalline amino acids. Consequently, the aim of this study was to evaluate the effects of soybean husk, cowpea husk, and palm kernel meal as protein sources on growth performance, feed utilization, intestinal histology, and health of catfish using full blood count and liver function test as indicators.

Materials and methods

Formulation of the experimental diets and feeding

Table 1 shows the experimental diets used for this study. In formulating the diets, substantial amount of fish meal was progressively replaced with soybean husk (SBH), cowpea husk (CPH) and palm kernel meal (PKM) until equal amounts of protein (approximately 35%) were obtained. Following procedures previously described by Ayisi et al. (2017), the formulated diets were prepared. In brief, the progressive enlargement method was used to mix all of the dry ingredients (Zhou et al., 2007). In a mixer, the dry ingredients were combined with vegetable oil and distilled water to form a moist dough that was then pelleted using a single screw dry type extruder (Model: LM 70) fitted with a 2-mm die. The dry extruded and sun dried 2-mm pelleted diets were then sealed in plastic bags and kept at room temperature until needed. *C. gariepinus* were fed to apparent satiation, three times daily at 8:00 am, 12 noon and 4:00 pm.

Table 1 Composition of experimental diets

Ingredients	FM	CPH	SBH	PKM
Fish meal	35.00	27.50	22.00	23.50
Soybean husk	30.50	25.00	30.50	30.50
Cowpea husk	0.00	15.50	0.00	0.00
Soybean husk	0.00	0.00	18.00	0.00
Palm kernel meal	0.00	0.00	0.00	15.50
Maize	13.50	13.00	10.50	11.50
Wheat bran	10.00	8.00	8.00	8.00
Premix	1.50	1.50	1.50	1.50
Vegetable oil	4.00	4.00	4.00	4.00
Starch	2.00	2.00	2.00	2.00
Salt	2.00	2.00	2.00	2.00
D-L methionine	0.50	0.50	0.50	0.50
D-L lysine	0.50	0.50	0.50	0.50
H-histidine	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00
Proximate composition				
Moisture	90.49	90.30	90.73	90.15
Protein	35.8	35.42	35.53	35.75
Lipid	11.51	10.78	11.05	10.93
Ash	10.07	10.04	10.85	10.35

Experimental conditions and design

The experiment was carried out in concrete tanks with dimensions of 1.5 m x 1.5m x 1.2 m (length, breadth and depth). Five hundred healthy *C. gariepinus* with initial weight of approximately 2.5 g were purchased from a commercial farm and transported to the rearing facility. Prior to the onset of the trial, fish were acclimatized to the rearing conditions for 2 weeks and fed on commercial diet with protein content of 32%. At the onset of the trial, the fish were distributed into four groups with duplicates and fed their respective diets. Each tank was stocked with fifty fish.

Measurements of the biological indices

Feed utilization and growth performance were measured following formulas previously used by Mutalib et al. (2023).

Feed intake = The total amount of feed consumed (g) during the total number of trial days is the feed intake (FI).

Feed conversion ratio (FCR) = Feed intake (g) / Weight gain (g).

Protein efficiency ratio (PER) = Wet weight gain (g) / Protein intake (g)

Weight gain (WG) = Final weight (g) – Initial weight (g)

Protein intake = protein content of feed x feed intake

Specific growth rate (SGR) (%) = (ln final weight (g) - ln initial weight (g)) /T × 100, where T is the number of feeding experimental (feeding) days

Blood biochemical analysis

After 10 weeks of feeding trial, blood from experimental fish were sampled as previously described by Abarike et al. (2018). Using a 2 mL disposable syringe, whole blood was drawn and then poured into two separate tubes—one for the liver and kidney toxicity test and the other for the haematological analysis—both of which contained EDTA to prevent the blood from clotting. The blood was subsequently sent to the laboratory of E-MED Diagnostic Services for the haematological parameters and plasma constituents to be determined using a haematological analyzer.

Proximate composition

Samples from whole body fish and experimental diets were sent to the laboratory for protein, lipid, moisture, and ash analyses. The AOAC (2003) standard methods, as reported by Ayisi et al. (2021), were employed to analyze the aforementioned parameters. Briefly, samples were oven dried at 105 °C to a constant weight to determine moisture content. Following digestion with concentrated H_2SO_4, crude protein was measured using the Kjeldahl method and a Kjeltec Auto 2300 Analyzer. Protein is expressed as a percentage of dry weight (% DW). The crude lipid content was measured by homogenizing the samples and extracting the lipids (Folch et al., 1957). The samples were burned at 550 °C for 4-6 hours in a muffle furnace to determine the amount of crude ash.

Histological examination

Six fish per group had sections of their intestines removed, which were then quickly preserved in a Bouin solution for histological examinations. Samples of tissue were promptly preserved in a Bouin solution. After that, fixed samples were subjected to a series of alcohol solutions with increasing grades (70–100 percent) to dehydrate them. Following the dehydration procedure, tissues underwent xylene deparaffinization, paraffin embedding, 5 µm sectioning, and Hematoxylin and Eosin (H&E) staining (Kim, 2013; Ismail, et al. 2020). A Leica light microscope was used to examine the slides, and an eyepiece camera was used to capture the images. ImageJ version 1.54 was used to determine the target cells in each section (National Institutes of Health, USA). An average of ten target cells per section served as the basis for each section's measurements.

Statistical analysis

The gathered data was statistically analyzed using Graph Pad Prism (V.5.03). The data is presented in tables using the standard error of the mean (SEM), which is represented as the mean ±. To compare treatment means, One-way Analysis of Variance and Tukey's multiple tests were applied to all the data. Differences are considered significant for all data at the 0.05 probability level ($P<0.05$). Pearson's correlation was conducted to ascertain the relationship between selected parameters. Results of correlation analysis is presented in figures.

Results

Effects of dietary protein sources on growth and feed utilization

Table 2 is a summary of the effects of different protein sources on the growth and feed utilization of *C. gariepinus*. FW and FL were significantly influenced by different protein sources (p = 0.0002 and 0.0044 respectively). The highest FW (122.0±68.12 g) and FL (25.07±4.00 cm) were observed in *C. gariepinus* fed diet SBH. Similarly, feeding *C. gariepinus* with diet SBH recorded the highest WG (119.5±68.02 g) and was significantly higher than *C. gariepinus* fed diet PKM with a WG of 86.73±31.51g (p<0.0001). There was no significant difference in feed intake (p = 0.1369). There was, however, a significant difference in feed conversion ratio (p=0.001). *C. gariepinus* fed with diets FM, CPH, SBH and PKM recorded FCRs of 1.27±0.53, 1.27±0.57, 1.25±0.57 and 1.52±0.56, respectively. There was no significant difference in protein intake (p = 0.9514). Protein intake (PI) ranged between 40.43±1.92 (FM) and 41.35±1.83 (PKM). *C. gariepinus* fed with diets CPH and SBH recorded PIs of 41.21±0.81 and 41.21±1.95, respectively. Protein efficiency ratio (PER) was significantly altered among groups (p = 0.0002). Feeding *C. gariepinus* with diet SBH recorded the highest PER (2.90±1.65) and was more significant than all other groups. The least PER (2.09±0.76) was observed in *C. gariepinus* fed with diet PKM, followed by diet FM (2.57±1.40) and diet CPH (2.74±1.28).

Table 2 Effects of different protein sources on growth and feed utilization of *C. gariepinus*

	FM	CPH	SBH	PKM	p-value
IW	2.65±0.96	2.53±0.79	2.56±1.01	2.50±0.79	0.6207
FW	$106.9±56.84^{ab}$	$115.8±53.29^{b}$	$122.0±68.12^{b}$	$89.21±31.42^{a}$	0.0002
FL	$24.43±3.82^{ab}$	$24.84±3.56^{b}$	$25.07±4.00^{b}$	$23.31±2.95^{a}$	0.0044
WG	$104.3±56.82^{ab}$	$113.2±53.14^{b}$	$119.5±68.02^{b}$	$86.73±31.51^{a}$	<0.0001
FI	105.0±5.00	116.3±2.30	116.0±9.53	115.7±5.13	0.1369
FCR	$1.27±0.53^{a}$	$1.27±0.57^{a}$	$1.25±0.57^{a}$	$1.52±0.56^{b}$	0.0013
SGR	$5.18±0.80^{ab}$	$5.36±0.69^{ab}$	$5.43±0.83^{b}$	$5.08±0.69^{a}$	0.0073
PI	40.43±1.92	41.21±0.81	41.21±1.95	41.35±1.83	0.9514
PER	$2.57±1.40^{b}$	$2.74±1.28^{b}$	$2.90±1.65^{c}$	$2.09±0.76^{a}$	0.0002

IW: Initial weight, FW: Final weight; FL: Final length; WG: Weight gain; FI: Feed intake; FCR: Feed conversion ratio; SGR: Specific growth rate; PI: Protein intake; PER: Protein efficiency ratio.

Proximate composition of whole body

A summary of the proximate composition of the whole body of *C. gariepinus* fed different protein sources is shown in Table 3. This study revealed a non-significant difference in protein content between the initial fish and the four experimental groups (p= 0.1441).

Table 3 Proximate composition of whole-body *C. gariepinus* fed different experimental diets

	Initial	FM	CPH	SBH	PKM	p-value
Moisture (% DM)	75.81±1.45	75.48±0.93	78.18±1.20	77.19±1.27	76.12±2.13	0.6769
Protein (% DM)	16.44±0.20	15.80±0.35	15.62±0.57	15.19±0.31	16.38±0.40	0.1441
Lipid (% DM)	10.17±0.26	9.05±0.24	9.88±0.30	9.84±0.32	9.88±0.21	0.0792
Ash (% DM)	3.78±0.38	3.93±0.28	3.68±0.22	3.64±0.24	3.78±0.38	0.9264

It is worth noting that the initial protein content was higher than that of the experimental groups. Protein content of fish fed diets FM, CPH, SBH, and PKM was 15.80±0.35, 15.62±0.57, 15.19±0.31, and 16.38±0.40, respectively. There was no

significant difference in ash content ($p = 0.9264$). Whereas the initial fish had ash content of 3.78±0.38, *C. gariepinus* fed diet FM had ash content of 3.93±0.28. *C. gariepinus* fed diets CPH, SBH, and PKM recorded ash contents of 3.68±0.22, 3.64±0.24, and 3.78±0.38, respectively. Similarly, there was a non-significant difference in moisture content of *C. gariepinus* fed different protein sources, as well as the initial fish ($p = 0.6769$). The initial moisture content was 75.81±1.45, while that of *C. gariepinus* fed diets FM, CPH, SBH, and PKM was 75.48±0.93, 78.18±1.20, 77.19±1.27, and 76.12±2.13, respectively. The lipid content of experimental groups and the initial fish did not vary significantly ($p = 0.0792$). Lipid content as recorded in this study ranged between 9.05±0.24 and 10.17±0.26.

Hematology

Table 4 shows hematology parameters of *C. gariepinus* fed four different protein sources. To a larger extent, different protein sources affected hematological parameters of catfish. In this study, WBC, RBC, HGB, HCT, MCH, PDW and MCHC of *C. gariepinus* were significantly altered by different protein sources ($p < 0.05$). Similarly, RDW, LYM, and GRA were all significantly altered by different protein sources ($p < 0.05$). There was however, no significant differences in MON, PCT, MVP, and PLT ($p > 0.05$). The highest WBC (133.0±2.51) was recorded in *C. gariepinus* fed diet FM and was significantly higher than all other groups ($p < 0.0001$). *C. gariepinus* fed diets CPH, SBH, and PKM recorded WBC of 107.6±3.44, 108.6±2.84, and 109.0±4.93, respectively. RBC recorded in this study ranged between 2.08±0.13 and 2.62±0.13. The least RBC was recorded in *C. gariepinus* fed diet and was significantly lower than *C. gariepinus* fed diets CPH and PKM ($p = 0.0133$). RBC recorded in this study ranged between 2.08±0.13 (FM) and 2.62±0.13 (CPH). HGB was induced in *C. gariepinus* fed diet SBH (8.66±0.29) and was significantly higher than *C. gariepinus* fed diet FM which recorded HGB of 6.47±0.19 ($p < 0.0001$). Also, feeding *C. gariepinus* with diet CPH recorded GRA level of 2.82±0.14 and was significantly lower than *C. gariepinus* fed diet FM (< 0.0001). Feeding *C. gariepinus* with plant protein sources led to elevated levels of LYM and were all significantly higher than *C. gariepinus* fed diet FM ($p < 0.0001$). LYM as recorded in this study ranged between 88.49±1.84 (FM) and 110.2±2.47 (SBH). RDW, MCHC, and PDW ranged from 5.21±0.28 to 8.00±0.25, 28.73±0.67 to 35.77±0.95, and 7.33±0.14 to 9.58±0.48, respectively. In the case of PDW and MCHC, the least values were recorded in *C. gariepinus* fed diet FM with the highest recorded in *C. gariepinus* fed SBH. In the case of RDW, the highest was recorded in *C. gariepinus* fed diet FM and the least observed in *C. gariepinus* fed SBH. There was significant difference in HCT, MCV, and MCH levels. Higher levels of HCT and MCH were observed in *C. gariepinus* fed plant protein diets (CPH, SBH, and PKM) and were significantly higher than *C. gariepinus* fed FM ($p < 0.05$).

Kidney function test

Table 5 shows kidney function of *C. gariepinus* fed diets with different protein sources. With the exception of serum potassium ($p = 0.0005$) and chloride ($p = 0.0047$), there were no significant modifications in creatinine ($p = 0.3945$), urea ($p = 0.8884$) or sodium ($p = 0.4724$). C. gariepinus fed diets with SBH and PKM diets recorded the highest concentrations of potassium (6.04±0.23 and 6.09±0.28, respectively), while the highest chloride concentrations were observed in C. gariepinus fed diets FM (102.7±3.58) and CPH (109.2±11.31). Creatinine concentration ranged between 33.25±2.49 and 39. 21±5.20, while urea ranged between 2.79±0.26 and 3.00±0.19.

Table 4 Erythrogram of *C. gariepinus* fed four different protein sources.

	FM	CPH	SBH	PKM	p-value
WBC	133.0±2.51^{b}	107.6±3.44^{a}	108.6±2.84^{a}	109.0±4.93^{a}	< 0.0001
RBC	2.08±0.13^{a}	2.62±0.13^{b}	2.50±0.14^{ab}	2.61±0.06^{b}	0.0133
HGB	6.47±0.19^{a}	8.06±0.21^{b}	8.66±0.29^{b}	8.21±0.35^{b}	< 0.0001
HCT	27.43±1.19^{a}	31.26±0.79^{b}	32.99±0.78^{b}	32.74±1.07^{b}	0.0011
MCV	138.3±1.82^{b}	113.1±3.89^{a}	116.6±4.66^{a}	117.4±3.46^{a}	< 0.0001
MCH	35.43±0.66^{a}	42.71±0.92^{b}	44.18±1.05^{b}	43.13±1.22^{b}	< 0.0001
PDW	7.33±0.14^{a}	9.25±0.34^{b}	9.58±0.48^{b}	7.63±0.34^{a}	< 0.0001
MCHC	28.73±0.67^{a}	34.86±0.47^{b}	35.77±0.95^{b}	34.29±0.88^{b}	< 0.0001
RDW	8.00±0.25^{c}	5.65±0.21^{ab}	5.21±0.28^{a}	5.80±0.27^{b}	< 0.0001
PLT	46.74±1.46	48.50±2.63	42.80±1.64	49.58±1.72	0.0862
MVP	6.10±0.22	5.12±0.18	5.38±0.31	5.68±0.37	0.1102
GRA	4.63±0.16^{c}	2.82±0.14^{a}	2.85±0.22^{a}	3.28±0.23^{b}	< 0.0001
LYM	88.49±1.84^{a}	103.8±2.97^{b}	110.2±2.47^{b}	109.9±2.98^{b}	< 0.0001
PCT	0.03±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.0898
MON	14.59±0.27	15.31±0.50	15.81±0.51	14.60±0.63	0.2552

Table 5 Variation in the kidney function test of blood of *C. gariepinus* fed different protein sources.

	FM	CPH	SBH	PKM	p-value
Creatinine	33.25±2.49	35.68±3.57	39.21±5.20	34.92±5.98	0.3945
Urea	2.89±0.24	2.79±0.26	3.00±0.15	3.00±0.19	0.8884
Sodium	168.7±8.44	159.5±19.77	157.4±21.43	159.5±19.63	0.4724
Potassium	5.16±0.36^{ab}	4.31±0.33^{a}	6.04±0.23^{b}	6.09±0.28^{b}	0.0005
Chloride	102.7±3.58^{ab}	109.2±11.31^{b}	95.41±6.06^{a}	99.05±11.10^{a}	0.0047

Liver function

Table 6 represents variations observed in the liver function of *C. gariepinus* fed different protein sources. AST and ALT levels were enhanced in *C. gariepinus* fed plant protein sources. The highest AST (121.7±6.71) and ALT (109.5±10.36) were observed in *C. gariepinus* fed diet CPH, with the least AST (82.13±4.77) and ALT (77.73±7.49) observed in *C. gariepinus* fed diet FM. Both AST and ALT were significantly different amongst groups (p = 0.0001 and 0.0140, respectively). There was no significant alteration in ALP (0.3750), irrespective of protein source. Feeding *C. gariepinus* with diet CPH recorded a GGT of 2.63±0.30, and was significantly higher than *C. gariepinus* fed diets SBH and PKM. In all cases, the highest concentrations of TB (0.93±0.11; p=<0.0001), DTB (0.69±0.12; p=0.0001), IDTB (0.35±0.07; p=0.0159) and TP (41.52±9.09; p=0.0002) were observed in *C. gariepinus* fed diet PKM. There was a significant difference in ALB levels among treatments (p=0.0039). It is worth noting that the highest concentration of ALB (16.42±3.42) was recorded in *C. gariepinus* fed diet SBH.

Table 6 Variation in the liver function test of blood of *C. gariepinus* fed different protein sources.

	FM	CPH	SBH	PKM	p-value
AST	82.13±4.77^{a}	121.7±6.71^{b}	114.4±12.54^{b}	109.2±7.18^{b}	0.0001
ALT	77.73±7.49^{a}	109.5±10.36^{b}	92.19±5.03^{ab}	82.0±3.30^{a}	0.0140
ALP	16.80±5.05	16.62±3.74	14.15±3.73	16.15±2.82	0.3750
GGT	2.00±0.30^{a}	2.63±0.30^{b}	1.54±0.15^{a}	1.81±0.18^{a}	0.0237
TB	0.48±0.04^{a}	0.40±0.03^{a}	0.64±0.05^{a}	0.93±0.11^{b}	<0.0001
DTB	0.29±0.02^{a}	0.26±0.02^{a}	0.43±0.08^{ab}	0.69±0.12^{b}	0.0001
IDTB	0.18±0.03^{a}	0.15±0.02^{a}	0.26±0.02^{ab}	0.35±0.07^{b}	0.0159
TP	31.40±4.59^{b}	27.18±8.83^{a}	38.61±6.63^{bc}	41.52±9.09^{c}	0.0002

ALB	13.35±3.49[a]	12.15±2.05[a]	16.42±3.42[b]	15.75±2.37[ab]	0.0039

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; ALP: Alkaline phosphatase; GGT: γ-glutamyl transferase; TB: Total bilirubin; DTB: Direct total bilirubin; IDTB: Indirect total bilirubin; TP: Total protein; ALB: Albumin

Intestinal histology

Table 7 and figure 1 summarizes changes in the mid-intestinal structures of *C. gariepinus* fed different protein sources. Villus height, villus width, and muscular thickness were significantly altered by protein source. The highest villus height was in fish fed diet FM (441.2±22.6), followed by SBH (398.3±7.51), PKM (279.2±15.65), and CPH (142.3±10.84). This pattern was also observed for villus width and muscular thickness, with the highest villus width (153.7±9.06) in fish fed diet FM, significantly higher than other groups ($p<0.0001$).

Table 7 Mid-intestinal histopathological examination of *C. gariepinus* fed diets with different protein sources

Item (*μ*m)	FM	CPH	SBH	PKM	p-value
Villus height	441.2±22.6[d]	142.3±10.84[a]	398.3±7.51[c]	279.2±15.65[b]	<0.0001
Villus width	153.7±9.06[b]	56.87±9.45[a]	69.42±3.65[a]	41.59±5.40[a]	<0.0001
Muscular thickness	114.2±2.925[d]	54.96±4.15[a]	96.28±5.23[c]	71.51±1.773[b]	<0.0001

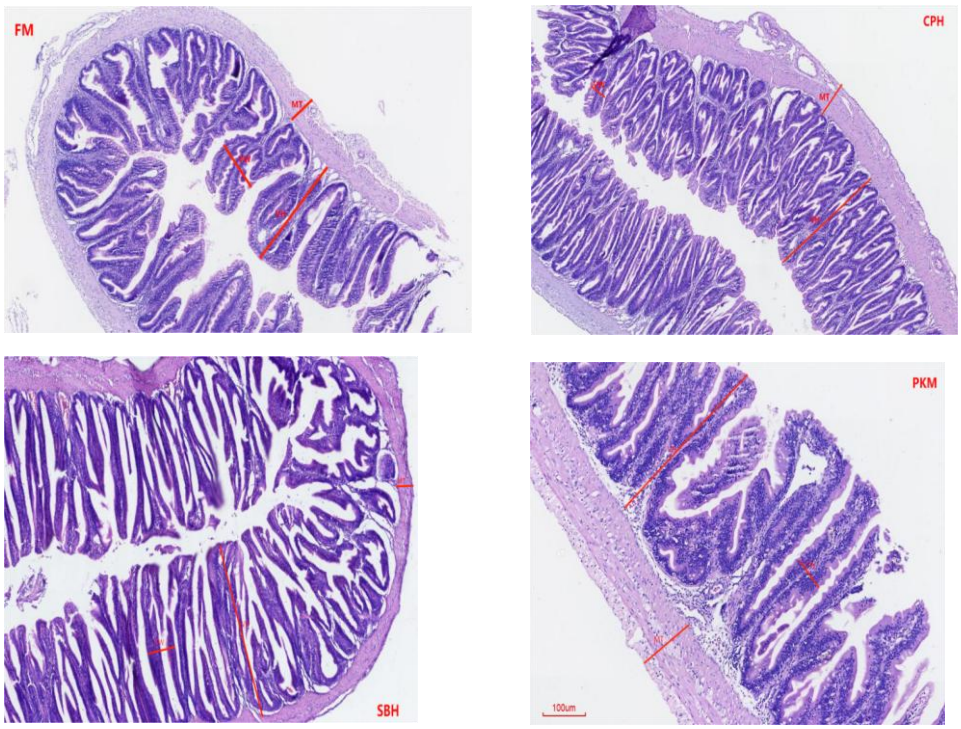

Fig 1. Morphological appearance of the mid intestines of *C. gariepinus* fed different plant protein diets (FM, CPH, SBH and PKM) under the light microscope. All photos were taken at 40X; the scale bar represents 100 μm.

