

Heavy Metal Contamination and Ecological Risk Assessment of River Birim under Illegal Artisanal Mining in Ghana

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Abstract

Illegal artisanal gold mining has emerged as a major environmental challenge in Ghana, with significant consequences for water resources. This study assessed contamination risks posed by heavy metals in water and sediments of the River Birim, a river system severely impacted by unregulated mining. A total of 60 samples, comprising 30 water samples and 30 sediment samples, were collected from five different sites along the river using appropriate standard procedures. The samples were then analysed for metals, including iron (Fe), manganese (Mn), nickel (Ni), cadmium (Cd), zinc (Zn), chromium (Cr), lead (Pb), and mercury (Hg), using atomic absorption spectrophotometry. Risk indices, such as the Potential Ecological Risk Index (PERI) and human health indices, including the hazard quotient (HQ), hazard index (HI), and TCGLR, were also employed. Sediment concentrations (mg/kg) followed the order Fe (8986.33) > Mn (425.90) > Ni (24.68) > Cd (17.67) > Zn (11.23) > Cr (2.50) > Pb (1.33) > Hg (0.50), while water concentrations (mg/L) ranked as Fe (5.36) > Cd (0.23) > Ni (0.08) > Zn = Hg (0.04) > Cr = Mn (0.03) > Pb (0.02). Concentrations of Cd, Fe, Pb, Hg, and Ni in water exceeded World Health Organisation (WHO) limits for potable water. Sediment quality indices indicated moderate to severe contamination by Hg and Cd, with cadmium alone contributing approximately 98% of the total ecological risk (PERI = 10,827.3). Non-carcinogenic risks were below the threshold of concern (HI < 1). However, carcinogenic risk assessments revealed that ingestion of Cd- and Ni-contaminated water and Cd-rich sediments exceeded permissible limits, suggesting potential long-term health implications. These findings highlight the urgent need for stricter environmental regulation, sustainable mining practices, and continuous monitoring to protect communities reliant on the River Birim.

Keyword: River Birim, Heavy metals, Galamsey, Ecological risk, River pollution, Sediment contamination, Ghana

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Introduction

Heavy metal contamination in freshwater systems is a global environmental and public health issue. Heavy metals are toxic, persistent, and capable of bio-accumulating in aquatic organisms, making them highly dangerous for ecosystems and humans alike. Once released, they persist for decades, travel across ecosystems, and magnify through food chains, thereby threatening biodiversity and human health (Meng et al., 2016). Exposure to heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) has been associated with carcinogenicity, neurological disorders, kidney damage, and multi-organ toxicity in humans, as well as bioaccumulation in aquatic organisms that disrupts ecological balance (Sati et al., 2026; Gavrilesco et al., 2021). In aquatic ecosystems, these contaminants reduce species diversity, impair reproduction in fish and invertebrates, and alter trophic interactions, thereby degrading ecosystem functioning over time (Gadd & Griffiths, 1977; Gadd, 2023). This directly undermines access to safe, clean water, a core target of SDG 6. Due to their environmental persistence and tendency to bioaccumulate, heavy metals can produce significant cumulative ecological and health impacts even at low levels of contamination.

Globally, heavy metals originate from both natural and anthropogenic sources, including volcanic activity, rock weathering, industrial effluents, and mining operations (Kumar et al., 2017). In aquatic systems, sediments serve as both sinks and secondary sources of contaminants; changes in pH or hydrodynamics can remobilise trapped metals into the water column, increasing bioavailability and ecological risk (Sun et al., 2018). To mitigate these risks, a range of remediation technologies has been developed, including physicochemical approaches such as chemical precipitation, adsorption, ion exchange, membrane filtration, and dredging; however, these methods are often

costly, energy-intensive, and may generate secondary pollutants (Ali et al., 2020; Foulquier et al., 2013). Emerging approaches in tropical river basins increasingly emphasise nature-based solutions such as phytoremediation and bioremediation, which use plants and microbial processes to remove, immobilise, or detoxify heavy metals in water and sediments (Yadav et al., 2025; Ayilara & Babalola, 2023). Such processes compromise water quality and safety, posing challenges to achieving universal access to clean water as outlined in SDG 6. In sub-Saharan Africa, and Ghana in particular, artisanal and small-scale illegal artisanal gold mining (ASGM)—commonly called *galamsey*—has become a dominant source of contamination. While prior research has reported mining impacts on water quality (Ansah-Asare & Asante, 2000; Amuah et al., 2022; Kazapoe et al., 2023), few studies have quantitatively assessed heavy metal accumulation in both sediments and water while integrating ecological and health risk indices. This constitutes a major gap in the literature.

The River Birim, located in Ghana's Eastern Region, exemplifies this challenge. It is an essential freshwater resource for domestic use, agriculture, and livelihoods, yet it is significantly degraded by illegal artisanal mining. In comparable tropical river systems, remediation strategies such as constructed wetlands, aquatic macrophyte deployment, and riparian buffer restoration have demonstrated effectiveness in removing heavy metals through processes such as phytoextraction, *rhizofiltration*, and phytostabilisation (Amrita & Dwiharto, 2026). Constructed wetlands, in particular, act as natural filtration systems that treat mining-impacted water while simultaneously enhancing biodiversity and ecosystem services, making them suitable for resource-limited settings (Vymazal, 2011; recent wetland reviews). Its deterioration threatens sustainable water supply and sanitation efforts, which are

central to SDG 6. Its role in supporting local communities, coupled with its vulnerability to contamination from *galamsey*, makes it a critical site for this study. By assessing contamination levels in this river, the study aims to provide crucial data to inform policy interventions and sustainable management strategies for both the river ecosystem and the surrounding communities.

The River Birim is a crucial freshwater resource for domestic use, agriculture, and livelihoods, yet it faces significant degradation from illegal artisanal mining. These mining operations introduce mercury for gold amalgamation, along with cadmium and lead from industrial waste, and nickel and iron from both geogenic and anthropogenic sources (Obasi & Akudinobi, 2020). While previous studies (Asare-Donkor et al., 2018; Afum & Owusu, 2016) have highlighted general declines in water quality, systematic assessments of heavy-metal risks to both ecosystems and human populations remain limited. In tropical environments, remediation effectiveness is influenced by hydrological variability, sediment dynamics, and biological interactions, necessitating integrated approaches that combine biological, chemical, and engineered solutions for sustainable outcomes (de Lima et al., 2022; Li et al., 2025). This gap constrains efforts to ensure water quality monitoring, pollution reduction, and safe water access, which are key targets under SDG 6. This lack of integrated ecological and human health risk evaluations has hindered the development of effective policy interventions.

This study aims to address this gap by analysing water and sediment samples from the River Birim to (i) quantify heavy metal concentrations, (ii) evaluate sediment pollution indices, (iii) assess ecological risks using the Potential Ecological Risk Index (PERI), and (iv) conduct non-carcinogenic and carcinogenic risk assessments for human health. By

integrating insights from remediation technologies and documented health impacts, the study not only quantifies contamination but also provides a scientific basis for targeted mitigation strategies in tropical river systems (Ali et al., 2020; Dagdag et al., 2023). By generating evidence to support water quality management and pollution control, the study contributes to achieving SDG 6 targets to improve water quality and reduce contamination. By combining ecological and public health perspectives, the study provides comprehensive evidence of the extent of heavy metal contamination. This paper presents the methods, results, and implications of these findings, and concludes with recommendations for sustainable mining governance and watershed management.

Materials and Methods

Study Area

The Birim River is a major freshwater system located in the Eastern Region of Ghana. Rising from the Atewa Range, it flows approximately 181 km before joining the Pra River. Along its course, the river supports several settlements, including Anyinam, Kibi, Oda, Akwatia, and Kade, which together host a population of about 57,000 residents (Adranyi et al., 2024).

The Birim River basin, located in the Eastern Region of Ghana, is a socio-ecological hotspot, with surrounding communities relying on the river for drinking water, agriculture, fishing, and small-scale industry (Aboah et al., 2026). However, widespread artisanal and illegal artisanal gold mining (*galamsey*) has placed the river under severe environmental stress. Mining activities in the catchment include dredging, open-pit extraction, and panning, often accompanied by mercury amalgamation for gold recovery (Donkor et al., 2024). Additional land uses include subsistence farming, palm oil production, and small-scale commercial agriculture.

Geologically, the basin is underlain by Birimian basement rocks and Voltaian metamorphic sediments, comprising schists, granites, and phyllites, overlain by quartz arenites and carbonate formations. The riverbed itself contains mud, limestone,

gravel, and sand. Still, sediment loads are significantly increased by artisanal mining, which accelerates erosion and mobilises heavy metals from soils and rocks into the aquatic system.

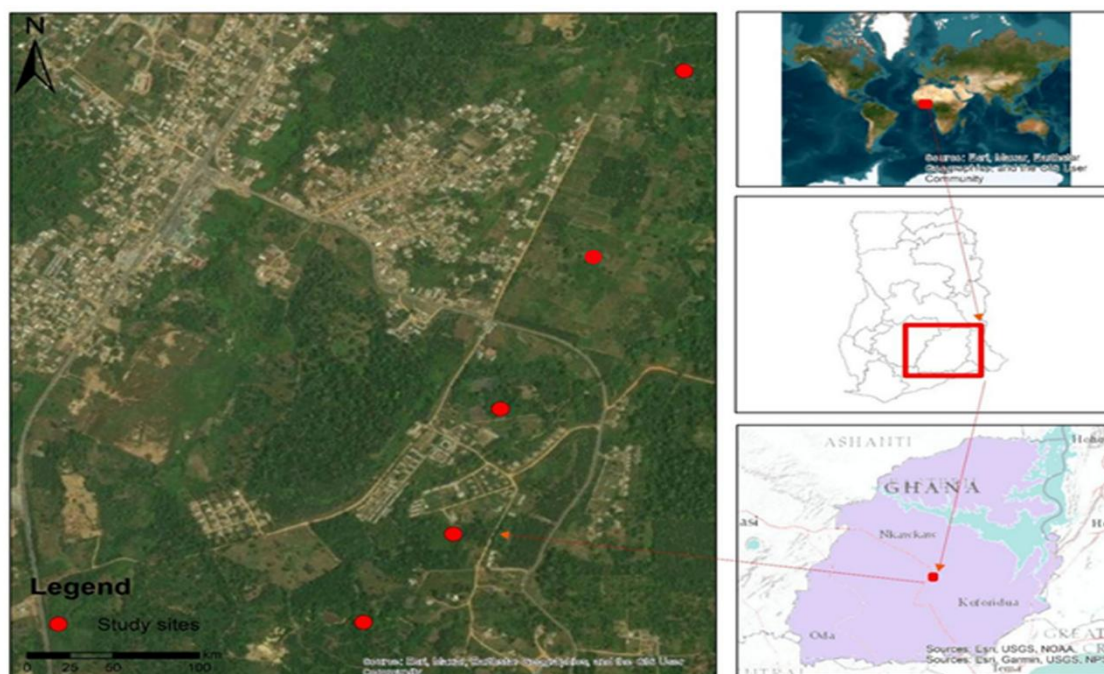


Figure 1: Map of the study area

Sampling Strategy

Water and sediment samples were collected from five purposively selected sites along the River Birim. The sites represented upstream, midstream, and downstream sections of the river, with an emphasis on areas visibly affected by illegal artisanal gold mining.

Sampling was conducted during the dry season, from January to March 2023, to reduce the influence of rainfall, surface runoff, and stormwater dilution on metal concentrations. Samples were collected twice monthly throughout the study period. Water samples were collected using Van Dorn polycarbonate bottles at depths greater than 20 cm below the surface. At each site, three 250 mL replicate samples were taken

during each sampling visit. The samples were immediately filtered through 0.45 μm filters and acidified with 1.0 mL of concentrated nitric acid (HNO_3) to prevent precipitation of metal hydroxides and preserve the stability of dissolved metals prior to laboratory analysis.

Sediment samples were collected within a 2 m radius using an Ekman grab sampler. Three sediment replicates were collected at each site during each sampling visit and composited to form a single representative sediment sample per site. Similarly, the three water replicates collected at each site were composited to produce one representative water sample per site for each sampling event.

In total, the study generated 30 composite water samples and 30 composite sediment samples for laboratory analysis. The compositing approach was adopted to minimise small-scale spatial variability and improve site-level representativeness. GPS coordinates were recorded at each sampling site to support spatial accuracy and future monitoring.

Sample Preparation and Analysis

Water samples: In the laboratory, 150 mL of each water sample was re-filtered using a 0.45 µm Whatman filter. The filtrate was acidified with 65% nitric acid and digested at 105 °C for 2 hours, reducing the volume to ~40 mL. The digested solutions were diluted to a final volume of 120 mL with deionised water and stored in pre-cleaned vials for metal analysis.

Sediment samples: Sediments were air-dried, pulverised in an agate mortar, and sieved (<0.15 mm). Five grams of each sediment sample was digested with aqua regia (HNO₃: HCl, 1:3) at 105 °C to extract acid-soluble metal fractions, rather than to achieve complete dissolution of silicate minerals. The resulting digest was diluted to

a final volume of 10 mL with ultrapure water before metal analysis.

Metal concentrations (Fe, Mn, Ni, Cd, Zn, Cr, Pb, Hg) were determined using atomic absorption spectrophotometry (AAS). Results were expressed as mg/L (water) and mg/kg (sediment).

Quality Assurance and Quality Control

To ensure analytical accuracy, precision, and reproducibility, comprehensive quality assurance and quality control procedures were implemented throughout the study. Certified reference materials, specifically CRM 320 for water and IAEA-405 for sediment, were employed to validate methodological performance. Calibration curves were generated from 1000 ppm stock standards (Sigma-Aldrich, Switzerland) and diluted to working solutions appropriate for each analyte. All glassware underwent acid washing with 10% nitric acid and subsequent oven-drying to eliminate potential contamination. Instrumental detection limits, method detection limits, and limits of quantification for the heavy metals in water and sediment samples are shown in **Table 1**.

Table 1: Instrumental Detection Limits, Method Detection Limits, and Limits of Quantification for Heavy Metals in Water and Sediment Samples

Metal	IDL (mg/L)	LOD (mg/L)	LOQ (mg/L)
Fe	0.001	0.003	0.010
Mn	0.0003	0.001	0.003
Ni	0.0007	0.002	0.007
Cd	0.0002	0.0005	0.0015
Zn	0.0003	0.001	0.003
Cr	0.0007	0.002	0.007
Pb	0.001	0.003	0.010
Hg	0.0001	0.0002	0.0007

Recovery tests demonstrated acceptable analytical performance, with water sample recoveries ranging from 84% to 109% and sediment recoveries from 90% to 103%. Relative standard deviations for replicate

measurements were consistently below 5%, confirming the precision of the atomic absorption spectrophotometric analyses. Multi-point calibrations were verified prior to sample analysis, with correlation

coefficients exceeding 0.995 for all metals. Method and reagent blanks were processed alongside each analytical batch to confirm the absence of contamination, and any detected blank values were subtracted or triggered re-analysis.

Duplicate and replicate analyses were routinely conducted to assess intra-sample precision, while continuing calibration verification standards were analysed intermittently during instrument runs to monitor stability. Observed concentrations of check standards remained within $\pm 10\%$ of expected values, ensuring instrument reliability throughout the analytical sequence. Non-detects below the method detection limit (LOD) were reported as $< \text{LOD}$, and concentrations between the LOD and the limit of quantification (LOQ) were interpreted with caution, reflecting the analytical constraints inherent to low-level metal detection.

Collectively, these QA/QC measures—including use of certified reference materials, calibration verification, procedural blanks, replicate analyses, and stringent contamination control—provided robust assurance of data validity and reliability, supporting the integrity of subsequent risk assessment calculations for both ecological and human health endpoints.

Sediment Pollution Assessment

Three indices were applied to evaluate sediment quality:

Geo-accumulation Index (I_{geo}): calculated following (Chen et al., 1991), comparing current metal concentrations against geochemical background levels (global shale values).

$$I_{geo} = \log_2 \left(\frac{C_i}{1.5GB_i} \right) \quad (1)$$

where C_i represents the concentration of the i^{th} metal in the sediment sample, and GB_i denotes its corresponding geochemical baseline value. The constant 1.5 is a background correction factor used to account for natural variations in the sediment matrix due to lithological differences. Based on I_{geo} values, contamination was classified into seven

categories: ≤ 0 (practically uncontaminated), 0–1 (uncontaminated to moderately contaminated), 1–2 (moderately contaminated), 2–3 (moderately to heavily contaminated), 3–4 (heavily contaminated), 4–5 (heavily to extremely contaminated), and > 5 (extremely contaminated). For this study, background concentrations were based on global average shale values (mg/kg): Fe = 47,200; Pb = 20; Mn = 850; Cd = 0.05; Ni = 68; Hg = 0.09; Zn = 95; and Cr = 90. Furthermore, the severity of sediment pollution due to heavy metal accumulation was evaluated using the pollutant load index (PLI). The PLI is calculated as the n^{th} root of the product of the metal contamination factor (CF).

Contamination Factor (CF): determined as the ratio of measured concentration to baseline value.

$$CF_{\text{metal}} = C_{\text{metal}} / C_{\text{background}} \quad (2)$$

where CF is the ratio of each metal's concentration in sediment to its baseline value (Derived from the average shale value); the PLI provides an assessment of the sample's overall toxicity status. As a result, a PLI value of 0 denotes perfection, a value of 1 denotes the presence of only threshold amounts of contaminants, and values greater than 1 imply continual deterioration in the site's quality. According to Udo et al. (2026), there are four levels of contamination factor (CF) for monitoring the occurrence of an individual metal over time: ($1 \leq CF < 3$) moderate degree, ($CF < 1$) low degree, ($CF \geq 6$) very high degree and ($3 \leq CF < 6$) high considerable degree.

Pollution Load Index (PLI): calculated as the n^{th} root of the product of CF values for all metals, providing a composite measure of overall sediment quality (Islam et al., 2015).

$$PLI = (CF_1 \times CF_2 \times CF_3 \dots \dots CF_n)^{\frac{1}{n}} \quad (3)$$

Potential Ecological Risk Index (PERI)

The PERI method (Hankanson, 1980) was employed to evaluate the ecological sensitivity of metals by integrating CF values with toxicity response factors (Trf). Metals assessed included Cr (2), Ni (5), Cd (30), Pb (5), Zn (1), Fe = Mn (1), and Hg (40).

The following formula was used to determine E_i :

$$E_i = Trf \times CF_i \quad (4)$$

The Potential Ecological Risk Index (PERI) is calculated by adding the ecological risk index (E_i) for each of the metals. To calculate PERI, the following formula was used:

$$PERI = \sum_i^n E_i \quad (5)$$

Where Trf is the toxicity response factor of the i^{th} metal, and CF is the contamination factor of the i^{th} metal. The ecological risk is classified into 5 classes: $E_i \geq 320$ (very high risk); $40 \leq E_i < 80$ (moderate risk); $E_i < 40$ (low risk); $160 \leq E_i < 320$ (high risk) and $80 \leq E_i < 160$ (considerable risk). However, Hankanson (1980) categorised PERI as follows: $40 \leq PERI < 80$ (moderate risk), $PERI < 40$ (low risk), $PERI \geq 320$ (very high risk), $160 \leq PERI < 320$ (high risk), and $80 \leq PERI < 160$ (considerable risk).

Human Health Risk Assessment

Health risk assessment considered two categories:

Non-carcinogenic risks were estimated using Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Hazard Index (HI). Exposure pathways included ingestion and dermal contact for water, and ingestion, dermal contact, and inhalation for sediments (USEPA 2015). The CDI of heavy metals in sediments and water via the ingestion and dermal pathways was estimated using equations 9 and 10, and equations 6 and 7, respectively, in Appendix 1. By dividing each metal's estimated chronic daily intake by its corresponding reference oral dose (RfD), the estimated HQ for each pollutant was determined. The HQ was established using equation 8 as seen in Supplementary 1. Accordingly, the vulnerable population is considered unsafe when $HQ \geq 1$ and safe when $HQ < 1$. The total risk to humans from exposure to a specific group of pollutants in water and sediments in an area was calculated using the HI estimated from equation 12 (Supplementary 1). Exposure to heavy metals with an HI level above 1 is deemed harmful to human health. All calculations and evaluations were conducted using adult exposure scenarios, reflecting the higher likelihood of prolonged environmental exposure among adults, as detailed in the Supplementary **Table (S1)**.

Children were not modelled as a separate exposure group because the study did not collect age-specific behavioural and anthropometric data for children in the sampled communities, including child-specific water ingestion rates, sediment ingestion rates, dermal exposure frequency, and body weight. The adult scenario was therefore retained as the primary screening assessment to avoid introducing unverified assumptions into the risk model. However, because children generally have higher exposure per unit of body weight and greater physiological vulnerability to Cd, Pb, Hg, and Ni, the absence of a child-specific scenario is acknowledged as an important limitation that may lead to an underestimation of risk among younger residents. Future work should conduct parallel child-risk calculations using age-appropriate USEPA exposure parameters and locally validated child exposure patterns.

Carcinogenic risks were evaluated using the Cancer Gradational Lifetime Risk (CGLR) and Total Cancer Gradational Lifetime Risk (TCGLR), as defined in equations 13 and 14 in Supplementary 1, respectively, based on slope factors from the International Agency for Research on Cancer (IARC 2012). The CGLR calculates a person's risk of developing any of the cancers linked to daily or 24-hour exposure to a specific dose of a carcinogenic agent over a 70-year lifespan. The International Agency for Research on Cancer classified Cr, Cd, and Ni as group 1 carcinogens since they are believed to be the metals most likely responsible for causing cancer. Pb has also been associated with potential carcinogenic effects. Acceptable lifetime cancer risk thresholds were defined as ranging from 10^{-6} to 10^{-4} .