Correlation between growth, feed utilization and serum biochemical parameters

Fig 2 shows correlation linear (R) Pearson correlation between growth, feed utilization and serum biochemical parameters. PDW correlated significantly with growth and feed utilization parameters. PDW correlated positively with FCR (0.005), and negatively with WG (0.024), ADWG (0.0247), PER (0.0247), and FW (0.0244). There was however no significant correlation between other serum biochemical parameters (WBC, RBC, HGB, HCT, MCV, MCH, MCHC, RDW, PLT, MPV, GRA, LYM and PCT) and growth performance, and feed utilization.

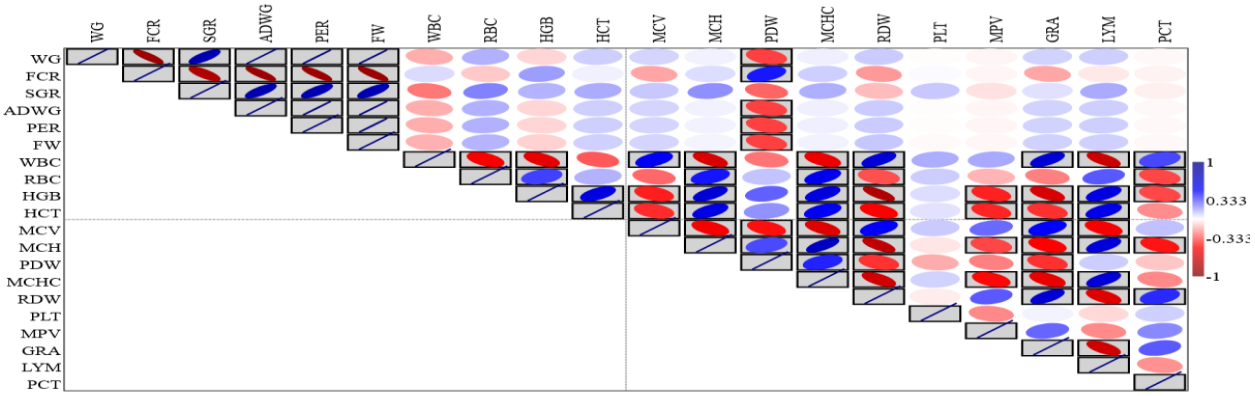

Fig 2. Correlation between growth, feed utilization and serum biochemical parameters

Correlation between growth, feed utilization and changes in intestinal morphology

Figure 3 shows correlation between growth, feed utilization and changes in intestinal morphology. No significant correlation was observed between intestinal structures (villi height, villi width and muscular thickness) and growth performance, and feed utilization.

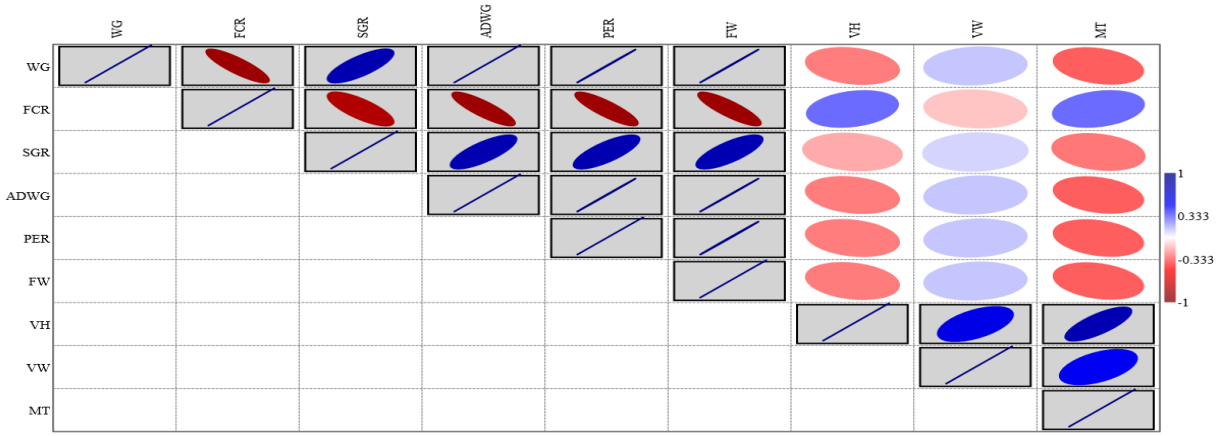

Table 8 shows P-values and R-values for Pearson correlation between intestinal structures and growth and feed utilization. There was a moderate positive correlation between villus width and ADWG (r = 0.4969, p = 0.1106), weight gain (r = 0.4969, p = 0.1106), and PER (r = 0.4969, p = 0.1106). Also, similar observation (moderate positive correlations) was observed between muscular thickness and ADWG (r = 0.0510), PER (r = 0.0510), and FW (r = 0.0516). Notably, villus height

showed negative, though non-significant, correlations with several parameters including weight gain FCR (r = 0.0748, p = 0.2886), (r = 0.1197, p = 0.2533), and SGR (r = 0.3180, p = 0.1641).

Table 8 P-values and R-values for Pearson correlation between intestinal structures and growth and feed utilization.

Parameter	P-value	R-value
Weight gain and Villus height	-0.25332	0.1197
Weight gain and Villus width	0.11059	0.4969
Weight gain and muscular thickness	-0.31467	0.0510
FCR and Villus height	0.28857	0.0748
FCR and Villus width	-0.11235	0.4900
FCR and muscular thickness	0.28831	0.0750
SGR and Villus height	-0.16413	0.3180
SGR and Villus width	0.08291	0.6110
SGR and muscular thickness	0.26546	0.1024
ADWG and Villus height	-0.25332	0.1197
ADWG and Villus width	0.11059	0.4969
ADWG and muscular thickness	0.31467	0.0510
PER and Villus height	-0.25332	0.1197
PER and Villus width	0.11059	0.4969
PER muscular thickness	0.31467	0.0510
FW and Villus height	-0.25491	0.1173
FW and Villus width	0.11103	0.4952
FW muscular thickness	-031388	0.0516

Weight gain (WG), feed conversion ratio (FCR), specific growth rate (SGR), average daily weight gain (ADWG), protein efficiency ratio (PER), and final weight (FW).

Discussion

Contrasting results have been reported with respect to the effects of substituting fish meal with plant-based protein in diets of different species (Cheng et al., 2010; Bu et al., 2018; Dossou et al., 2018; Al-Thobaiti et al., 2018; Egerton et al., 2020; Kari et al., 2021; Cai et al., 2022; Roslan et al., 2024; Serrano et al., 2024). This study reports that FL, FW, WG, SGR, ADWG and FCR were significantly altered by the source of protein, with *C. gariepinus* fed with CPH and SBH performing better. This is in agreement to previous studies that reported that substituting FM with plant-based meals did not compromise growth (Sheikhzadeh et al., 2012; Kpundeh et al., 2015; Guo et al., 2016). It is not surprising SBH performed better than the control diet and PKM. This is because soy products, with their high digestibility, high protein content, and well-balanced amino acid composition, have long been used as the most effective substitute for fish-meal in aquaculture diets (Macusi et al., 2023).

In order to estimate the amount of feed required for the fish's growth cycle, the feed conversion ratio (FCR) is a crucial metric for aquaculture farmers to calculate the activity's profit margin (Kari et al., 2021). Based on actual feeding practices, the FCR can be used to predict the feed cost (Roslan et al., 2024). The FCR (1.25±0.57) of *C. gariepinus* fed SBH diets was the highest.

This suggests that this group was able to utilize feed more effectively (Aglago et al., 2021). This finding suggests that the best course of action for African catfish future growth in the aquafeed industry may be to replace FM with SBH. Serrano et al. (2024) observed no significant alteration in PER when FM was replaced with Anean lupin in diets of Rainbow trout.

When introducing a new feed, it is crucial to investigate the proximate composition of body tissue (Rani et al., 2016; Roslan et al., 2024). There were no discernible changes in proximate composition of this study. The absence of a significant difference between the dietary groups implies that FM, CPH, SBH, and PKM were successfully incorporated into *C. gariepinus* diets to achieve nutritional balance. The non-significant differences in whole body proximate composition observed in this study is consistent with earlier findings that no appreciable changes in proximate composition were observed in summer flounder (Enterria et al., 2011) or blunt snout bream (Ahmed et al., 2019) fed varying protein sources. Similarly, there was no discernible change in the proximate composition of rockfish when plant protein sources were substituted for FM in their diets (Kim and Cho, 2024). Also, there was no significant alteration in the proximate composition of the whole body when *C. gariepinus* was fed diets with fish meal replaced by plant protein (Nasr et al., 2021). In contrast to this study, the proximate composition of pearl gentian grouper (Chen et al., 2019) and red drum (Minjarez-Osorio et al., 2016) changed when different plant-based protein sources were substituted for fish meal.

The age or size of the fish as well as the varying rates of nutrient deposition in tissues among various species are the reason for the variations observed in the effects of replacing FM with different plant-based proteins as reported in different studies (Mzengereza et al., 2022).

The activities of aminotransferases, such as γ-glutamyl transferase (GGT), aspartate aminotransferase (AST), and alanine aminotransferase (ALT), catabolize amino acids and transfer amino groups to α-keto acids. These processes also mirror the balance of amino acids in the diet (Cheng et al., 2010). AST and ALT are known to be important indicators for protein metabolism and/or ammonia excretion (Zhang et al., 2019). The transaminases (ALT and AST) and ALP catalyze trans-amination reactions to help the body metabolize other macromolecules and xenobiotics. They also regulate physiological functions. As a result, changes in their behavior enable the immediate detection of harm to the liver and kidney functions and serve as indicators of the organisms' ability to maintain the integrity of these tissues (*Bharti and Rasool, 2021*). As a result, we also looked at the enzyme activity (IU/L) of ALT, AST, and ALP in the serum of *C. gariepinus* that were fed diets varying in protein sources in this study. In this study, substituting fish oil with plant protein sources (Palm kernel meal, Soybean husk and Cowpea husk) resulted in an increase of AST concentration. This is in line with previous report by *Zhang et al (2020) which documented an increase in AST levels when fish meal was replaced with rapeseed meal* in diets for juvenile Asian red-tailed catfish (*Hemibagrus wyckioides*). Feeding *C. gariepinus* with plant-based protein diets led to an increase in both ALT and AST. The heightened levels of ALT and AST in these groups could potentially result from altered protein catabolism metabolism or hepatic cell membrane lysis, which allows these enzymes to seep into the fish's bloodstream (Bharti and Rasool, *2021*). *The hepatic cell's degeneration could be the cause of the rise in AST (Abalaka, 2013). These cytoplasmic serum enzymes are only released into the bloodstream following the damage that has been done to these cells (Jafarpour, and Fard., 2016).* Elevated levels of ALT and AST in the plasma are indicative of liver impairment and cellular or hepatocellular damage resulting from

anti-nutritional factors (ANFs) present in plant-based ingredients in the liver, heart, or muscle (Kari et al., 2021).

Contrary to this study, Cai et al. (2022) observed no significant differences in the concentration levels of TP when gibel carp were fed diets with different protein compositions. The increase in total protein as observed in *C. gariepinus* fed SBH and PKM could be due to an increase in the non-specific immune response (Mohamad and Abasali, 2010). When diagnosing different liver and kidney diseases, albumin is required. Albumin, the most prevalent protein in blood plasma, serves as a transporter for a variety of compounds in circulation, thereby maintaining the health of the body (van de Wouw and Joles, 2022). In this investigation, ALB levels were raised when *C. gariepinus* was fed SBH and PKM. However, *C. gariepinus* fed CPH showed a marked decline. As noted by Andrews et al. (2011), a decrease in some essential plasma levels may be the cause of this drop in ALB levels.

In this study, feeding *C. gariepinus* with plan-based protein generally led to hyperbilirubinemia blood conditions. An obstruction of the bile ducts is most likely the cause of the hyperbilirubinemia (Bharti and Rasool, *2021*). The haematological variable known as gamma-glutamyltransferase (GGT) enzyme is clinically measured as a biomarker for liver health (Rastiannasab et al., 2016). GGT modifies and breaks down movable proteins. The ability of *C. gariepinus* fed diet CPH to catalyze the transfer of glutathione's gamma-glutamymoiety to an acceptor, which could be an amino acid, peptide, or water, may be explained by the higher GGT content seen in this group (Adamu and Nwadukwe, 2013).

Haematological variables such as white blood cells (WBC), red blood cells (RBC), hemocrit (Hct) and hemoglobin (Hb) are increasingly being used to monitor fish health (Maftuch, 2018). WBC in blood aid in an organism's immune responses; RBC controls the amount of oxygen delivered to bodily tissues; Hb is essential for metabolism; and haematocrit (Ht) establishes the volume of RBC (*Esmaeili, 2021*). According to Fagbenro et al. (2010), blood analysis is an important indicator for assessing the physiological condition of cultured fish as well as the effects of diets and other stressors on the health of fish. Hematological test results can be impacted by food, feeding schedule, age, sex, and environmental factors (Teixeira et al., 2000; Ibrahim et al., 2022). The assessment of various physical conditions in fish is frequently done through hemato-biochemical studies (Pradhan et al., 2012; Sharmin et al., 2016; Jahan et al., 2019; Billah et al., 2022; Howlader et al., 2023). Feeding *C. gariepinus* with plant protein sources (CPH, SBH, and PKM) led to lower levels of RBC. This is in agreement with a previous report that suggested that higher levels of soybean meal fed to beluga lowered RBC (Hosseini and Khajepour, 2013). *C. gariepinus* fed diet SBH recorded the highest HGB in the blood. Better oxygen transport in tissues leading to improved growth may be the cause of the highest level of HGB seen in C. gariepinus fed diet (Esmaeili, 2021; Hossain et al., 2022; Howlader et al., 2023). One of the most important indicators of fish health is WBC count (Khieokhajonkhet et al., 2023). In this study, feeding *C. gariepinus* with plant-based protein lowered WBC levels in the blood and could be inferred to have compromised the cellular defense of *C. gariepinus*. According to Clauss et al. (2008), an increase in WBC counts within the normal range indicates that fish have stronger cellular defenses against infections. There was significant alteration on levels of HGB, HCT, MCHC, MCV, and MCH in this study. This is contrary to earlier report that documented no significant differences in theses parameters when fish meal was replaced with kernel meal and sunflower meal (Kumar et al., 2010; Rahmdel et al.,

2018). Replacing FM with SBH, CPH and PKM significantly altered HCT levels. This indicates that *C. gariepinus* suffered negative effects when FM was substituted with these plant protein sources because higher hematocrit values are thought to pose a risk to farmed fish's health (Hardy, 2010). However, as previously noted by Lall and Kaushik (2021), the lower level of haematocrit seen in *C. gariepinus* fed FM diet is indicative of the inhibitory impact of phytate and glucosinolates on the bioavailability of important minerals for cell synthesis, such as iron and zinc.

The hemoglobin level in each red blood cell is known as the mean corpuscular hemoglobin concentration (MCHC), and it can be used to measure animal anemia (Habotta et al., 2022; Zakaria et al., 2022). A MCHC value of less than 28 g/dL frequently denotes anemia. All groups' MCHC values in this study ranged from 28.73 to 35.77 g/dL, indicating that none of the experimental fish were anaemic. There was an increase in MCHC and MCH levels in *C. gariepinu* fed plant-based diets. Elevation of MCH, a hemoglobin marker in erythrocytes, and MCHC suggest that feeding *C. gariepinus* plant-based diets may affect hematopoiesis and damage red blood cells in circulation (Hassan et al., 2023). The highest mean corpuscular volume (MCV) content was observed in *C. gariepinus* fed FM diet. This may be due to the inhibition of erythropoiesis which to a larger extent is confirmed by the least RBC observed in this study (Ahmed and Ahmad, 2020).

In this study, there was no significant difference in levels of creatinine and urea and is similar to previous report by Nasr et al. (2021). With the exception of ALP ($p= 0.3750$), all other parameters were significantly different. In this study, substituting fish oil with plant protein sources (palm kernel meal, soybean husk and cowpea husk) resulted in an increase of AST concentration. This collaborates with previous report by Zhang et al (2020) which reported an increase in AST levels when fish-meal was replaced with rapeseed meal in diets for juvenile Asian red-tailed catfish (*Hemibagrus wyckioides*). The hepatic cell's degeneration could be the cause of the rise in AST (Abalaka, 2013). These cytoplasmic serum enzymes are only released into the bloodstream following the damage that has been done to these cells (Jafarpour, and Fard., 2016). Contrary to this study, Cai et al. (2022) observed no significant differences in the concentration levels of TP when gibel carp were fed different diets with different protein compositions. In this study, there was a decrease in GGT concentration when C. Gariepinus was fed SBH and could imply healthy liver. This is because, a decrease in Gamma-glutamyl transferase (GGT) concentration in plasma may have a positive impact on liver health (Bongiorno et al., 2022).

A metabolic waste product excreted with urine, creatinine levels rise in blood when renal malfunction occurs (Bharti and Rasool, 2021). Elevated levels of urea and creatinine may be caused by decreased kidney clearance or renal tissue breakdown, glomerular dysfunction, or both (Amin and Hashem, 2012). In this study, there was no significant elevation of urea and creatinine levels and signify no renal malfunction. The non-significant effects of different protein sources on creatinine levels observed in this study is comparable to previous report by Ismail, et al. (2020) when fish mean was replaced with soybean or/and corn gluten meal in Nile tilapia (*Oreochromis niloticus*) diets.

When introducing a novel feed, it is important to evaluate the length and width of the villus in order to gain an understanding of the processes involved in the digestion and absorption of proteins (Roslan et al., 2024). During feeding trials, the histological structures of the digestive organ are assessed to provide crucial information on the fish's capacity to digest food as well as potential health effects of the

new diets (Dzifa et al., 2022). The measurement of intestinal villi height, muscle layer thickness, and goblet cell count are used to assess the health of the intestines, including absorptive capacity and digestive functions (Khojasteh, 2012; Pirarat et al., 2011). A decrease in the height and width of intestinal villi as well as muscular thickness as observed in fish fed CPH, SBH as well as PKM diets may indicate a reduction in the digestive tract's absorption area and nutrient absorption (Mahmoud et al., 2020). The reduction in VH, VW and MT as observed in this study may also be attributed to the presence of anti-nutritional factors in the plant-based protein sources which could lead to lots of deteriorations in intestinal morphology (Zhang et al., 2013). The reduced villus length as observed in *C. gariepinus* fed diets CPH, SBH and PKM as compared to FM could imply the inability of *C. gariepinus* to adapt and protect the guts as a response to the anti-nutritive factors in plant-based protein sources (Mzengereza et al., 2020). The perceived lower nutrient absorption did not correlate positively with growth and nutrient utilization and call for further studies to elucidate the clear relationship. This study is in agreement with previous studies that reported decrease in villi height and width when FM were replaced with plant-based protein sources (Roslan et al., 2024). On the contrary, earlier reports showed that substituting FM with plant-based protein in diets of fish resulted in an increase in the length of villus (Ur´an, et al., 2008; Bansemer et al., 2015; Matuli´c et al., 2020). Kari et al. (2021) observed that histopathological changes of the intestines may vary depending on the feed utilized in the experiments and the species under consideration and that might have accounted for the variation in impacts of diets in different studies. The correlation analysis of the histological structures of the intestines and growth, and feed utilization observed in this study did not have any influence on growth and feed utilization.

Conclusion

This study concludes that inclusion of soybean husk as alternative protein sources had significant positive effect on growth performance or feed utilization compared to fish meal diet. Also, feeding *C. gariepinus* with plant-based protein sources significantly altered haematological parameters, function of the liver and kidney. Histological examination, also, indicated significant modifications in tissue morphology, pointing to possible metabolic adjustments to the novel dietary formulations. All things considered, adding PKM, CPH, and SBH to catfish diets as protein sources seems like a viable replacement for conventional fishmeal-based diets; however, more study is required to determine the ideal levels of inclusion for optimum development and well-being as well as their comprehensive effects on health and nutritional composition of fish.

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INVESTIGATION INTO THE SOURCE OF SALINITY IN WATER SAMPLES FROM A COASTAL AQUIFER. CASE STUDY NINGO-PRAMPRAM AREA, SOUTHERN GHANA.

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Abstract

To contribute towards understanding the state of coastal groundwater resources in Ghana, this study employs field sampling, laboratory analysis, statistical and geochemical analysis to reveal the possible sources of mineralization/salinization in an unconfined gneissic aquifer in the eastern part of the Accra, Ghana. To do this, samples from 16 groundwater sources 11 shallow hand dug wells and 5 deep boreholes were sampled and analyzed for physical and chemical parameters. Ionic ratios involving chloride and other ratios (Ca2+/SO42- , Ca2+/Mg2+, Ca/(HCO3+SO4)), scatter plots: Ca/(HCO3+SO4) and Na+/Cl- were employed to understand possible contribution of the sea to groundwater salinization. Geochemical tools were employed to understand various mechanisms responsible for salinization and hydrochemical water types. Results indicated that groundwater in the study area is saline with average EC values > 1mS/cm and water hardness ranging from moderately hard water to very hard water. The dominant ions (Na, Ca, Cl and HCO3) are implicated as the major determinants of mineralisation. Ionic ratios > 1 for Ca2+/SO42- , Ca2+/Mg2+ and Cl/HCO3 and low ratios (<1) for SO42-/Cl-, K+/Cl-, and Mg2+/Cl- indicate seawater in the aquifer. Observed hydrochemical water types: Na-Ca-Cl-HCO3, Na-Ca-Cl, Na-Cl and Na-Cl-HCO3 confirm the influence of seawater in the aquifer. Base ion exchange processes influence the groundwater chemistry of almost all the samples (93.8%). Seawater intrusion in deep groundwater sources inferred from high mineralization of deep groundwater (depth > 20 m) and high average Seawater mixing Index (SMI) of 1.2 in boreholes. Silicate weathering, evaporite dissolution and wastewater infiltration are additional processes contributing to salinization of the aquifer.

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Introduction

The crucial role groundwater resources play in the socio-economic development of many communities and settlements scattered across the World is indicated by the large number of countries that rely on aquifers for both rural and urban water supply. It is estimated that over 2.5 billon people worldwide (Shaji et al., 2021) out of the 8 billion people depend on groundwater as their sources of water for many uses including drinking.

In spite of its importance, groundwater available for many of its uses is under threat from poor quality and declining water table. Generally, natural and anthropogenic influences have been implicated for the poor groundwater quality worldwide (Rakib et al., 2022, Li et al., 2020), whereas the transient groundwater levels (rising and declining) in aquifers have been attributed to global warming (Visvalingam et al., 2024, Ostad-Ali-Askari et. al., 2019, Salimi et al., 2021). It is open knowledge that population growth coupled with increment in economic activities results in high demand for resources (e.g. Zhang et al., 2020) including water for its various uses.

As a result of rapid urbanization and industrialization within coastal areas (Visvalingam et al., 2024) a substantial fraction of the World's population live along coastlines (Wang et al., 2021, Kummu et. al., 2016, MacManus et al., 2021) which are regions stretching distances less than 100 km from the Coast (Idowu & Lasisi, 2020). Moreover, populations in these areas have been projected to increase (Maul & Duedall, 2019) in the coming years indicating a rise in water demand in these coastal regions. In many cases, coastal regions with high population densities rely on aquifers for their water needs (Basack et al., 2022), and indicate the importance of groundwater as a scarce freshwater resource in coastal communities (e.g. Ayeta et. al., 2024).

Major environmental challenge associated with groundwater use in coastal areas is the poor water quality due to high salinity and contamination by nutrients and heavy metals together with microbial pathogens from anthropogenic sources; domestic and industrial wastewater and agricultural practices (Alorda-Kleinglass et al., 2024' Boumaiza et al., 2023; Malki et al., 2017, Ayeta et al., 2024, Lutterodt et al., 2021). Both the quality and quantity of groundwater available for use are affected by natural and anthropogenic influence including climate change (Rakib et al., 2022; Li et al., 2020, Macrae et al., 2013; Ostad-Ali-Askari et. al., 2019; Salimi et al., 2021).

Salinity is a measure of the total dissolved solids in water (Li et al., 2020) and is quantified by both the Total Dissolved Solids (TDS) in groundwater and its dependent physical quality parameter, the Electrical conductivity (EC). High salinity causes water shortage in coastal areas limiting availability of water for various purposes, and therefore affect the development of such areas (Wen et al., 2019). Both EC and TDS show groundwater affected by salinization (Jeen et al., 2021; Park et al., 2012; Rabinove, 1958). Salinization may be caused by seawater intrusion, evaporite dissolution, and wastewater infiltration. Jeen at al. (2021) and Rabinove (1958) have, respectively, indicated that EC values > 1 mS/cm and TDS > 1000 mg/l show groundwater affected by seawater intrusion and salinization.

In addition, water hardness is also used to infer mineralisation of groundwater. Water hardness is directly quantified based on magnesium and calcium content in water, and generally classified by the method of Sawyer and McCarthy (1967). From the classification, water hardness values of between 75-150 mg/l is considered moderately hard water, and 150 -300 mg/l r and water with hardness > 300 mg/l are considered as hard water and very hard water, respectively. According to Li and co-workers (2020), more than 1 billion people in the world live in areas affected by saline

aquifers. Salinizations of coastal aquifers are caused by Seawater Influence (SWI) through two important processes; seawater intrusion and atmospheric sea aerosol deposition (Ganyaglo et al., 2017; Motevalli et al., 2018; Meira et al., 2007). Seawater intrusion is the lateral movement of seawater into fresh groundwater on the coast. The mechanisms and processes controlling seawater intrusion have variously been reviewed (Prusty & Farooq, 2020; Li et al. 2020). The reviews and other works published in the literature points out to natural and classical factors: e.g. hydraulic gradient and hydraulic connection between the sea and the coastal aquifers which are basic requirements for inland movement of seawater and local geological controls of groundwater occurrence (Prusty & Farooq, 2020), in addition to global climate change and se-level rise. Sea aerosol deposition is also an important source of groundwater salinity in coastal aquifers, and are generated and transported by wind blowing towards land (Marks, 1990; Fitzgerald, 1991; Gong et al., 1997) and show their importance and contribution to the salinization of coastal aquifers. .

Improper water management practices, mainly over exploitation/abstraction of groundwater from coastal aquifers is an important factor causing seawater intrusion (Telahigue et al. 2020a). High groundwater abstraction duet to population growth has been implicated by many researchers as a contributor to seawater intrusion into coastal aquifers (van camp et al., 2014, Manivannan and Elango, 2019). The process of over abstraction leads to a drop in fresh groundwater levels and reverses the hydraulic gradient causing inland movement of the sea. (Telhagigue tet al., 2018b).

Apart from indirect geophysical methods employed in the study and assessment of seawater intrusion (e.g. Asare et al., 2022), hydrochemistry and Hydrogeochemical methods (Telahigue et al., 2020a, b, Telahigue et al., 2018a, 2018b, Sunkari et al., 2021, Argamasilla et al., 2017, Abdalla, 2016, Rajendiran et al., 2021) have proved to be valuable in understanding the source of salinity in coastal aquifers. Due to the high chloride concentration in seawater and its unique tracer characteristics in groundwater environments, ionic ratios involving the ion has widely been used to assess seawater intrusion into coastal aquifer (Telahigue et al., 2018a,b , 2020a, Jampani et al., 2020, Slama & Bouhlila, 2017), with especially Br/Cl as an important indicator of seawater influence (Senthilkumar & Gnanasundar, 2021, Nair et al., 2016) due to the uniform concentrations of Br^- and Cl^- in seawater (Custodio & Herrera, 2000) and their good characteristics as tracers in groundwater environments (Acala & Custodio, 2008, Davis et al., 2004).

At present, more than 100 countries and regions in the world are threatened or affected by seawater intrusion ; Adyasari et al., 2019) Similarly in Ghana, there is growing evidence of the influence of the sea on groundwater in the coastal regions (Ganyaglo et al.2017, Lutterodt et al. 2021, Osiakwan et al., 2021, Asare et al., 2021, Darko et al., 2022), with the reasons for salinization unclear. Lutterodt et al. (2021) and Asare et al (2021) attribute their observations to seawater intrusion, whereas Ganyaglo et al. (2017) link their findings to sea aerosol deposition. Even though research into water has focused on groundwater in general, not much attention has been given to coastal aquifers (Ayeta et al. 2024). The Ningo-Prampram area is a coastal municipality in the Greater Accra Region of Ghana. The area is undergoing rapid urbanization, and evidenced by the rapid population growth in recent years (Obeng et al., 2015). Major climatic impacts have been reported in the area; both socio-economic and physical impacts due to sea level rise have been reported with coastal inundation and submersion, collapse of buildings due to the force of the sea and seawater intrusion (Darko et al., 2022). The forces of waves physically impact the coast, and frequently rise to greater heights

(Appeaning, 2011). Like many other communities in the country, the area suffers from irregular water flow in their pipes and tends to rely on other sources including groundwater (Ningo Prampram District Assembly Composite Budget Report 2023). To contribute towards understanding the state of coastal groundwater resources in Ghana, this work employs field sampling, laboratory analysis, statistical and geochemical analysis to reveal the possible sources of mineralization in the costal aquifer of the Ningo-Prampram area in the eastern part of Accra, the capital of Ghana. The objectives of this study include the use of: physical water quality property EC/TDS and TH values to assess the salinization/mineralization of groundwater in the study area, ionic ratios involving chloride (Telahague et al., 2018, 2020, Jampani et al., 2020, Slama & Bouhlila, 2017) and other ionic ratios (Ca/SO_4 , Ca/Mg, $Ca/(HCO_3+SO_4)$), scatter plots: $Ca/(HCO_3+SO_4)$ and Na/Cl to understand possible contribution of the sea to groundwater mineralization/salinization, geochemical tools to understand various mechanisms responsible for mineralization/salinization.

Methods

Study Area

Ningo and Prampram are two neighbouring peri-urban settlements located within the Ningo-Prampram district in the south eastern part of Accra plains of the Greater Accra Region of Ghana. The area is bordered on the south by the Atlantic Ocean (Figure 1). The area is characterised by coastal grassland and scrub vegetation interspersed with baobab trees. Relief is generally low, and slopes towards the sea with heights ranging from 5 m below sea level to about 60 m. The climate is characterized by two rainfall maxima. The major rainy season occurs between May and July and the minor wet season occurs between September and November. Mean annual rainfall ranges between 700 mm in the southern part of the district and increases to 1220 mmm in the Northern part with mean annual rainfall of 900 mm. The mean temperature is 26 C. (Dickson and Benneh, 1980). The Ningo-Prampram area forms part of the southeastern section of the Accra plains which are underlain by the Precambrian Dahomeyan rocks and the Togo formations. Migmatites and bands of acidic and basic gneisses and, quartzites, phyllites and schists, respectively form the Dahomeyan and Togo formations (Kesse, 1985). Groundwater occurrence in the Accra Plains restricted to discontinuities in the formations (Foppen et al., 2020). Near surface groundwater (depths < 10 m) is mainly controlled by weathering, weathering; the acidic rock types of the Dahomeyan weather to slightly permeable calcareous clay whereas the basic rocks weather
to impermeable clay (Junner & Bates 1945) . Aquifers in the weathered zone can extend up to 25 m (Kortatsi, 2006), and are either semi-confined or unconfined (Foppen et al., 2020, Kortatsi, 2006).

Groundwater recharge in the plains is by rainfall (Kortatsi, 2006). Drainage pattern in the area is dendritic, the Akwapim Togo ranges which bounds the plains in the North is the source of rivers in the area. Surface water draining the area is the Dawhenya / Gyrokorgyor River which takes its source near Afienya. Sections of the river are silted due to their use as refuse dump (AFDB, 2008). The general pattern of drainage in the Ningo-Prampram district is dendritic with most of the streams taking their source from the Akwapim range which also serves as a watershed and flows in a northwest to southwest directions into lagoons on the coast. The people mainly practice Fishing and Trading in addition to farming. Water supply in the Ningo and Prampram area follows similar trends of unreliable water supply in other parts of the country (Obeng et al., 2015), communities within the district therefore rely on other sources for water, e.g. protected and unprotected boreholes, hand dug wells and springs, rivers and streams. They mostly rely on on-site

sanitation facilities to manage their excreta (Obeng et al., 2015).

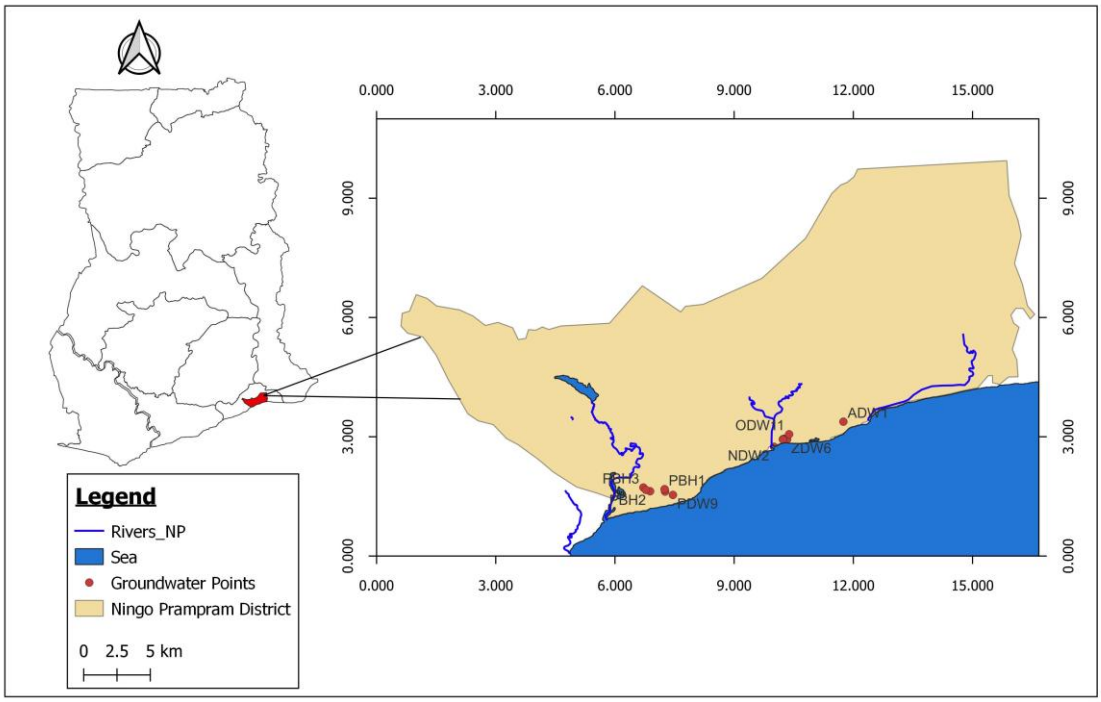

Figure 1: Location map of the Ningo-Prampram area showing groundwater points

Field Sampling

Physico-chemical water quality field work was undertaken in December 2023 to characterise the hydrochemistry. Physical parameters: EC, TDS and pH were measured on site. TDS and EC were measured using a conductivity meter Cond340i (WTW GmbH, Weilheim Germany) calibrated at 25 ˚C and pH was determined using a pH meter pH340i (WTW GmbH, Weilheim Germany). Sixteen (16) groundwater points made up of 5 boreholes (BH) and 11 shallow hand dug wells (HDWs) were sampled for physical quality and hydro chemical characterisations of the aquifer. Two samples each of volume 250 mL were taken and filtered through through 0.45 µm cellulose acetate filter (Whatman), into separate polystyrene bottles for major ion analysis. Samples for major cations (Na, Ca^{2+}, Mg^{2+}, K^{+}) were acidified with 3 drops of HNO_3 acid. All samples were placed in a cool box containing ice and transported to the laboratory of the National Nuclear Research Institute (NNRI) of the Ghana Atomic Energy Commission for hydrochemical analyses.

Laboratory Analyses

The concentrations of the cations Na^{+}, K^{+}, Mg^{2+} and anions SO_4^{2-} and NO_3^{-} were determined using Shimadzu Ion Chromatograph LC-20AD SP. Other parameters (Total hardness, Chloride and calcium concentrations) were determined via the use of analytical protocols described in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

Total hardness (TH) and Ca^{2+} amounts in the samples were titrimetrically determined using 25 ml of sample with a standard EDTA (Ethylene diamine tetra acetic acid) of concentration 0.01M. Ammonium buffer

and Eriochrome Black T (EBT) were used in TH determination whiles 1M NaOH solution and murexide indicator were used in Ca^{2+} determination and results expressed as mg/L. Chloride (Cl^-) ion content was determined argentometrically using 25 ml of sample with 0.0141M $AgNO_3$ (silver nitrate) as titrant and potassium chromate (K_2CrO_4) as the indicator and the result reported in mg/L.

Data Analyses

Statistical summary, correlations between water quality parameters, piper plots and Ionic ratios

Mixing with seawater, cation exchange processes, dissolution and precipitation reactions and wastewater infiltration are some of the processes known to influence salinity in groundwater. To identify possible mineralization processes of groundwater , a number of tools including statistical analysis; Statistical summary and correlation between chemical parameters involving relationship between Chloride as a tracer, EC and other water quality parameters, Piper's diagram (Piper, 1944), Chadha's diagram A plot between (Ca + Mg) − (Na + K) and $HCO_3 - (SO_4 + Cl)$ applied to reveal the source of salinization in groundwater and gives four possible sources i.e. re-charge water (Ca-HCO_3 type), reverse ion exchange (Na-HCO_3-type), seawater effect (Na-Cl type) and Base-ion exchange (Ca-Mg-Cl type) (Chadha, 1999).

Ionic ratios, mainly ion/chloride ratios and other ratios, scatter plots of Na^+/Cl^- vrs $Ca^{2+}/ (HCO_3^{2-}+SO_4^-)$ (Abdalla, 2016) and Na normalized molar ratios after Gaillardet et al., (1999) are used to characterized water samples, understand the various geochemical processes occurring, reveal the dominant ion exchange processes and understand the sources of ions in the aquifer. Scatter plot of Cl^-/HCO_3^- as a function of chloride concentration is applied to understand the possible effect of seawater on groundwater samples from the wells.

Seawater Mixing Index

A modified form of the Seawater Mixing Index (SMI) by Sinclair (1974) and Park et al. (2005) was employed to evaluate the degree of mixing of groundwater and seawater (Bhagat et al., 2021, and Park et al., 2005). The SMI is based on the concentrations of four major ionic components (Na, Cl, Mg and SO4) in Ocean and given by the equation below:

$$SMI = a\frac{C_{Na}}{T_{Na}} + b\frac{C_{Mg}}{T_{Mg}} + c\frac{C_{Cl}}{T_{Cl}} + d\frac{C_{SO_4}}{T_{SO_4}} \quad (1)$$

where the a, b, c, and d, are constants and reflect the relative concentration proportion of Na^+, Mg^{2+}, Cl^-, and SO_4^{2-} in seawater, respectively (a=0.31, b=0.04, c=0.57, d=0.08); C is measured concentration (mg/l), T is the regional threshold values of the respective ions. In this work, T is determined by plotting ionic concentrations (mg/l) against cumulative probabilities. The cumulative probability curves are fitted with a third order polynomial, points of inflection are obtained by the second differential of the concentration with respect to the cumulative probability to obtain the T values. SMI value > 1 indicate seawater mixing with groundwater.

Chloro-alkaline Indices

Possible occurrence of base ion exchange between groundwater and the solid rock was assessed by using the chloralkaline indices which involves two equations:

$$CAI - I = \frac{Cl - (Na + K))}{Cl} \quad (2a)$$

$$CAI - II = \frac{Cl - (Na + K)}{(SO_4 + HCO_3 + NO_3)} \quad (2b)$$

Direct base ion exchanges of Na^+ and K^+ in the fluid phase with Ca^{2+} and Mg^{2+} in the solid rock is inferred when the CAI-I&II values are negative, for positive values, the exchange occurring is reverse and indirect

(Schoeller, 1965, Zhang et al., 2021, Mahmoudi et al., 2017).

Results and discussions

Physical parameters

Statistical summary of measured water quality parameters for hydrochemical characterisation are presented in Table 1. EC values ranged from 842.0 µS/cm to 10.78 mS/cm with a mean of 2,693.8 µS/cm, TDS 463. 5 to 5929.0 mg/l mean 1481.5 mg/l, mean values of EC and TDS are comparatively higher in deep groundwater, i.e. BH (5.3mS/cm and 2917 mg/l) than in shallow HDWs (2.85 mS/cm and 1567 mg/l), four boreholes and a HDW recorded TDS values higher than the maximum of 1500 mg/l for fresh water (Rabinove, 1958). Results of average concentrations of anions, cations and values of physical quality parameters (TDS, TH and EC) implies that groundwater in the study area is mineralised, with higher mineralisation in deep groundwater compared to water samples from shallow hand dug wells (Table 1) The higher average EC/TDS values can be attributed to the influence of the sea due to the nearness of the groundwater sources (HDWs and BHs) to the sea. Both EC and TDS values have been used as indicators of salinization (Jeen et al., 2021, Park et al., 2012, Rabinove, 1958) EC values > 1 mS/cm may reflect Seawater intrusion into coastal aquifers (Jeen et al., 2021), in this work, the EC of all groundwater sources were > 1mS/cm with the exception of two shallow HDWs with values < 1 mS/cm (ECs of 0.98mS/cm and 0.84 mS/cm, for wells KDW 10 and ZDW8, respectively) and can be considered as fresh based on the classification of Park et al. (2012). Average values of TDS in both groundwater sources (> 1000 mg/L, Table 1) confirms the salinization of groundwater according to the classification by Rabinove, (1958). High values of the EC and TDS in the boreholes can be attributed to the intrusion of high-density seawater at lower levels in the aquifer in addition to the possibility of long residence time of groundwater in deeper levels. The assertion of SWI is attributable to the high average concentrations of anions and cations, and also higher TDS/EC and TH in deep groundwater sources (BHs) compared to shallow groundwater (HDW). This points out to the possible inflow of dense seawater at lower depths into the aquifer through forced convection due to groundwater over exploitation (Vallejos et al., 2020, Vengosh and Rosenthal, 1994.). Groundwater conditions showed neutral to near alkaline with pH varying between 7.85 to 8.99 and an average of 8.53. Average pH in HDWs and BHs are respectively, 8.6 and 8.3. The alkaline nature of groundwater in the area has been observed within similar coastal aquifers (e.g. Moorthy et al., 2024, Bourjila et al., 2024, Lutterodt et al., 2021, Abdalla, 2016). In the current work, the near neutral to alkaline nature of groundwater is attributable to the possible inflow of seawater (Lutterodt et al., 2021), dissolution of seashells and calcareous materials within the beach sands in addition to the possible infiltration of wastewater from the surface.

Total Hardness (TH) values were between 112.1 mg/l to 1232.3 mg/l and a mean of 373.7 mg/l. Computed average TH is higher in BH (544 mg/l) than in HDW (296 mg/l). Based on classification of water hardness (Sawyer and McCarthy, 1967), hardness test for samples from all 5 BHs and one HDW (43.8%) indicated very hard water (i.e. TH> 300 mg/l). For the rest of the HDWs, three (18.8%) are moderately hard (75-150 mg/l), Six (6). 37.5% hard water (150-300 mg/l). The observed hardness can be attributed to high concentrations of Ca and Mg from seawater.

From the EC/TDS values and TH it is concluded that all groundwater sources are mineralised, with hardness water ranging from moderately hard water to very hard water. Mineralistaion is higher in deep groundwater than hand dug wells.

Ions contributing to salinization/mineralization

From Table 1, it can be concluded that the order of concentration of anions and cations, respectively, follow Cl^{-}> HCO_3^{-}> PO_4^{2-} >NO_3^{-}>SO_4^{3-} and Na^{+}>Ca^{2+}>Mg^{2+}>K and show high chloride and sodium content in water samples. Generally, average concentrations of the ions are higher in BHs compared to the shallow HDWs. The high Na^{+} and Cl^{-} content can be attributed to the proximity of the wells to the sea (Telahagiue et al., 2018a, Nair et al., 2020) note that all groundwater points sampled are at short distances from the sea (< 2 km). A number of workers (e.g. Telahigue et al., 2018a, b, Bhagat et al., 2021) have linked the abundance of Na and Cl in groundwater in coastal aquifers to seawater intrusion. The observed wide variation in Cl (mean 428.8, SD 564.3) and Na (Mean 270.8, SD 334.3) in shallow groundwater (HDW) compared to the deeper boreholes (BH) (Na: mean 769.4, SD 265.7, Cl: mean 1181.8, SD 455.9) (Table 1), may indicate additional sources of Cl^{-} and Na^{+} input apart from direct seawater influence. Silicate weathering (Shin et al., 2020) and possible leachate of wastewater from improper wastewater management facilities e.g. sullage drains and rubbish dumps may be the additional sources of ion input into shallow groundwater (e.g. Jeen et al., 2021). In addition, the overall strong correlation between Na^{+} and Cl^{-} ($r = 0.99$) is an indication that two ions are released from sources with equivalent concentrations of the two ions (e.g. halite, seawater, domestic salt). High standard deviations of Na^{+} and Cl^{-} in HDWs indicate shallow groundwater chemistry in the study area may be affected by additional factors including rock weathering (Shin et al., 2020) and infiltration of wastewater from on-site sanitation facilities (Lutterodt et al., 2021).