Exposure parameters (e.g., ingestion rate, exposure frequency, body weight) for Carcinogenic and non-carcinogenic exposures were adopted from USEPA guidelines and are summarised in Supplementary 1, Tables S1 and S2.

Statistical Analysis

Descriptive statistics (mean, standard deviation, range) were computed using SPSS version 18, and metal concentrations were compared against WHO standards.

Results and Discussion

Water quality parameters

The physico-chemical parameters of the River Birim are presented in **Table 2**. The mean river temperature was 28.2 °C, which falls within the typical range for tropical surface waters and the WHO-recommended range of 25–30 °C (WHO, 2011). The mean pH value was 6.45, indicating slightly acidic conditions and falling marginally below the WHO-recommended range of 6.5–8.5 for drinking water (WHO, 2011). The slightly acidic condition is important because lower pH can increase the solubility, mobility, and bioavailability of some metals in aquatic systems, thereby increasing their potential ecological and human health risks (Sun et al., 2018).

Dissolved oxygen recorded a mean value of 6.82 mg/L, which is above the minimum level of 5 mg/L generally required to support aquatic life (USEPA, 2011). This

suggests that despite high suspended-sediment and mining pressures, the river still retains some capacity to support aerobic aquatic organisms. However, turbidity was extremely high, with a mean of 604.25 NTU, far exceeding the WHO/GEPA-recommended limit of 50 NTU. This high turbidity indicates substantial suspended solids in the water column, most likely associated with sediment disturbance, riverbank erosion, dredging, the washing of excavated materials, and the direct discharge of mining residues into the river, all of which are common features of mining-affected watersheds (Hilson, 2002; Kazapoe et al., 2023).

The mean conductivity, total dissolved solids and total hardness values were 255.7 µS/cm, 140.00 mg/L and 140.33 mg/L, respectively. These values were within acceptable limits, suggesting that the overall dissolved ionic load was not excessively high. Nevertheless, the high turbidity and slightly acidic pH provide important supporting evidence that mining-related disturbance may be influencing the mobility and transport of metals in the river (Sun et al., 2018).

Table 2: Water quality parameters of River Birim in Ghana

Parameters	pH	DO (mg/L)	Conductivity (µS/cm)	Turbidity (mg/L)	TDS (mg/L)	TH (mg/L)	T/°C
Mean	6.45	6.82	255.7	604.25	140.00	140.33	28.2
SD	0.52	1.12	35.2	25.42	15.45	40.40	8.5
Min.	6.02	5.32	95.7	104.52	84.00	50.00	21.5
Max.	7.10	8.11	488.5	889.35	192.28	246.00	30.4
WHO/GEPA	6.5-8.5	5	1500	50	600	300	

Heavy metals in water: exceedances and comparisons

The mean concentrations of heavy metals in the River Birim water (**Figure 2**) followed the order: Fe (5.36 mg/L) > Cd (0.23 mg/L) > Ni (0.08 mg/L) > Zn = Hg (0.04 mg/L) > Mn = Cr (0.03 mg/L) > Pb (0.02 mg/L). These results show that Fe was the most abundant metal in the water samples, while

Pb recorded the lowest mean concentration among the metals analysed.

When compared with WHO guideline values for drinking water, Fe, Cd, Pb, Hg and Ni exceeded recommended limits (WHO, 2011). Fe recorded a mean concentration of 5.36 mg/L, nearly 18 times the WHO guideline value of 0.3 mg/L. This concentration is higher than values reported for Badagry Creek, Nigeria, and the Yautepec River in Mexico (Ndimele &

Kumolu-Johnson, 2012; Vargas-Solano et al., 2022). Cadmium was particularly elevated, with a mean of 0.23 mg/L, exceeding the WHO limit of 0.005 mg/L by approximately 46-fold. This level is comparable to findings from mining-affected communities in northern Ghana but higher than values reported in the Fenghe River Basin in China (Cobbina et al., 2015; Luo et al., 2021). Lead also exceeded the WHO guideline value of 0.01 mg/L, while Hg exceeded the 0.01 mg/L limit. Nickel was slightly above the WHO guideline value of 0.07 mg/L. In contrast, Cr, Mn and Zn were within acceptable guideline limits (ATSDR, 2007; WHO, 2011).

In addition to WHO standards, comparison with Ghanaian drinking water standards is important for interpreting local regulations. Based on Ghana Standards Authority guideline values, exceedances were also observed for Fe, Cd, Pb and Hg. For example, Fe exceeded the Ghanaian acceptable limit of 0.3 mg/L, Cd exceeded the national limit of 0.003 mg/L, Pb exceeded the 0.01 mg/L limit, and Hg exceeded the 0.006 mg/L limit (Ghana Standards Authority [GSA], 2013). The agreement between international and

national standards indicates that the River Birim water is not suitable for direct domestic consumption without treatment. This is particularly important because surrounding communities depend on the river for domestic use, farming, fishing and livelihood activities (Adranyi et al., 2024).

The elevated concentrations of Fe, Cd, Hg, Pb and Ni can be explained by both geological and anthropogenic factors. Geologically, the River Birim basin is underlain by Birimian rock formations, which are associated with mineralisation and may naturally release iron-bearing minerals and other trace metals into the aquatic environment through weathering (Baki et al., 2018). Under acidic conditions, these naturally occurring metals may become more soluble and mobile (Sun et al., 2018). However, the magnitude of the recorded concentrations, particularly for Cd and Hg, suggests that natural weathering alone is unlikely to account for the observed contamination.

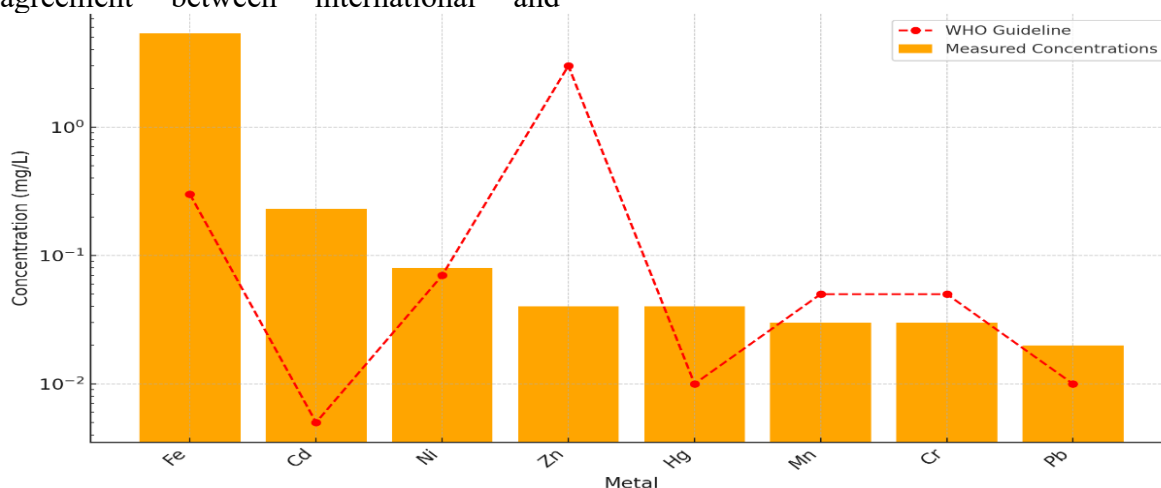


Figure 2: Heavy Metals Concentrations in River Birim compared with the WHO benchmark value.

Anthropogenic activities, especially illegal artisanal gold mining, appear to be a major contributor to the high metal concentrations. Galamsey activities disturb river sediments, expose mineralised soils and rocks, and increase the transport of metal-rich particles into the river (Hilson, 2002; Kazapoe et al., 2023). Ore washing, dredging, excavation, and tailings discharge can increase the concentrations of Fe, Cd, Pb, and Ni in surface water. Mercury contamination is particularly associated with gold amalgamation practices, in which Hg is used to recover gold and may be released directly into the aquatic environment (Asamoah-Boateng, 2009; Donkor et al., 2024). Reduced river flow during the dry season may also have increased metal concentrations by limiting dilution. Therefore, the high metal concentrations likely reflect the combined influence of local geology, acidic water conditions, dry-season concentration effects, and intensive illegal mining activities (Qin & Tao, 2022; Sun et al., 2018)

Heavy metals in sediments: exceedances and comparisons

The mean concentrations of heavy metals in sediments followed the order: Fe (8986.33 mg/kg) > Mn (425.90 mg/kg) > Ni (24.68 mg/kg) > Cd (17.67 mg/kg) > Zn (11.23 mg/kg) > Cr (2.50 mg/kg) > Pb (1.33 mg/kg) > Hg (0.50 mg/kg) in **Figure 3**. As expected, Fe and Mn occurred at relatively high concentrations, reflecting their natural abundance in geological materials. However, elevated Cd and Hg levels are of

greater environmental concern due to their high toxicity, persistence, and potential for bioaccumulation (Ali et al., 2020; Tchounwou et al., 2012).

Compared with global background values, Cd and Hg were substantially enriched in the sediments. Cadmium, in particular, was far above its background concentration, suggesting strong anthropogenic influence. Mercury enrichment is also consistent with mining-related inputs, especially the use of Hg in gold extraction (Donkor et al., 2024). Sediments serve as both sinks and secondary sources of metals in aquatic systems. Metals deposited in sediments may remain stored for long periods but can be released back into the water column when environmental conditions change (Förstner & Wittmann, 2012; Sun et al., 2018). Dredging, flooding, changes in pH, sediment resuspension, and mining-related disturbance can remobilise sediment-bound metals, increasing their bioavailability to aquatic organisms (Varol, 2011).

The high sediment concentrations, therefore, indicate that contamination in the River Birim is not limited to the water column. Rather, the sediments represent a long-term reservoir of heavy metals. This is critical because even if direct discharge into the river is reduced, contaminated sediments may continue to release metals into the water column and aquatic food web over time (Förstner & Wittmann, 2012; Islam et al., 2015).

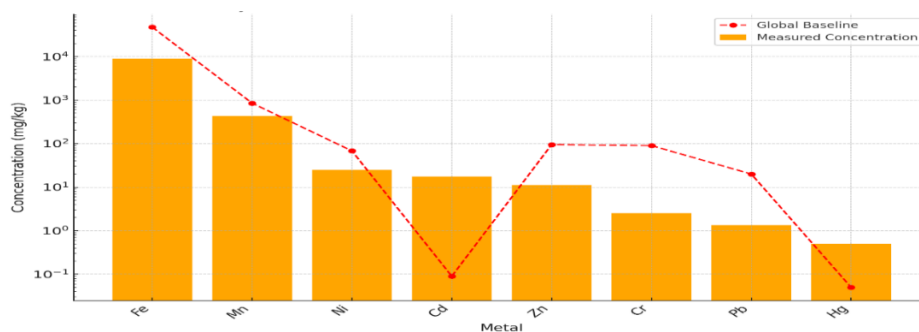


Figure 3: Heavy metal concentrations in River Birim sediments compared with global background values

Sediment pollution indices and ecological risk

The contamination factor values in **Table 3** showed that Cd was the most serious pollutant in the sediments, with a CF value of 353.4, indicating extreme contamination. Mercury recorded a CF value of 5.56, indicating considerable contamination, while the remaining metals had CF values below 1, suggesting low contamination relative to background levels. Similarly, the geo-accumulation index classified Cd as extremely polluted and Hg as moderately polluted. These classifications are consistent with the use of contamination factor and geo-accumulation index approaches in sediment pollution assessment (Chen et al., 1991; Islam et al., 2015).

The Pollution Load Index value of 0.594 suggested that the overall sediment pollution load was moderate when all metals were considered together. However, the Potential Ecological Risk Index gave a more serious indication of ecological threat. The PERI value of 10,827.318 classified the

sediments as presenting very high ecological risk according to the Hakanson ecological risk classification (Hakanson, 1980). Cadmium alone accounted for approximately 98% of the total ecological risk, largely due to its high toxicity response factor and very high contamination factor. Similar Cd-dominated ecological risk patterns have been reported in mining-affected environments in Ghana and elsewhere (Jian-Min et al., 2007; Owusu-Prempeh et al., 2022).

This result shows that the ecological risk posed by the River Birim sediments is driven not simply by the total number of metals detected, but also by the toxicity and enrichment levels of specific metals, particularly Cd. Mercury also remains important because it can be transformed into methylmercury under suitable environmental conditions. Methylmercury is highly toxic, readily absorbed by aquatic organisms, and capable of biomagnifying through the food chain (Tchounwou et al., 2012).

Table 3: Heavy metal pollution indices found in sediments from the sampling sites

Metals	I_{geo}	CF	$Trf \times CF$
Zn	-3.665	0.118	0.118
Fe	-2.978	0.190	0.190
Mn	-1.582	0.501	0.501
Pb	-4.495	0.067	0.333
Ni	-1.982	0.380	1.898
Cr	-5.755	0.028	0.056
Cd	7.880	353.400	10602
Hg	1.889	5.556	222.222
		PLI = 0.594	PERI = 10827.318

I_{geo} -Geo-accumulation index, CF-contamination factor, PLI- pollution load index, PERI-potential ecological risk index

Human health risks

Non-carcinogenic risk: The hazard quotient and hazard index values for both water and sediment, as shown in **Tables 4 and 5**, were below 1, indicating no immediate non-carcinogenic risk under the exposure assumptions used in this study. This interpretation is consistent with

USEPA risk assessment guidance, where HQ or HI values below 1 are generally considered to indicate no significant non-carcinogenic risk (USEPA, 2011, 2015). In water, ingestion was the dominant exposure pathway, with Cd recording the highest ingestion-related hazard quotient. Dermal exposure values were considerably lower

than ingestion values, suggesting that direct consumption of untreated water is a more important route of exposure than skin contact.

For sediments, ingestion also contributed more to non-carcinogenic risk than dermal contact or inhalation. Although the hazard index values were below the threshold of concern, this should not be interpreted to mean that the river is safe for unrestricted use. Heavy metals such as Cd, Pb and Hg can accumulate in the body over time and may cause chronic health effects after prolonged exposure (Jaishankar et al., 2014; Tchounwou et al., 2012). Therefore, communities that depend on untreated river water may still face long-term health concerns, especially where exposure occurs through multiple routes, including drinking water, fish consumption, irrigation and contact with contaminated sediments (Wongsasuluk et al., 2014)

Carcinogenic risks. The estimated lifetime carcinogenic risk values for selected metals are presented in **Table 6**. In this study, cancer risk values were interpreted using the commonly applied risk range of 10^{-6} to 10^{-4} . Values below 10^{-6} were considered negligible, values between 10^{-6} and 10^{-4} were regarded as falling within a tolerable or potential concern range, while values above 10^{-4} were considered to indicate an unacceptable carcinogenic risk.

For water exposure, the carcinogenic risk through ingestion was highest for Cd, followed by Ni. The risk value for Cd ingestion in water was 4.14×10^{-5} , while that of Ni was 1.92×10^{-6} . These values exceeded the lower benchmark of 10^{-6} but remained below the upper threshold of 10^{-4} . This indicates that exposure to Cd and Ni through water ingestion may pose a long-term carcinogenic risk, particularly for populations with prolonged reliance on the River Birim as a water source. However, the values should not be interpreted as exceeding the upper unacceptable risk threshold.

For sediment exposure, Cd ingestion recorded a carcinogenic risk value of $4.48 \times$

10^{-6} , which also falls within the 10^{-6} to 10^{-4} tolerable risk range. The carcinogenic risks associated with Pb and Cr were at or below negligible levels across the assessed pathways. Across both water and sediment, ingestion contributed more substantially to carcinogenic risk than dermal contact or inhalation, indicating that oral exposure remains the dominant pathway of concern. Although the total cancer risk values did not exceed the upper unacceptable threshold of 10^{-4} , the presence of Cd and Ni within the potential concern range suggests the need for precautionary management. Continuous exposure to untreated water, contact with sediment, or indirect food-chain transfer could increase long-term health risks, especially among vulnerable groups. Therefore, the findings support the need for regular monitoring, public health awareness, and provision of safer alternative water sources for communities dependent on the River Birim.

Uncertainty and conservative assumptions in cancer risk assessment: The cancer risk estimates should be interpreted within the assumptions of the USEPA-based exposure model. The assessment used adult exposure parameters, adopted reference doses and cancer slope factors from established literature, and assumed repeated exposure via ingestion and dermal contact. These assumptions provide a conservative screening-level estimate rather than a direct prediction of actual disease occurrence. The use of adult parameters may underestimate risk for children, who often have lower body weight and higher intake per unit body mass. In contrast, the use of default slope factors and exposure frequencies may either overestimate or underestimate risk, depending on local behaviour, water-use patterns, exposure duration, and metal bioavailability. In addition, risks based on total metal concentration may not fully reflect the fraction that is bioavailable or present in the most toxic chemical form.

Sensitivity of HI and TCGLR estimates: The non-carcinogenic and carcinogenic risk

outputs are most strongly influenced by exposure parameters and toxicological constants. For HI, the dominant drivers are metal concentration, ingestion rate, exposure frequency, exposure duration, body weight, and the selected reference dose. For TCGLR, the most influential parameters are the chronic daily intake and the cancer slope factor, particularly for Cd and Ni, which contributed most to the calculated cancer risks. Because ingestion

produced higher risk values than dermal contact, changes in daily water intake, incidental sediment ingestion, and exposure frequency would have the greatest effect on the final HI and TCGLR. This means that communities with higher consumption of untreated water, more frequent river contact, or greater dependence on river-derived fish and irrigated crops may face higher risks than the adult screening scenario suggests.

Table 4: Hazard indices and hazard quotients of heavy metals in water from the River Birim

Exposure pathways	Zn	Ni	Hg	Pb	Fe	Cr	Cd	Mn	HI
<i>HQ_{ingestion}</i>	3.81E-06	1.14E-04	3.81E-03	1.63E-04	2.19E-04	7.62E-04	6.57E-03	9.52E-04	1.26E-02
<i>HQ_{dermal}</i>	3.58E-09	2.39E-09	5.97E-09	2.98E-10	7.99E-07	2.39E-08	3.43E-08	1.19E-08	8.82E-07

Table 5: Hazard indices and hazard quotients of heavy metals in sediment from River Birim

Exposure pathways	Zn	Fe	Mn	Pb	Ni	Cr	Cd	Hg	HI
<i>HQ_{ingestion}</i>	5.13E-05	1.76E-02	2.43E-01	2.23E-04	7.24E-04	4.89E-04	1.03E-02	6.85E-03	2.79E-01
<i>HQ_{dermal}</i>	1.02E-06	6.29E-05	2.42E-04	8.85E-06	1.07E-05	9.76E-05	4.14E-03	1.37E-05	4.58E-03
<i>HQ_{inhalation}</i>	2.64E-08	9.05E-06	6.01E-03	1.14E-07	3.62E-07	2.64E-05	5.34E-06	1.1E-06	6.05E-03

Table 6: Carcinogenic risks of heavy metals in sediment and water from the sampling area

	Pathways	Ni	Cd	Pb	Cr	TCGLR
<i>Water</i>	<i>CGLR_{ingestion}</i>	1.92E-06	4.14E-05	4.86E-09	4.29E-07	4.38E-05
	<i>CGLR_{dermal}</i>	4.11E-09	5.91E-08	5.14E-09	1.54E-08	8.38E-08
<i>sediment</i>	<i>CGLR_{ingestion}</i>	8.35E-07	4.48E-06	4.55E-10	5.03E-08	5.37E-06
	<i>CGLR_{dermal}</i>	3.33E-09	1.79E-08	1.82E-12	2.01E-10	2.14E-08
	<i>CGLR_{inhalation}</i>	4.29E-10	2.31E-09	2.35E-13	2.59E-11	2.76E-09

TCGLR-Total Cancer gradational Lifespan Risk, *CGLR*-Cancer gradational Lifespan Risk

Bioaccumulation and food chain implications

Heavy metals in aquatic systems do not remain confined to water and sediments but are taken up by aquatic organisms and biomagnify along the food chain. Metals such as mercury (in its methylated form), cadmium, and lead accumulate in fish tissues, with higher concentrations observed

in predatory species (Burger & Gochfeld, 2005). Communities relying on fish from the River Birim are therefore at risk of dietary exposure. Chronic consumption of contaminated fish can lead to severe health outcomes, including neurological impairment from mercury, kidney damage from cadmium, and cognitive deficits from lead exposure (FAO/WHO, 2011; USEPA,

2018). Furthermore, the use of contaminated water for irrigation may introduce metals into crops, expanding exposure pathways beyond aquatic systems (Nagajyoti et al., 2010).

Expanded ecological implications beyond pollution indices: Although CF, Igeo, PLI, and PERI provide useful screening evidence of contamination, the ecological significance extends beyond numerical index classification. Elevated Cd and Hg concentrations in sediments can impair benthic invertebrates living in direct contact with contaminated sediment, reducing feeding activity, growth, emergence, reproduction, and survival. Such effects may alter benthic community composition and reduce prey availability for fish. Sediment-associated metals may also be transferred into organisms through direct sediment ingestion, gill uptake, and dietary exposure, creating the possibility of biota-sediment accumulation. Where biota-sediment accumulation factors exceed 1, this implies that organisms may accumulate metals at levels above sediment-normalised concentrations, thereby increasing exposure for predators and humans who consume fish. Although this study did not directly measure fish tissue or calculate site-specific biota-sediment accumulation factors, the elevated Cd and Hg burdens indicate a need for future biomonitoring of benthic macroinvertebrates and fish tissues to more precisely assess trophic transfer and food-chain risk.