Table 1: Statistical summary of physical and chemical quality parameters of samples from groundwater points:(Hand dug wells (HDW) and Boreholes (BH). All units in Mg/l unless given

			HDW				BH		
Parameters	**min**	**max**	**Mean**	**SD**	**min**	**max**	**mean**	**SD**	**Average (HDW and BH)**
EC (µS/cm)	842.8	2850.0	1568.4	655.9	2450.0	10780.0	5304.0	3291.6	2735.7
TDS (mg/l)	463.5	1567.5	862.6	360.7	1347.0	5929.0	2917.0	1810.6	1504.6
pH (-)	8.1	9.0	8.6	0.3	7.9	8.5	8.3	0.3	8.5
Ca	32.1	346.3	82.7	89.6	121.5	223.8	164.2	42.9	108.2
Mg	4.8	89.2	22.0	23.1	17.3	51.4	32.1	13.4	25.2
Na	48.3	1242.3	270.8	334.3	396.5	1100.0	769.4	265.7	426.6
K	0.9	3.8	2.4	1.0	2.7	3.6	3.1	0.4	2.6
Cl	106.0	2099.0	428.8	564.3	499.9	1736.2	1181.8	455.9	664.1
NO_3	7.2	69.5	36.4	19.4	23.3	53.0	42.3	12.0	38.2
PO_4	28.5	189.8	73.5	48.1	79.0	123.0	96.3	18.4	80.6
HCO_3	84.0	648.0	239.7	161.8	306.0	444.0	379.0	51.6	283.3
TH (mg/l)	112.1	1232.3	296.3	316.3	395.2	630.8	544.1	92.7	373.7
SO_4	7.1	47.4	18.4	12.0	19.7	30.8	24.1	4.6	20.2

The concentrations of HCO_3^{-} and Ca^{2+} ions as the second dominant ions in the aquifer can be attributed to fresh groundwater recharge, in addition, the presence of calcareous shells in the aquifer might have contributed to the HCO_3 in the samples, a similar observation was made by Raja and Co-workers (2021) In addition, seawater is known to contain higher concentrations of the two ions. The strong correlation (r = 0.92) between the HCO_3^{-} and Ca^{2+}ions (Table 2) supports the observation.

Additionally, weathering of primary minerals in the gneissic rock types of the area might have contributed to the Ca in groundwater. This assertion is supported by the near neutral to alkaline pH of the samples due to Ca-enrichment. Observed high SD of Ca and HCO_3^- content in HDW (Table 1) can also be attributed to a possibility of diverse sources of input of the ions. For Ca^{2+}, sources may include mineral dissolution in the saprolite of the shallow zones and wastewater infiltration, with HCO_3^- content linked to groundwater recharge in the shallow zones. Low deviation of the concentrations of the ions (HCO_3^- and Ca^{2+}) from the mean in samples from the BHs may be due to limited sources of input and can be ascribed to the possible intrusion of seawater with more stable ionic concentrations at lower levels, and also explains the higher Ca^{2+} concentration in BHs than in HDWs. According to Kumar et al. (2014) high concentrations of Mg^{2+} in a coastal aquifer may be an indication of seawater intrusion, in this work, Mg ranks as the third most abundant Cation in groundwater of the area contribution may be coming from effect of the sea and also dissolution of minerals containing the magnesium ion. Low Nitrate content can be attributed to (Lutterodt et al., 2021). The low potassium content in the aquifer may be due to its adsorption to clay minerals (Sarin et al.,1989), note that the aquifer is predominantly made up of the Dahomeyan gneisses that weather into clay mineral, in addition groundwater occurrence in the shallow gneisses are controlled by weathering (Foppen et al., 2020) which produces clayey soils. It is difficult to explain the low sulfate content in the water samples, for the ion is one of the major components in seawater. It is speculated that sulfate ions may be undergoing precipitation and or sorption by the positive clay minerals of the area.

Scatter plots of sum of cations against major cations (Na^+, Ca^{2+}, Mg^{2+} and K^+) and also sum of anions against the anions (Cl^-, HCO_3^-, PO_4^{3-} and SO_4^{2-}) and correlation analyses of measured water quality parameters (Table 2) and (Figure 2), were used to, respectively, understand the contribution of specific ions to mineralization of groundwater and the sources of mineralization (Telahaguie et al., 2020). Results indicate a strong correlation between sum of cations and Na^+ ($R^2 = 0.91$) , and also for Ca^{2+} ($R^2 = 0.91$), and an almost perfect correlation ($R^2 = 0.99$) was observed between the dominant anion Cl^- and sum of anions. The results confirm the dominance of Na^+, Ca^{2+}, and Cl^- in the aquifer.

Table 2; Correlation matrix of physico-chemical parameters. Substantially large correlation coefficients ($r \geq 0.7$) are in bold.

	pH	***EC***	***TDS***	***Cl***	***SO_4***	***HCO_3***	***NO_3***	***PO_4***	***Na***	***K***	***Ca***
EC	-0.64										
TDS	-0.64	**1.00**									
Cl	-0.61	**0.87**	**0.87**								
SO4	**-0.86**	**0.79**	**0.79**	**0.73**							
HCO_3	-0.44	**0.89**	**0.89**	**0.83**	0.60						
NO_3	-0.29	0.49	0.49	0.50	0.32	0.62					
PO_4	-0.57	0.23	0.23	0.28	0.53	0.26	0.14				
Na	-0.59	**0.85**	**0.85**	**0.99**	**0.71**	**0.85**	0.52	0.32			
K	-0.34	0.57	0.57	0.59	0.54	**0.79**	0.40	0.32	0.61		
Ca	-0.60	**0.97**	**0.97**	**0.92**	**0.77**	**0.92**	0.46	0.31	**0.91**	0.65	
Mg	-0.65	**0.85**	**0.85**	**0.70**	**0.70**	**0.81**	0.65	0.38	**0.69**	0.52	**0.81**

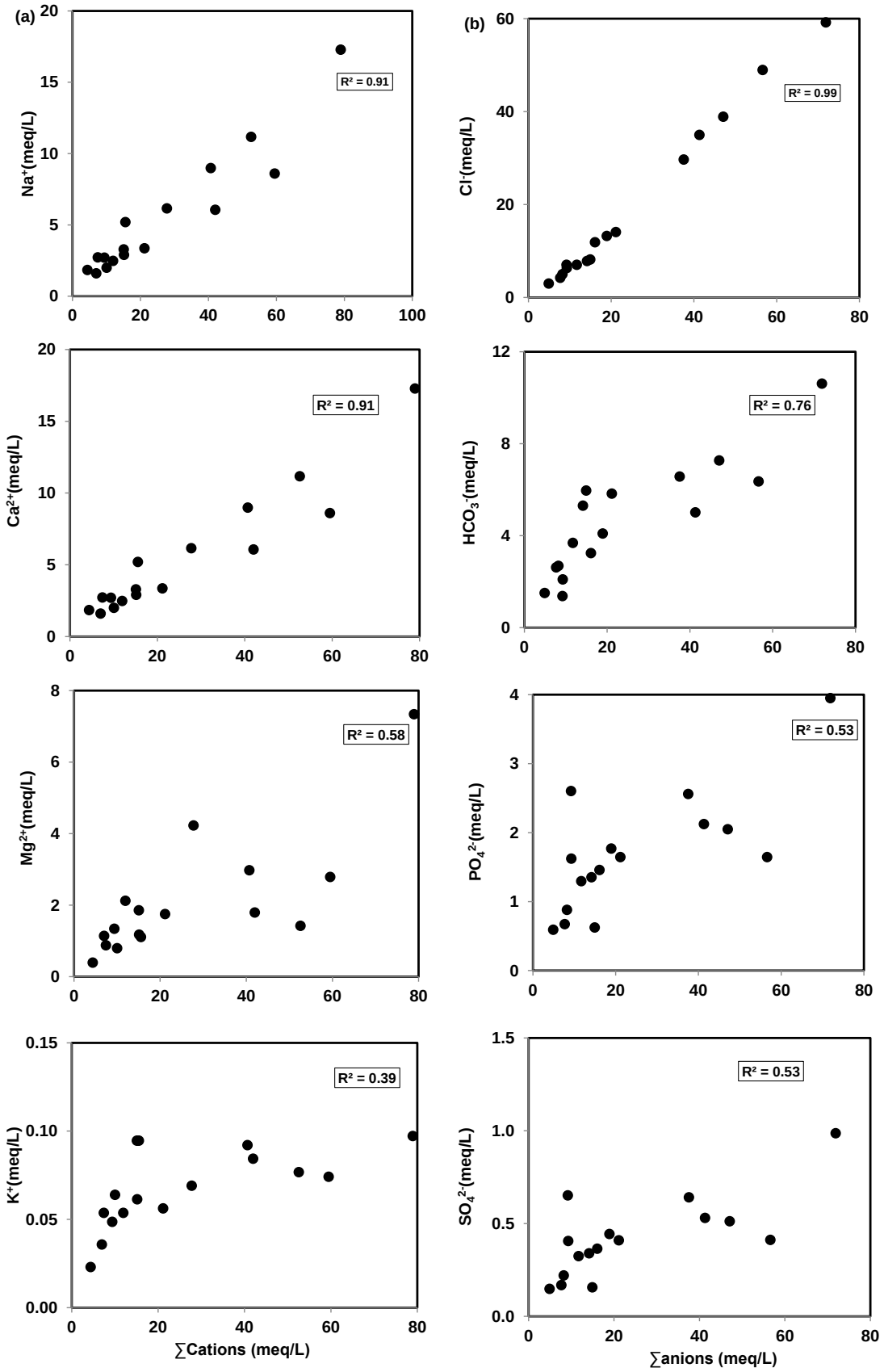

Figure 2: Association between (a) ∑ cations and Na, Ca^{2+}, Mg^{2+} and K^{+} (meq/L) and (b) ∑ Anions and Cl^{-}, HCO_3^{-},PO_4^{2-} and SO_4^{2-}

Also, HCO_3^- showed a good correlation with sum of anions (R^2=*0.76*). The observation is an indication that the dominant ions (Na^+, Ca^{2+} and Cl^-) are responsible for the mineralization of the Ningo-Prampram Aquifer. The observed low correlation between sum of cations and Mg $^{2+}$ (R^2 = *0.58*), and between sum of anions and PO_4^{2-} and SO_4^{2-} both with R^2 = *0.53* show moderate contribution to the mineralization process of the aquifer. The correlation matrix (Table 2) reiterates the observed relationship between EC/TDS and other chemical parameters known to be related to dissolved solids (*Cl: r = 0.87, SO_4, r =0.79, HCO_3, r =0.89, Na, r =0.85, Ca: r = 0.97, Mg: r = 0.85*). Results support the mixing of seawater with fresh groundwater in addition to cation exchange processes within the aquifer systems, this assertion is linked to the strong correlation between EC and with major components of seawater (Cl^-, Na^+, and Mg^{2+}) and cations released into the groundwater systems either through base exchange processes (Ca^{2+} and Mg^{2+}), dissolution of rock-minerals and or infiltration of wastewater from the surface.

The results indicate that ions in groundwater of the area may be due to contribution from multiple sources, likely SWI, dissolution of rock minerals and infiltration of wastewater and mineralization of the aquifer is due to the higher concentrations of the dominant cations Na^+ and Ca^{2+} and major anions Cl^- and HCO_3^-.

Base Exchange processes

Figure 3 show the occurrence of both direct and reverse base ion exchanges, respectively, in seven (7 i.e. 3 BHs and 4 HDWs) and eight (8 2 BHs and 6 HDWs) of the samples .

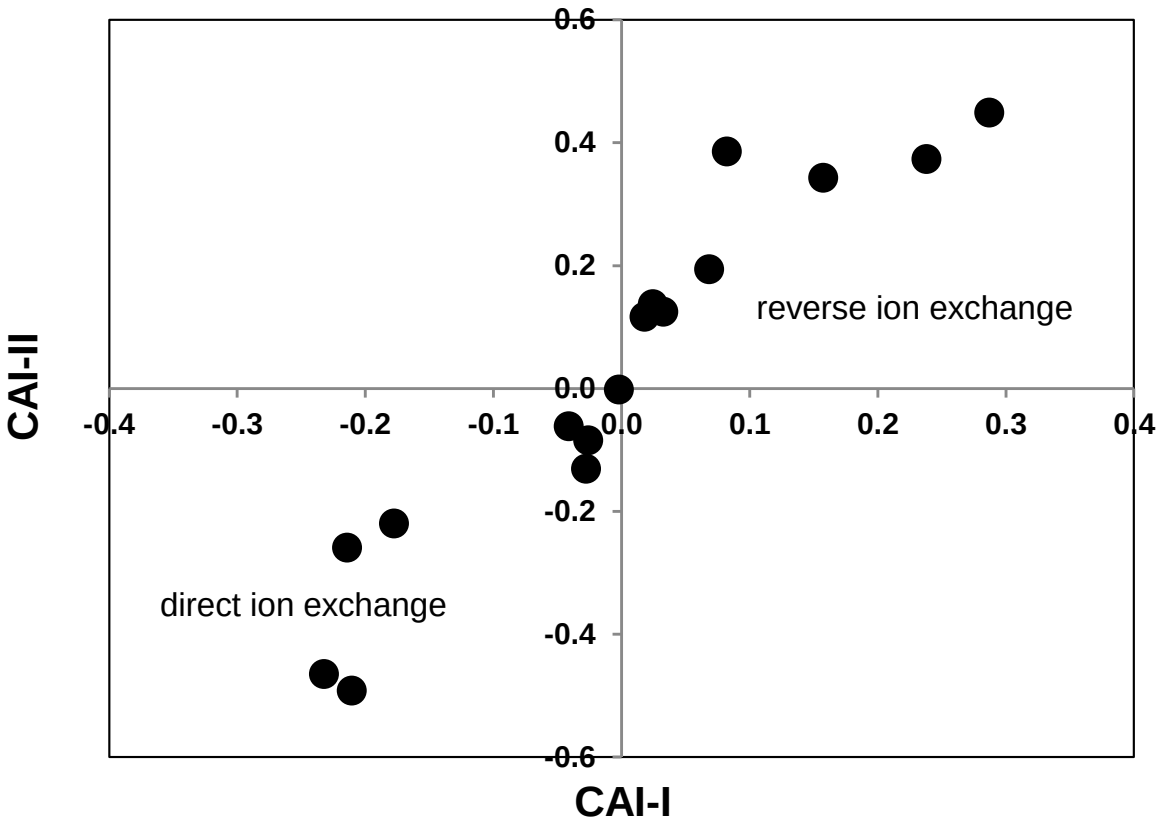

Figure 3: Chloro-Alkaline indices showing reverse ion exchange and direct ion exchange.

For one sample from a HDW (PWD9) there seem to be no net effect of Base Exchange processes, and can be attributed to the possibility of equal rates of direct and indirect exchanges. Base ion exchange processes are therefore independent of the depth of groundwater sources. Both mechanisms might have occurred via the introduction of saline water into the aquifer via atmospheric aerosol deposition and seawater intrusion. From the results it can be concluded that in addition to the base exchange processes mixing between seawater and recharge and or fresh groundwater might have occurred. It can be concluded that base ion exchange processes influence the groundwater chemistry of almost all the samples (93.8%).

Ionic ratios

Like many other workers (Asare et al., 2021, Sunkari et al., 2021, Hajj et al., 2021, Telahaguie et al., 2018, 2020) ionic ratios (Table 3) involving ions with high concentrations in seawater was used as index to assess the influence of seawater on the samples. In addition, ionic ratios as a function of Chloride (salinity) concentration (meq) were used to understand and infer the possible mixing of seawater and freshwater. It is important to note that ionic ratios are also useful in revealing water-rock interaction processes (Kura et al., 2014), wastewater infiltration and other process that alter ionic concentrations and influence the chemistry of groundwater.

Salinization of coastal fissure groundwater in the Ningo-Prampram area, southern Ghana.

Results show that for all samples, values of ratios Ca^{2+}/SO_4^{2-} , Ca/Mg and Cl^-/HCO_3^- were all greater than 1 and Cl dominance showed in the ratios SO_4/Cl and Mg^{2+}/Cl^- with all values < 1 and $K^+/Cl^- < 0.02$. The reported ratios have variously been used to indicate seawater intrusion into coastal aquifers ($Mg^{2+}/Cl^- <1$: Al-Qurnawy et al., 2023, Asaer et al., 2021, K/Cl<0.02: Asare et al., 2021, Jones et al. 1999, Vengosh and Rosenthal., 1994, $Ca^{2+}/Mg^{2+}>1$, Bear et al., 1999) In this work, the low values of ion/chloride ratios (<1) confirms the dominance of Cl^- in groundwater of the area (Jones et al. 1999) with the sea as the possible source of Cl^- due to its nearness to the groundwater sources sampled for the study (<5 km from the Coast) (Al-Qurnawy et al., 2023, Hajj et al. 2021, Telahaguie et al., 2018, 2020). Possible pathways for seawater influence (SWI) on groundwater in the area may be through seawater intrusion and atmospheric aerosol deposition. The low values of the ion/chloride ratios in BHs compared to shallow HDW (Table 3) is an indication of high influence of the chloride sources at deeper groundwater level and this may be attributed to seawater intrusion.

Results showed that deep groundwater (depth > 20 m) sources are more mineralized compared to shallow groundwater and reflected in the higher average values of molar ratios (meq) (e.g. Ca^{2+}/Mg^{2+}, Cl^-/SO_4^{2-}, Ca^{2+}/SO_4^{2-}, $(Ca^{2+}+Mg^{2+})/Cl^-$, $(Ca^{2+}+Mg^{2+})/(HCO_3^{2+}+SO_4^{2-})$ in the boreholes compared to HDW. Low average values of Ca/Na and Ca/Cl in BHs (Table 3) were also obtained. The observation is attributable to seawater intrusion in deep groundwater due to its dissolved constituents, and also the possibility of long residence time of deep groundwater might have contributed to the higher mineralisation.

For all samples $Ca^{2+}/SO_4^{2-}>1$ with high ratios in BHs (11.42 to21.8, average 16.62) compared to shallow groundwater sources (3.07 to 21.03, average 11) $Ca^{2+}/SO_4^{2-}> 1$ has been attributed to Seawater influence/Intrusion (Asare et al., 2021). The non-correlation between Ca^{2+}/SO_4^{2-} and Cl^- concentration (Figure 4d) may be an indication of a complex combination of processes determining the concentrations and fate of Ca^{2+} and SO_4^{2-} in groundwater of the area. SO_4 may be undergoing sorption processes on clayey soils as speculated earlier with additional input of Ca^{2+} from wastewater in addition to contributions from

Base Exchange processes contributing to removal and addition of Ca^{2+} to the fluid phase from the solid aquifer.

Computed Na^{+}/Cl^{-} values indicated similar concentrations in meq with average value of 1 for both HDW and BHs, indicating these ions may be emanating from similar sources e.g. seawater, deposited sea aerosol, halite dissolution and anthropogenic influence from on-site sanitation facilities. Note that the influence of seawater on coastal aquifers results in Na: Cl ratio of 0.86 or less (Telahigue et al., 2020a, Bear et al., 1999). In this work, 13 out of the 16 samples have Na^{+}/Cl^{-} ratios > 0.86 (see figure 4a.) and give an indication of additional sources of Na input into groundwater of the area. In addition, the non-correlation between Na/Cl as function of salinity confirms the possible multiple sources of Na in groundwater of the area. The observation can be linked to rock weathering (Jena et al., 2024), contribution from wastewater infiltration and mixing of seawater and groundwater. Wide variation of Na and Cl content in groundwater of the area confirms the possible multiple sources.

For all samples results indicate Ca^{2+}/Mg^{2+} >1. According to Bear et al. (1999) this result could indicate Ca enrichment in both shallow groundwater and the deeper boreholes. Average values in BH (3.76) > that of HDW (2.53 (Table 3). Ca^{2+}/Mg^{2+} ratio has variously been used as an important natural tracer of seawater intrusion in coastal aquifers (Pulido-Leboeuf et al., 2003, Ouhamdouch et al., 2021). A combination of processes might have contributed to the Ca^{2+}/Mg^{2+}> 1. At high water hardness, Mg prevents the precipitation of Ca^{2+} in groundwater (Juarez et al, 2023). In this work, all water sampled showed water hardness with more than 80% of the samples (13 sampling points) showing hard water to very hard water.

Table 3: Summary of Ionic ratios computed in Meq and Base Exchange Index (BEX) from respective parameters for HDW and BH and combined averages.

	HDW				BH				
Ionic ratios	**Min**	**Max**	**mean**	**SD**	**Min**	**Max**	**mean**	**SD**	**Avg (HDW and BH)**
Na/Cl	0.71	1.21	0.98	0.17	0.96	1.23	1.03	0.11	1.00
Mg/Cl	0.10	0.30	0.18	0.07	0.04	0.30	0.11	0.11	0.15
K/Cl	0.002	0.012	0.008	0.003	0.002	0.005	0.003	0.001	0.006
Cl/SO_4	10.82	60.00	28.56	14.99	34.38	118.80	68.28	32.59	40.97
Ca/Cl	0.24	0.66	0.40	0.14	0.17	0.44	0.28	0.11	0.36
(Ca+Mg)/Cl	0.34	0.80	0.58	0.16	0.22	0.74	0.38	0.21	0.52
NO_3/Cl	0.02	0.16	0.07	0.04	0.01	0.06	0.03	0.02	0.06
Cl/HCO_3	1.37	5.58	2.80	1.47	2.42	7.70	5.39	2.09	3.61
HCO3/Na	0.19	0.72	0.46	0.20	0.13	0.23	0.17	0.04	0.38
Ca/Mg	1.17	4.68	2.55	1.18	1.46	7.85	3.76	2.41	2.93
Ca/SO_4	3.07	21.03	11.00	5.31	11.42	21.80	16.62	4.51	12.76
Ca/Na	0.21	0.87	0.44	0.21	0.18	0.36	0.26	0.08	0.38
$Ca/(HCO_3+SO_4)$	0.54	1.49	0.89	0.28	0.99	1.43	1.21	0.17	0.99
$(Ca+Mg)/(HCO_3+SO_4)$	0.84	2.12	1.28	0.35	1.42	1.68	1.61	0.11	1.38

This might have led to Ca-enrichment as Mg^{2+} may be preventing Ca^{2+} from precipitation; the strong positive correlation(*r = 0.81*) supports this assertion. Most importantly, base exchange analysis indicate that 7 out of the sixteen samples are influenced by direct ion exchange process involving exchange of Ca^{2+} and Mg^{2+} on solid aquifer with Na from the fluid phase. Values of Ca^{2+}/Mg^{2+} >1 may indicate

seawater intrusion (Sudaryanto and Naily, 2018, Carol and Kruse, 2012, Carol and Kruse, 2009, Sudaryanto and Naily, 2018) with high ratios (> 2) and low ratios (Ca^{2+}/Mg^{2+}, ≤ 2), respectively, showing additional input from silicate mineral weathering and calcareous mineral weathering (Abu et al., 2024). Strong positive correlation between Ca^{2+} and Mg^{2+} (*r = 0.81*) may indicate higher fraction of the ions emanate from the same source mainly direct ion exchange and possibly wastewater.

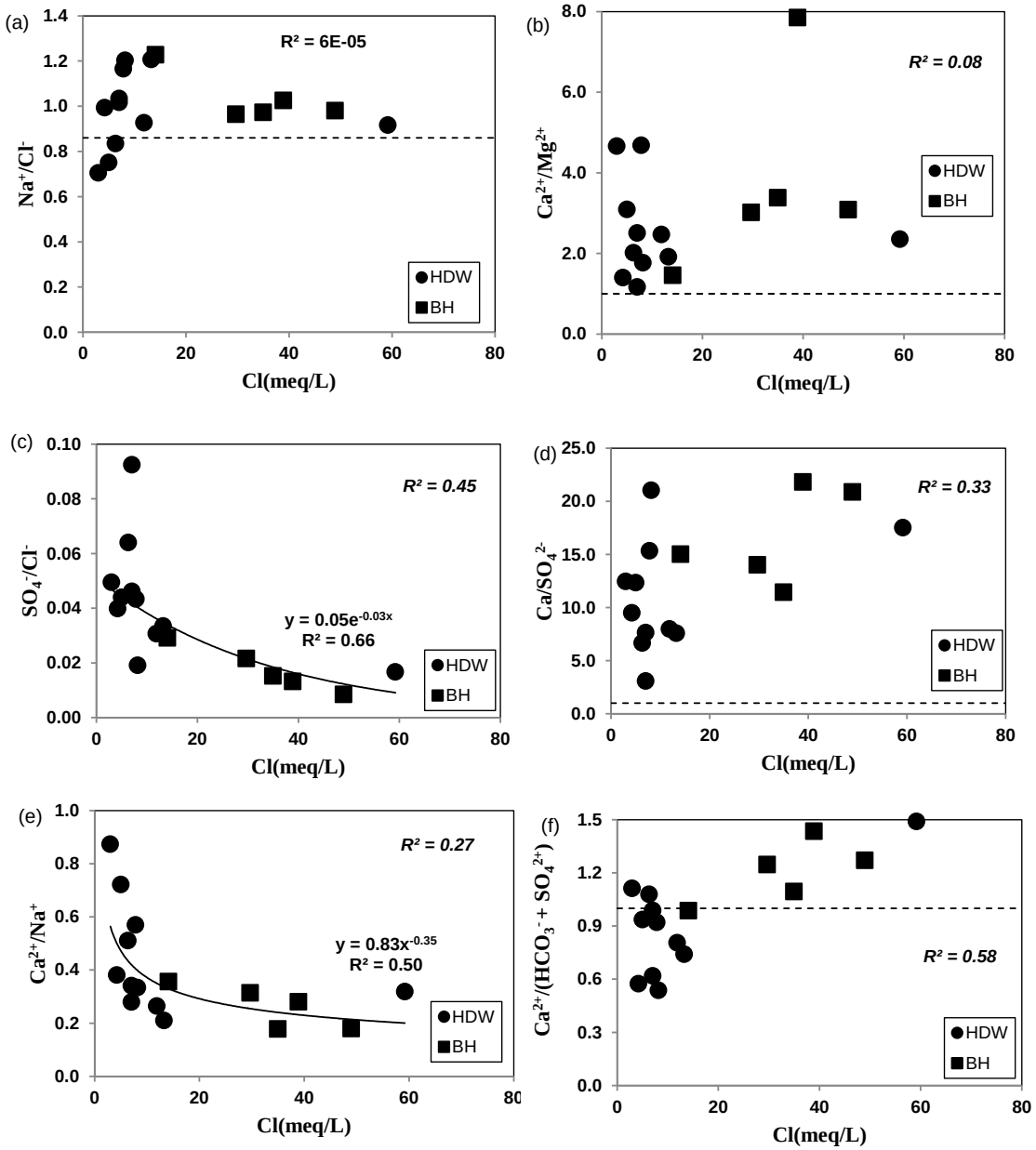

Figure 4: Scatter plots of ionic ratios: (a) Na^+/Cl^- (b) Mg^{2+}/Ca^{2+}(c) SO_4^{2-}/Cl- (d) Cl^-/HCO_3^- (e) Ca^{2+}/Na^+ (f) $Ca^{2+}/(HCO_3+SO_4^{2-})$ as a function of Cl^- (meq):

Scatter plot of Ca^{2+}/Mg^{2+} as a function of salinity (Cl) (Figure 4b) did not show any correlation and may indicate that mixing with seawater may not be the main source of the Ca^{2+} and Mg^{2+} in groundwater of the area.

More than half of the samples (56%) show $Ca^{2+}/(HCO_3^-+SO_4^{2-})$ >1, (Figure 4f) and

include all deep groundwater sources sampled and three of HDWs, the result can be linked to seawater intrusion (Klassen et al, 2014, Carol and Kruse, 2012, El Moujabber et al., 2006, Sudaryanto and Naily, 2018). Also, SO_4^{2-}/Cl^- as a function of salinity indicated an exponential (R^2 = *0.7*) (See figure 4c) reduction with increasing salinity indicating that the low SO_4^{2-} content in the aquifer may be coming from other sources. This observation is similar to the findings of Paulido-Leboeff, et al. (2003) who observed a power law reduction in the ratio with increasing fraction of seawater.

Dominance of Na in groundwater of the area is confirmed by low values (ratios<1) of Ca/Na and HCO_3/Na (Table 3), both ratios (Ca^{2+}/Na^+ and HCO_3^-/Na^+) are important indicators of mineralization due to water-water rock interactions, silicate and carbonate weathering and evaporite dissolution (Ruiz-Pico et al., 2019; Xu et al., 2022). Na dominance can be traced to multiple processes including indirect Base Exchange releasing Na+ and K+ into groundwater as noted earlier and also mixing of groundwater with seawater.

Ca^{2+}/Na^+ as a function of salinity (Cl^-) (Figure 4e) did not show a linear correlation (R^2=*0.27*) but indicated a power law (R^2 =*0.50*) reduction in the ratio with increasing salinity confirming multiple sources of input of the two minerals into the aquifer system with fractional input from seawater for both. The plots of the Na- normalized molar ratios (Gaillardet et al., 1999) i.e. the relationship between HCO_3^-/Na versus Ca^{2+}/Na^+, and Mg^{2+}/Na^+, versus Ca^{2+}/Na^+(Figure 5) were used to contribute towards understanding of the sources of mineralization. The importance of the relationships is linked to the fact that ratios are neither affected by any of the physical processes; dilution, flow rate, dilution and evaporation and therefore the Hydrochemical origin of the ions can be traced (Zhang et al., 2023). In figure 5 (a and b) the plots cluster within the evaporite (Seawater) region. The observation can be largely attributed to seawater influence via intrusion and atmospheric sea aerosol deposition and the dissolution of evaporite minerals that may be present in the aquifer.

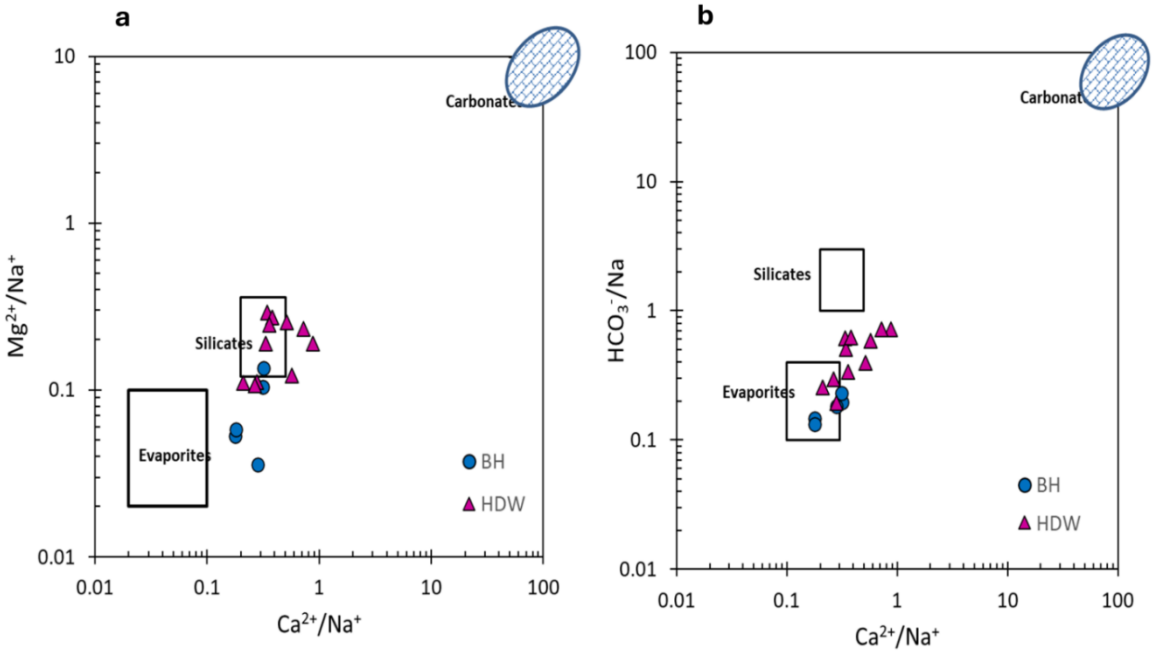

Figure 5; Na normalized molar ratios after Gaillardet et al. (1999) showing the relationship between (a)HCO_3^-/Na^+ and Ca^{2+}/Na^+ and (b) Mg^{2+}/Na^+ and Ca^{2+}/Na^+

The presences of data points in the silicate region, particularly in Figure 6a, indicate interactions with silicate minerals that release magnesium, further influencing groundwater chemistry. The low presence of data in the carbonate zone could indicate either the limited presence of carbonate minerals in the aquifer materials or a geochemical environment where the dissolution of carbonate minerals is not the dominant geochemical process compared to evaporite dissolution and silicate weathering.

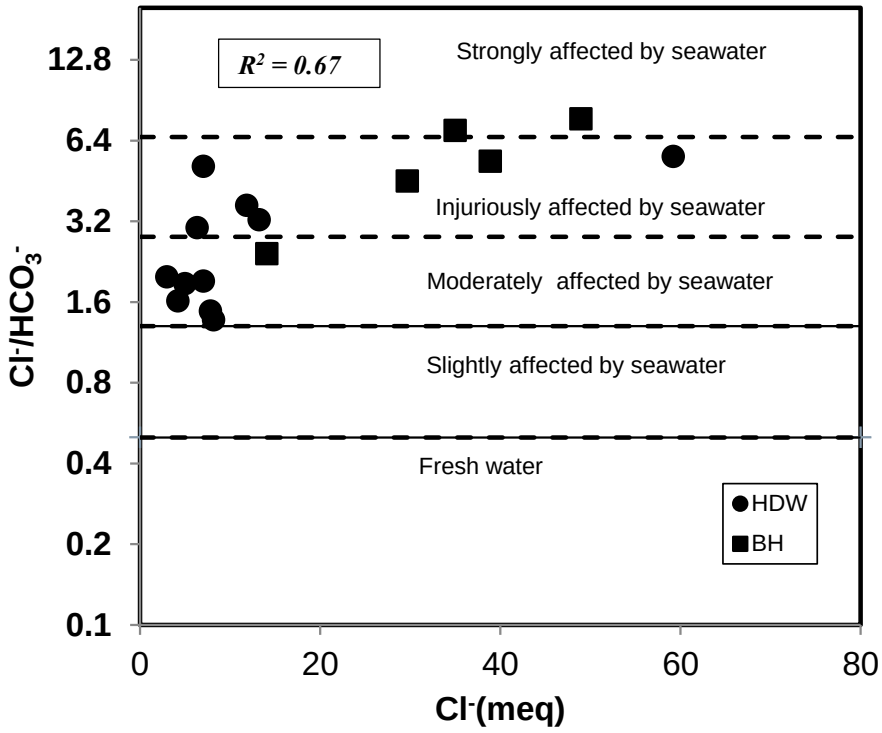

Figure 6: Hydrochemical facies distribution based on Cl/HCO_3 as a function of Cl^-.

A modified form of the Simpson's ratio, Cl^-/HCO_3^- as a function of Cl has proved to be an important tool in the classification of groundwater affected by seawater (Todd, 1959, Revelle, 1941 and Raja et al., 2021). Computed values for Cl^-/HCO_3^- were all > 1, with an average value of 3.61 indicating an influence by the sea (Al-Qurnawy et al., 2023, Shin et al., 2020, Revelle, 1941). Cl^-/HCO_3^- as a function of Cl^- is employed to classify samples from the groundwater sources (Figur**e** 6); Seven (43.8%) of the samples from HDW recorded ratios $1.3 < Cl^-/HCO_3^- < 2.8$ (Figure 6) indicating moderate effect of seawater, seven shallow HDW and 2 BHS are injuriously and strongly affected by seawater, respectively (Shin et al., 2020, Revelle, 1941). The strong effect of the seawater on deep boreholes can be attributed to seawater intrusion (El Moujabber et al., 2006).

Both Chadha's diagram (Figure 4a) and the relation between the ratios $Ca^{2+}/(HCO_3^- + SO_4^{2-})$ and Na^+/Cl^- (Figure 7b) (Chadha, 1999, Abdalla, 2016, Agoubi et al., 2014) have proved to be useful in characterizing water types and understanding ion exchange processes in aquifers. From Chadha's diagram all samples are influenced by seawater (Na-Cl water type). The observation is attributable to the dominant Cl^- and Na^+ ions in the water samples coming from the sea's strong influence on the aquifer through encroachment (Abdalla, 2016) and deposition of sea aerosols due to the nearness of the wells and boreholes to the sea. Scatter plots of $Ca^{2+}/(HCO_3^- + SO_4^{2-})$ against Na^+/Cl^- (Figure 7b) reveals that six groundwater sources (1 BH and 5 HDWs)

and 3 HDWs, respectively have Ca-excess and Chloride excess indicating that 56 % of the groundwater sources are influenced by seawater. The rest of the sources (2 HDW and 3 BHs) have Calcium excess (Ca-excess) and a single BH in a natural state

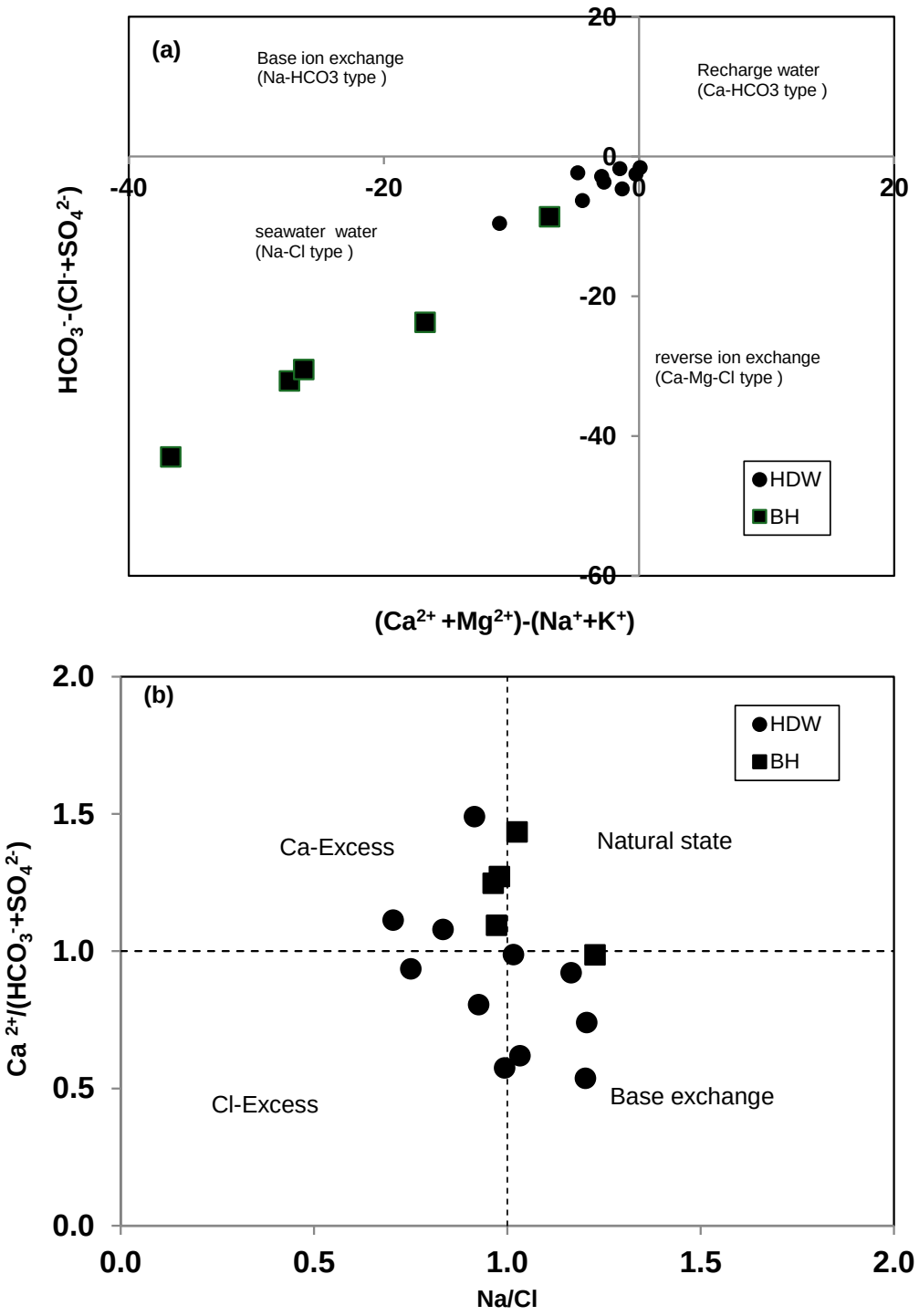

Figure 7: (a) Chadda plot showing salinization of the aquifer (b) Scatter plot of Ca/ (HCO3+SO4) against Na/Cl showing possible geochemical processes in the aquifer.

From ionic ratios (Ca^{2+}/SO_4^{2-} ,Ca^{2+}/Mg^{2+} and Cl^-/HCO_3^-) values >1 and for low values of ratios SO_4^{2-}/Cl^-, K^+/Cl^-, and Mg^{2+}/Cl^- all <1 , the Na-Cl water type produced from the Chadha's diagram it is concluded that seawater has influenced

groundwater in the area. Based on $Ca^{2+}/(HCO_3^-+SO_4^{2-})$ >1 and the scatter plot between $Ca^{2+}/(HCO_3^-+SO_4^{2-})$ and Na^+/Cl^- it is concluded that 56% of the samples are influenced by the sea. From high average ratios for Ca^{2+}/SO_4^{2-} , Ca^{2+}/Mg^{2+} and Cl^-/HCO_3^-) and much lower values all in BHs compared to shallow HDW seawater intrusion is inferred in deep boreholes (depth > 20 m) m. Silicate weathering, evaporite dissolution and infiltration of wastewater contribute to mineralization of the aquifer.

Hydrochemical facies Evolution

Piper plots shown in figure 8 give four (4) main water types in the area and reflect distinct ion combinations. The common water types observed are Na-Ca-Cl-HCO_3 (8 HDW), Na-Ca-Cl (3BHs), Na-Cl (2 BHs and 1 HDW) and Na-Cl-HCO_3 (2 HDW) and respectively represent 50%, 18.75%, 18.75% and 12.5% of the samples. The five deep groundwater sources are characterized by Na-Ca-Cl (3) and Na-Cl (2) water types with the rest of the water types observed in shallow hand dug wells.

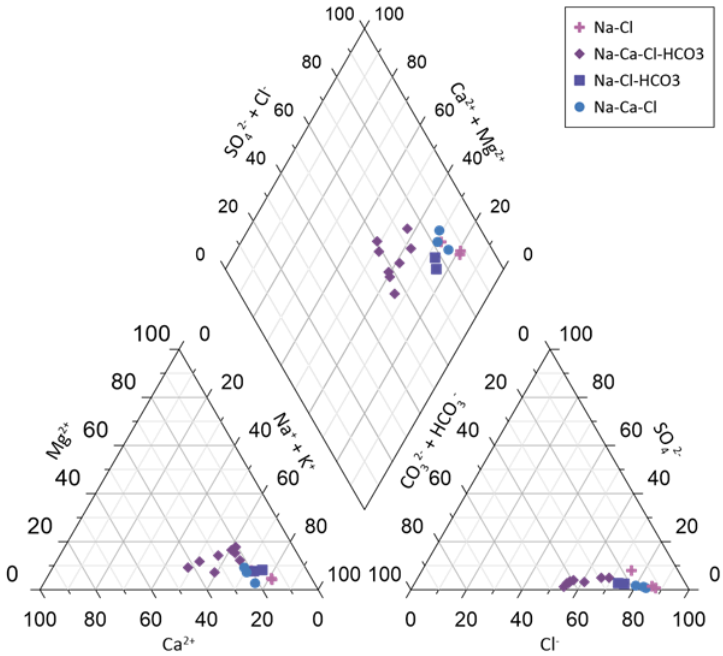

Figure 8: Piper plots showing four distinct classes/types of water in the Ningo-Prampram area

The observed common Na-Ca-Cl-HCO_3 water type in the shallow zone (<10 m depth) can be attributed to a mixture of higher fractions of saline water produced from dissolution of deposited sea aerosols and dissolution of carbonate rocks and recharge low fractions of fresh groundwater with Ca^{2+} and HCO_3^- content produced from rock-water interaction and dissolution of material from the saprolites of the aquifer. Seawater facies-Na-Cl, observed in a HDW and 2 BHs may be due to the possibility of two different processes; for HDW a combination of upconing of seawater inflow due to groundwater abstraction creating a forced convection in addition to contribution of sea aerosol from the surface and for the BH lateral intrusion of the seawater at deeper groundwater levels may be implicated (Mao et al., 2021). Boreholes characterized by intrusion facies-Na-Ca-Cl (Raja et al., 2020) may represent a mixture of different water sources mainly seawater intrusion and multiple geochemical processes e.g. initial cation exchange process between Na from seawater and Ca from the solid aquifer material followed by saturation by seawater. Na-Cl-HCO_3 water

types could be the result of ion exchange processes, carbonate dissolution, mixing of recharge water with seawater and/or silicate weathering.