Remediation and management implications

Mitigating heavy metal contamination in the River Birim requires integrated remediation strategies. Nature-based solutions such as phytoremediation and constructed wetlands have shown effectiveness in tropical river systems by removing or stabilising metals through plant uptake and microbial

processes (Vymazal, 2011; Ali et al., 2013). In addition, physicochemical methods such as adsorption using activated carbon or biochar, ion exchange, and chemical precipitation can be applied for water treatment (Fu & Wang, 2011). However, these methods must be adapted to local socio-economic conditions.

At the source level, stricter enforcement of mining regulations, adoption of mercury-free gold extraction technologies, rehabilitation of degraded mining sites, and restoration of riparian vegetation are critical to reducing contamination inputs (Hilson & McQuilken, 2014). Public awareness and community-based monitoring programs are also essential to minimise human exposure and promote sustainable water use practices.

Policy and practical feasibility of interventions: The recommended interventions are most likely to succeed when they combine enforcement with technically feasible, socially acceptable alternatives for miners and riverine communities. Mercury-free gold recovery technologies, such as gravity concentration and improved processing methods, can reduce direct Hg discharge. However, adoption depends on miner training, access to equipment, financing, and sustained regulatory support. Community-based monitoring is also feasible in the Birim context because residents are direct users of the river and can support early reporting of turbidity changes, illegal dredging, fish kills, and visible discharge. Comparable mining-affected settings show that interventions are more sustainable when paired with alternative livelihoods, formalisation of artisanal mining, routine water-quality surveillance, and locally managed reporting systems, rather than enforcement alone (Hilson & McQuilken, 2014; Kazapoe et al., 2023). Practical

implementation should therefore prioritise phased actions: immediate provision of safe water sources, short-term monitoring and public health education, medium-term miner training in mercury-free methods, and long-term rehabilitation of riparian buffers, abandoned pits, and contaminated sediment hotspots.

Synthesis with global evidence

The River Birim presents a contamination profile characteristic of ASGM hotspots: Fe dominance from geology, Cd and Hg enrichment from mining, and elevated Ni from mixed geogenic/anthropogenic origins. Compared with African, Asian, and Latin American mining rivers, Birim exhibits especially high Cd burdens in both water and sediments, making it a critical ecological and public health concern. Discrepancies with other studies reflect differences in geology, land use intensity, seasonality, and methodological baselines. Together, the findings indicate that the River Birim is highly impacted by cadmium-driven ecological risk and mercury pollution, with important implications for community health and watershed sustainability. Overall, the interaction between natural geological conditions and intensified anthropogenic activities has created a highly contaminated system where ecological integrity, water quality, and human health are at significant risk. Without urgent intervention, contamination levels may persist or worsen, undermining the long-term sustainability of the river system.

Conclusion

This study assessed heavy metal contamination in the water and sediments of the River Birim, a major freshwater resource in Ghana affected by illegal artisanal gold mining. The findings showed that concentrations of Fe, Cd, Ni, Pb and Hg in water exceeded recommended drinking water limits, indicating that the river is currently unsuitable for direct human

consumption without appropriate treatment. Sediment analysis also revealed substantial enrichment of Cd and Hg, with cadmium contributing the largest proportion of the ecological risk. The Potential Ecological Risk Index classified the sediments as posing very high ecological risk, suggesting that the riverbed may serve as a long-term reservoir of contamination.

Human health risk assessment showed that non-carcinogenic risks were below the threshold of concern under the exposure assumptions used in this study. However, carcinogenic risk values for Cd and Ni via water ingestion, and for Cd via sediment ingestion, fell within the tolerable or potential concern range of 10^{-6} to 10^{-4} . Although these values did not exceed the upper unacceptable risk threshold of 10^{-4} , they indicate the need for precautionary public health action, especially for communities that have relied on the River Birim for prolonged periods for domestic, agricultural, and livelihood purposes.

Despite the current level of contamination, the condition of the River Birim should not be regarded as irreversible. The river has potential for ecological recovery if further pollutant inputs are controlled and appropriate remediation measures are implemented. Reducing illegal mining activities, preventing direct tailings discharge, adopting mercury-free gold recovery technologies, restoring degraded riverbanks, and improving sediment management could gradually reduce contaminant loads and improve water quality. Nature-based approaches such as phytoremediation, bioremediation, constructed wetlands and riparian buffer restoration may also support long-term recovery by stabilising or removing metals from contaminated water and sediments. This study has some limitations. Sampling was conducted only during the dry season and therefore may not fully represent seasonal variations in metal concentrations, particularly during periods of high rainfall,

flooding, runoff and sediment resuspension. The study also focused on water and sediment samples and did not assess heavy metal accumulation in fish tissues, crops irrigated with river water, or human biological samples. In addition, the health risk assessment was based on standard exposure assumptions that may not fully capture local differences in water use, fish consumption, occupation, age, body weight, and exposure frequency among river-dependent communities. These limitations suggest that the findings should be interpreted with caution and supported by longer-term, site-specific monitoring. Based on the findings, urgent remediation and management actions are recommended. Regulatory agencies should intensify monitoring and enforcement against illegal mining along the River Birim and its tributaries. Contaminated hotspots should be mapped and prioritised for sediment management, with dredging considered only where it can be safely conducted without resuspending pollutants downstream. Mercury-free mining technologies should be promoted, while degraded mining sites and riverbanks should be rehabilitated through

reforestation and the establishment of riparian buffers. Communities depending on the river should be provided with safe alternative water sources, and public health education should be strengthened to reduce direct consumption of untreated river water. Future studies should include wet-season sampling, metal analysis in fish and food crops, and more localised human exposure assessments to guide effective remediation and protect both ecosystem and public health.

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CRedit authorship contribution statement

Emmanuel Kaboja Magna: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualisation. **Cecilia Asemah:** Writing – review & editing, Validation, Software, Methodology. **Elliot Haruna Alhassan:** Supervision. **Michael Dabi:** Visualisation, Supervision, Formal analysis. **William W. Anku:** Visualisation, Resources.

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Supplementary1

Non-carcinogenic Risk

Equations 6 and 7 below, formulated by the Environmental Protection Agency (Assessment 1998), were applied to calculate the pollutants' chronic daily intake (CDI) via ingestion and dermal contact.

$$CDI_{\text{ingestion (Water)}} = \frac{CW \times DI \times EF \times ED \times ABS}{AT \times BW} \quad (6)$$

$$CDI_{\text{dermal (water)}} = \frac{CW \times KP \times SA \times ET \times ABS \times EF \times CF \times ED}{AT \times BW} \quad (7)$$

Where:

ABS (unitless) is the dermal absorption factor; *CW* (mg/L) is the measured concentration of each metal in water; *ED* the duration of exposure; *AT* the mean time; *BW*, the body weight; *EF* (day/year) denotes the annual exposure frequency; *KP* (cm/hour) is the permeability coefficient; *Contact-prone region of the skin (SA, in cm²); CF (cm³) denotes the conversion factor; ET (h/event) is the exposure time; DI (L/day) is the daily mean consumption of water;*

Table S₁ lists the relevant standard values and additional requirements needed to calculate the chronic daily intake (CDI) by oral ingestion and superficial absorption.

$$HQ = \frac{CDI}{RFD} \quad (8)$$

Where:

HQ is the hazard index of the metal; *RFD* is the reference oral dose of the contaminant and *CDI* is the metal's estimated chronic daily intake

The CDI of toxic metals in sediments for various exposure pathways is given by the following formulas.

$$CDI_{\text{ingestion (sediment)}} = \frac{CS \times CF \times IRS \times ED \times EF}{AT \times BW} \quad (9)$$

$$CDI_{\text{dermal (sediment)}} = \frac{CS \times AF \times SA \times CF \times ABS \times ED \times EF}{AT \times BW} \quad (10)$$

$$CDI_{\text{inhalation (sediment)}} = \frac{CS \times ED \times EF \times ET}{PEF \times AT \times 24} \quad (11)$$

Where:

CS = contaminant exposure point level (mg/kg); *ED* (exposure duration) = 30 For adults, *IRS* is 100 mg/kg every day; *EF* = 350 d/year; *CF* (conversion factor) = 0.000001 mg/kg; *AT* (average time) = 365 × *ED*; *ET* (exposure period) = 24 h per day; *AF* (adherence factor) = 0.7 mg/cm²; *BW* (mean body weight) = 70 kg; *AT* (average time for carcinogens) = 365 × 70 d; *ABS* (dermal absorption fraction) = 0.0001; *SA* (Skin area susceptibility contact after exposure) = 5700 cm²; *PEF* (Particle emission factor) = 1.36 × 10⁹

Table S₁: Standard parameters for evaluating the health risk of contaminants in water

Parameters	Units	Dermal adsorption	Ingestion
CW	mg/L	-	-
DI	L/day	-	2
ET	Hr/event	0.58	-
SA	cm ²	18000	-
EF	Day/years	350	365
CF	L/cm ³	0.001	-
ED	Year	30	70
ABS	All	0.001	0.001

BW	kg	70	70
AT	Days	350×30	365×70
(Jolaosho et al., 2023)			

$$HI = \sum_{i=1}^k [HQ(Pb) + HQ(Fe) + HQ(Mn) + HQ(Ni) + HQ(Zn) + HQ(Hg) + HQ(Cd) + HQ(Cr)] \quad (12)$$

Carcinogenic Risks

The cancer gradational lifespan risk (CGLR) was calculated using Equation 13 below:

$$\text{Cancer gradational Lifespan risk (CGLR)} = CDI_k \times SF_k \quad (13)$$

Where:

Cancer gradational lifespan risk (CGLR); Chronic daily intake (mg/kg/day) of carcinogens (CDI) and the slope factor (mg/kg/day) of carcinogens (SF_k).

Equation 14 was used to determine the cumulative CGLR. Table 2 contains the reference dosage (RFD) values for ingestion, inhalation, and skin absorption.

$$TCGLR = \sum_{i=1}^k (CDI_k \times SF_k) \quad (14)$$

Table S2: Cancer slope factors and Reference dose exposure limits of heavy metals

Heavy metals	RFD _{ing} (mg/kg)	RFD _{inh} (mg/kg)	RFD _{dem} (mg/kg)	KP (mg/kg/d)	SF (mg/kg)
Pb	0.0035	0.00352	0.0000525	0.001	0.0085
Fe	0.7	0.7	0.78	0.001	-
Mn	0.0024	0.00005	0.0096	0.001	-
Ni	0.02	0.0206	0.0054	0.0002	0.84
Zn	0.3	0.3	0.06	0.0006	-
Hg	0.001	0.0002	0.005	0.001	
Cd	0.001	0.001	0.00001	0.001	6.3
Cr	0.003	0.0000286	0.00006	0.002	0.5

KP-Dermal permeability coefficient; RFD_{ing}-RFD for ingestion, RFD_{inh}-RFD for inhalation; RFD_{dem} – RFD for dermal source: (Jolaosho et al., 2023)

Financial Attitudes and Micro pension Scheme Participation Among Informal Economy Workers in Ghana: Application of the Theory of Planned Behavior

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Abstract

Micro pension schemes (MPS) have been instituted to guarantee economic security for informal economy workers after retirement, yet a substantial proportion of these workers remain excluded from such schemes. This study applied the Theory of Planned Behaviour to examine how financial knowledge, planning, and risk tolerance shape MPS participation among informal workers in Ghana. Employing a mixed-methods design, the study analysed quantitative survey data from 400 informal workers using logistic regression, alongside thematic synthesis from 15 qualitative key informant interviews. The logistic regression analysis revealed that financial attitudes significantly determine enrolment. Financial planning emerged as the strongest predictor, with workers who budget and set goals being over three times more likely to participate in an MPS. Financial knowledge also significantly increased participation probabilities, despite critically low baseline literacy levels. Conversely, financial risk tolerance was not statistically significant, indicating that workers perceive the MPS as a low-risk savings tool rather than a volatile investment. Qualitative insights highlighted that participation is heavily constrained by structural barriers, including income volatility, institutional mistrust, and a cultural preference for traditional informal networks. The study concludes that individual savings behaviour is restricted by low financial literacy and rigid institutional frameworks. To enhance uptake, it is recommended that the National Pensions Regulatory Authority and scheme administrators design flexible MPS products with variable contribution rates and emergency withdrawal options. Additionally, policymakers should deploy targeted financial literacy campaigns through mobile money platforms and trusted community channels to dismantle systemic barriers.

Keyword: Behavior, Financial Attitude, Ghana, Informal Economy Workers, Micro Pension, Savings

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Introduction

Securing financial stability for informal economy workers during their old age is a critical development challenge, particularly in nations like Ghana where a vast majority of the workforce operates outside formal structures. Micro pension saving (MPS) schemes serve as essential mechanisms to mitigate aging-related economic risks, providing a pathway to security consistent with international social protection standards (Mukherjee, 2014; Sahu, 2014). By filling the void left by traditional pension systems, these schemes offer a rights-based approach to safeguarding individuals against the poverty and economic crises that often plague informal economy workers who lack access to conventional pension coverage (Hu & Stewart, 2009; ILO, 2011; Lugilde et al., 2017).

The effectiveness of these schemes, however, is heavily influenced by the psychological and behavioural dimensions of individual participation. While traditional economic models like the Life Cycle Hypothesis often fail to account for the irregular incomes of informal economy workers, the Theory of Planned Behaviour (TPB) offers a more robust framework for understanding these decisions (Ajzen, 1991; Deaton, 1992; Lugilde et al., 2017). Research suggests that financial attitudes, specifically financial knowledge, planning, and risk tolerance are central determinants of whether an individual chooses to participate in a pension scheme, acting as the primary drivers of conscious savings efforts and retirement preparedness (Chou et al., 2014; Lee & Kim, 2016).

Ghana serves as an ideal case study for this issue, as it faces the dual challenges of a massive informal economy and a rapidly aging population (GSS, 2015; WHO, 2014). Although the National Pensions Act of 2008 was designed to extend coverage, enrolment rates remain critically low, often hovering around three to four percent of eligible informal workforce (Asafu-Adjaye, 2022;

MELR, 2017). Recent studies indicate that while workers are often willing to contribute, they are frequently hindered by limited financial literacy, a poor understanding of pension tiers, and institutional barriers (Asiamah, 2023; Segbenya et al., 2024). These realities highlight an urgent need to transition from focusing solely on institutional supply to better understanding the underlying attitudes of the workers themselves.

This study seeks to address the gap in existing literature by applying the TPB framework to investigate how specific financial attitudes such as knowledge, planning, and risk tolerance influence MPS participation among Ghana's informal workforce. By moving beyond traditional analyses of institutional barriers, this research aims to provide a nuanced understanding of the behavioural motivations that shape pension enrolment (Boyetey, 2020; Lee & Kim, 2016). This perspective is vital for designing more effective policies that resonate with the preferences and capabilities of informal workers, ultimately fostering greater long-term financial security for this vulnerable demography.

To achieve this, the study utilizes a mixed-methods research design, integrating quantitative logistic regression with qualitative insights from key informant interviews. This methodology ensures a comprehensive analysis of both statistical correlations and the contextual factors that influence savings decisions. The remainder of this paper is structured to provide a thorough review of the relevant literature, a detailed description of the research methodology, a presentation of empirical findings, and a final discussion of policy recommendations aimed at enhancing MPS uptake across the informal sector.

Literature Review

Micro pension schemes and informal economy workers

Micro pension schemes are designed to extend social security to informal economy workers by offering low-contribution thresholds, flexible payment schedules, and simplified administration. These features are specifically intended to accommodate the unique challenges faced by informal workers, such as chronic income volatility, the absence of employer-sponsored support, and restricted access to formal financial institutions (Hu & Stewart, 2009; Mukherjee, 2014; Sahu, 2014). This inclusion is particularly vital in developing nations like Ghana, where roughly 86% of the workforce operates informally, leaving the majority of the population without a safety net and at significant risk of poverty during old age (GSS, 2015; Kpessa & Bland, 2013).

Despite the potential of these schemes, participation rates in programs like Ghana's Tier 3 voluntary pension remain dismally low, often falling below 5% in the informal economy (Asafu-Adjaye, 2022; MELR, 2017). Research identifies a range of barriers, including low financial literacy, administrative hurdles, and deep-seated mistrust of formal institutions (Asiamah, 2023; Segbenya et al., 2024). Studies indicate that product design is a decisive factor; for instance, increased withdrawal flexibility has been shown to significantly boost uptake among vulnerable groups like cocoa farmers (Kos & Lensink, 2023). International evidence from countries like Tanzania and Nigeria further suggests that unless reforms address income volatility and align with the realities of informal labour, formal schemes will continue to struggle against systemic and regulatory impediments (Obuobi, 2024; Wango, 2023). Ultimately, MPS must contend with the prevalence and reliability of well-established, informal savings mechanisms. Workers frequently turn to community-based strategies such as *susu* groups, church

welfare, and reciprocal lending that offer immediate liquidity and high levels of social trust (Danso-Wiredu, 2021; Obuobi, 2024). Because these informal arrangements are deeply embedded in the social fabric of these communities. They often function as effective substitutes for formal social protection. Consequently, formal pension initiatives must innovate to become competitive, ensuring their designs offer the same flexibility and social relevance as the informal systems they seek to complement.

The theory of planned behavior and financial attitudes

The Theory of Planned Behaviour (TPB), introduced by Ajzen (1991), provides a robust framework for analysing human decision-making by positing that behaviour is primarily driven by intention. This intention is shaped by three core dimensions: the individual's attitude toward the behaviour, subjective norms regarding social expectations, and perceived behavioural control over the ability to perform the act. In the realm of financial decision-making, this model is particularly effective for understanding retirement savings, as it accounts for the complex psychological and social motivations that influence whether an individual chooses to participate in pension schemes.

Within this framework, financial attitudes encompassing knowledge, planning, and risk tolerance are viewed as critical components that define an individual's evaluation of pension savings (Lee & Kim, 2016). Recent empirical applications, such as those by Mohd and Kim (2024) in Malaysia, demonstrate that these factors, alongside subjective norms, are strong predictors of actual savings behaviour. These findings validate the TPB as a reliable theoretical lens for examining the unique barriers and drivers of pension participation among populations similar to those in Ghana's informal economy.

Financial knowledge

Financial knowledge, or financial literacy, is foundational to effective personal financial management, budgeting, and retirement planning. Scholars such as Lusardi and Mitchell (2011) and Remund (2010) highlight its role in enabling individuals to navigate complex pension products and ensure long-term security. Empirical research consistently confirms a positive correlation between higher financial knowledge and increased pension participation, with recent studies in sub-Saharan Africa, such as Asiamah (2023) in Ghana and Nchise and Akosso (2024) in Cameroon, demonstrating that literacy is a significant driver of retirement preparedness, particularly when integrated with formal and informal financial service usage.

Despite these findings, the relationship between knowledge and financial behaviour is complex and context-dependent. While some studies confirm that literacy directly influences retirement planning and net worth, others, such as Janposri (2020) and Agabalinda and Ndi (2020), indicate that financial attitudes may not always be a significant predictor of wealth accumulation. In the specific context of Ghana's informal economy, where literacy remains limited, fostering financial knowledge is essential for empowering workers to understand the benefits of pension schemes, streamline enrolment, and make informed decisions regarding their long-term investment options.

Financial planning

Financial planning is the essential process of establishing goals and developing strategies, such as budgeting and expense tracking, to secure long-term financial well-being (Ortega, 2008; Stawski et al., 2007). Research consistently demonstrates that individuals who engage in structured financial planning accumulate greater wealth and are more likely to participate in pension schemes (Chou et al., 2014; Lusardi

& Mitchell, 2011). However, for workers in the informal economy, this process is often complicated by income volatility and the necessity of prioritizing immediate consumption (Deaton, 1992; Hu & Stewart, 2009). Despite these significant obstacles, financial planning remains a critical driver of pension participation, as it serves as a tangible expression of an individual's commitment to future financial stability.

Financial risk tolerance

Financial risk tolerance, defined as the maximum uncertainty an individual is willing to accept when making financial decisions (Grable & Lytton, 1999), is a critical factor in determining engagement with long-term savings products like pension schemes. While empirical evidence indicates that individuals with higher risk tolerance are more likely to participate in such schemes (Chou et al., 2014; Xiao et al., 2011), this relationship is often moderated by financial knowledge and perceived behavioral control. Within Ghana's informal economy, risk tolerance is further shaped by income volatility and institutional trust, necessitating design strategies that address the specific concerns of workers who may view pension investments as unreliable.