Seawater Mixing Index

Figure 9 show cumulative probability curves for ions, and show inflections points and threshold concentrations of the ions (Na = 598.2 mg/l, Mg 32.1 mg/l, Cl = 976.5 mg/l and SO_4 = 21.8 mg/l), which differentiate samples with seawater mixing effect in the study area (Park et al., 2005). SMI values for all shallow groundwater sources (HDW) was < 1 with the exception of ODW11 (SMI=2.2) and all BHs had SMI values > 1 with the exception of PBH1 (SMI= 0.6).

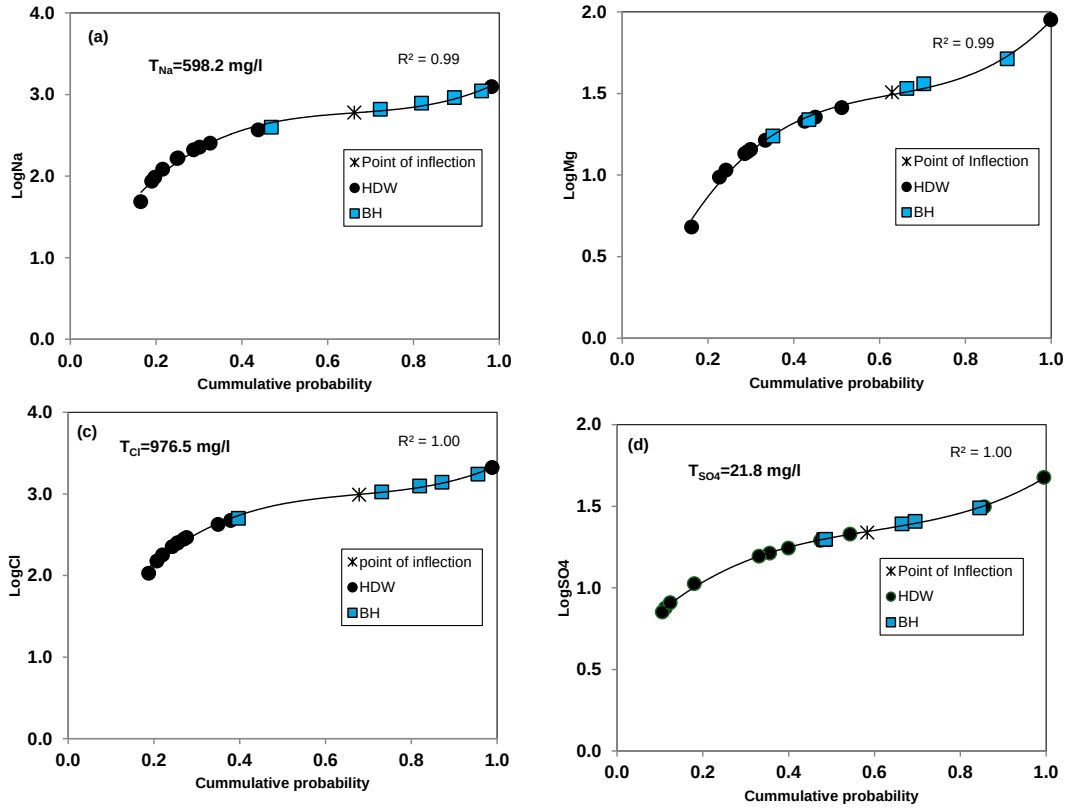

Figure 9: Cumulative probability curves for (a) Na (b) Mg (c) Cl and (d) SO_4 showing the point of inflection determined from the second differential of the third order polynomial obtained from the relation between the concentrations and cumulative probabilities

Again, results confirm a greater influence of the sea in deep groundwater within the study area with average SMI value of 1.2 for the BHs, mixing might have been caused by intrusion as previously explained. Average SMI value for HDW was 0.5. The high SMI value of HDW ODW11 may be due to a combination of Hydrogeochemical processes including upwelling of seawater due to abstraction and also infiltration of wastewater from the surface.

Summary and Conclusions

In this case study, physical and chemical quality of groundwater samples from shallow (<10 m deep) hand dug wells (HWDs) and boreholes (BHs) (Depths > 20 m), were respectively analyzed in the field and laboratory. The limited sample size of the boreholes, and the methodological limitation of the inability to analyse for Br- in water samples are potential limitations associated with the study. However, the complex combination of geochemical tools

used in the analyses of the results and the distinctly high values of the physical and chemical parameters in borehole samples associated with highly mineralised seawater validates interpretation and findings of the work.

A summary of results of key geochemical processes and characteristics obtained at individual groundwater points are presented in Table 4.

Table 4: Summary of water characteristics in relation to effect by seawater using various methods factor's likely to influence salinity of groundwater in the area

Well ID	Source	Geology	Water Type Piper plot	Depth (m)	Distance from the sea (Km)	Interpretation from Chadda's diagram	CAI-I & II (Base exchange)	Ca/(HCO_3+ SO_4) vrs Na/Cl	SMI	Effect by seawater (Cl/HCO_3)	EC
ADW 1	HDW	Gneiss	Na-Cl	8.2	0.94	SWE	Reverse	Base exchange	0.4	Inj. affected	1209.0
NDW 2	HDW	Gneiss	Na-Ca-Cl-HCO_3	4.3	0.41	SWE	Reverse	Base exchange	0.3	Mod. affected	1970.0
ZDW 3	HDW	Gneiss	Na-Ca-Cl-HCO_3	2.2	0.35	SWE	Reverse	Base exchange	0.3	Mod. affected	1870.0
ZDW 4	HDW	Gneiss	Na-Ca-Cl-HCO_3	2.2	0.34	SWE	Direct	Ca-excess	0.3	Mod. affected	1240.0
ZDW 5	HDW	Gneiss	Na-Ca-Cl-HCO_3	1.36	0.31	SWE	reverse	Base exchange	0.3	Mod. affected	1530.0
ZDW 6	HDW	Gneiss	Na-Cl-HCO_3	1.6	0.31	SWE	Direct	Cl-excess	0.5	Inj. affected	1215.0
ZDW 7	HDW	Gneiss	Na-Cl-HCO_3	1.7	0.31	SWE	Reverse	Base exchange	0.6	Inj. affected	2510.0
ZDW 8	HDW	Gneiss	Na-Ca-Cl-HCO_3	1.4	0.28	SWE	Direct	Ca-excess	0.1	Mod. affected	842.8
PDW 9	HDW	Quartzite	Na-Ca-Cl-HCO_3	3.2	0.69	SWE	No reaction	Cl-excess	0.2	Mod. affected	1032.0
KDW 10	HDW	Quartzite	Na-Ca-Cl-HCO_3	4.7	1.12	SWE	Direct	Cl-excess	0.2	Mod. affected	983.1
ODW 11	HDW	Quartzite	Na-Ca-Cl-HCO_3	5.14	0.71	SWE	Direct	Cl-excess	2.2	Mod. affected	2850.0
PBH 1	BH	Quartzite	Na-Ca-Cl	>20	1.30	SWE	Reverse	Base exchange	0.6	Mod. affected	10780.0
PBH 2	BH	Quartzite	Na-Ca-Cl	>20	1.33	SWE	Reverse	Natural state	1.4	Inj. affected	5820.0
PBH 3	BH	Quartzite	Na-Ca-Cl	>20	1.74	SWE	Direct	Ca-excess	1.1	Inj. affected	3830.0
PBH 4	BH	Quartzite	Na-Cl	>20	1.53	SWE	Direct	Ca-excess	1.2	strongly affected	2450.0
PBH 5	BH	Quartzite	Na-Cl	>20	1.30	SWE	Direct	Ca-excess	1.7	strongly affected	3640.0

Statistical summary of physical quality parameters, EC/TDS and TH were used to infer salinization/mineralization of the aquifer and correlation matrix, geochemical tools including ionic ratios and scatter plots, Seawater Mixing Index (SMI), chloro-alkaline indices, and hydrochemical facies evolution were used to understand the possible geochemical and geohydrological processes controlling the hydrochemistry of the aquifer.

From the results it is concluded that :

- Groundwater in Ningo-Prampram area is saline with average EC values > 1mS/cm , and water samples show moderately hard water to very hard water.
- Salinity is mainly caused by higher concentrations of dominant cations (Na^+ and Ca^{2+}) and dominant anions (Cl^- and HCO_3^-)
- Aquifer is influenced by seawater through mixing processes and inferred

from : ionic ratios >1 for Ca^{2+}/SO_4^{2-} , Ca^{2+}/Mg^{2+} and Cl^-/HCO_3^- and low ratios (<1) for SO_4/Cl, K^+/Cl^-, and Mg/Cl all for all water samples.

- Seawater (Na-Cl water type) for all samples on Chadda's diagram and the dominance of Na and Cl in all the water types (Na-Ca-Cl-HCO_3 , Na-Ca-Cl , Na-Cl and Na-Cl-HCO_3) revealed by hydrochemical facies evolution.
- Base ion exchange processes influence the groundwater chemistry of almost all the samples (93.8%).
- Seawater intrusion might have occurred in deep groundwater sources and inferred from Higher mineralization of deep groundwater (depth > 20 m) and high average Seawater Mixing Index (SMI) of 1.2 in boreholes
- Silicate weathering, evaporite dissolution and wastewater infiltration contribute to the salinization of the aquifer.

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URBAN POVERTY AND HOUSEHOLD ADOPTION OF CLEAN COOKSTOVES IN GHANA

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Abstract

The rising levels of urban poverty due to rapid urbanisation have increased health risks associated with the use of traditional cookstoves in overcrowded households. However, the potential differences in the adoption of clean cookstoves between urban poor and non-poor households in Ghana remain poorly understood, as current studies focus mainly on the rural-urban divide despite the high vulnerabilities of the urban poor. This paper examines the factors influencing household use of clean cookstoves for cooking, with a focus on the urban poor. The study used data from the 2022 Ghana Demographic and Health Surveys (DHS). Descriptive analysis and binary logistic regression were employed to investigate the determinants of clean cookstoves. The results indicate that urban poverty, the age of the household head, and educational levels are significantly associated with the use of clean cookstoves. Urban poor households are significantly less likely than their urban non-poor counterparts to use clean cookstoves. The findings provide insights that can inform pro-poor inclusive energy policy interventions aimed at accelerating progress toward multiple SDGs—particularly SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), and SDG 11 (Sustainable Cities).

Keyword: Clean cookstoves, urban poverty, urban poor, households, Ghana.

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Introduction

Globally, exposure to household air pollution from traditional cookstoves and open fires fuelled by traditional cooking fuels is a major public health issue. About one-third of the world's population cooks using open fires or inefficient stoves powered by biomass (Pratiti et al., 2020; World Health Organisation, 2024). Estimates from the World Health Organisation (WHO) in 2024 indicate that household air pollution caused 3.2 million deaths in 2020, including over 237,000 deaths of children under age 5 (World Health Organisation, 2024). The problem is especially severe in sub-Saharan African countries, such as Ghana, where women and children—who are mainly responsible for household cooking and collecting firewood—bear the highest health risks from using polluting fuels and technologies in their homes (Odo et al., 2021). Additionally, household smoke exposure from cooking is associated with a wide range of health issues, such as acute respiratory infections, maternal and neonatal mortality, stunting, wasting, cardiovascular disease, low birth weight, and burns (Odame & Adjei-Mantey, 2024; Odo et al., 2021; Pratiti et al., 2020; Clean Cooking Alliance, 2021).

To address these public health concerns, various development agencies and the Government of Ghana have launched projects to promote cleaner-burning, efficient cookstoves and cleaner fuels as strategies to tackle energy poverty (Africa Energy Portal, 2024; Bawakyillenuo, 2021; World Health Organisation, 2018; Relief International, 2019). Clean cookstoves and technologies refer to modern cookstoves designed to be less harmful to human health and the environment than traditional cookstoves, both by using cleaner, less polluting fuels and by changing conventional designs to address specific issues (Valenti, 2021). Obviously, some clean cookstoves (CCSs) still rely on polluting fuels, but their higher efficiency means they consume less fuel compared to traditional stoves. Consequently, adoption of clean cookstoves has the potential to improve cooking energy efficiency, reduce carbon emission levels, and enhance fuel savings, thereby contributing to the attainment of Sustainable Development Goals (SDGs), especially SDG targets 3.9.1 (reduce the number of deaths and illnesses attributed to household and ambient air pollution) and SDG 7.1.2 (proportion of population with primary reliance on clean fuels and technology).

The Government of Ghana's interventions to promote improved cookstoves gained prominence in the 1990s, when the Ministry of Energy initiated the distribution of the Ahibenso charcoal pot programme in 1989 (WHO, 2018). This simple cookstove is easy to construct from scrap metal using basic tools, such as hammers. It uses relatively less fuel for cooking, reduces cooking time, and minimises accidental burns. To mitigate the adverse effects of traditional three-stone and inefficient charcoal cookstoves, Relief International collaborated with vulnerable communities in Ghana to develop, produce, and market a fuel-efficient charcoal cookstove called the Gyapa (Relief International, 2019; UNFCCC, n.d). Other interventions to promote clean cookstoves include green energy financing in the form of grants, soft loans, and donor support strategies, and public education on the benefits of improved cookstoves in Ghana. Recently, the government has introduced a cylinder recirculation programme to distribute LPG to households. This programme requires licensed distributors to procure, brand, maintain, and fill empty cylinders and distribute them to households through retail outlets (WHO,2018).

Previous studies on household air pollution have mainly focused on the factors influencing the choice of household cooking fuel (Mensah & Adu, 2015; Odo et al., 2021). Empirical evidence from most sub-

Saharan African countries highlights several socio-economic factors, such as income, education, household size and age, time spent at home, and ownership, age, and type of dwellings, that affect both cooking fuel and cookstove choices (Mensah & Adu, 2015; Karimu et al., 2016; Odo et al., 2021; Odame & Amoah, 2024). The choice of cookstoves and technologies has not been thoroughly investigated (Prah et al., 2021; Adams, 2023). Meanwhile, the environmental impact, efficiency of household cooking fuel, and safety of household members depend not only on the cooking fuel itself but also on the nature of the cookstoves and technologies (WHO, 2018). Consequently, the type of cookstove determines how completely fuels are burnt, how much smoke is emitted, and how much fuel is needed, directly influencing health outcomes, fuel consumption patterns, and environmental degradation. A focus on clean cookstove adoption is therefore essential for a comprehensive understanding of household energy transitions. This will inform the design of interventions that promote cleaner, safer, and more sustainable cooking practices, particularly among urban poor communities, where energy poverty persists.

One key contributing factor to current environmental challenges, especially in SSA countries, is rapid urbanisation and the resulting increase in the percentage of the population living in urban poverty (MacTavish, 2023). Traditionally, studies on poverty in sub-Saharan Africa (SSA) often focus on rural areas, with less attention paid to urban poverty (Damba et al., 2019; Prah et al., 2021; Hassan et al., 2024). However, the poor urbanise faster than the general population, resulting in a greater proportion of households lacking secure land tenure, housing ownership, and tenancy; improved sanitation; better drinking water; and poor access to clean energy for cooking (Janz et al., 2023; Poku-Boansi et al., 2020). This situation makes the urban poor not only vulnerable to climate change-related risks but also contributors to environmental degradation. Further, the continued reliance on traditional cookstoves in urban poor households worsens the burden of household air pollution and respiratory diseases, which disproportionately affect the health of women and children (Odo et al., 2021; Odame & Adjei-Mantey, 2024). Rural-urban variations in the choice of household cooking technologies have received considerable attention in the study of household air pollution in Ghana (Odame & Amoah, 2024; Karimu & Adu, 2016). Such studies, however, have failed to highlight the hidden consequences for the urban poor, who primarily reside in overcrowded housing located in informal settlements and rapidly growing urban areas, where the risks of indoor air pollution and fuel scarcity are more pronounced. A study focusing on urban poverty is therefore necessary to reveal intra-urban inequalities in household choices of cooking technologies, which will inform targeted interventions aimed at addressing the needs of the growing urban vulnerable population. This study aims to examine the patterns of clean cookstove adoption by households and identify the socio-economic and demographic determinants in Ghana, with a specific focus on the differences between the urban non-poor and urban poor households. The study further makes a major contribution to research on household air pollution (HAP) by highlighting gaps in existing studies, which most often prioritise rural-urban disparities over the realities of the urban poor. This paper aims to provide a deeper understanding of the emerging issues surrounding household energy transitions in the context of urban poverty in Ghana, where the adoption of clean cookstoves remains limited despite ongoing policy interventions.

This study is theoretically informed by the energy ladder hypothesis, which suggests that as household wealth improves, energy

consumption shifts from traditional biomass toward modern, cleaner fuels (Ali et al., 2024; Adams, 2023; Karakara & Osabuohien, 2020). The study is further underpinned by the Theory of Change (Valenti et al., 2021), which posits that households' adoption of clean cookstoves has the potential to provide several positive socio-economic and environmental outcomes. This adoption could contribute to SDG 1 (No Poverty) by reducing household expenditures on inefficient fuels and freeing up time for income-generating activities, and to SDG 7 (Affordable and Clean Energy) by promoting access to modern, safe, and sustainable energy solutions. To this end, the adoption of clean cookstoves and cooking technology would most likely be influenced by household characteristics, which may vary depending on the interaction of demographic and socio-economic contexts within households. (Agbokey et al., 2019; Owusu-Amankwah et al., 2023; Adams et al., 2023)

Materials and Methods

Source of data

The study used the household recode dataset of the 2022 Ghana Demographic and Health Survey (GDHS). The GDHS is conducted by the Ghana Statistical Service (GSS) with support from the Demographic and Health Surveys Program and other partners. The data was collected from 17 October 2022 to 14 January 2023 (Ghana Statistical Service (GSS) & ICF 2024). The GDHS is a cross-sectional, nationally representative, population-based survey[1] that collected diverse demographic and health data from a nationally representative sample of household heads, women, and men. The 2022 GDHS used a stratified, representative sample of 18,450 households, selected from 618 clusters. This was designed to yield a representative sample at the national level, for urban and rural areas, and for each of the country's 16 regions, for most of the DHS indicators. The unit of analysis was defined to include a household that is exposed to HAP from the use of all types of cookstoves for cooking in an urban area.

Measurement of the Dependent Variable

The dependent variable used for this study is the household's adoption of clean cookstoves and technologies. During the DHS interviews, heads of households were asked the question, "In your household, what type of cookstove is mainly used for cooking?" Different kinds of cookstoves were given in response. Based on WHO guidelines, electric stoves, solar cookers, LPG/natural gas stoves, piped natural gas stoves, and biogas stoves were classified as "clean cookstoves" and coded as "1". In contrast, all others (manufactured solid fuel stoves, traditional solid fuel stoves, and three-stone stoves/open fires) were categorised as unclean cookstoves and coded as "0".

2.2

2.3 Measurement of the main Independent Variables

The main independent variable of interest in this study is urban poverty, based on household characteristics, which measures whether urban areas are classified as urban poor or urban non-poor. The operationalisation of this variable is based on the UN-HABITAT definition of a slum household as a guide for identifying urban poor households, from which the urban poverty cluster variable is constructed. The measurement of this outcome variable followed protocols similar to those in an earlier study by Asaaf et al. (2022) for the computation of urban poverty. Using the GDHS data, an urban poor household is therefore identified as a household in an urban area that lacks two or more of the following:

a. A household made of durable materials for the floor, wall, and roof Durable wall

[1] Detailed information on the survey is available at http://dhsprogram.com.

materials include cement stone with lime, cement, bricks, cement blocks, covered adobe, wood planks/shingles, and other finished surfaces. For flooring, durable options include: parquet or polished wood, vinyl or asphalt strips, ceramic/marble/porcelain tiles, terrazzo, cement, woollen or synthetic carpets, linoleum, or rubber mats. Similarly, durable roofing materials consist of zinc, aluminium, wood, ceramic tiles, cement, roofing shingles, asbestos, or slate roofing sheets.

b. Not more than three persons per sleeping room
c. Access to improved water
   Improved water sources include piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.
d. Access to improved sanitation
   According to the WHO standards, an improved sanitation facility is one that hygienically separates human excreta from human contact. Improved sanitation facilities include: - Flush or pour-flush toilets connected to a piped sewer system, septic tank, or pit latrine, - Ventilated improved pit latrines, - Pit latrines with slabs, and - Composting toilets.

Thus, the urban poverty variable was constructed based on household characteristics with two categories: urban poor and urban non-poor. The STATA code that was used to construct the urban poverty variable can be found on the DHS Program GitHub website in the Analysis Code repository.[2]

Based on previous studies (Adams et al., 2023; Owusu-Amankwah et al., 2023), the study used a range of household socio-demographic variables as potential covariates. The variables include the sex of the household head, the age of the household head, the highest educational level of the household head, and the marital status of the household head.

Statistical Analysis

With the aid of Stata software version 19 (Stata Corp: College Station, TX, USA), frequency and percentage were used to describe the characteristics of households, while the chi-square test was used to explore the association between each independent variable and the outcome variable. Given the binary nature of the dependent variable — household use of clean cookstove (Yes = 1, No = 0) — a binary logistic regression (logit model) is used to estimate the probability that a household uses clean cookstoves. The logit model estimates the relationship between a binary dependent variable and a set of independent variables by modelling the log odds of the probability of the outcome. The model is specified as:

$$\text{logit}(P) = \log(P / (1 - P)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k$$

Where:

- *P is the probability that the household uses a clean cookstove or otherwise.*
- *β_0 is the intercept.*
- *$\beta_1, \beta_2, \ldots, \beta_k$ are coefficients of independent variables X_1 to X_k.*

Similar to Amoah and Addoah (2021), marginal effects are computed to describe the change in the propensity of the dependent variable (i.e., the household adopting clean cookstoves) that occurs when an independent variable changes by one unit, holding all else constant. In a logit model, the marginal effect of a variable X is computed as:

$$\partial P/\partial X = \beta * P * (1 - P)$$

Where:

- *β is the logit coefficient of the variable.*
- *P is the predicted probability of the outcome.*

[2] https://github.com/DHSProgram/DHS-Analysis-Code/tree/main/AS81_urbanpoverty.

The initial model included only the main independent and dependent variables, and the final models were adjusted for all potential covariates.

Results

Descriptive statistics

A total of 10,320 urban households were considered for this study. Only 41.7% of the households used clean cookstoves, with the majority (58.3%) not using them (Figure 1).

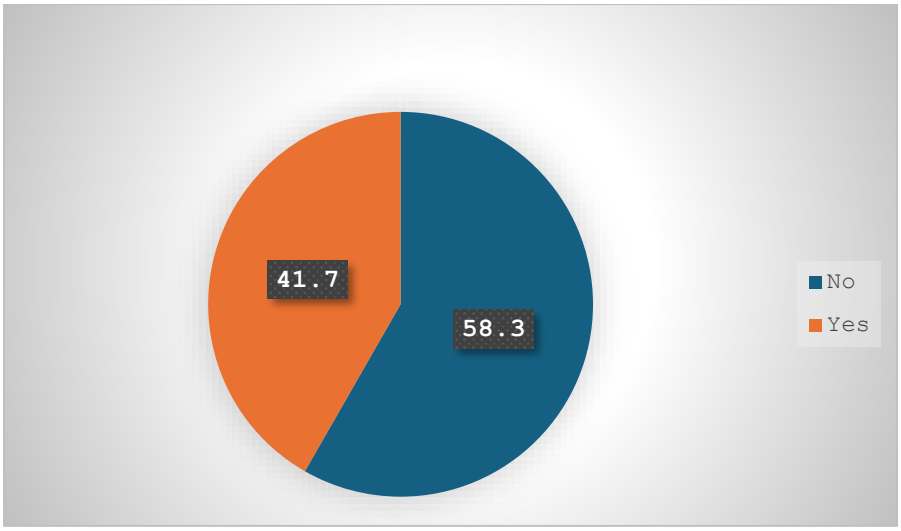

Figure 1: Percent of urban households using clean cookstoves

Table 3: Socio-demographic characteristics of urban households by household use of a clean cookstove for cooking

		Household uses a cleanstove for cooking		
		No	Yes	
Variables	**Frequency (%)**	**%**	**%**	**P-value**
Urban poverty based on household characteristics				0.000
Urban non-poor	9014 (87.3)	54.1	45.9	
Urban poor	1307 (12.7)	87.4	12.6	
Age of head of household				0.000
15 to 35 years	3477 (33.7)	49.8	50.2	
36 to 60 years	5101 (49.4)	59.9	40.1	
61+ years	1743 (16.9)	70.5	29.5	
Highest educational level of head of household				0.000
No Education	1343 (13.0)	90.3	9.7	
Primary	1098 (10.7)	80.7	19.3	
Secondary +	7858 (76.3)	49.7	50.3	
Current marital status of head of household				0.000
Never married	2118 (20.5)	46.6	53.4	
Currently married	5691 (55.1)	56.9	43.1	
Formerly Married	2511 (24.3)	71.3	28.7	
Sex of head of household				0.000
Male	6256 (60.6)	54.4	45.6	
Female	4065 (39.4)	64.3	35.7	

Table 1 summarises the background characteristics of the households, as well as the association between the use and non-use of clean cookstoves. The majority of the households (87.3%) lived in urban, non-poor households. Most of the household heads are aged 36-60 (49.4%), currently married (55.1%), and are males (60.6%) (See Table 1).

Table 2: Logit Model

Variables	(1) Logit	(2) Logit	(3) Logit	(4) Logit	(5) Logit	dy/dx
Urban poverty based on household characteristics						
Urban non-poor (RC)						
Urban poor	-1.4790***	-1.5091***	-1.3671***	-1.3632***	-1.3966***	-0.2518
	(0.147)	(0.146)	(0.149)	(0.148)	(0.147)	(0.0214)
Age of head of household						
< 35 years (RC)						
36 to 60 years		-0.4792***	-0.3118***	-0.3108***	-0.2570***	-0.0509
		(0.067)	(0.072)	(0.071)	(0.075)	(0.0150)
61+ years		-0.9358***	-0.6274***	-0.6291***	-0.4821***	0.0948
		(0.111)	(0.114)	(0.114)	(0.115)	(0.0224)
Highest educational level attained						
None (RC)						
Primary			0.5012**	0.4955**	0.4876**	0.0697
			(0.198)	(0.198)	(0.199)	(0.0286)
Secondary +			1.8199***	1.7735***	1.7402***	0.3159
			(0.149)	(0.149)	(0.149)	(0.0207)
Current marital status						
Never married (RC)						
current married					0.0974	0.0194
					(0.093)	(0.0184)
Formerly married					-0.3921***	-0.0765
					(0.125)	(0.0243)
Sex of head of household						
Male (RC)						
Female				-0.1838**	-0.0213	-0.0042
				(0.077)	(0.080)	(0.0156)
	(0.348)	(0.352)	(0.344)	(0.346)	(0.346)	
Constant	-0.0201	0.3696	-1.2838***	-1.1760***	-1.2198***	
	(0.222)	(0.235)	(0.263)	(0.266)	(0.274)	
Observations	8,795	8,795	8,779	8,779	8,779	

Dependent Variable: Household Clean Stove for Cooking
RC: Reference Category
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results further show that the association between household use of clean cookstoves and urban poverty is statistically significant at $p < 0.05$. This indicates that the type of cookstove used by urban households is influenced by urban poverty, with only 12.6% of urban poor households using clean cookstoves compared to 45.9% among urban non-poor households. Furthermore, with $p < 0.05$, a statistically significant association is observed between the educational attainment of household heads

and the use of clean cookstoves. The use of clean cookstoves is observed to be highest (50.3%) for household heads with secondary education or higher, compared to only 9.7% for those without any formal education.

Table 2 shows the coefficients, standard errors, and estimated marginal effects of key variables in the logit model predicting household adoption of clean cookstoves in Ghana. The marginal effect is used in this study to describe how a small change in an independent variable affects the probability that the outcome, in this case, the adoption of clean cookstoves, will occur. As shown in the table, the age of the household head, educational level, and urban poverty have a significant association with the use of clean cookstoves. For instance, urban poverty has a statistically significant negative relationship with the use of clean cookstoves in all the estimated models.

The negative coefficient and marginal effect provide enough evidence that urban poverty reduces the likelihood of using clean cookstoves. The results indicate that, "all else held constant", living in an urban poor household relative to an urban non-poor household is associated with a 25.2% decrease in the use of clean cookstoves.

Households where the head is aged above 61 years are 9.5 percentage points less likely to adopt clean cookstoves than those with younger heads (less than 35 years), indicating that higher ages are associated with a lower likelihood of adopting clean cookstoves. Moreover, the positive coefficients and significant marginal effects in the table further indicate that education is a strong predictor of clean cookstove adoption. Specifically, households where the head has secondary or higher education are 31.6 percentage points more likely to adopt clean cookstoves than those with no formal education. In contrast, those with primary education would have a nearly 7% increase in the likelihood of using clean cookstoves compared to household heads without any formal education.

After providing empirical evidence of a negative relationship between household use of cookstoves and urban poverty, the data were disaggregated by the sex of household heads to investigate whether the use of clean cookstoves and the urban poverty nexus remain robust across male-headed and female-headed households. The study still finds a negative and statistically significant relationship between urban poverty and the use of clean cookstoves for both male- and female-headed households. This means that urban poor households are less likely to use clean cookstoves compared to urban non-poor households, irrespective of the sex of the household head (see Table 3).

Evidence from the disaggregated model shows some variation between male- and female-headed households in their use of clean cookstoves. While statistically significant relationships were observed for both groups in the overall model, significance was found only at the level of primary education among female household heads. This suggests that primary education may be particularly important for women in shaping household decisions about clean cookstove use, possibly reflecting their central role in energy transition and health-related choices. By contrast, higher education appears to strengthen the adoption of clean cookstoves across both male- and female-headed households, underscoring the role of education as a critical determinant of clean energy transitions.

Differences also emerged based on marital status in the disaggregated model. Among male household heads, currently married men were significantly more likely to use clean cookstoves relative to never-married men, indicating that marriage may strengthen men's capacity or motivation to adopt clean cookstoves for their households. Conversely, among female household

heads, being formerly married was associated with a significantly lower likelihood of using clean cookstoves compared to never-married women.

Table 3: Logit Model

Variables	(Male) Logit	Marginal effect dy/dy	(Female) Logit	Marginal effect dy/dx
Urban poverty based on household characteristics				
Urban non-poor (RC)				
Urban poor	-1.4220***	-0.2722	-1.3729***	-0.2209
	(0.150)	(0.0239)	(0.262)	(0.0317
Age of head of household				
<35 years (RC)				
36 to 60 years	-0.2705***	-0.0549	-0.2289*	-0.0425
	(0.097)	(0.0198)	(0.125)	(0.0235)
61+ years	-0.6188***	-0.1251	-0.2644	-0.0489
	(0.137)	(0.0274)	(0.194)	(0.0359)
Highest educational level				
None (RC)				
Primary	0.0731	(0.1026)	0.7699***	0.1065
	(0.285)	(0.0401)	(0.241)	(0.0327)
Secondary +	1.6902***	0.3213	1.7225***	0.2898
	(0.215)	(0.0318)	(0.196)	(0.0252)
Current marital status				
Never Married (RC)				
Currently married	0.2063*	0.0415	-0.0361	-0.0070
	(0.125)	(0.0249)	(0.158)	(0.0308)
Formerly married	-0.0105	-0.0022	-0.7095***	-0.1326
	(0.176)	(0.0354)	(0.168)	(0.0317)
Constant	-1.2062***		-1.1873***	
	(0.328)		(0.322)	
Observations	5,464		3,315	

Dependent Variable: Household Clean Stove for Cooking
RC: Reference Category
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Discussions

The findings of this study provide insights into how socio-demographic factors influence household use of clean cookstoves among urban non-poor and urban poor households. This study has become increasingly important in response to the global demand for promoting cleaner, safer, and more sustainable cooking practices, especially among the urban poor in low-income countries (WHO, 2024). The study found that a majority of urban households still do not use clean cookstoves for cooking, despite the government's effort to promote their use. This finding is particularly concerning for Ghana's progress towards achieving multiple SDGs, especially as the country's population becomes increasingly urbanised, with projections indicating a rise in the urban poor.

Additionally, it emerged that the proportion of Ghanaians using clean cookstoves is lower among the urban poor compared to the urban non-poor. The continued use of traditional cookstoves, characterised by their poor energy efficiency and high emissions among dense, poorly ventilated urban poor households, particularly exacerbates the risk of higher emissions of harmful pollutants, such as PM2.5 and

carbon monoxide, which are often linked to various respiratory infections in children (Odo et al., 2021). Additionally, previous studies have emphasised how the search for firewood to fuel traditional cookstoves reinforces gender inequalities and contributes to time poverty (Prah et al., 2021). Therefore, transitioning to clean cooking technologies should be a priority for the country.

Furthermore, urban poverty status is found to be a driving factor in the propensity of a household to adopt clean cookstoves. This finding supports the energy ladder hypothesis, which posits that household consumption of cleaner energy sources increases with rising income levels (Ali et al., 2024; Adams, 2023; Karakara & Osabuohien, 2020). A recent study in Ghana, for instance, found that any unit increase in household income leads to a 65% higher chance of the household choosing LPG over charcoal (Ali et al., 2024). Consequently, wealthier urban households would find it most convenient to transition upward on the energy ladder toward LPG or electric cookstoves; the urban poor would risk being limited to dependence on wood fuel and inefficient stoves, reinforcing the "energy divide". Thus, the promotion of cleaner energy (SDG 7.1) through the adoption of clean cookstoves in Ghana cannot succeed without sustained progress in eradicating extreme poverty (SDG 1.1), implementing nationally appropriate social protection programmes (SDG 1.3), and reducing multidimensional poverty (SDG 1.2).

The age of the household head is observed to be negatively related to the use of clean cookstoves, and older households are less likely to adopt clean cookstoves. This is understandable since older household heads often resist change and may have more conservative cooking practices due to their attachment to traditional methods, which can lead to continued household exposure to smoke emissions. This aligns with Mensah and Adu's (2015) study, which found that the marginal effect of the household head's age is positive but decreasing between the ages of 18 and 30 years and negative for all ages above 30 years. The age-related gap in cookstove adoption highlights the importance of age-sensitive energy policies and behaviour change strategies. Without targeted messaging and financial support mechanisms (such as subsidies and microfinance), older household heads may be left behind in the transition to clean energy. Promoting intergenerational awareness can help bridge this gap and ensure that no demographic group is excluded from Ghana's transition to cleaner energy.

There is evidence to show that a household head with secondary education or higher is more likely to adopt a clean cookstove relative to a head with no formal education. This confirms previous studies that have consistently identified formal education as a key driver for the clean energy transition in SSA. For instance, Owusu-Amankwaah et al.'s (2023) study examining the determinants of household cookstoves finds that primary cooks with a university-level education are 14 times more likely to use LPG stoves as their primary stoves relative to primary cooks who have no formal education. Household heads with higher levels of education are most likely to be aware of the environmental benefits of using clean cookstoves and will consequently adopt their use. Overall, this study reinforces the notion that higher levels of education are linked to the adoption of cleaner energy (Ali et al., 2024; Karakara & Osabuohien, 2020). To this end, increasing access to formal education in Ghana, particularly among women and the urban poor, and implementing energy policies can be used to accelerate the transition to clean cooking and reduce household air pollution, which aligns with SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy).

This study further highlights the vulnerability of formerly married women, who may face economic and social constraints, compared to their never-married counterparts. This contrasts with a previous study, which finds that marital status is not a significant determinant of improved cookstove adoption in Ghana (Adams et al., 2023). There is evidence to indicate that marriage exerts different influences on the use of clean cookstoves, favouring households headed by married men while disadvantaging those headed by formerly married women in urban Ghana. In Ghana, as is the case in most countries in SSA, husbands typically control household financial decision-making, while wives are responsible for managing daily chores, such as cooking. Consequently, in married households, a husband's ability to influence the adoption of clean cookstoves may be stronger due to their ability to pool more resources, which would most likely make them more able to afford the initial cost of accessing a clean cookstove.

Conclusion

This study has examined household-level factors that influence the adoption of clean cookstoves and related technologies in urban areas of Ghana. There is evidence to suggest that the use of clean cookstoves in households is relatively low. The logit model reveals that the socio-economic and demographic conditions of households significantly determine the propensity to adopt clean cookstoves. Specifically, urban poverty and the age of the household head were negatively associated with the adoption of a clean cookstove. In contrast, the educational attainment of the household head was positively associated with the adoption of a clean stove. These findings suggest that targeted interventions aimed at improving education and alleviating poverty could enhance the uptake of clean cookstoves. Additionally, raising awareness about the benefits of the adoption of clean cookstoves may further encourage urban households to transition towards cleaner cooking methods.

It is evident that the clean cook stove holds the potential to transform the lives of the urban poor in Ghana. By positioning clean cooking as both a climate mitigation strategy and a sustainable development policy, Ghana can unlock the benefits of clean energy transitions by designing more effective interventions, including subsidies for older adults and marginalised groups, and awareness campaigns tailored to the needs of urban poor and rural communities. This study has provided insights into the adoption of clean cookstoves in urban areas through the use of quantitative analysis. However, this approach has limitations for fully explaining the sociocultural and behavioural practices that affect household choices regarding clean cookstoves. To further the achievement of the Sustainable Development Goals—especially SDG 7 and SDG 13—future research should integrate qualitative methods. Such approaches would facilitate the discovery of the underlying perspectives, lived experiences, and contextual factors that influence energy transitions, thereby enabling the development of more inclusive and effective pro-poor policy interventions that account for the diverse needs of communities. By combining quantitative data with qualitative insights, researchers can gain a more comprehensive understanding of energy transitions and their implications for health and environmental sustainability.

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EVALUATION OF THE PNEUMONIA SURVEILLANCE SYSTEM IN CHILDREN UNDER – FIVE YEARS, AHANTA WEST DISTRICT, WESTERN REGION – GHANA, 2019

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Abstract

Background: Pneumonia is the leading cause of under-five mortality globally. In Ghana, pneumonia ranks third with 5,000 mortalities yearly. Surveillance is key to achieving a target of SDG 3, to reduce pneumonia deaths to < 3/1000 live births by 2025. The surveillance system in Ahanta West District is for early case identification and epidemics, antibiotic resistance monitoring, and reduction of severe cases. We evaluated the system to assess its usefulness, attributes and whether it was meeting its objectives.

Methods: This was a cross-sectional design. Quantitative data were collected using semi-structured questionnaire. Quantitative data were by abstracting 2010-2017 under-five pneumonia data set from DHIMS-2 and reviewing outpatient registers. Qualitative data were analysed under themes, using CDC-updated guidelines for evaluating public health surveillance systems. Quantitative data were analysed descriptively using Epi-Info 7 to generate frequencies and proportions. The study was conducted between December 2017 and January 2018.

Results: The system generated data to guide public health interventions in the district. It detected 1,891 cases; no severe cases, and no epidemics. Cases were disaggregated in facility registers but not in DHIMS-2. There was no evidence of antibiotic monitoring. Case definition was easily applied and timeliness of reporting was 100%. Data quality was 66.8% (16/24) and 91.7% (22/24) at district and regional levels respectively. All four sub-districts reported cases throughout the period.

Conclusion: The system was useful but partially met its objectives. It was sensitive, simple, timely, representative, and of good data quality. Lack of antimicrobial resistance monitoring threatens the systems' effectiveness.

Keywords: Pneumonia, surveillance, system, evaluation, Ahanta West, Ghana.

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Introduction

Pneumonia is vaccine-preventable, yet it remains the leading infectious cause of death among children under five years globally. In 2019, 14% of all deaths among children under five years globally were due to pneumonia (Villavicencio et al., 2024; WHO, 2022). Sub-Saharan Africa carries the greatest burden, with an estimated 35.13 million new cases yearly (Rudan et al., 2008). Although there has been a general decline in under-five mortality from 2000–2019 worldwide, regional estimates on cause-specific mortality indicate pneumonia still contributes significantly (16.8%) to child mortality in West and Central African countries (Villavicencio et al., 2024). The high mortality rate in children is mainly attributed to a lack of knowledge of both healthcare workers and caregivers in identifying the symptoms of pneumonia for early treatment (Runchina, 2016). There is a lack of adequate data regarding pneumonia in Ghana (Abbey et al., 2018). Although analysis of mortalities at the Accra Children's Hospital revealed a decrease in deaths among the under-fives, there is a significant burden of deaths of about 18% associated with pneumonia (Abbey et al., 2018). In Ghana, pneumonia ranks third in under-five mortality, causing about 5,000 mortalities every year, which exceeds 100 per 100,000 (Abbey et al., 2018).

Pneumonia is a lower respiratory infection caused by infectious agents such as viruses, bacteria, and fungi. The most common causative agents of pneumonia are bacteria and viruses. *Streptococcus pneumonia, Haemophilus influenza* type B, and respiratory *syncytial virus* are the most implicated organisms (*Pneumonia in Children*, n.d.). Moreover, pneumococcal disease is the most prevalent in Ghana (Ibrahim et al., 2024).

Risk factors for pneumonia in children under five include malnutrition, indoor air pollution from cooking with biomass fuels such as wood, living in crowded homes, and parental smoking, Children below six months, rural residents, not up to date with immunization schedules, severe acute malnutrition, and lack of exclusive breastfeeding (Rudan, 2008; Baffour Appiah et al., 2020; Kiconco et al., 2021). Again, the Ghana Randomized Air Pollution and Health Study (GRAPHS) in 2023 found a positive correlation between household air pollution exposures during prenatal life and increased risk of pneumonia among children under five years (Kaali et al., 2023).

Management of pneumonia in children under five can be done at the primary healthcare level using the strategy for the Integrated Management of Childhood Illnesses (IMCI) (Hamade M., 2002). One of the strategies of the global Action plan for pneumonia and diarrhea for prevention of pneumonia in children under five aims at vaccination, and Ghana has intensified actions to control pneumonia by introducing the 13-valent Pneumococcal Conjugate Vaccine (PCV) in 2012 (Gavi, 2012).

Public health surveillance systems are established to provide timely scientific and factual data essential for public health action and to guide public health interventions (Nsubuga et al., 2006). The pneumonia under-five surveillance system is one of the surveillance systems established for diseases of public health importance that exists within the Integrated Disease Surveillance and Response (IDSR) for early detection and timely response to public health emergencies to protect public health. The surveillance system on pneumonia in children under five years was set up with the objectives of early identification of cases and epidemics using clinical case definitions, to monitor antibiotic resistance, and to reduce severe pneumonia cases (Hamade M., 2002).

As part of efforts to achieve one of the targets of the Sustainable Development Goal (SDG) 3, of reducing child mortality,

World Health Organization (WHO) via the Integrated Global Action Plan for the Prevention and Control of Pneumonia and Diarrhea (GAPPD) set a target to reduce pneumonia deaths to fewer than 3 deaths/1000 live births by 2025 (Abbey et al., 2018). Therefore, the importance of the surveillance system via provision of data to guide interventions such as vaccination and health education cannot be underestimated. Nonetheless, the surveillance system on Pneumonia in children under five years old in Ahanta West district has been evaluated before since it was established. We therefore evaluated the system to assess whether it was meeting its objectives and to assess its usefulness and attributes.

Methods

Study Design

The evaluation was a cross-sectional design, involving both qualitative and quantitative data. Qualitative data was collected using semi-structured interviewer-administered questionnaires. The updated guidelines of the Centers for Disease Control and Prevention (CDC) (German et al., 2001), for evaluating public health systems (2001), the GHS Integrated Diseases Surveillance and Response (IDSR) (*Integrated-Disease-Surveillance-and-Response-Ghana-Guidelines.Pdf*, n.d.) were used. The period under evaluation was from 2010 to 2017. The study was conducted between December 2017 and January 2018.

Study setting

We conducted this evaluation in the Ahanta West District, one of the 14 districts in the Western Region of Ghana. Its capital is Agona Nkwanta, and it is mostly rural. The district is about 25 kilometers from the regional capital, Sekondi-Takoradi, and is 636 km2 in area with over 120 settlements. The Ahanta West District is divided into four sub-districts, namely, Dixcove, Apowa, Princess, and Agona sub-districts. The total population of the district in 2017 was 12,2029 with an under-five population of 4,881. There is a total of 16 health facilities in the district, with the district hospital located at Dixcove. The district also has three health centers, eight Community Health Planning and services (CHPS) compounds, and four clinics. Out of these facilities, three are privately owned with 82 outreach posts (*AHANTA WEST.Pdf*, n.d.). (Fig 1).

Figure 2 Map of Ghana showing Ahanta West District

Standard case definition

Suspected case definition per Integrated Management of Childhood Illnesses (IMCI) for pneumonia:

A child presenting with cough or difficulty breathing and:

50 or more breaths per minute for infants aged 2 months up to 1 year.

40 or more breaths per minute for young children 1 year up to 5 years.

(Note: A young infant aged 0 up to 2 months with cough and fast breathing is classified in (IMCI) as a "serious bacterial infection" and is referred for further evaluation.)

Suspected case definition (IMCI) for severe pneumonia:

A child presenting with cough or difficulty breathing and any general danger sign, or chest in-drawing or stridor is a calm child. General danger signs for children 2 months to 5 years are: unable to drink or breastfeed, vomiting everything, convulsions, lethargy, or unconsciousness.

Confirmed case:

Radiographic or laboratory confirmation of pneumonia will not be feasible in most districts (Hamade M., 2002).