Empirical evidence on financial attitudes and pension participation

Empirical research consistently links financial literacy and retirement planning to increased pension participation, establishing a positive relationship across both developed and developing economies. Studies in the Netherlands and Australia (Van Rooij et al., 2011; Worthington, 2006) demonstrate that financially literate individuals are better equipped to accumulate pension wealth. Similarly, research in sub-Saharan Africa (Boyetey et al., 2021; Kpessa & Bland, 2013) highlights how financial knowledge and proactive planning are vital drivers for promoting participation among informal workers, often

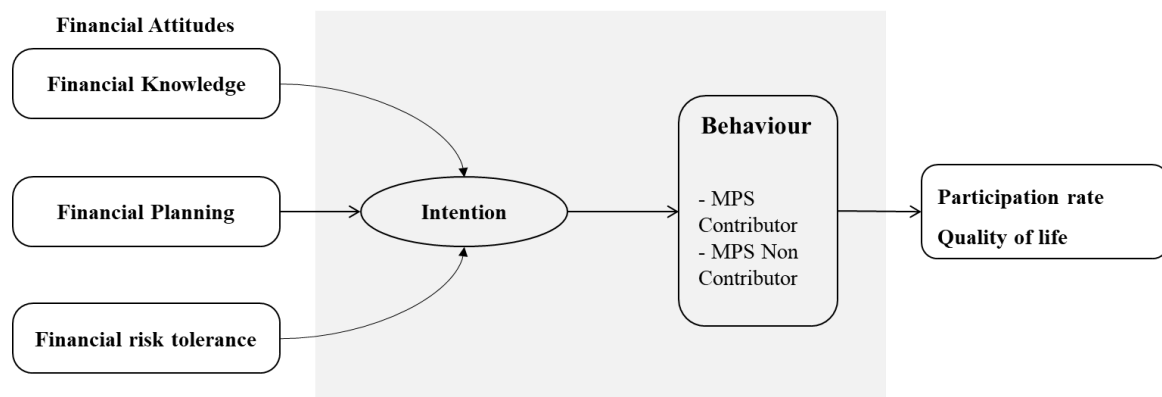
facilitated by access to formal and informal financial services (Nchise & Akosso, 2024). However, the predictive power of financial attitudes remains contested, with recent evidence suggesting that knowledge and behaviour are more reliable indicators of retirement preparedness than attitudes alone (Janposri, 2020; Agabalinda & Ndi, 2020). While studies in Thailand and Uganda indicate that attitudes may not significantly predict wealth accumulation, the specific role of these factors in Ghana's informal economy remains under-researched. This study aims to fill that gap by applying the Theory of Planned Behaviour (TPB) to evaluate how financial knowledge, planning, and risk tolerance collectively influence participation in Ghana's micro pension schemes.

Conceptual framework

Based on the literature review, this study proposes a conceptual framework that integrates the Theory of Planned Behavior with financial attitudes to explain MPS participation among informal economy

workers in Ghana. The framework posits that financial attitudes comprising financial knowledge, financial planning, and financial risk tolerance influence individuals' attitudes toward MPS, which in turn affect their intentions to participate and their actual participation behavior. The framework also acknowledges the role of subjective norms (social influences) and perceived behavioral control (perceived ease or difficulty of participation) in shaping intentions and behavior.

The conceptual framework is illustrated in Figure 1. The framework suggests that informal economy workers with higher financial knowledge, stronger financial planning behaviors, and greater risk tolerance are more likely to have positive attitudes toward MPS, leading to higher intentions to participate and ultimately higher participation rates. The framework also recognizes that external factors, such as income level, age, education, and access to financial services, may moderate these relationships.



Theory of Planned Behaviour (TPB)

Figure 1: Conceptual framework of financial attitudes and MPS

Source: Authors' construct based on reviewed literature (2026)

Material and Methods

Research design

This study employed a mixed-methods research design, combining quantitative and qualitative approaches to provide a comprehensive understanding of the relationship between financial attitudes and

MPS participation among informal economy workers in Ghana. The mixed-methods approach is particularly appropriate for this study, as it allows for the triangulation of findings from different data sources and provides both statistical

evidence and contextual insights (Johnson & Onwuegbuzie, 2004; Zohrabi, 2013).

The quantitative component of the study involved a cross-sectional survey of informal economy workers in selected urban and peri-urban areas of Ghana. The survey collected data on respondents' demographic characteristics, financial attitudes (financial knowledge, financial planning, and financial risk tolerance), and MPS participation status. The data were analyzed using logistic regression to examine the association between financial attitudes and the likelihood of MPS participation.

The qualitative component involved semi-structured interviews with key informants, including informal workers, pension scheme administrators, and policymakers. The interviews explored the contextual factors influencing MPS participation, the barriers and enablers to participation, and the lived experiences of informal workers in relation to pension savings. The qualitative data were analyzed using thematic analysis to identify recurring themes and patterns.

Study area and population

The study was conducted in selected urban and peri-urban areas of Ghana, including Accra Metropolitan area, Kumasi metropolitan area, and Somanya (capital of Yilo Krobo district). These areas were chosen because they have significant concentrations of informal economy workers engaged in diverse activities such as petty trading, artisanal work, and small-scale manufacturing. The target population consisted of informal economy workers aged 18 years and above who were not

enrolled in any formal pension scheme at the time of the study.

According to the Ghana Statistical Service (Baah-Boateng & Vanek, 2020; GSS, 2015), the informal economy accounts for approximately 86% of total employment in Ghana, with the majority of workers engaged in agriculture, trade, and services. The study focused on non-agricultural informal workers, as they are the primary target group for urban-based micro pension schemes.

Sample size and sampling procedure

The sample size for the quantitative survey was determined using Yamane's (1967) formula for finite populations:

$$n = \frac{N}{(1 + N(e)^2)}$$

where n is the sample size,

N is the population size (see Table 1), and e is the margin of error (set at 5%). Based on available data on the informal economy workforce in the study areas, a sample size of 400 respondents was determined to be adequate for the study.

A multi-stage sampling procedure was employed to select respondents. In the first stage, three urban/peri-urban areas (Accra, Kumasi, and Somanya) were purposively selected based on their high concentrations of informal workers. In the second stage, specific markets, trading centers, and artisanal clusters within each area were randomly selected. In the third stage, individual respondents were selected using systematic random sampling, with every 10th informal worker was approached for participation.

Table 1: Population size of the studied areas

Study Area	Population (N)	Percent (%)
Accra Metropolitan area	284,124.00	36
Kumasi Metropolitan area	443,981.00	56
Urban Yilo Krobo Municipal	58,096.00	7
Total	786,201.00	100

Source: Compiled from the Assemblies' web sites, May 2026.

For the qualitative component, a purposive sampling approach was used to select key informants. A total of 15 key informants were interviewed, including 10 informal workers, 3 pension scheme administrators, and 2 policymakers from the National Pensions Regulatory Authority (NPRA) and the Ministry of Employment and Labour Relations (MELR).

Data collection

The quantitative data were collected using a structured questionnaire administered through face-to-face interviews. The questionnaire was developed based on the literature review and the study's conceptual framework. It consisted of four main sections: first, the demographic characteristics. This section collected information on respondents' age, gender, education level, marital status, household size, and monthly income. Second, financial knowledge. This section assessed respondents' understanding of basic financial concepts and pension products. It included questions on compound interest, inflation, risk diversification, and the structure of Ghana's pension system. Responses were scored, and a composite financial knowledge index was created.

The third section assessed financial planning. The section measured respondents' financial planning behaviors, including budgeting, setting savings goals, tracking expenses, and planning for retirement. Respondents were asked to indicate the frequency with which they engaged in these behaviors on a Likert scale (1 = never, 5 = always). A composite financial planning index was created by summing the scores. Finally, on the financial risk tolerance, respondents were assessed on their willingness to take financial risks. It included questions on their preferences for safe versus risky investments, their comfort with uncertainty, and their willingness to invest in long-term savings products. A composite risk

tolerance index was created based on the responses.

Further, on MPS participation, respondents were asked whether they were currently contributing to any micro pension scheme (Tier 3 of Ghana's pension system). This was coded as a binary variable (1 = participating, 0 = not participating). The questionnaire was pre-tested with a sample of 30 informal economy workers to ensure clarity and reliability. Based on the pre-test results, minor modifications were made to improve the wording and structure of some questions. The final questionnaire was administered by trained research assistants over a period of one month.

The qualitative data were collected through semi-structured interviews with key informants. The interview guide included open-ended questions on the following topics: Awareness and understanding of micro pension schemes; Perceived benefits and barriers to MPS participation; Financial attitudes and behaviors related to pension savings; Experiences with formal and informal savings mechanisms; and Recommendations for improving MPS uptake among informal workers.

The interviews were conducted in English or the local language (Twi or Ga or Dangme), depending on the preference of the respondent. Each interview lasted approximately 30-45 minutes and was audio-recorded with the consent of the respondent. The recordings were transcribed verbatim and translated into English where necessary.

Data analysis

The quantitative data were analyzed using SPSS version 25. Descriptive statistics (frequencies, percentages, means, and standard deviations) were computed to summarize the demographic characteristics of respondents and their financial attitudes. Bivariate analysis (chi-square tests and t-tests) was conducted to examine the

association between demographic variables, financial attitudes, and MPS participation. Logistic regression analysis was employed to examine how financial attitudes shape the

likelihood of MPS participation, controlling for demographic variables. The logistic regression model was specified as follows:

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1(\text{Financial Knowledge}) + \beta_2(\text{Financial Planning}) + \beta_3(\text{Financial risk tolerance}) + \beta_4(\text{Age}) + \beta_5(\text{Gender}) + \beta_6(\text{Education}) + \beta_7(\text{Income}) + \varepsilon$$

where p is the probability of MPS participation, β_0 is the intercept, β_1 to β_7 are the regression coefficients, and ε is the error term. The model's goodness of fit was assessed using the Hosmer-Lemeshow test, and the overall model significance was evaluated using the likelihood ratio test. The predictive accuracy of the model was assessed using the classification table and the area under the ROC curve.

The qualitative data were analyzed using thematic analysis, following the six-step process outlined by Braun and Clarke (2006). The analysis was conducted manually, with codes and themes organized using Microsoft Excel. To enhance the rigor and credibility of the analysis, the responses were independently coded by two analysts and the transcripts were compared. Discrepancies were resolved through discussion and consensus.

Ethical considerations

Ethical approval for the study was obtained from the Institutional Review Board of the University of Environment and Sustainable Development. Informed consent was obtained from all participants prior to data collection. Participants were informed of the purpose of the study, their right to withdraw at any time, and the measures taken to ensure confidentiality and anonymity. All data were stored securely and used solely for research purposes.

Results and discussion

Demographic characteristics of respondents

Table 2 presents the demographic characteristics of the 400 respondents who participated in the quantitative survey.

Majority of respondents were female (58.5%), reflecting the gender composition of the informal economy in Ghana, where women predominate in petty trading and food vending. The age distribution showed that most respondents were between 30 and 49 years (33.0%), with a mean age of 38.7 years (SD = 10.2). This age profile is consistent with the economically active population in the informal sector.

In terms of education, 42.8% of respondents had completed primary education, 35.5% had secondary education, and only 12.3% had tertiary education. About 9.5% had no formal education. This distribution reflects the generally low educational attainment among informal workers in Ghana. The majority of respondents were married (64.8%), and the average household size was 4.6 persons (SD = 2.1).

Monthly income varied widely among respondents, with a mean of GH¢ 850 (approximately USD 71 at the time of the study) and a median of GH¢ 600. About 38.5% of respondents earned less than GH¢ 500 per month, while only 15.3% earned more than GH¢ 1,500 per month. This income distribution highlights the economic vulnerability of informal workers and the challenges they face in setting aside funds for long-term savings.

Out of the 400 respondents, only 47 (11.8%) reported that they were currently contributing to a micro pension scheme (Tier 3). This participation rate, while higher than the reported national figure of less than 5% (Asafu-Adjaye, 2022; MELR, 2017), is still remarkably low and indicates significant barrier to MPS uptake among informal workers. The higher rate in this sample may be attributed to the study's focus on urban and peri-urban areas, where awareness of pension schemes and access to

financial services are relatively better than in rural areas.

The low participation rate is consistent with recent findings from Ghana. Segbenya et al. (2024) reported that most informal workers had partial or poor understanding of pension tiers, and Asiamah (2023) found that financial literacy was extremely low among informal workers in Accra. These studies underscore the persistent challenges in extending pension coverage to the informal sector despite policy reforms.

Table 2: Demographic characteristics of respondents

Variables	Category	Frequency	Percentage
Gender	Male	166	41.50
	Female	234	58.50
	Total	400	100.00
Age	18 to 29 years	78	19.50
	30 to 39 years	132	33.00
	40 to 49 years	117	29.25
	50 years & above	73	18.25
	Total	400	100.00
Education	No formal education	38	9.50
	Primary	171	42.75
	Secondary	142	35.50
	Tertiary & higher	49	12.25
	Total	400	100.00
Marital status	Single	98	24.50
	Married	259	64.75
	Divorced/widowed	43	10.75
	Total	400	100.00
Monthly income	Less than ₵500	154	38.50
	₵500 to ₵999	138	34.50
	₵1000 to ₵1499	47	11.75
	₵1,500 & above	61	15.25
	Total	400	100.00
MPS participation status	MPS contributor	47	11.75
	Non-contributor	353	88.25
	Total	400	100.00

Financial attitudes of respondents

Table 3 presents the results of the financial knowledge assessment. Overall, respondents demonstrated low levels of financial knowledge, with a mean score of 3.8 out of 10 ($SD = 2.1$). Only 18.5% of respondents scored 7 or above, indicating adequate financial knowledge, while 26.75% scored below 3, indicating very low financial knowledge. The questions on compound interest and inflation were particularly challenging, with only 22% and

28% of respondents answering correctly, respectively.

These findings are consistent with previous studies documenting low financial literacy among informal workers in Ghana and other developing countries (Asiamah, 2023; Lusardi & Mitchell, 2011). The low financial knowledge levels suggest that many informal workers lack the basic understanding needed to make informed decisions about pension savings and other financial products.

Table 3: Distribution of financial knowledge scores

Score Range	Frequency	Percent	Interpretation
0 to 2	107	26.75	Very Low
3 to 4	145	36.25	Low
5 to 6	74	18.5	Moderate
7 to 10	74	18.5	High
Total	400	100	
Statistic		Mean	Std. Dev
Financial knowledge index		3.8	2.1

Table 4 presents the results of the financial planning assessment. Respondents' financial planning behaviors were measured on a scale of 1 to 5, with higher scores indicating more frequent engagement in planning activities. The mean financial planning score was 2.6 ($SD = 1.1$), indicating that most respondents engaged in financial planning behaviors only occasionally. Specific planning behaviors showed considerable variation. While 52.3% of respondents reported that they "sometimes" or "often" or "always" set aside money for emergencies, only 28.5% reported that they regularly tracked their expenses, and only 20.1% reported that they

had a written budget. Planning for retirement was particularly uncommon, with only 15.3% of respondents reporting that they "sometimes" or "often" or "always" thought about their financial needs in old age.

These findings highlight the limited financial planning capacity among informal workers, which may be attributed to several factors, including low financial literacy, income volatility, and competing immediate financial needs. The low levels of retirement planning are particularly concerning, as they suggest that many informal workers are not actively preparing for old age.

Table 4: Financial planning behaviors (N = 400)

Sn	Behaviour	Never		Rarely		Sometimes		Often		Always		Mean	S.D
		Count	%	Count	%	Count	%	Count	%	Count	%		
1.	Set aside money for emergencies	74.0	18.5	117.0	29.3	131.0	32.8	58.0	14.5	20.0	5.0	2.6	1.1
2.	Track expenses regularly	143.0	35.8	143.0	35.8	74.0	18.5	30.0	7.5	10.0	2.5	2.1	1.0
3.	Have a written budget	169.0	42.3	151.0	37.8	50.0	12.5	21.0	5.3	9.0	2.3	1.9	1.0
4.	Plan for retirement	194.0	48.5	145.0	36.3	38.0	9.5	16.0	4.0	7.0	1.8	1.7	0.9

Overall Planning Score: Mean = 2.6 with S. D = 1.1

Table 5 presents the results of the financial risk tolerance assessment. The mean risk tolerance score was 2.4 (SD = 1.0), indicating that most respondents were risk-averse. Specifically, 62.8% of respondents indicated a preference for "safe" investments with guaranteed returns, even if the returns were low. Only 15.5% expressed willingness to invest in products with uncertain returns for the possibility of higher gains.

When asked about their comfort with locking funds away for long periods (a key

feature of pension schemes), 58.3% of respondents expressed discomfort or strong discomfort. This finding is particularly relevant for understanding barriers to MPS participation, as micro pension schemes typically require long-term commitment and restrict early withdrawals. The preference for liquidity and flexibility among informal workers is consistent with findings from Kos and Lensink (2023), who found that uptake of pension accounts was significantly higher when greater withdrawal flexibility was offered, particularly among women.

Table 5: Financial risk tolerance (N = 400)

Sn	Behaviour	Strongly Disagree		Disagree		Neutral		Agree		Strongly Agree		Mean	SD
		Count	%	Count	%	Count	%	Count	%	Count	%		
1.	I prefer safe investments with guaranteed returns.	21.0	5.3	48.0	12.0	80.0	20.0	171.0	42.8	80.0	20.0	3.6	1.1
2.	I am willing to take risks for higher returns.	154.0	38.5	113.0	28.3	71.0	17.8	48.0	12.0	14.0	3.5	2.1	1.2
3.	I am comfortable locking funds for long periods.	131.0	32.8	102.0	25.5	88.0	22.0	61.0	15.3	18.0	4.5	2.3	1.2

Overall Risk Tolerance score: Mean = 2.4 with S.D =1.0

Financial attitudes and MPS participation

Table 6 presents the results of bivariate analysis comparing financial attitudes between MPS participants and non-participants. Independent samples t-tests were conducted to examine whether there

were significant differences in financial knowledge, financial planning, and financial risk tolerance between the two groups.

The results show that MPS participants had significantly higher financial knowledge

scores ($M = 5.8$, $SD = 1.9$) compared to non-participants ($M = 3.5$, $SD = 1.9$), $t(398) = 7.82$, $p < 0.001$. Similarly, MPS participants had significantly higher financial planning scores ($M = 3.9$, $SD = 0.9$) compared to non-participants ($M = 2.4$, $SD = 1.0$), $t(398) = 9.45$, $p < 0.001$. However, the difference in financial risk tolerance between participants ($M = 2.7$, $SD = 1.0$) and non-participants ($M = 2.3$, $SD = 1.0$) was smaller and marginally significant, $t(398) = 2.15$, $p = 0.032$.

These findings provide preliminary evidence that financial knowledge and financial planning are strongly associated with MPS participation, while the relationship with risk tolerance is weaker. The strong association between financial planning and participation is particularly noteworthy, as it suggests that individuals who engage in proactive financial management are more likely to recognize the value of pension savings and take steps to enroll in MPS.

Table 6: Comparison of financial attitudes by MPS participation status

Financial attitude	MPS Contributors, n = 47		MPS non-contributors, n = 353		t – value	p - value
	Mean	SD	Mean	SD		
Financial knowledge	5.80	1.90	3.50	1.90	7.82	<0.001**
Financial planning	3.90	0.90	2.40	1.00	9.45	<0.001**
Financial risk tolerance	2.70	1.00	2.30	1.00	2.15	0.032*

* $p < 0.05$; ** $p < 0.001$

Logistic regression analysis: Predictors of MPS participation

Table 7 presents the results of the logistic regression analysis examining the predictors of MPS participation. The model

included financial knowledge, financial planning, and financial risk tolerance as the main independent variables, along with demographic control variables (age, gender, education, and monthly income).

Table 7: Logistic regression results (N = 400)

Variable	B	SE	Wald	p-value	Odd Ratio	95% CI
Financial knowledge	0.42	0.10	17.64	<0.001**	1.52	[1.24, 1.86]
Financial planning	1.23	0.23	28.56	<0.001**	3.42	[2.18, 5.37]
Financial risk tolerance	0.17	0.16	1.15	0.284	1.18	[0.87, 1.61]
Age	0.02	0.02	1.00	0.1317	1.02	[0.98, 1.06]
Gender (female)	0.28	0.35	0.64	0.424	1.32	[0.67, 2.61]
Education (Ref: No formal)			8.42	0.038*		
Primary	0.65	0.52	1.56	0.212	1.92	[0.69, 5.34]
Secondary	0.82	0.54	2.31	0.129	2.27	[0.79, 6.52]
Tertiary & higher	1.05	0.48	4.79	0.028*	2.85	[1.12, 7.24]
Income (ref: Less than ₦500)			7.85	0.049*		
₦500 to ₦999	0.54	0.38	2.01	0.156	1.72	[0.82, 3.61]
₦1000 to ₦1499	0.68	0.45	2.28	0.131	1.97	[0.82, 4.74]
₦1,500 & above	0.90	0.42	4.59	0.032*	2.47	[1.08, 5.65]
Constant	-6.82	1.12	37.05	<0.001**	0.001	

Note: Model $\chi^2(7) = 142.35$, $p < 0.001$; Hosmer-Lemeshow $\chi^2(8) = 8.42$, $p = 0.394$; Nagelkerke $R^2 = 0.48$; Classification accuracy = 89.3%;

* $p < 0.05$; ** $p < 0.001$

The overall model was statistically significant, $\chi^2(7) = 142.35$, $p < 0.001$, indicating that the set of predictors reliably distinguished between MPS participants and non-participants. The Hosmer-

Lemeshow test indicated good model fit, $\chi^2(8) = 8.42$, $p = 0.394$. The model correctly classified 89.3% of cases, and the area under the ROC curve was 0.87, indicating excellent predictive accuracy.

The results from Table 7 further show that financial planning was the strongest predictor of MPS participation (OR = 3.42, 95% CI [2.18, 5.37], $p < 0.001$). For each one-unit increase in the financial planning score, the odds of MPS participation increased by 242%. This finding underscores the critical role of financial planning behaviors in driving pension savings decisions. Informal workers who engage in budgeting, expense tracking, and goal-setting are significantly more likely to participate in MPS, as these behaviors reflect a forward-looking orientation and a commitment to long-term financial security. Financial knowledge was also a significant predictor of MPS participation (OR = 1.52, 95% CI [1.24, 1.86], $p < 0.001$). For each one-unit increase in the financial knowledge score, the odds of MPS participation increased by 52%. This finding is consistent with previous research demonstrating that financial literacy enhances retirement planning and savings behavior (Asiamah, 2023; Lusardi & Mitchell, 2011; Nchise & Akosso, 2024; Van Rooij et al., 2011). Financially knowledgeable individuals are better equipped to understand the benefits of pension savings, navigate enrollment procedures, and make informed decisions about contribution levels.

Interestingly, financial risk tolerance was not a significant predictor of MPS participation (OR = 1.18, 95% CI [0.87, 1.61], $p = 0.284$) after controlling for other variables. This finding suggests that risk tolerance may play a less important role in MPS participation decisions than financial knowledge and planning. One possible explanation is that micro pension schemes in Ghana are generally perceived as low-risk savings products with guaranteed returns, rather than as risky investments. Consequently, risk tolerance may be more relevant for decisions about investment portfolios within pension schemes rather than for the initial decision to participate.

Among the demographic control variables, education and monthly income were significant predictors of MPS participation. Respondents with tertiary education had 2.85 times higher odds of MPS participation compared to those with no formal education (OR = 2.85, 95% CI [1.12, 7.24], $p = 0.028$). Similarly, respondents with monthly income of GH¢1,500 or above had 2.47 times higher odds of participation compared to those earning less than GH¢ 500 (OR = 2.47, 95% CI [1.08, 5.65], $p = 0.032$). These findings are consistent with previous research showing that education and income are important determinants of pension participation (Kibona, 2021; Kpessa & Bland, 2013).

Age and gender were not significant predictors of MPS participation in this model. The non-significance of age may be due to the relatively narrow age range of the sample (most respondents were between 30 and 49 years). The non-significance of gender is somewhat surprising, given that previous studies have found gender differences in pension participation (Kos & Lensink, 2023). However, this finding may reflect the specific context of Ghana's informal economy, where both men and women face similar barriers to pension savings.

The quantitative results of this study demonstrate that financial attitudes, specifically financial planning and financial knowledge, are major determinants of MPS participation among informal economy workers in Ghana. The logistic regression model reveals that financial planning is the single strongest predictor of enrolment, with workers who practice budgeting and goal-setting being more than three times as likely to participate compared to those who do not. Viewed through the Theory of Planned Behaviour, these structured behaviours foster a forward-looking mindset and positive evaluations regarding the long-term benefits of retirement savings (Ajzen, 1991). This theoretical interpretation aligns

with recent regional and global literature applying TPB to savings behaviour; for instance, Boyetey (2020) demonstrated that TPB constructs effectively predict financial savings behaviour among informal workers in Ghana, while Mohd and Kim (2024) similarly found that financial literacy, attitudes, subjective norms, and intentions significantly drive savings outcomes among youth.

Furthermore, cognitive capacity in the form of financial knowledge emerged as a statistically significant predictor of MPS enrolment. Individuals with higher financial literacy are fundamentally better equipped to comprehend complex pension structures, navigate bureaucratic registration processes, and optimize contribution schedules, a finding that strongly corroborates a well-established body of global and regional empirical research (Asiamah, 2023; Lusardi & Mitchell, 2011; Nchise & Akosso, 2024; Van Rooij et al., 2011). However, the remarkably low baseline financial knowledge observed in this sample (a mean score of 3.8 out of 10) signals a severe structural barrier to voluntary program adoption. Interestingly, financial risk tolerance was not a significant predictor of participation when controlling for other variables. While this contrasts with some traditional economic literature highlighting risk tolerance as a key investment determinant (Chou et al., 2014; Xiao et al., 2011), the non-significance in this context likely reflects the fact that Ghanaian micro pensions are widely perceived as safe, low-risk, and guaranteed savings vehicles rather than volatile asset investments.

Qualitative findings: Barriers and enablers to MPS participation

The qualitative interviews with key informants provided rich contextual insights into the barriers and enablers to MPS participation among informal workers. The thematic analysis identified five major themes: (1) low awareness and understanding of MPS, (2) income volatility

and competing financial priorities, (3) mistrust of formal financial institutions, (4) preference for informal savings mechanisms, and (5) the role of financial education and outreach.

Low awareness and understanding of MPS

A recurring theme across the interviews was the low level of awareness and understanding of micro pension schemes among informal workers. Many respondents reported that they had heard of pension schemes but did not understand how they worked or how to enroll. As one informal trader explained:

"I have heard about pension on the radio, but I don't really understand it. Is it like a bank account? How do I join? Nobody has come to explain it to us." (Female trader, age 42 years)

This finding is consistent with recent research by Segbenya et al. (2024), who found that most informal workers in Ghana had partial or poor understanding of pension tiers. Pension scheme administrators interviewed for this study acknowledged that outreach efforts have been limited and have not effectively reached informal workers in markets and trading centers. One administrator noted:

"We have done some sensitization programs, but they are mostly in formal workplaces. Reaching informal workers is challenging because they are scattered and mobile. We need a different approach." (Pension scheme administrator)

Income volatility and competing financial priorities

Informal workers consistently cited income volatility and competing financial priorities as major barriers to MPS participation. Many respondents explained that their incomes fluctuate from day to day and month to month, making it difficult to commit to regular pension contributions. As one artisan stated:

"Some days I make good money, other days I make nothing. How can I promise to pay a fixed amount every month? I have to feed my family first." (Male artisan, age 38)

This finding aligns with the broader literature on informal workers' savings behavior, which emphasizes the challenges posed by irregular income streams (Hu & Stewart, 2009; Wango, 2023). Respondents also highlighted competing financial priorities, including children's education, healthcare, and housing, which often take precedence over long-term savings. One respondent explained:

"I would like to save for old age, but right now I need to pay school fees for my children. That is more urgent. Maybe when they finish school, I can think about pension." (Female trader, age 45 years)

These findings underscore the need for flexible pension products that accommodate irregular incomes and allow for variable contribution amounts. Kos and Lensink (2023) demonstrated that greater withdrawal flexibility significantly increased uptake of pension accounts among cocoa farmers in Ghana, particularly among women, suggesting that product design features can effectively address these barriers.

Mistrust of formal financial institutions

Several respondents expressed mistrust of formal financial institutions, including pension schemes. This mistrust was often rooted in negative experiences with banks or concerns about the safety of their savings. As one respondent explained:

"I don't trust these big institutions. What if they collapse and I lose my money? I prefer to keep my money where I can see it." (Male trader, age 50 years)

This finding is consistent with research from other sub-Saharan African contexts,

where mistrust of formal institutions has been identified as a significant barrier to pension participation (Lambin & Nyssola, 2022; Obuobi, 2024). Ethnographic research in Northern Nigeria has similarly critiqued market-based micro-pension approaches for failing to account for mistrust and reliance on informal supports (Obuobi, 2024). Building trust through transparent communication, reliable service delivery, and community-based outreach may be critical for enhancing MPS uptake.

Preference for informal savings mechanisms

Many respondents reported that they relied on informal savings mechanisms, such as susu (rotating savings and credit associations), church welfare groups, and family networks, for financial security. These mechanisms were perceived as more flexible, accessible, and socially embedded than formal pension schemes. As one respondent explained:

"I save with my susu group. Every week I contribute, and when it is my turn, I get a lump sum. It is flexible, and I trust the people in my group. With pension, I have to wait until I am old." (Female trader, age 36 years)

This finding is consistent with research by Danso-Wiredu (2021), who documented that urban informal workers in Ghana institutionalize interest-free, reciprocal saving and loan arrangements that substitute for formal social protection. Obuobi (2024) similarly found that most informal workers in Ghana rely on informal strategies such as church welfare, rental property, and susu rather than formal pension tiers. These findings suggest that formal micropension schemes must compete with well-established informal mechanisms that offer immediate liquidity, social support, and flexibility.

The role of financial education and outreach

Both informal workers and key informants emphasized the importance of financial education and targeted outreach in promoting MPS participation. Respondents expressed a desire for clear, simple information about pension schemes, delivered in accessible formats and languages. As one respondent stated:

"If someone could come and explain pension to us in our language, and show us how it benefits us, I think more people would join. We need education." (Male artisan, age 44 years)

Pension scheme administrators and policymakers also recognized the need for enhanced financial education efforts. One policymaker noted:

"Financial literacy is very low among informal workers. We need to invest in education programs that are tailored to their needs and delivered through channels they trust, such as community leaders and market associations." (NPRA official)

This finding is strongly supported by recent empirical evidence. Asiamah (2023) found that financial literacy was extremely low among informal workers in Accra but positively and significantly associated with participation in the personal pension scheme, suggesting that education interventions could substantially increase uptake. Nchise and Akosso (2024) found that usage of both formal and informal financial services mediated the relationship between financial literacy and retirement preparedness among informal-sector workers in Cameroon, indicating that financial education should be coupled with efforts to improve access to financial services.

The qualitative findings enrich the quantitative results by demonstrating that

low baseline awareness, profound income volatility, institutional mistrust, and a cultural preference for informal savings mechanisms are structural barriers deeply embedded within Ghana's informal economy. Rather than substituting formal systems for traditional arrangements, research suggests formal micro pension schemes must complement and build upon existing networks. This is underscored by Danso-Wiredu (2021), who documented how urban informal workers institutionalize reciprocal, interest-free saving and loan structures as durable old-age coping strategies, while Obuobi (2024) similarly confirmed that most informal workers structurally rely on these informal strategies over formal pension tiers. To bridge this gap, scheme administrators should partner directly with established *susu* groups and market associations to leverage their embedded social capital and localized trust for enrolment and contribution collection.

A paradigm shift toward product flexibility and technological integration is also critical to accommodate the irregular incomes of informal workers. Kos and Lensink (2023) provided experimental evidence demonstrating that account uptake rises significantly when greater withdrawal flexibility is offered, particularly among women, showing that rigid regulations act as severe deterrents. Furthermore, Segbenya et al. (2024) established that informal workers explicitly prefer mobile money or agent collection methods paired with variable contribution rates to match fluid incomes. This requires a holistic transformation of the social protection architecture; as Lambin and Nyssola (2022) observed, competitive informal arrangements naturally attract workers away from formal structures if the formal options fail to align with their economic capacities. Similarly, Wango (2023) found that while informal organizations play a vital protective role that can be leveraged to expand coverage, standard formal

administrative procedures actively deter informal actors.

Finally, targeted financial education and accessible outreach emerge as vital catalysts for expanding participation. Given the low levels of financial literacy observed alongside its strong correlation with program enrolment, interventions must be delivered directly to marketplaces, trading hubs, and artisanal clusters using simple language and partnerships with trusted community leaders. Asiamah (2023) confirmed that financial literacy is positively and significantly associated with personal pension participation, reinforcing the value of localized educational campaigns. Moreover, Nchise and Akosso (2024) demonstrated that the usage of both formal and informal financial services mediates the relationship between financial literacy and overall retirement preparedness. This indicates that financial education must not exist in a vacuum but must be strategically coupled with structural reforms that reduce transaction costs, improve physical and digital access, and transparently communicate how benefits are safeguarded.

Conclusion and policy implications

This study applied the Theory of Planned Behaviour through a mixed-methods research design, to investigate how financial knowledge, financial planning, and financial risk tolerance, which collectively constitute a worker's financial attitude, shapes the likelihood of saving in an MPS. Quantitative analysis reveals that proactive financial planning (budgeting, tracking expenses) makes workers over three times more likely to enrol, while financial knowledge enables them to safely navigate administrative processes. Conversely, financial risk tolerance plays a negligible role because these schemes are largely perceived as safe, low-risk savings instruments. However, widespread uptake remains heavily constrained by socioeconomic disparities, as enrolment is

heavily concentrated among higher-income and tertiary-educated demographics, leaving the broader, low-earning informal workforce structurally excluded.

Qualitative insights further reveal that participation is severely impeded by systemic barriers, including pronounced income volatility, immediate consumption priorities, low baseline pension awareness, institutional mistrust, and a cultural preference for traditional savings. To mitigate these bottlenecks, policymakers and the National Pensions Regulatory Authority (NPRA) must move away from rigid, formal-sector frameworks and implement a multifaceted strategy. First, administrators should deploy targeted financial literacy interventions focused on practical budgeting and planning skills. Rather than generic campaigns, these should be delivered using simplified language through culturally embedded mediums, such as market associations, religious organizations, and mobile platforms.

Second, expanding financial inclusion requires a paradigm shift in product design and macro-level regulatory frameworks. Micro pension designs must be modernized to incorporate flexible, non-fixed contribution rates that accommodate fluctuating incomes, short vesting periods, and emergency partial withdrawal options. Such features are supported by experimental evidence to increase enrolment among vulnerable groups. Also, these flexible systems must be integrated with mobile money networks and localized *susu* groups to inherit existing social capital and build institutional trust. Ultimately, scaling up coverage demands that the state simplify bureaucratic enrolment, expand agent banking into underserved zones, provide matching contributions for low-income earners, and reform regulatory structures that remain fundamentally biased toward formal, salaried employment models.

Limitations and directions for future research

While this study establishes an empirically grounded baseline for expanding financial inclusion in sub-Saharan Africa, its cross-sectional design, reliance on self-reported data, and urban/peri-urban focus limit its causal verification, measurement precision, and generalizability to rural contexts. To address these limitations, future research should adopt longitudinal frameworks, incorporate objective administrative records, and expand into rural areas to capture localized savings behaviors.

Furthermore, future scholarship must move beyond individual-level analyses toward a holistic, socio-ecological paradigm by utilizing structural equation modeling to explore the mediating roles of subjective norms and perceived behavioral control, employing randomized controlled trials (RCTs) to test flexible product design variations, and examining the complex interplay between individual cognitive attitudes, micro-pension structures, and macro-level regulatory frameworks.

Declarations

Availability of data and materials

The dataset used and/or analysed in this study can be made available upon a reasonable request from the corresponding author.

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Eco-pavement Bricks from Waste: Assessing Demographic Determinants of Adoption in Bunso, Ghana

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Abstract

The exponential growth in solid waste generation, driven by rapid industrialisation, population expansion and economic development, has severe consequences for human health, biodiversity and environmental sustainability. In response, this study investigates the feasibility of reusing solid waste materials to develop eco-pavement bricks. A survey-based approach was employed to assess the influence of demographic factors on the willingness of individuals to pay for eco-pavement bricks. Conducted at Bunso, Abuakwa South Municipality in Ghana, the study utilised a questionnaire-based methodology to collect data, which was subsequently analysed using descriptive statistics and binomial logistic regression. The study's results reveal that 89% of the respondents were willing to pay for eco-pavement bricks, suggesting a strong potential for the adoption of sustainable waste management practices and environmentally conscious products. Notably, the findings indicate that demographic factors do not significantly influence the willingness to pay with all p-values > 0.05, implying a broad-based support for eco-friendly infrastructure solutions. This suggests that eco-pavement bricks could be a viable option for promoting sustainable development and reducing environmental impacts associated with traditional pavement materials.

Keyword: Circular Economy; Demographic determinants; Eco-pavement bricks; Sustainable waste management; Willingness to Pay (WTP).

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Introduction

The rapid growth of urban populations and increasing anthropogenic activities have led to a significant generation of various types of waste. The world generates approximately 2.01 billion tonnes of municipal solid waste annually, with predictions suggesting this number will grow to 3.8 billion tonnes by 2050 (Rahman and Ahmed, 2024). This staggering volume of waste highlights the pressing need for effective waste management strategies to mitigate the environmental and health impacts associated with waste disposal. Decay of the organic proportion of solid waste is contributing to about 5 per cent of global greenhouse gas (GHG) emissions, which in turn accelerates climate change and other adverse effects on human health and the environment (Gautam and Agrawal, 2020). There is the necessity to develop a municipal solid waste management structure that utilises the waste management hierarchy, sustainable development principles and integrated solid waste management approach (Oji et al., 2020).

The concept of circular economy is an emerging notion that has the potential to be utilised as waste minimisation approach (Esa et al., 2017), which has led to the concept of eco-pavement bricks as a means of recycling waste materials. Eco-pavement bricks are paving bricks designed to be eco-friendly. They are usually made from various materials, such as concrete, brick, stone, or recycled plastic, offering flexibility in design and functionality. The long service-life, fast and easy production and easy replacement for maintenance purposes of eco-pavement bricks have increased its popularity for use (Yeo et al., 2021). This has made individuals adapt to using waste materials as substitutes in building. Manjunatha et al. (2021) stated that, cement is a commonly used binding material for the preparation of concrete. They stated further that the manufacture and utilisation of cement in concrete can be contributor to Greenhouse Gas (GHG)

emission and climate change. Hence, when cement is partially or totally replaced with other materials, such ecological problems were reduced. Therefore, the state of the art for sustainable, unconventional, natural and recycled building materials should be taken into account (Kawereaki & Achal, 2020).

According to conclusions by Khan et al. (2021), Solid Waste Management (SWM) is a significant challenge that arises from local issues but with global consequences for a society. In low-income countries, over 90% of waste is often disposed of at unregulated dumps or openly burnt, creating serious health, safety and environmental consequences (World Bank Group, 2019).

As global population growth persists, resulting in a corresponding surge in waste production, there is an increasing need for innovative solutions that can effectively manage waste while promoting sustainability. In response to this challenge, this study aims to assess the willingness to patronize pavement bricks made from waste materials, thereby exploring the potential for waste reduction and resource conservation through the adoption of sustainable products manufactured using recycled waste materials. By exploring the relationship between demographic characteristics and willingness to pay, this research seeks to provide valuable insights into the potential demand for sustainable infrastructure solutions and inform strategies for promoting environmentally responsible practices among diverse population segments.

General Properties of Eco-Pavement Bricks

Ecological pavements represent a sustainable approach to infrastructure development, characterized by the incorporation of waste materials as additives in their construction. This innovative method not only reduces the environmental footprint of pavement construction but also promotes the efficient

use of resources. To ensure their sustainability, the construction and maintenance of ecological pavements must be carried out in a manner that minimizes natural resource depletion and energy consumption (Pratico et al, 2020).

Moreover, the production process associated with ecological pavements should prioritize the reduction of harmful emissions and by-products, thereby safeguarding the environment from adverse impacts. The design of these pavements is also crucial, as it must be carefully planned to avoid disrupting the natural surroundings and ecosystems (Austin, 2014).

The performance and durability of ecological pavements are determined by their physical and mechanical properties (Jiang et al, 2018). Key physical properties include water absorption, porosity, and specific gravity, while mechanical properties such as compressive strength, density, and tensile strength are essential for assessing their structural integrity (Akinyele et al, 2021). By understanding and optimizing these properties, it is possible to develop ecological pavements that are not only sustainable but also durable and functional.

Ultimately, the development of ecological pavements offers a promising solution for sustainable infrastructure development, one that balances the needs of human activity with the imperative of environmental protection. By adopting sustainable design principles and prioritizing environmental stewardship, ecological pavements can play a vital role in creating a more sustainable future. The findings of this study contribute to a better understanding of the influence of demographic factors on individuals' willingness to adopt eco-friendly technologies and practices, ultimately informing policy and decision-making processes aimed at reducing waste and promoting sustainable development.

Composition of Solid Waste Materials for Eco-pavement Bricks

Tailings

The processes involved in mining activities generate more and more solid wastes, which mainly include waste rock, tailings and slag. Tailings are by-products of the ore beneficiation processes. According to Jones and Boger (2012), 14 billion tons of tailings are produced annually, worldwide. The overall utilisation of reduced storage amounts of tailings has become the focus of research as construction materials. For example, it is used in brick production (Zhu et al., 2017). Most published researches have revealed that mortar or concrete containing tailings as fine aggregate, have a higher water absorption percentage due to capillarity.

The process of cement production consumes a lot of energy and emits a significant amount of CO₂. According to Aprianti et al. (2015), to lessen these amounts, all kinds of industrial solid wastes, containing high silica are used to replace cement as supplementary cementitious materials (SCMs). Gayana (2018) investigated the properties of interlocking concrete block paver mixed with iron ore tailings as partial replacement of cement. According to the summarised findings, the utilisation of tailings as aggregate often resulted in an increase in the compressive strength.

Coconut shell powder

Coconut (*Cocos nucifera*) is a highly versatile and widely cultivated palm tree species, renowned for its multifaceted utility and significance. According to Bheel et al. (2021), coconut has been aptly described as "the most useful tree for humanity". Globally, coconut is extensively cultivated in over 92 countries, with optimal growth conditions requiring adequate sunlight and soil rich in calcium and phosphorus, typically found in sandy coastal areas (Gummadi & Srikanth, 2012).

The global coconut production is substantial, with an estimated 51 billion nuts produced annually across 12 million hectares of cultivated land. Notably, more than 50% of the global coconut production is processed into dried coconuts, highlighting the significance of this commodity in international trade (Rogers et al., 2012). Furthermore, coconut shell is a valuable natural filler material, with considerable potential for utilization in various industrial applications (Leman et al., 2017).

A coconut shell refers to the non-food hard part of a coconut which is considered as agricultural waste. Coconut shells have no economic value and their disposal causes ecological problems. Hence, there is the need to recycle them into useful materials to minimise their negative impacts on the environment. In short, both the cost of construction materials and disposal of waste can be reduced if agricultural waste can be reused. Research conducted by Itam et al. (2022) demonstrates that the utilization of coconut shell as a constituent material in ecobrick production leads to notable improvements in strength development, thereby underscoring its potential as a valuable additive in ecobrick manufacture.

Plastic waste

According to Agyemang et al. (2019), Ghana generates approximately 22,000 tons of plastic waste annually, with a recycling rate of only 2%. Furthermore, the study reported that the national waste generation rate for non-recyclable materials is estimated to be 0.096 kg per person per day. The high rate of population growth and increasing per capita income have resulted in the generation of huge volumes of heaped solid wastes. This is a serious menace to environmental quality and human health (Agyemang et al., 2019). Plastic manufacturing accounts for 6% of global oil consumption and is one of the world's fastest-growing waste streams (Hossain et al., 2022).