Data Collection

The Center for Disease Control and Prevention (CDC) updated guidelines for surveillance system evaluation (2016) and was used as our reference tool for this evaluation. We assessed the objectives, usefulness, components, purpose and operation of the system, and resource requirements. We interviewed fourteen surveillance officers on the case definition, the first line of antibiotic treatment, and how antibiotic resistance in patients is monitored. The officers included Physician assistants Community Health Nurses, Disease Control Officers, Health Information Officers, and Public Health Nurses selected from the health facility, sub-district, district, and regional levels. We also abstracted and reviewed the 2010-2017 pneumonia under five electronic data sets from the District Health Information Management System -2 (DHIMS-2). We reviewed monthly Integrated Disease Surveillance and Response (IDSR) forms, out-patient and inpatient pneumonia records, and summary reports to assess the system's attributes in terms of sensitivity, simplicity, representativeness, stability, flexibility, predictive value positive (PVP) data quality, timelines and acceptability.

Assessment of the system attributes

Simplicity was assessed by the clarity and the ease with which the case definition was applied and the length of time to establish a diagnosis; sensitivity was by the ability of the system to detect cases; Flexibility was assessed by the system's ability to adapt easily to changes in information needs and mode of operation; timeliness by the length of time to report cases from one level to another within the system; for data quality, we assessed the accuracy and completeness of monthly data into the DHIMS-2 and monthly morbidity forms submitted to the Regional Health Directorate (RHD). We sampled data for 2014 and 2015 assessed for completeness and accuracy at three sub-district facilities and compared DHIMS-2 data with hard copies. We assessed acceptability by the level of participation of all reporting sites, assessed representativeness by cases reported by person, place and time across sub populations throughout the period under review; stability was by stakeholder involvement and level of integration into the system; Predictive Value Positive (PVP) was by the number of positives cases confirmed by laboratory or X-ray out of the total number of cases suspected. We also assessed the amount of resources needed to operate the system and the cost of treatment for pneumonia. The evaluation took three weeks from mid-December 2017 to early January 2018.

Data analysis

We performed both qualitative and quantitative analyses. The qualitative data were analyzed under themes based on

updated guidelines for evaluating public health surveillance systems as recommended by the CDC. The thematic areas included: the purpose and operations of the system, components of the system, operational resource requirements, and the nine (9) system attributes. We used Epi-info 7 to analyze quantitative data to generate frequencies and proportions and presented the results as tables and charts. For data quality, a four-point Likert scale was used to grade the scores as poor (0%-30%), average (31%-50%), good (51%-70%), and good (above 70%).

Results

Overall, a total of fourteen (14) officers who were directly involved with surveillance activities in Ahanta West district were interviewed. These officers were selected from the sub-districts, district, and regional levels and comprise four (4) PAs, three (2) DCOs, four (4) technical officers three (2) CHNs, and two (2) Health Information Officers (HIOs). About 64% (9/14) were males. The mean age of the respondents was 33±7.5years. About 86% (12/14) knew the case definition for Pneumonia in children under five. The majority (79%: 11/14) had knowledge of the objectives and the communication flow within the system. All the Prescribers said they adhered to the IMCI strategy in the management of cases and knew the treatment of pneumonia based on the Standard Treatment Guidelines of Ghana. However, none of the officers interviewed could tell how antibiotic resistance monitoring of the cases was done. All of them knew that pneumonia is reported monthly using the morbidity forms from one level to the next. They all agreed that the system exists to generate timely and quality data essential for effective public health action to reduce morbidity and mortality.

Purpose and Operation of the System

Data reporting for the system

The data reporting system for the pneumonia under-five surveillance system is passive as the system relies on routinely collected data from the health facilities. It begins at the community level where caregivers decide to seek care at the health facility level. Data is then sent to the district level, regional, national, and finally to partners. Feedback is given from the national level to the district level, health facility level, and finally to the community level. (Fig 2.)

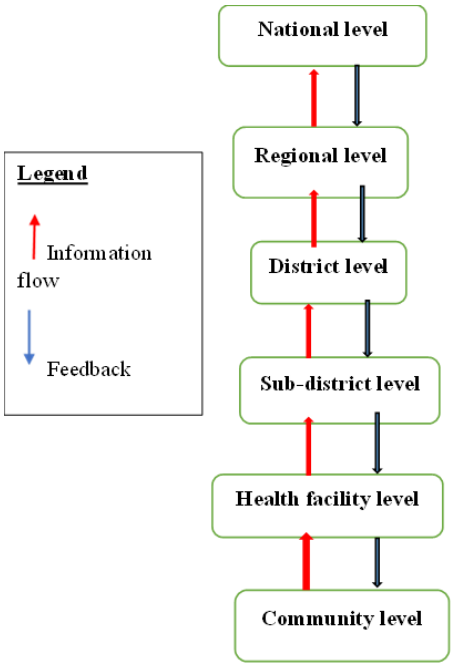

Fig 2. Flow chart for a surveillance system for Pneumonia under five, Ahanta West district.

Components of the system

Cases of pneumonia in children under five years in the community are detected at the health facility level by a prescriber using clinical case definitions. The cases are recorded in consulting room registers as severe and non-severe cases based on the prescriber's diagnosis. Hospitalized cases are considered severe pneumonia cases and hospitalization depends on the presence of danger signs (unable to drink or breastfeed, convulsions, lethargy, etc.). The cases are then reported to the district level as aggregated data using the monthly IDSR forms.

All sub-district officers attend a validation exercise at the district level where entries on the forms are compared with source documents to check for data accuracy, consistency, and completeness before entries are made into the DHIMS-2 database. At the regional level, officers also validate data entered into the DHIMS-2 database by the various districts to address data quality issues. Sometimes phone calls are made to reporting districts for more clarification when necessary. Data analysis was done at district and regional levels to show trends and distributions of cases. Soft copies of the data were stored with a password and only authorized persons can release the data under strict conditions when necessary. The hard copies are kept in a file and placed in cupboards.

Resource requirements for the system

The surveillance system on pneumonia under five is integrated with other diseases and events of public health importance under the IDSR framework and, hence has no special funding. The Government of Ghana provides computers, stationery, phone calls, and money for internet data through the District Health Directorate (DHD). The system also received indirect support from the Ente Nazionale Idrocarburi (ENI) Foundation (an Italian Oil company) that provided laptops and data management skills for most staff in the district.

The DHD spent about GHC 500 and GHC 50 on internet data and phone calls respectively every month. The monthly cost of internet data at the health facility level ranged between GHC 50 and GHC 30 and GHC 30 and GHC 50 for phone calls depending on the facility level. Families of sick children bear the full cost of treatment which was GHC 50 including basic laboratory and X-ray costs. The government of Ghana also pays the salaries of personnel involved in the surveillance activities. The same personnel handled other public health duties and programs in the district. Personnel spent on average 30 – 45 minutes at the health facility and the district levels to enter data into the DHIMS-2.

The System on Meeting Its Objectives

Cases of under-five pneumonia are identified using clinical signs and symptoms. Pneumonia cases are reported monthly from one level to the next. Both severe and non-severe pneumonia cases are recorded as pneumonia cases in the DHIMS-2 and the monthly IDSR forms. All the cases recorded by the system were treated as out-patient cases. There was no documented evidence of antibiotic resistance monitoring. Interviews with Key stakeholders revealed antibiotic resistance was not monitored due to lack of laboratory capacity. Culture and sensitivity tests were done at the Zonal Public Health Laboratory located in the regional capital, about 25km away.

The usefulness of the system

The system recorded a total of 1,891 cases with no deaths and no epidemics. The highest proportion of cases 8.98% was recorded in 2013. (Table 1)

Table 1. The proportion of pneumonia under five cases, Ahanta West, 2010-2017

Year	Population	No. of cases	Proportion
2010	4249	158	3.72
2011	4334	281	6.48
2012	4420	325	7.35
2013	4509	405	8.98
2014	4599	312	6.78
2015	4692	211	4.50
2016	4786	108	2.26
2017	4881	91	1.86
Total		1891	

No. of cases: number of reported pneumonia cases in under five five

Distribution of cases by sub-districts

Overall, the Dixcove sub-district recorded about 61.1% (258/422) of the cases, and 51% (964/1891) of cases, were recorded in 2013 by the Agona sub-district. (fig. 3).

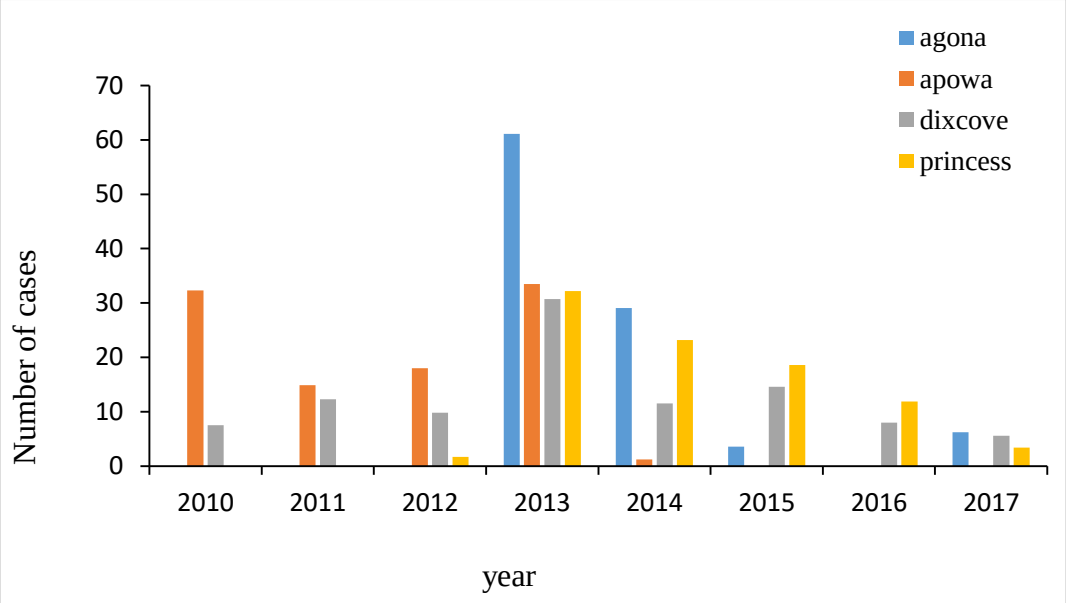

Fig 3. Distribution of cases by sub-district, Ahanta West district, 2010-2017.

Data from the system was used to monitor the trend of pneumonia cases and evaluation of PCV vaccination outcomes among the under-five population. It is also used for planning other disease control activities such as health education.

Attributes of the system

Simplicity

The system was simple. Case definition is clear and easy to apply and less time is required to establish diagnosis using the clinical signs and symptoms. Moreover, laboratory and X-ray confirmation takes about 30 minutes to about two hours to complete. However, these investigations are not routine to establish diagnoses but rather prescribers rely on clinical signs and symptoms. The system does not involve lengthy reporting sources as the one collecting the data is the same person making the diagnosis. No filling of special forms (case-based forms) is required in its reporting.

Sensitivity

The system was sensitive as it recorded a total of 1,891 cases with no deaths and no epidemics. Cases were recorded at all the four sub-districts throughout the eight years under evaluation. The highest proportion of cases 8.98% occurred in 2013. Dixcove sub-district recorded most of the cases.

Predictive value positive (PVP)

A predictive value positive could not be assessed. Severe pneumonia under five can be diagnosed using the clinical signs and symptoms. Laboratory and X-ray confirmations are not routinely done. (*Integrated-Disease-Surveillance-and-Response-Ghana-Guidelines.Pdf*, n.d.) Due to the lack of capacity in the district, hence all suspected cases are considered confirmed cases.

Flexibility

The system was flexible as it is integrated with other surveillance systems. Cases of pneumonia are recorded and reported together with other priority diseases under surveillance on the same monthly morbidity forms.

Timeliness

The system was timely as it takes on average 30 minutes from data collection to diagnosis. Reporting cases from the health facility to the district level also takes a month because the cases are recorded on the monthly IDSR forms. Health facilities are to meet a deadline of the 10th of the ensuing month to the DHD. The DHD is also given the 15th of the succeeding month to send its reports to the regional level. Timeliness was 100% as all the levels were able to meet their deadlines for the eight years.

Data quality

Generally, data quality was 66.7% (16/24) at the district level and 91.7% (22/24) at the regional level. Data completeness was 100% as there were no missing fields in all the forms examined.

Acceptability

The system was well accepted among its stakeholders. All sixteen (16) health facilities both government and private report cases consistently all year round to their sub-districts which in turn report to the district level. All reporting sites including sub-districts met their timelines throughout the period under evaluation.

Representativeness

The system was not fully representative. Cases were reported from all four sub-districts in Ahanta West District. The district also recorded cases throughout the years under review (2010- 2017). However, cases were not disaggregated by sex and sub-age categories of the under-five population.

Stability

The system was fairly stable. It did not have a direct source of funding. Nonetheless, it was integrated into the other priority diseases and public health events under surveillance. Logistics such as personnel salaries, computers, stationery, funds for phone calls, and internet data are provided by the government of Ghana through Ghana Health Service and subsequently the DHD. Due to the integration of the system with other systems, the same personnel conduct all surveillance activities together. However, challenges with internet connectivity in the district sometimes delay surveillance activities and so sometimes personnel travel outside the district for stable internet services. All the health facilities and the district health directorate did not have computer backups. Only the regional and the national offices had backups for their computers at the time of this evaluation.

Discussion

The surveillance system for pneumonia in children under five years was set up for the early identification of cases and epidemics for prompt management and response to reduce severe pneumonia cases and to

monitor antibiotic resistance among the cases. However, the system is partially meeting these objectives. This can lead to misguided interventions and wastage of resources as the main objective of a surveillance system is to provide information to guide public health actions.

The system did not detect epidemics, severe cases, or deaths from 2014 to 2017. this finding is contrary to the findings of a similar evaluation by Dadzie et al done at Tema Metropolis, Ghana, where the system detected deaths and missed epidemics from 2012 to 2016 (Dadzie et al., 2020). Ahanta West is a relatively small district compared to Tema, an industrial hub of Ghana with people of diverse socio-economic backgrounds and economic activities. Therefore, the difference in population in terms of size and other characteristics such as level of exposure to household and environmental pollutants are major risk factors for pneumonia in children under five years could have accounted for this variation. This may also imply that the cases in Ahanta West could have been detected early and managed swiftly to prevent severe cases with subsequent complications. However, early identification of cases mostly depends on caregivers' ability to seek care early due to knowledge of signs of the disease, educational level, and availability of financial resources among other factors. Moreover, the cost of treatment for non-severe pneumonia is affordable and covered under the National Health Insurance Scheme (NHIS) in Ghana which could have influenced early reporting of the cases. Seeking care early for pneumonia symptoms helps reduce mortalities associated with the disease. Nonetheless, caregivers in rural areas are expected to be less educated with low financial resources and therefore may delay seeking care for their wards. Perhaps further research is needed to investigate the care-seeking behavior, population dynamics, and characteristics of these vastly heterogeneous populations.

The system did not detect severe cases during the record review from all facilities visited.

The Prescriber's competence with correct diagnosis and appropriate and timely management by adhering to standard treatment guidelines could have accounted for the absence of severe cases in Ahanta West. Nonetheless, our result is based on what the prescribers said during the interviews, which could not be validated. An evaluation of the treatment was needed to verify the adherence levels to treatment guidelines, to ascertain the quality of the interventions, and other contributing factors. On the other hand, there could be potential misclassification/misdiagnosis of severe pneumonia cases, especially when diagnoses were primarily based on clinical manifestations and not detailed X-ray confirmations. This may subsequently result in under-reporting of severe cases and making the system less sensitive.

At the level of case detection, cases are disaggregated by age and sex. Beyond that, cases are recorded as aggregated data on the monthly IDSR forms and into the DHIMS-2. This makes detailed data analysis challenging and subsequent targeted interventions to those who need it most. In a cohort study conducted in South Africa, 60% of pneumonia cases were recorded among males, and the under-one-year age group was the most affected. Adding more variables to the data field in the DHIMS-2 system will make early identification of vulnerable groups much easier for timely response and efficient use of scarce resources.

Further, there was no evidence of antibiotic monitoring due to a lack of laboratory capacity, guidelines, and protocols. Dadzie et al also reported a lack of data on antibiotic resistance monitoring which exposes the weak teamwork between laboratory and disease surveillance activities (Dadzie et al.,

2020). Another study by Musa et al reported that lack of laboratory capacity is a challenge to monitoring antimicrobial resistance in resource-limited settings (Musa et al., 2023). Antibiotic monitoring is essential to detect early resistant strains of organisms that could pose a serious threat to public health. Again, the identification of the actual causative agent (virus, bacteria, fungi) of pneumonia cannot be determined. This undermines the district's ability to early detect, respond to and control the spread of resistant infections. On a larger scale, decisions may be made based on assumptions rather than facts because accurate and timely data on resistance trends, outbreaks, and important information on the effectiveness of programs against antibiotic resistance may be lacking. As clinical guidelines depend on local resistance patterns, prescribers may be compelled to administer broad-spectrum antibiotics, which can result in treatment failures, threaten patient safety, and increase healthcare costs (Frost et al., 2021; Dadgostar, 2019).
There is therefore a need to strengthen laboratory capacity across districts and establish an antimicrobial resistance surveillance system for the control and prevention of antimicrobial resistance, which has become a global public health challenge.

The principal objective of detecting cases all year round from all sub-districts makes the system useful. Generated data from the system was vital for planning and disease control activities. Trends of the cases were compared with PCV coverage to assess vaccine effectiveness at all levels of the surveillance system for targeted interventions.

The clarity and easy nature of the case definition make the system simple; no routine laboratory confirmation was done for case confirmation, inconsistent with what Dadzie et al found in Tema Metropolis, where laboratory and X-ray confirmation were done as routine confirmatory examinations in most of the facilities (Dadzie et al., 2020). Unlike Ahanta West, which is mostly a rural setting with mostly health centers and a polyclinic without laboratories, Tema is an urban area with more advanced hospitals and clinics with laboratory and X-ray capacity to confirm pneumonia diagnosis. The lack of confirmatory diagnostic tests in the Ahanta West district did not permit the assessment of predictive value positive. This makes the system less robust to identify true positive cases of pneumonia and subsequent identification of actual causative agents/organisms. This is also likely to cause misdiagnosis, as pneumonia is not the only lower respiratory condition. The system was flexible and well-accepted among its stakeholders. Despite the challenge of poor access to internet connectivity in the district, staff were motivated to meet the deadline for data entries, partly because they had been made to see it as part of their job duties. The quality of the data was partly due to the support from the ENI Foundation and the monthly data validation exercises. Nevertheless, the system was not fully representative as cases were not described by sex and sub-age categories among the under-fives. This system is likely to delay timely intervention to specific populations most at risk.

Timeliness for reporting cases from one level to the next level was impressive (100%) as deadlines were met at all times during the review period. The timeliness of reporting enhances the early detection of outbreaks and swift response. Few studies have attributed the improvement in the timeliness of reporting in a surveillance system to electronic forms of reporting. (Baffour Appiah et al., 2020; Dadzie et al., 2020). Health facilities reported cases on time to the district level, while the district and the regional levels also met their deadlines for the entire evaluation period. The integration of the system with the other

priority diseases and public health events under surveillance contributed to the system's stability. The same Ghana Health Service staff perform surveillance and disease control activities at all levels. However, stability was threatened at the district level due to a lack of stable internet access. Personnel responsible for data entries sometimes travel to other locations for stable internet to make entries into the DHIMS-2 each month by public transport. Some documents could be lost or damaged on the way. One health facility visited was without a functional laptop, and so data entry was sometimes done at an internet café in town. This may compromise data privacy and confidentiality. Routers can be provided, especially at the health facility level, to support surveillance activities. Again, the lack of computer backup systems at the district and health facilities was dangerous for the system, as data retrieval could be a challenge in case of system failures, such as crashes and missing computers.

Limitations of the study

There were no inpatient records for review, so we could not monitor the quality of the interventions (treatments) that could have been given to hospitalized patients. Surveillance officers had to recall past information during the interview, and there is the possibility of recall bias. A lack of laboratory capacity to monitor antibiotic resistance weakens the system and can lead to misguided interventions and wastage of funds in an already resource-constrained environment.

Conclusion

Overall, the system was useful as it generated quality data to guide public health interventions at various levels. The system was sensitive, simple, flexible, timely, and acceptable to all its stakeholders, fairly stable, but not fully representative. The lack of laboratory capacity for confirmatory tests and antibiotic resistance monitoring threatens the achievement of the system's objectives. The government of Ghana, through the Ministry of Health, should urgently invest in upgrading laboratory infrastructure, systems, and workforce capacity strengthening through partnerships with local and international agencies and dedicated local funding sources.

Data Availability

All data have been fused into the manuscript and its supporting information files.

Conflicts of Interest

The authors declare that they have no conflicts of interest

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Abbreviations

AIDS: Acquired Immunodeficiency Syndrome
CD: Compact Disc
CD2: Communicable Disease Form 2
CDC: Center for Disease Control and Prevention
CHN: Community Health Nurse
CHPS: Community Health Planning and Services
DCO: Disease Control Officer
DHD: District Health Directorate
DHIMS: District Health Information Systems
GHC: Ghana Cedis
GFELTP: Ghana Field Epidemiology and Laboratory Training Program
GIS: Geographic Information Systems

HIO: Health Information Officer
IDSR: Integrated Disease Surveillance and Response
IMCI: Integrated Management of Childhood Illnesses
OPD: Out Patient Department
PA: Physician Assistant
PCV: Pneumococcal Conjugate Vaccine
PHN: Public Health Nurse
PVP: Predictive Value Positive
RHD: Regional Health Directorate
TO: Technical Officer

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Ethics Approval and Consent to Participate

The permission to access and use data for this evaluation was approved by the Ghana Field Epidemiology and Laboratory Training Program under the Department of Epidemiology and Disease Control at the University of Ghana School of Public Health and Ghana Health Service which are co-partners in the training of Field Epidemiologists in Ghana. Using existing data for surveillance system evaluation within the context of the Integrated Surveillance System and response does not require ethical approval. However, permission was sought from the mandatory authorities. Individual consent to participate was also obtained from respondents during the study and confidentiality was ensured as their responses could not be traced to them. Data for this evaluation was encrypted with a password on a computer and hard copies were kept under lock and key.

Consent for Publication

Not applicable

Availability of data and materials

Available data has been uploaded as an Excel sheet (Additional file)

Competing Interest

The authors declare no competing interest

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Authors Contribution

Conceptualization of the idea – STA. Data collection – STA, EA, TR. Data analysis – STA. Draft manuscript – STA, EA, TR, KMN. Review of the manuscript – TR, EA, KMN. All authors read and approved the final manuscript.