Wood ash dust/sawdust

Wood ash is generated as a by-product of combustion in wood-fired power plants, paper mills, and wood-burning factories (Ghorpade, 2012). Wood is a potential source of energy and environmentally friendly material. There will be an increased usage of wood in energy production in the future. As a result, the quantity of ash generated will also increase concurrently, raising the issues of disposal. Currently, wood ashes are frequently used as soil supplement to improve the alkalinity of soil for agriculture applications and also as a filler material in the construction of flexible pavements for roads and highways. (Ghorpade, 2012).

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 use in building construction.

Eco-Pavement Brick Preparation

The eco-pavement brick was formulated by incorporating a composite mixture of tailings, shredded plastics, coconut husk powder, and sawdust. The production process adhered to the standards outlined by the Ghana Standards Authority for brick manufacturing. The mixture was moulded into a brick shape, similar to conventional concrete bricks, using a standardized moulding procedure. These components were combined in a specific ratio to achieve the desired properties. The mixture was then moulded into a brick shape, following established protocols for brick production.

Conformity to Standards

The production process and material composition of the eco-pavement bricks adhered to the Ghana Standards Authority specifications, as outlined by Danso and Akwaboah (2021). The incorporation of waste materials, including tailings, shredded plastics, coconut husk powder, and sawdust, aimed to mitigate waste disposal issues and promote sustainable

construction practices. A comparative analysis with conventional concrete bricks (Figure 1) highlights the benefits of utilizing waste materials in pavement brick production, including reduced environmental impact, enhanced

sustainability, and improved aesthetic appeal. This innovative approach underscores the potential for waste-to-resource applications in sustainable infrastructure development.

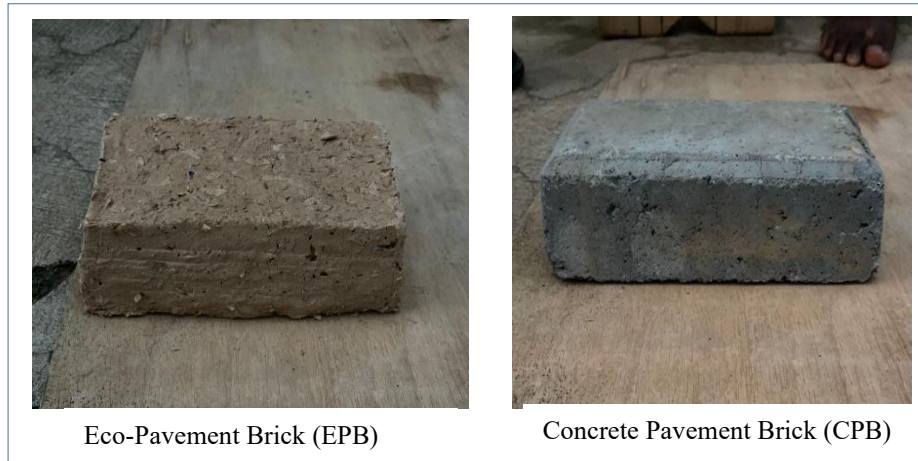


Figure 1: Eco-pavement brick and concrete pavement brick.

Materials and Methods

Study area

The study was conducted in Bunso, a notable ecozone community situated in the Abuakwa South Municipality of Ghana's Eastern Region. This ecologically significant area is distinguished by its rich biodiversity, featuring a diverse array of plant and animal species that thrive in harmony with the built environment. Bunso's unique blend of natural and constructed elements creates an eco-friendly enclave. Geographically, Bunso is located between longitude 0.56° West and 0.15° West, and latitude 6.03° North and 6.35° North, within the Wet semi-equatorial climatic zone characterized by a bimodal rainfall pattern (Abass, 2009). The area experiences an average annual temperature of 29.06°C (84.31°F), slightly higher than Ghana's national average. The Eastern Region of Ghana, where Bunso is located, generally exhibits a high rainfall pattern due

to its tropical location and proximity to the coast.

As an ecozone community, Bunso showcases a harmonious relationship between its residents and the natural environment, with community members deriving various benefits from ecosystem services that support their livelihoods. The area's eco-friendly environment and biodiversity make it an attractive location for eco-tourism, promoting sustainable practices and environmental conservation. This unique setting provides an ideal context for studying sustainable infrastructure development and assessing the community's willingness to adopt and pay for environmentally friendly solutions, such as eco-pavement bricks.

Sampling and Data collection

The data collection process employed a questionnaire survey methodology, utilizing a convenience sampling approach to select

household heads from the study area. This technique was chosen primarily due to its practical advantages, including ease of access to respondents, time efficiency and cost-effectiveness, which were important considerations given the study's limited resources and field logistics. Convenience sampling enabled the research team to reach participants who were readily available and willing to participate, thereby facilitating smooth data collection within the study's timeframe.

Trained university students administered the questionnaires, which were designed to elicit information on respondents' willingness to pay for pavement bricks produced from waste materials compared to conventional concrete pavement bricks. To support informed decision-making, the data collection team presented respondents with tangible samples of both eco-pavement bricks and conventional bricks, allowing participants to visually inspect and physically examine the materials. This hands-on approach enhanced respondents' comprehension and improved the reliability of their expressed preferences.

Before data collection, the questionnaire was peer-reviewed to ensure clarity, logical flow, and validity of items. The target population comprised residents of Bunso Township, and a sample size of 150 respondents was determined to ensure a statistically adequate subset of the population. According to Bartlett et al. (2001), a sample size of 150 provides a reasonable balance between precision and resource constraints, yielding reliable estimates for many social science studies.

The convenience sampling approach employed in this study facilitated the collection of insightful data on community attitudes toward eco-pavement bricks in Bunso Township. By engaging with readily available participants, the research team was able to gather valuable preliminary insights into the community's perceptions

and willingness to adopt sustainable building materials. This approach enabled the study to achieve its exploratory objectives, providing a foundation for future research and informing strategies to promote environmentally sustainable practices in the region.

Data analysis

The data was analysed and summarised using Microsoft Excel 2016 package and with descriptive statistics in Statistical Package for the Social Sciences. Binomial logistic regression was used to predict factors that influence WTP for the eco-pavement bricks by regressing the independent variables against the dependent variable. That is, to assess associations or relationships between demographic variables and WTP for eco-pavement bricks.

Results

Responses from the survey

Analysed submissions made by the respondents from the survey are presented in **(Table 1)**. Majority of the respondents were males (68 %, n=102) and the rest were females (32%, n=48). From the responses and observations of the survey, it was observed that the male population was higher than that of the female because most of the interviewed houses were owned or rented by the males.

Also, greater number of respondents who answered to the questions were in the ages of 36 years and above (60); followed by those in the ages of 15 to 25 (51). Those in the ages 26-35 years (39) were the least group that responded to the questionnaire. Likewise, (86) of the respondents were single; (48) were married; (12) were

divorced; the remaining (4) respondents were separated.

Respondents who had no formal education were quite less than those with some education. Table 1 clearly indicates that, tertiary respondents were the highest 56% (n=84); followed by JHS respondents with (n=33); SHS/Vocational respondents were (n=23); (n=10) were respondents who had no formal education. Similarly, out of the total number of respondents over the survey period, (70) were employed; (69) were students; (9) were unemployed; (2) were retired.

Moreover, (n=73) respondents had 2 to 10 years of experience in their profession; (57) of the respondents had less than a year experience; (10) had 11 to 20 years of experience; whereas only (1) respondent had over 21 years of experience.

Based on the occupation or current job status of the respondents, (47) said that, they receive a monthly income of 20 to 299 Ghana cedis; (41) receive 1000 Ghana cedis and above as their monthly income; (31) also stated that, they receive 300 to 599 Ghana cedis; the remaining (31) obtain a monthly income of 600 to 999 Ghana cedis.

Table 1: Demographic Characteristics of Sampled Household Heads at Bunso.

Parameters		Frequency	Percent
Total Respondents		150	100
Gender	Female	48	32
	Male	102	68
Age Group(Years)	15 to 25	51	34
	26 to 35	39	26
	36 and above	60	40
Marital Status	Single	86	57.3
	Married	48	32
	Divorced	12	8
	Separated	4	2.7
Highest Educational Level	No formal education	10	6.7
	JHS	33	22
	SHS/Vocational education	23	15.3
	Tertiary	84	56
Occupation/ Current Job Status	Student	69	46
	Unemployed	9	6
	Retired	2	1.3
	Employed	70	46.7
Monthly Income (GH¢)	20 to 299	47	31.3
	300 to 599	31	20.7
	600 to 599	31	20.7
	1000 and above	41	27.3

The survey results indicate that 95% of respondents endorse eco-pavement bricks as a viable solid waste management solution, with only 5% expressing disagreement. Majority of the respondents

(89%) stated that, they will be willing to pay for bricks made from waste materials as compared to bricks made from concrete but the remaining 11% of the population responded no. (**Figure 2**)

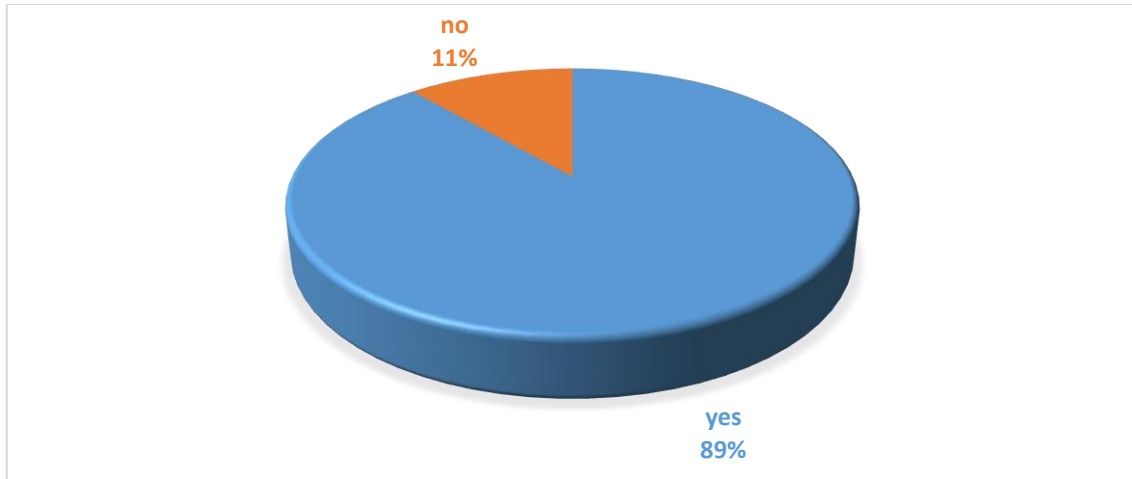


Figure 2: Willingness to pay for an eco-pavement brick.

A binomial logistic regression analysis at 95% confidence level reveals in **(Table 2)** that, all the demographic features did not have any impact on the willingness to pay (p-values >0.05).

From the **(Table 2)**, there was no significant differences between the demographic

characteristics (independent variables) that is, gender, age group, marital status, highest educational level, occupation and monthly income against the willingness to pay (dependent variable) for eco-pavement bricks.

Table 2: Results from the binomial logistics regression analysis performed using SPSS.

Parameter	B	S.E.	Wald	df	Sig.	Exp(B)
Gender	.630	.562	1.256	1	.262	1.877
Age Group	.371	.405	.840	1	.359	1.449
Marital Status	-.242	.494	.240	1	.625	.785
Highest educational level	-.218	.285	.587	1	.444	.804
Occupation/Current job status						
	-.124	.290	.183	1	.669	.884
Monthly income (GHC)	-.190	.264	.518	1	.472	.827
Constant	-2.775	1.786	2.415	1	.120	.062

Discussion

The survey findings indicate a positive perception of eco-pavement bricks as a viable initiative for solid waste management. A significant majority of respondents recognised the numerous benefits of eco-pavement bricks, including their extended service life, rapid and effortless production and easy replacement

for maintenance purposes. As indicated by Yeo (2021), these attributes have collectively contributed to the growing popularity of eco-pavement bricks for various applications.

A significant proportion of respondents expressed a willingness to pay for eco-pavement bricks, demonstrating a potential

market demand for this innovative product. The positive response suggests that consumers are increasingly recognising the value of sustainable and environmentally friendly solutions, such as eco-pavement bricks, which can effectively mitigate the environmental impacts associated with traditional waste management practices (Agyemang et al., 2019).

The binomial logistic regression analysis conducted to investigate the factors influencing respondents' willingness to pay for eco-pavement bricks yielded positive results. Contrary to expectations, the analysis revealed that the willingness to pay for eco-pavement bricks was not significantly dependent on any of the independent variables examined.

The insignificant p-values (> 0.05) obtained for all independent variables in the logistic regression analysis imply that the willingness to pay for eco-pavement bricks is a robust and consistent phenomenon, unaffected by external influences. This outcome has important implications for marketing strategies and consumer behaviour, as it highlights the potential for eco-pavement bricks to transcend traditional market segments and appeal to a broader audience.

The survey findings and logistic regression analysis collectively underscore the immense potential of eco-pavement bricks as a game-changing innovation in solid waste management. The willingness to pay for this product demonstrate a growing demand for sustainable solutions, which can be leveraged to drive environmental stewardship and promote eco-friendly

practices in various sectors as asserted by (Ramakrishna, 2022).

Conclusions and recommendation

The pursuit of sustainable development, including initiatives like eco-pavement bricks, is essential for building a brighter future for generations to come. The findings of the study revealed a notable absence of a significant association between demographic factors and willingness to pay for eco-pavement bricks. Specifically, the analysis showed that variables such as gender, age group and monthly income did not have a statistically significant impact on individuals' willingness to pay for eco-pavement bricks. This outcome suggests that the decision to pay for eco-pavement bricks is not influenced by demographic characteristics, rather by a broader commitment to environmental protection.

The lack of a significant association between demographic factors and willingness to pay for eco-pavement bricks has important implications for environmental policy and sustainability initiatives. It suggests that individuals are willing to prioritise environmental quality and pay for products that promote sustainability, regardless of their demographic backgrounds. This finding is consistent with the growing body of research on environmental behaviour, which highlights the increasing awareness and concern of environmental issues among individuals.

Further research is necessary to comprehensively assess the environmental and economic implications of eco-pavement bricks. Specifically, it is recommended that future studies conduct thorough Life Cycle Assessment (LCA) studies to evaluate the

environmental benefits and potential drawbacks of eco-pavement bricks in comparison to traditional bricks. Additionally, a detailed cost-benefit analysis should be performed to determine the economic feasibility and potential cost savings associated with adopting eco-pavement bricks in construction projects.

Moreover, to facilitate the widespread adoption of eco-pavement bricks, it is essential to develop and refine regulatory frameworks and standards governing their production and use. This would provide clarity on quality control, material specifications and environmental standards, thereby instilling confidence in stakeholders and promoting the uptake of eco-pavement bricks in the construction industry. By

addressing these knowledge gaps, future research can help unlock the full potential of eco-pavement bricks as a sustainable alternative to traditional building materials.

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Declarations

Human and animal rights: The author confirm that humans and animals were not used for experiments in this study.

Additional information: Questionnaire used for data collection is available and can be requested from the author.

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Social Isolation and Loneliness Among Older Adults in the UK: A Review

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Abstract

This study conducted a critical systematic review of the literature, focusing on the causes, effects, and intervention strategies for social isolation and loneliness among older adults in the UK. Through a systematic review process, 766 articles were initially identified and screened based on geographical focus, relevance, clarity and justification of the research design, quality of analysis and synthesis, and the robustness of the evidence. Of the 766 articles identified, 20 published between 2011 and 2021 met the inclusion criteria and were included in the final review. The findings revealed that loneliness and social isolation among older adults in the UK are driven by a range of interconnected factors, including life transitions and social bereavement, health-related problems, socioeconomic challenges, environmental and community factors, and demographic changes. The review also found that social isolation and loneliness are associated with adverse outcomes such as poor mental health, frailty, hypertension, cardiovascular diseases, and increased mortality. Identified intervention strategies include primary healthcare prevention, community-based support, social prescribing programmes, and individual-focused interventions. Overall, the findings suggest that implementing appropriate and evidence-based intervention strategies can substantially reduce the impact of social isolation and loneliness among older adults in the UK.

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Introduction

Human beings are a social species whose sustenance depends on cooperation and connectedness (Mughal, 2021). Evidence from the literature, dating back to Sheldon (1948) and Halmos (1952), Wenger (1996), and relatively more recently Komulainen et al. (2026), shows that social isolation and loneliness have generally been described as problems of old age. In the United Kingdom (UK), 11–17 percent of older adults (65 years and above) experience social isolation or loneliness (Victor et al., 2003). Victor and Bowling (2012) found that 9 percent of adults aged 65 and over experience severe loneliness, while 30 percent sometimes feel lonely. Further analysis from the same study indicates that 20–25 percent are persistently lonely, and 15 percent suffer from more severe, long-term loneliness. These findings are noteworthy, given the adverse impact loneliness and social isolation have on both mental and physical health.

Indeed, several factors contribute to older adults feeling lonely and socially isolated in the UK. Social isolation and loneliness have been consistently associated with adverse mental health outcomes, such as depression, anxiety, and cognitive decline (Cacioppo et al., 2014; Shankar et al., 2011; Khondoker et al., 2017). They are also linked to adverse effects on physical health, including an increased risk of heart disease, high blood pressure, and weakness (Valtorta et al., 2018; Gale et al., 2018; Kobayashi and Steptoe, 2018). Furthermore, evidence indicates an elevated risk of mortality among socially isolated individuals (Steptoe et al., 2013; Rafnsson et al., 2020). These findings underscore the substantial health burden associated with loneliness and social isolation (Bu et al., 2020; Hodgson et al., 2020). However, there is a paucity of empirical evidence that synthesises the causes, effects and intervention strategies, especially for older adults. As a contribution to the literature

This review, therefore, seeks to explore the causes, effects and intervention strategies of these phenomena as evidenced in the literature. Although these concepts are sometimes used interchangeably in the empirical literature (see Hakulinen et al., 2018), several studies have sought to distinguish between them. For instance, Malcolm et al. (2019, p. 2) define loneliness as “a perceived deficit between actual and desired quality or quantity of relationships,” while describing social isolation as “the objectively quantified shortfall in an individual’s social relationships, often measured in terms of social network size, diversity, or frequency of contacts.” Similarly, Steptoe et al. (2013, p. 1) describe social isolation as “an objective and quantifiable reflection of reduced social network size and paucity of social contact,” and loneliness as “the psychological embodiment of social isolation, reflecting the individual’s experienced dissatisfaction with the frequency and closeness of their social contacts, or the discrepancy between the relationships they have and the relationships they would like to have.” Courtin et al. (2017, p. 2) also define social isolation as “the lack of integration of individuals in their social environment,” and describe loneliness as “the subjective state of negative feelings associated with perceived social isolation, a lower level of contact than that desired, or the absence of a specific desired companion.” Taken together, these definitions reveal overlapping features between social isolation and loneliness, suggesting that the two terms can, to a large extent, be used interchangeably in the context of this study.

Other studies, however, have sought to define social isolation independently and with greater nuance. Cotterell et al. (2018, p. 3) describe it as “an objective measure reflecting an individual’s lack of contacts or ties with others, such as family, friends, acquaintances, and neighbours.” Findlay et al. (2003, p. 2) similarly define social isolation as “an objective measure of social

interaction, and social loneliness or emotional isolation, the subjective expression of dissatisfaction with a low number of social contacts.” Barry (2002, p. 4) characterises social isolation as the “phenomenon of non-participation (of an individual or group) in a society’s mainstream institutions,” while Luskin et al. (2013, p. 1) frame it as “a loss of place within one’s group(s).”

Loneliness has also been defined in various ways. Killeen (1998, p. 2) describes it as a “pervasive, depressing, debilitating condition that can affect all of one’s life.” Wright-St Clair et al. (2017, p. 1) take a broader view, defining loneliness as a “deficiency in the number or quality of personal, social, or community relationships, resulting in feelings of distress, dissatisfaction, or detachment.” Similarly, Bandari et al. (2019, p. 1) characterise loneliness as an “internal, unpleasant subjective experience that begins when an individual’s social network undergoes a qualitative or quantitative loss.”

These definitions suggest that, while the two terms are related and sometimes used interchangeably, they remain distinct in certain contexts and can be applied differently. In this review, therefore, instances where the terms are used independently will be treated as such, and where they are used interchangeably, they will be considered together. From the various definitions, loneliness can be understood as an unplanned, cognitive state that results from the quality and quantity of social contact. It is difficult to overcome and often has long-term effects. Social isolation, by contrast, may be deliberate or unplanned, is not cognitive in nature, and can lead to loneliness, though the reverse is not true. Unlike loneliness, social isolation can be measured quantitatively, though not qualitatively. Despite these differences, both are significant social issues that shape the life course of older adults. In both cases, the effects are severe, leading to negative

behaviours and associated consequences, particularly in relation to mental health, social relationships, and overall wellbeing.

In terms of contribution, this study advances the literature and highlights key insights that can inform policy direction. To achieve this, this review provides a comprehensive synthesis of evidence on the causes, effects, and interventions related to social isolation and loneliness among older adults in the UK. By systematically reviewing studies published between 2013 and 2022, this review highlights key contributing factors such as life transitions, health challenges, and socioeconomic conditions, alongside significant mental and physical health outcomes. Importantly, the review identifies effective intervention strategies, including community support and social prescribing, demonstrating that targeted approaches can reduce the burden of loneliness and social isolation.

Methods

The study analysed already published secondary information. It is a deductive study that seeks to understand, using published empirical data, how social isolation and loneliness affect older adults, with a focus on the UK. In this study, older adults are defined as those who are 40 years and above (Refer to Table 1).

This study obtained 321 articles from EBSCOhost, 424 from Google Scholar (GS)/PubMed (PM) and only 21 from the other sources (e.g., PsycINFO, CINAHL, etc.). This yielded a total of 766 academic articles obtained from the various search sources already identified. The outcome and search strategy are summarised in Figure 1.

Keywords

The search strategy combined keywords across four main concept blocks: Social isolation/loneliness, older adults, UK context and health-related outcomes or related factors. Details of the search have been presented in Table 3 in the Appendix.

Inclusion and Exclusion criteria

The inclusion criteria were: 1) studies reporting on social isolation or loneliness among older adults in England or the UK; and 2) studies that reported impacts, effects, or policy recommendations. Only English-language publications were included.

The exclusion criteria were: 1) studies that did not report all relevant data; 2) duplicate studies; and 3) conference papers, theses, and working papers without a corresponding peer-reviewed published version.

Selection Process

From the initial 766 records, 301 duplicate articles were identified and removed,

leaving 465 articles for screening. After screening the titles, 109 articles were excluded. A further 200 were excluded after reviewing the abstracts, leaving 156 articles for full-text assessment.

After evaluating the full text, 136 articles were excluded for the following reasons: 52 were unrelated to the subject, 50 were not focused on the UK, 20 were outdated (published over ten years ago), and 14 were non-English publications. Applying these criteria yielded a total of 20 articles that focus on the impact or effects of social isolation and loneliness among older adults in the UK, spanning the period 2011 to 2021.

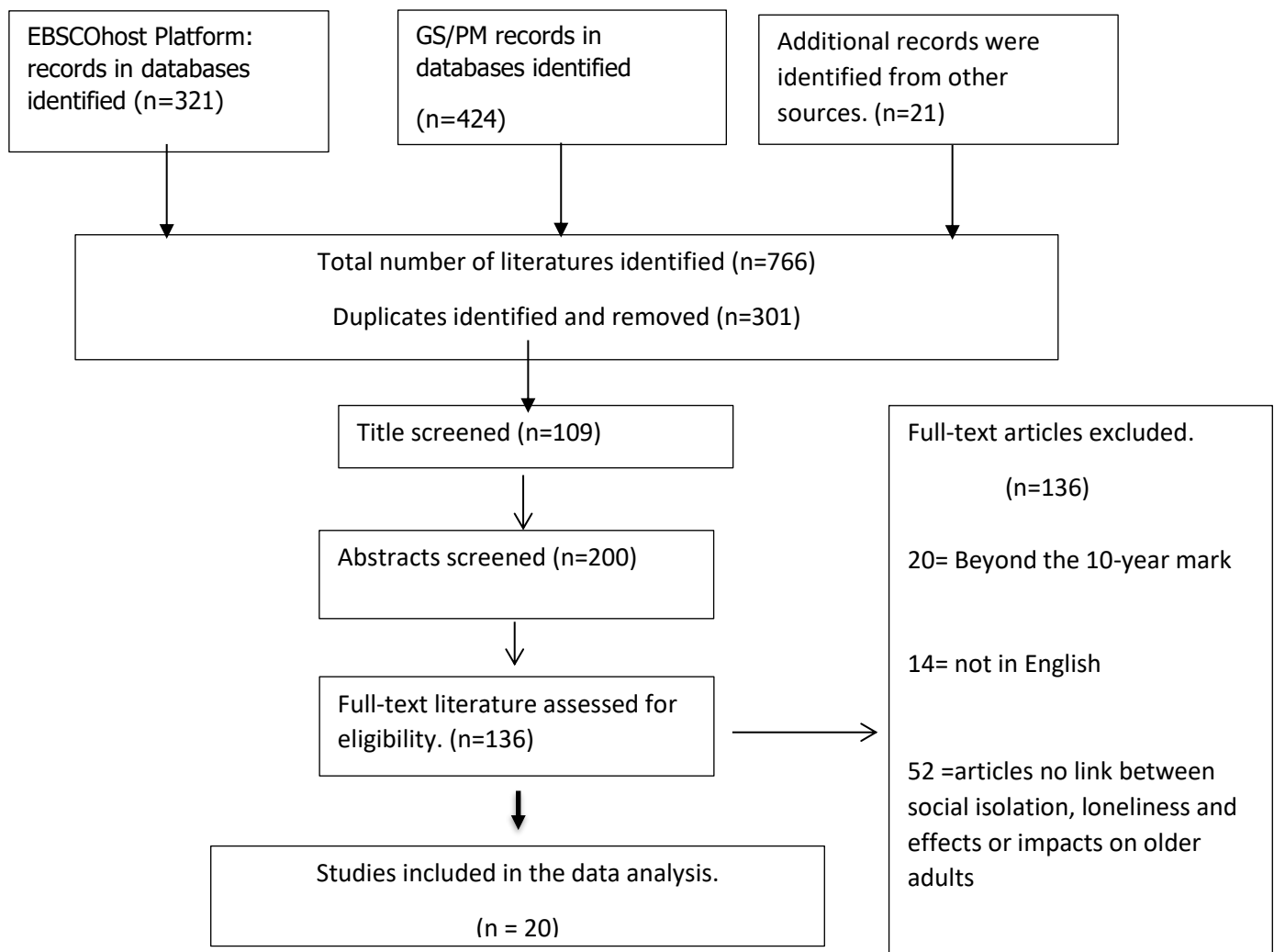


Figure 1: PRISMA diagram showing the sifting process.

Results

The inclusion and exclusion criteria provided the basis for the identification of

twenty-one peer-reviewed papers (Refer to Table 1).

Table 1: Review of Literature

Author (Year)	Methodology	Sample	Age	Findings & Conclusion
Hodgson et al. (2020)	Systematic Review	122 Articles	>=65	There is an association between loneliness, social isolation, and mortality.
Steptoe et al. (2013)	Longitudinal panel study	6500 participants	>=52	Both social isolation and loneliness were associated with increased mortality
Hakulinen et al. (2018)	Survey with a questionnaire	502 632 participants	40 and 69	Social isolation, but not loneliness, was associated with increased mortality
Davies et al. (2021)	Longitudinal study	9171 participants	>=50	Social isolation and loneliness lead to the risk of developing frailty
Gale et al. (2018)	Longitudinal study	2,817 participants	>=60	High social isolation increases the risk of becoming physically frail in men
Shankar et al. (2011)	Longitudinal study	8,688 participants	>=50	Social isolation and loneliness have effects of inactive, smoking, multiple health-risks behaviours and cardiovascular diseases. Social isolation has effects on blood pressure, C-reactive and fibrinogen.
Philip et al. (2020)	Longitudinal study	8,780 Participants	>=50	Loneliness, isolation and social disengagement have effects on lower physical performance (worse sit-to-stand ability, balance and slower walking speed)
Kobayashi et al. (2018)	Longitudinal study	3,392 participants	>=50	Both Social isolation and loneliness are associated health-related behaviours such as mortality.
Valtorta et al. (2018)	Longitudinal study	11,391 participants	>=50	Loneliness, but not social isolation is associated risks of cardiovascular diseases.
Smith et al. (2019)	Longitudinal study	9,299 participants	>=50	Both loneliness and social isolation are associated musculoskeletal pain.
Rafnsson et al. (2020)	Longitudinal study	6,677 participants	>=50	Both loneliness and social isolation are associated with developing dementia.
McHugh et al. (2016)	Longitudinal study	4,714 participants	>=50	Both loneliness and social isolation are associated depression and cognitive function. Social isolation alone is not.
Smith et al. (2017)	Longitudinal study	11,391 participants	>=50	Both loneliness and social isolation have negative physical and psychological on older adults who undergo THA and TKA
Cacioppo et al. (2014)	Longitudinal health survey	8,630 participants	>=50	Loneliness and social isolation are associated with poorer cognitive function.
Saadi et al, (2021)	Longitudinal study	4,672 participants	>=50	Loneliness is associated depression in dementia partner caregiving.
Evans et al, (2019)	Longitudinal study	1,449 participants	>=65	Social isolation is associated with poor cognitive function.
Khondoker et al, (2017)	Longitudinal study	10,055 participants	>=50	Negative social support (loneliness and social isolation) is associated with increased risks of dementia.
Bu et al, (2020)	Longitudinal study	4,478 participants	>=50	Both loneliness and social isolation are associated with respiratory diseases leading to mortality.
Smith et al, (2018)	Longitudinal study	7731 participants	>=50	Higher social isolation is a risk factor to mortality.
Bu et al. (2021)	Longitudinal study	8,218 participants	>=64	Loneliness has a strong association with cardiovascular diseases, whiles social isolation has little evidence of the same relationship.

From Table 1, we outline the emerging themes on the effects of social isolation and loneliness. The study defined recent studies as those within the 10-year mark. That is, all studies that fell beyond the 10-

year mark were treated as outdated and not included in the studies; emphasis is placed on the most recent studies. Through the review process, it was observed that social isolation and loneliness studies are

predominantly studied in developed countries. In most of the studies reviewed, it is evident that studies on the UK and the USA dominate in the most recent studies. Table 1 presents only studies on the UK or with the UK as the study area because this study aims to investigate the effect of social isolation and/or loneliness in the UK. That is, non-UK-related studies on social isolation or loneliness are also excluded. It is also important to acknowledge that there is no developing country study in the studies reviewed.

Again, most of the studies sought to define older adults based on the age brackets used. From Table 1, it can be shown that the minimum age used in the studies to describe older adults is 40 years, while the maximum age is 60 years. It can be inferred that the majority of the twenty studies reviewed in this study used 50 years or older as the average age for older adults.

On average, the majority of the studies in the UK, as reviewed, made use of the longitudinal dataset from the English Longitudinal Study of Ageing, with a few relying on self-administered surveys and systematic reviews. They predominantly focused on examining the relationship between either social isolation and/or loneliness and its effect. The outcomes, which are outlined as the themes, include mortality, frailty, blood pressure, cardiovascular diseases, dementia, and mental health. These themes, with their respective authors, are summarised in Table 2 below.

Analysis of Themes and Sub-themes

Table 2 shows evidence of the themes identified in the studies reviewed to be the effects of social isolation and/or loneliness in the UK. The themes are individually presented and discussed below.

Table 2: Themes and papers from the interpretive analysis

Themes and sub-Themes	Papers
Mortality	Hodgson et al. (2020); Steptoe et al. (2013); Smith et al. (2018); Kobayashi et al. (2018); Hakulinen et al. (2018)
Mental Health/ Dementia	Cacioppo et al. (2014); Smith et al. (2017); Rafnsson et al. (2020); McHugh et al. (2016); Saadi et al. (2021); Khondoker et al. (2017); Evans et al. (2019)
Frailty	Davies et al. (2021); Gale et al. (2018); Shankar et al. (2017) Smith et al. (2017).
High Blood Pressure	Shankar et al. (2011)
Heart Problems	Valtorta et al. (2018); Bu et al. (2020), Bu et al. (2021)

Causes of Loneliness and Social Isolation

Loneliness and social isolation in the UK are commonly driven by changes in social relationships and life circumstances. Bereavement, living alone, and reduced family contact are consistently identified as major contributors, especially among older adults. For example, Shankar et al. (2011) and Steptoe et al. (2013) highlight how weakened social networks and infrequent social contact significantly increase the risk of loneliness. Similarly, Bu et al. (2020, 2021) show that people who live alone or lack regular interaction with friends and

family are more vulnerable to persistent loneliness over time.

Health-related factors are another important cause. Chronic illness, disability, and declining physical functioning can limit individuals' ability to participate in social activities. Gale et al. (2018) and Rafnsson et al. (2020) found that poor physical health and frailty are strongly associated with both social isolation and loneliness. In addition, mental health conditions such as depression can both result from and contribute to loneliness, creating a reinforcing cycle

(Cacioppo et al., 2014; Khondoker et al., 2017). Sensory impairments and reduced mobility further restrict opportunities for engagement, particularly in older populations.

Socioeconomic disadvantage also plays a key role in the UK context. Lower income, limited education, and living in deprived areas are linked to higher levels of loneliness. Studies such as Davies et al. (2021) and Evans et al. (2019) suggest that financial constraints can reduce access to transport, community activities, and social spaces. Digital exclusion is another emerging factor, with Philip et al. (2020) noting that those without access to or skills in using digital technologies may become increasingly isolated as services and communication shift online.

Changes in society and demographics have made loneliness even worse. More people moving around, smaller families, and weaker ties between communities make it harder to have regular social interactions. Valtorta et al. (2018) and Kobayashi et al. (2018) underscore that structural and environmental determinants, including neighbourhood attributes and social capital, affect degrees of isolation. Transitional periods, including retirement or relocation, can also disrupt established social connections (Hodgson et al., 2020; Smith et al., 2017, 2018, 2019).

Effects of Loneliness and Social Isolation Mortality

Generally, mortality simply means the condition of being subject to death or the lifeless state of a person. In the view of Cutler et al. (2006), mortality is the state of not being alive to enjoy the pleasures of life. That is, where the pleasures of life are worth nothing to a person. Just as individuals live life to prevent premature mortality, so do governments enact laws and formulate policies towards promoting good health and

longevity. This concern for mortality has led to several research studies (For example, Pentaris, 2011; Pentaris, 2012; Pentaris and Mehmet, 2019; Pentaris and Jacobs) on mortality. Historically, there is evidence that the mortality rate globally has taken a nosedive, albeit the case of developing countries still leaves much to be desired (Cutler et al., 2006).

From the evidence provided by the studies, which include Komulainen et al. (2026), Hodgson et al. (2020), Steptoe et al. (2013), Smith et al. (2018), Kobayashi et al. (2018), and Hakulinen et al. (2018), there is empirical evidence to support the claim that mortality is the final negative outcome of social isolation and loneliness. The underlying cause of the mortality, as outlined by the studies (see especially Steptoe et al., 2013), has its baseline in mental and physical health challenges. For the gender differences in the outcome variable as caused by social isolation and loneliness, most of the studies found no such evidence. That is, there is no study that reported significant gender differences in these findings. This implies that, be it male or female, mortality is a key outcome of social isolation and loneliness. The evidence so far attests to the fact that mortality is associated with social isolation and loneliness.

Mental Health/ Dementia

The concept of mental health has been described by Boorse (1976) as a complex web of obscurity. Evidence in the literature so far suggests that progress has been made in dealing with mental health issues as well as providing relief for mental health patients (Keyes and Lopez, 2009). Although developed countries have made significant strides in the provision of improved services to mental health patients. That notwithstanding, it goes without saying that mental disorders increase the risk for communicable and non-communicable diseases and contribute to unintentional and intentional injury (Prince et al., 2007). In an

attempt to identify mental health and associated risks, we examine how social isolation and loneliness drive mental health. In line with the present study, one of the reported themes is mental health challenges, poor cognitive function or dementia (see Cacioppo et al., 2014; Rafnsson et al., 2020; McHugh et al., 2016). Another consequence of mental health is the sedative medication that puts patients to bed over a long period of time. This could be described as one of the penultimate health stages participants go through, and if their conditions persist, mortality becomes evident.

Frailty

According to Clegg et al. (2013, p.1), “frailty is a state of increased vulnerability to poor resolution of homeostasis after a stressor event, which increases the risk of adverse outcomes, including falls, delirium, and disability” Frailty has been described as the most problematic condition associated with old age (Clegg et al., 2013). Older adults who fail to mingle and engage in social activities can easily be susceptible to frailty. Thus, confinement as a result of loneliness and social isolation weakens patients physically (frailty) (Example, Davies et al. (2021); Gale et al. (2018); Shankar et al., 2017). If such a frail condition persists without proper care, mortality becomes inevitable.

High Blood Pressure and Heart Problems

Again, social isolation and loneliness lead to inactivity. This can easily contribute to physiological decline and high blood pressure. The associated weight build-up,

lack of exercise, leads to high blood pressure (Shankar et al., 2011). High blood pressure, without its consequences, such as stroke and heart problems (Valtorta et al., 2018), and dementia (Rafnsson et al., 2020), among others. Given that cardiovascular disease is now the world’s top cause of death, accounting for one-third of deaths in the world (Mackay and Mensah, 2004), carers and families must become mindful of the devastating nature of high blood pressure and heart diseases as a result of loneliness and social isolation. Indeed, if this problem persists without the right care, mortality cannot be escaped.

In all, these studies have shown that, generally, social isolation and loneliness are associated with some negative effects. These include mental health challenges, physical health (frailty) challenges, high blood pressure and heart problems, mortality and comorbidities. So far, the studies show no empirical evidence on gender disparity regarding mortality. This seeks to suggest that the effect of social isolation and loneliness on mortality is not gender sensitive, as it affects both males and females alike. Thus, gender disparity is irrelevant when mortality is caused by social isolation and/or loneliness.

So far, it is evident that loneliness and social isolation have psychological, physiological, social and behavioural effects, which can result in diseases and finally death. In the next section, we show the conceptual framework of these four effects, which can lead to disease and mortality.

Conceptual Framework

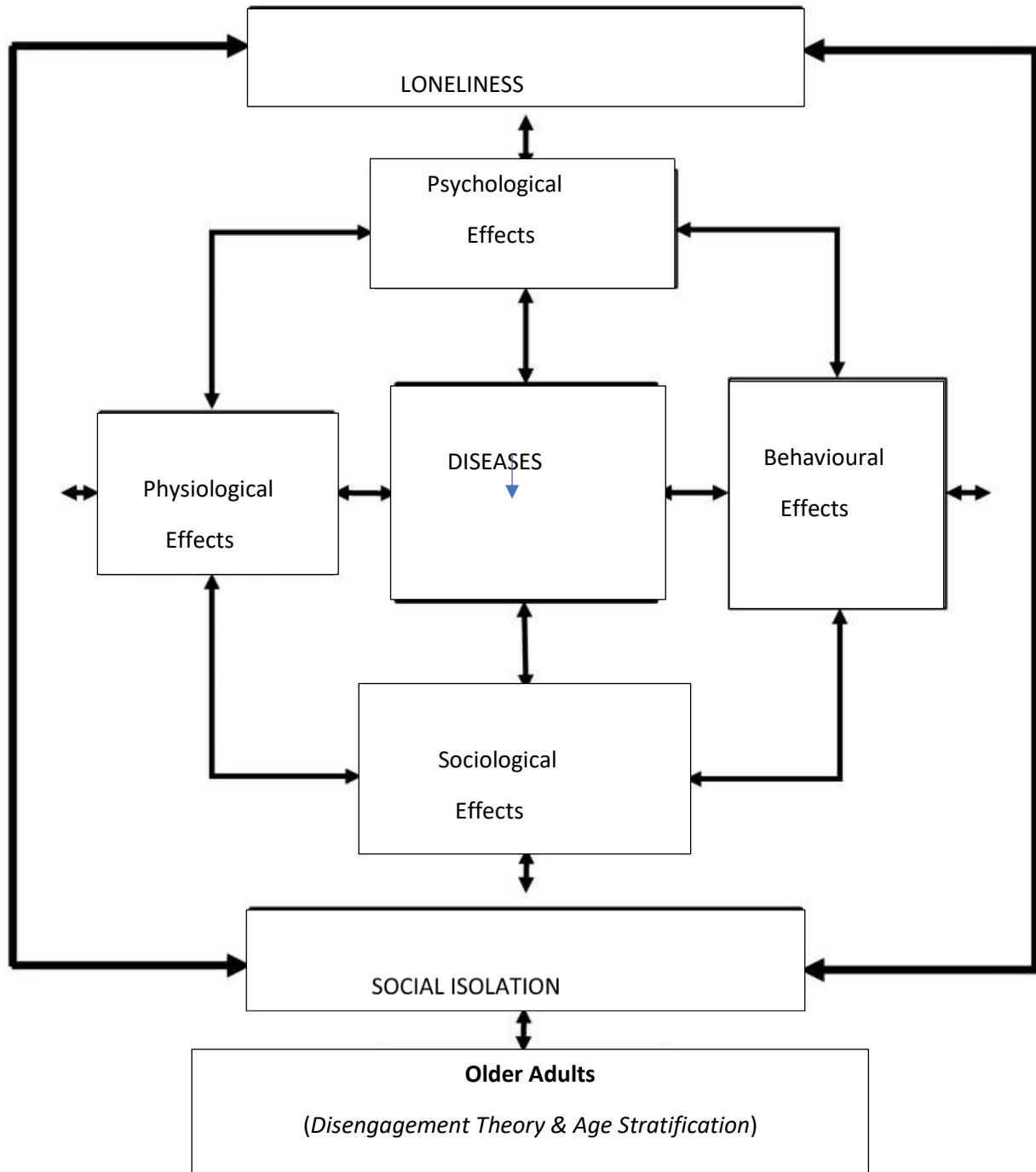


Figure 2: Conceptual Framework¹

Figure 2 presents the conceptual framework of this study. This is best understood from the starting point of older adults depicted as an outer box of the model. Not perceiving

older adults as a homogeneous group, they are likely to experience social isolation and loneliness. Evidently, older people in the UK experience reduced care-related

¹ Source: Adapted from Hodgson et al. (2020).

support, deprived community engagement needs, loss of social contact, negatively impacting their emotions, which were heightened during the COVID-19 pandemic (Ward et al., 2020). Themes such as loneliness and social isolation were further exacerbated by inequalities associated with digital exclusion or older adults living in areas with poor connectivity, or the non-existence of communication networks (Pentaris et al., 2020). Research undertaken by Age UK (2018) shares a similar view that persistent loneliness and social isolation can have a significant negative impact on well-being and quality of life.

It is important to observe that social isolation and loneliness are more pronounced among older adults in the UK and most developed countries. Following the theory (disengagement and age stratification), this interdependence is represented with bi-directional arrows. The broader impact of loneliness and social isolation can also be attributed to further pathways captured inside the model and grouped into four simple concepts of physiological, psychological, behavioural and sociological effects. The psychological impact of loneliness and social isolation can lead to cognitive decline, depression and suicidal ideation. Similarly, the behavioural impact of loneliness and social isolation can lead to alcoholism, smoking, etc. Also, the physiological impact of loneliness and social isolation can lead to excessive sleeping and inflammation. Lastly, the individual sociological impact of loneliness and social isolation can lead to poor health management by health professionals, limited access to frequent health services, among others. Indeed, the rising sedentary lifestyle coupled with poor health care can easily trigger cardiovascular disease, with mortality as the outcome.

Generally, no single individual's impact may follow the same pathway but rather varies according to the importance and the value of connectivity. The power a

community attaches to the individual is vital in reducing the negative impact of social isolation and loneliness. For example, as people age, they, on average, experience reduced connectivity due to loss, disengagement, or how society is stratified. The individual then moves on to the outer pathway of the conceptual framework to experience social isolation and loneliness. These conditions will be further impacted by the effects of the four inner constructs, namely physiological, psychological, behavioural and sociological. The severity and variation of the negative impact of these four constructs on the individual will depend on the value and importance society attaches to them. For example, if the individual is negatively impacted by a psychological effect like cognitive decline, this may result in other diseases, such as dementia, especially where connectivity is toxic, and care and value to the individual is non-existent. These correlates of an increased rate of cognitive decline may promote conditions with known increased mortality risk, as mentioned earlier. In fact, 1 in 14 people over the age of 65 (7 percent) and 1 in 6 people over the age of 80 have dementia (17 percent) (Alzheimer's Research UK, 2019; Alzheimer's Society, 2019b). Reduced cognition, neglect, lack of care or increased hibernation may also fuel social and behavioural risk factors, for example, excessive alcohol consumption and negatively impact daily social living, leading to mortality.

In short, the psychological, physiological, social and behavioural effects of social isolation and loneliness, if no intervention is administered to check the eventual outcome, may lead to mortality.

Discussion

This discussion draws together the key findings of the review, situating them within the broader context of ageing, health inequalities, and social care provision in the UK. Over the past decade, loneliness has increasingly been recognised as a major

public health and social concern, linked to adverse outcomes including dementia, cardiovascular disease, and premature mortality. Its growing prominence has been driven by national initiatives such as Age UK, the Campaign to End Loneliness, and the Jo Cox Commission, culminating in the appointment of a UK Minister for Loneliness in 2018. These developments reflect a shift towards recognising loneliness and social isolation as complex societal challenges requiring coordinated policy and practice responses.

The findings of this review highlight that loneliness and social isolation among older adults are driven by a combination of interrelated individual, social, and structural factors. Key among these are life transitions such as bereavement, retirement, and changes in marital status, which often lead to a reduction in social networks and support systems. Declining physical health, reduced mobility, and chronic illness further restrict opportunities for social engagement, while socioeconomic disadvantage and environmental barriers can exacerbate disconnection. These factors are often compounded by demographic changes, including an ageing population, which increases the number of individuals at risk. Comparative evidence, such as that from the Republic of Ireland (Donnelly et al., 2018), also underscores how reliance on informal, family-based care can leave gaps in support when such networks are limited or absent.

The review demonstrates that the effects of loneliness and social isolation are wide-ranging and extend beyond emotional wellbeing to significant physical and mental health outcomes. Physiologically, social isolation has been associated with elevated blood pressure and inflammatory responses, increasing the risk of cardiovascular disease (Shankar et al., 2011; Hawkley et al., 2010). Prolonged isolation is also linked to frailty and functional decline, with evidence suggesting that it contributes both to the onset and progression of frailty, while

loneliness influences adverse health behaviours (Davies et al., 2021; Gale et al., 2018).

In addition, strong associations were identified between loneliness, mental health disorders, and cognitive decline. Studies consistently show increased risks of depression, dementia, and impaired daily functioning among socially isolated older adults (Cacioppo et al., 2013; Rafnsson et al., 2020). These outcomes are often accompanied by behavioural risk factors such as smoking and poor management of chronic conditions, further compounding health inequalities. Ultimately, both loneliness and social isolation are significant predictors of mortality, operating through behavioural and biological pathways (Steptoe et al., 2013; Kobayashi et al., 2018; Hakulinen et al., 2018). Together, these findings reinforce the notion that social disconnection is a critical determinant of health in later life.

Addressing these challenges requires comprehensive and multi-level intervention strategies. Primary prevention approaches delivered through primary care and community-based services are essential for early identification and support. General practitioners, community pharmacies, and allied health professionals are well-positioned to identify at-risk individuals and facilitate timely interventions. Social prescribing schemes, in particular, have emerged as a promising approach, enabling healthcare providers to connect older adults with community resources such as social groups, physical activities, and voluntary services (Bu et al., 2020). Tailored support for individuals with chronic conditions is especially important, as this group is at heightened risk of isolation and its associated health consequences.

Broader community and policy-level initiatives also play a vital role. Campaigns and programmes such as the Campaign to End Loneliness, as well as international

initiatives like age-friendly cities promoted by the WHO and EU, highlight the importance of fostering inclusive environments that support social participation. Interventions such as befriending and mentorship schemes, including those adapted during the COVID-19 pandemic, further demonstrate the value of sustained social engagement (Amoah and Amoah, 2020; Kugbey et al., 2021). However, despite these efforts, gaps remain in identifying the most effective and scalable interventions. Critiques of current systems also point to fragmentation in care provision due to marketisation and the division between voluntary, charitable, and statutory sectors (Pentaris et al., 2020).

Moving forward, a coordinated, person-centred approach is essential. Interventions must be tailored to the diverse needs of older adults, particularly those experiencing major life transitions or living with complex health conditions. Strengthening collaboration between government, healthcare providers, and community organisations will be critical to delivering sustainable solutions. Furthermore, continued research is needed to evaluate intervention effectiveness, particularly in relation to frailty and long-term health outcomes, and to establish clearer causal pathways. In the context of a rapidly ageing population in the UK, such efforts will be vital to reducing the burden of loneliness and social isolation and improving the overall health and wellbeing of older adults.

In summary, as highlighted by Philip et al. (2020), research evidence is essential for informing social prescribing, clinical practice, and policy development in the UK. There remains a clear need for further research to evaluate the effectiveness of social interventions, particularly in relation to frailty, and to establish any causal relationships.

Conclusion

This review has provided a comprehensive synthesis of the current evidence on the

causes, effects, and intervention strategies associated with social isolation and loneliness among older adults in the UK. The findings demonstrate that loneliness and social isolation are multifaceted phenomena, shaped by an interplay of life transitions such as bereavement and retirement, declining physical and mental health, socioeconomic disadvantage, and environmental as well as demographic changes. These interconnected factors highlight the complexity of the issue and the need for holistic and sustained responses.

The review further establishes that the consequences of loneliness and social isolation extend beyond social and emotional domains, significantly affecting physical and mental health outcomes. Evidence consistently links these conditions to increased risks of depression, cognitive decline, frailty, hypertension, cardiovascular disease, and ultimately, mortality. Such outcomes not only diminish the quality of life for older adults but also place a growing burden on health and social care systems, particularly in the context of an ageing UK population.

Importantly, the study identifies a range of intervention strategies that show promise in mitigating these adverse effects. Primary health prevention approaches, community-based support systems, and the expansion of social prescribing schemes offer practical pathways for early identification and engagement of at-risk individuals. In addition, person-centred and group-based interventions tailored to the specific needs of older adults can enhance social connectedness and improve overall wellbeing. However, despite these advances, the review highlights persistent gaps in the evidence base, particularly regarding the long-term effectiveness and scalability of such interventions.

The findings underscore the necessity for coordinated cross-sectoral collaboration involving healthcare providers,

policymakers, community organisations, and voluntary services. Strengthening integration across these sectors will be critical in delivering sustainable and inclusive solutions. Furthermore, there is a pressing need for continued research to evaluate intervention outcomes, establish causal pathways, and identify best practices that can be adapted across diverse contexts within the UK.

Overall, this study reinforces the importance of prioritising loneliness and social isolation as key public health concerns. By implementing evidence-based, targeted, and person-centred interventions, there is significant potential to reduce their impact, enhance quality of life, and support healthier ageing among older adults in the UK.

Searched Keywords

Keywords	Lists
Social Isolation / Loneliness Terms	“social isolation”, loneliness, “social exclusion”, “social disconnectedness”, “social disconnection”, “social relationships”, “social participation”, “social engagement”, “social support”, “living alone”, “perceived isolation”, “emotional isolation”, “objective isolation”, “social networks”, “community connectedness”
Older Adult Terms	“older adults”, elderly, ageing, aging, “older people”, seniors “older persons”, “older population”, retirees, geriatric, “later life” “aged 60 and over”, “aged 65 and over”
UK Context Terms	“United Kingdom”, UK, Britain, British, England, Scotland, Wales “Northern Ireland”
Outcome / Contextual Terms	Health Outcomes Depression, anxiety, wellbeing, “mental health”, dementia “quality of life”, mortality, and frailty. Causes / Risk Factors Bereavement, widowhood, retirement, disability, “digital exclusion”, mobility, poverty, “housing conditions” Interventions Intervention, program, initiative, “social prescribing”, “community intervention”, “befriending services”, “support groups”

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Project Management Methods for Digital Transformation in Ghana's Education Sector

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Abstract

Ghana's education sector. This national priority aligns with Sustainable Development Goal 4. Many digital education projects fail to deliver intended outcomes. Poor planning organizational resistance and limited institutional capacity contribute to these failures. This desktop analytical study reviews national and institutional policy documents. It also reviews international development reports. A SWOT analysis evaluates project management approaches for digital initiatives in Ghanaian education. The SWOT analysis identifies hybrid methods as optimal. These methods integrate Waterfall structure with Agile adaptability. Strengths include flexibility, governance, alignment and stakeholder engagement. Weaknesses encompass skill gaps and coordination challenges. Opportunities arise from donor partnerships and policy harmonization. Threats involve institutional resistance and funding rigidity. The study proposes a context specific hybrid framework. This framework spans five phases. These phases include strategic planning stakeholder co creation iterative delivery institutional integration and dual loop evaluation. The approach aligns with Ghana's institutional realities. It enables responsive scalable and sustainable digital transformation. Targeted capacity building is recommended to pilot and refine the model for wider adoption.

Keyword: Digital, Transformation, Education, Project and Methods.

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Introduction

Digital Transformation (DT) is increasingly recognized as a cornerstone of educational reform and a catalyst for national development, particularly in emerging economies such as Ghana. The integration of digital technologies into teaching, learning, and administrative processes is central to the country's broader strategy for achieving Sustainable Development Goal (SDG) 4, which focuses on inclusive and equitable quality education and lifelong learning opportunities for all (Adipat & Chotikapanich, 2022). In recent years, Ghana has witnessed a growing number of digital initiatives in the education sector, ranging from school infrastructure upgrades and teacher training programs to e-learning platforms and digital libraries (Ministry of Education, 2018).

Despite these efforts, many projects have not yielded their intended outcomes. The shortcomings are often linked to systemic issues such as insufficient planning, under-resourced implementation, ineffective stakeholder engagement and coordination, and the absence of clear accountability structures (World Bank, 2020; Adarkwah, 2020). These challenges underscore the importance of adopting more strategic approaches to manage DT initiatives within the education system in Ghana.

One of the most promising strategies for addressing these challenges is the application of PMMs. Project management (PM) offers a disciplined framework for defining objectives, allocating resources, managing risks, monitoring progress, and ensuring that intended benefits are realized (Kerzner, 2017). This paper focuses on three main PM approaches: Waterfall, Agile, and Hybrid. It examines their potential in improving the design and delivery of digital project initiatives in education in Ghana. Agile methodologies, such as Scrum and Kanban are of particular interest due to their emphasis on adaptability, stakeholder collaboration, iterative planning, and continuous

improvement (Beck et al., 2001). These features make Agile a compelling option for educational environments, which often face changing requirements and high stakeholder expectations.

However, the practical implementation of Agile in Ghana's education sector faces several constraints. This paper adopts a literature-based approach, drawing on existing empirical and theoretical studies to assess the applicability of Agile Project Management (PM) within Ghana's educational context. A SWOT analytical framework is applied to the reviewed literature to evaluate the alignment of Hybrid PMMs with the sector's characteristics and constraints. The findings therefore represent a synthesis of documented evidence, highlighting strengths such as adaptability, iterative processes and stakeholder engagement. The synthesis is made alongside reported challenges including limited institutional familiarity with Agile practices, bureaucratic procurement systems, resistance to change and infrastructural deficits

While opportunities are evident in the form of increasing investments in digital infrastructure and the emergence of innovation-driven education, persistent threats such as bureaucratic inefficiencies and inconsistent policy support pose significant challenges to successful implementation (World Bank, 2020).

Further, the paper draws on documented case studies from existing literature, to highlight key enablers and constraints to digital transformation in Ghana. The challenges identified were policy inconsistencies, funding gaps, and capacity constraints (Ministry of Education, 2018). These findings highlight the essential role of PM in ensuring that digital education initiatives are effectively aligned with institutional priorities, optimized for efficient resource use, designed to anticipate and mitigate risks, and structured to

promote meaningful collaboration among all stakeholders involved.

To address these challenges, this paper proposes a context-specific hybrid Project Management (PM) framework for Ghana's educational system. The framework is conceptually developed from insights drawn from the reviewed literature and is not based on primary empirical analysis. It emphasizes iterative planning, stakeholder involvement, capacity building, and pilot implementation. The expected benefits are, improved strategic alignment, change management and sustainability of digital interventions.

Digital transformation (DT) in education reduces paper waste through digitized documents and e-learning platforms while minimizing physical travel via virtual classes thus lowering carbon footprints. Despite Ghana's national push for DT aligned with SDG 4 many projects underperform due to planning gaps resistance and capacity limits. Existing studies overlook context-specific project management solutions for Ghana's bureaucratic education systems. This paper fills that gap by evaluating hybrid PM methods via SWOT analysis.

This study contributes to the evolving discourse on DT in education by offering practical, evidence-based recommendations for policymakers, educators, and technology professionals. Ultimately, aligning PMMs with digital educational goals, provides a structured yet flexible pathway for bridging the digital divide and fostering a more inclusive, innovative, resilient and sustainable educational ecosystem in Ghana.

Review of Related Literature

Globally, governments and institutions are investing in digital platforms, learning management systems (LMS), and e-governance tools to enhance both access and effectiveness in education delivery (UNESCO, 2022; World Bank, 2024).

PMMs play a central role in these transformations, providing structured approaches to plan, execute, and evaluate digital education initiatives. While traditional methodologies such as Waterfall emphasize compliance, control, and linear sequencing, Agile frameworks prioritize flexibility, rapid iteration, and stakeholder responsiveness (PMI, 2021). However, the singular use of either model has revealed limitations, particularly in public education systems where structure and adaptability are both required.

Several studies have examined the suitability of Agile methodologies for digital education reform. Agile is lauded for promoting collaboration, iterative design, and real-time feedback - valuable features in user-centred digital learning environments (Beck et al., 2001). Nonetheless, the practical adoption of Agile in the education sector of developing countries has encountered resistance due to bureaucratic hierarchies, procurement rigidity, and limited Agile literacy (Nuottila et al., 2016). On the other hand, Waterfall approaches, common in donor-funded or government-led infrastructure projects offer predictability and alignment with public sector governance structures but are often criticized for being inflexible and unresponsive to user feedback during implementation (PMI, 2021).

In Ghana, the strategic importance of digital education has been emphasized in the Education Strategic Plan (ESP) 2018–2030 and the ICT in Education Policy (ICTEP) (Ministry of Education, 2015). Flagship projects such as eTransform Ghana and GALOP have significantly enhanced ICT infrastructure and teacher digital literacy across basic and tertiary institutions (World Bank, 2020, 2024). Institutional strategies from public universities including the University of Ghana (UG) and Kwame Nkrumah University of Science and Technology (KNUST) further underscore this national commitment (Omollo, 2011).

Yet, empirical evidence suggests that these efforts remain fragmented, under-evaluated, and often hampered by weak PM capacity and low stakeholder participation (UNESCO, 2022).

Digital Maturity Models (DMMs) help assess how advanced institutions are in terms of infrastructure, skills, governance, and innovation. In Ghana's education sector, most institutions remain at low to mid-level maturity, characterized by capacity gaps, rigid structures, and uneven digital integration. This limits the effective adoption of fully Agile PMMs, which require high adaptability and digital readiness. Consequently, Hybrid PMMs are more suitable, as they balance existing bureaucratic structures with gradual, adaptive innovation. While the global literature increasingly advocates for hybrid approaches that integrate Agile's adaptability with Waterfall's structure, there is a scarcity of studies that contextualize hybrid PMMs within the governance and operational realities of African education systems. Few studies have systematically analysed how hybrid frameworks can align with both the compliance needs of government education projects, and the innovation demands of DT. Furthermore, the discourse tends to overlook the triangulation of national policy documents, institutional practices, and international development frameworks as a way of validating best-fit models for specific countries.

This paper addresses these gaps by conducting a triangulated thematic and comparative analysis across policy-level documents (e.g., ESP, ICTEP), institutional strategies (UG, KNUST, UEW, UCC, UDS), and development agency reports (World Bank, UNESCO, GIZ). In doing so, it offers an evidence-based, context-specific hybrid PMM tailored to Ghana's education sector. The proposed hybrid model advocates for mixed approaches in complex public sector projects, while grounded in the

practical realities of digital education in Ghana. By integrating iterative Agile cycles within Waterfall-oriented institutional structures, the proposed framework balances compliance and adaptability, which are key to achieving sustainable and inclusive digital transformation in education in Ghana.

Theoretical framework

The theory underpinning this paper is the Adaptive Governance Theory. Adaptive Governance Theory (Folke et al., 2005; Chaffin et al, 2014) provides a conceptual foundation for understanding how institutions manage complex and dynamic systems in contexts of uncertainty and rapid change. Originally developed in environmental governance, the theory highlights the importance of flexibility, learning, stakeholder participation and polycentric decision-making in achieving sustainable outcomes. Adaptive governance emphasizes that rigid, top-down structures are often insufficient in dynamic environments. Instead, successful governance requires iterative adjustment, experimentation and responsiveness to stakeholder needs and feedback.

This theory is highly relevant for analyzing the adoption of project management methods (PMMs) in digital transformation (DT) within Ghana's education sector. The sector is characterized by both institutional rigidity manifested in procurement systems, bureaucratic hierarchies and donor accountability frameworks, and rapidly changing technological demands that require adaptive responses. Purely traditional approaches like Waterfall align with the compliance needs of government and donor-funded projects but lack the responsiveness necessary for digital innovation. Conversely, Agile methods foster flexibility and collaboration but often clash with entrenched institutional structures. Adaptive Governance Theory helps explain why a hybrid PMM is contextually appropriate for Ghana. Hybrid approaches operationalize adaptive

governance by integrating the formal, compliance-driven structures of Waterfall with the iterative, learning-oriented practices of Agile. This dual approach allows institutions to maintain legitimacy and accountability while simultaneously adapting to evolving user needs and technological opportunities (Joslin & Müller, 2016).

Moreover, adaptive governance reveals the critical role of stakeholder engagement, experimentation and feedback loops in institutional transformation. In Ghana, involving teachers, students, ICT professionals and administrators in iterative co-creation processes enhances ownership and contextual relevance of digital education projects (Adarkwah, 2020). By embedding adaptive governance principles into project management, the education sector can better navigate uncertainty, overcome resistance to change, and sustain digital innovations beyond donor-driven phases. Thus, Adaptive Governance Theory provides a robust framework for understanding how Ghana's education sector can reconcile structural rigidity with the need for innovation. It positions hybrid PMMs not merely as a technical choice but as a governance innovation that enables flexibility, collaboration and long-term sustainability in digital transformation initiatives.

Methodology

This study adopts a desktop analytical approach, utilizing existing literature, policy documents, institutional reports, and publicly available case studies to examine how PMMs are applied to DT initiatives in the education sector in Ghana. This methodology is appropriate given the availability of diverse secondary sources and the study's exploratory and comparative nature. A systematic review was conducted across academic databases such as Google Scholar, JSTOR, ERIC, and Scopus using keywords including "project management in education", "Agile project management

Africa," and "digital transformation Ghana." The review focused on publications from 2010 to 2024 to ensure relevance and contemporary applicability. In addition, policy documents such as the ESP 2018–2030, the ICTEP 2015 and ICT policies from five (5) public universities were examined. Reports from international agencies (e.g., World Bank, GIZ, UNESCO) on ICT for Education (ICT4E) projects were also included in the analysis. These documents were assessed thematically to identify project goals, implementation strategies, challenges faced, and outcomes.

The study also employed a comparative framework analysis, evaluating the features, benefits, and drawbacks of major PMMs (Agile, Waterfall, and Hybrid) and assessing their contextual suitability based on Ghana's educational landscape. A SWOT analysis was conducted to systematically evaluate the strengths, weaknesses, opportunities, and threats associated with adopting hybrid PMMs in Ghana's education sector. The findings were triangulated across multiple sources to ensure credibility and to identify both consensus and divergence in the data. Through this desktop analytical approach, the paper offers a nuanced and evidence-based examination of how different PMMs align with institutional capacity, digital infrastructure, and policy frameworks for educational transformation in Ghana.

Thematic Assessment of ICT Policy Implementation in Education in Ghana

Analysis of Ghana's key educational policy documents, namely the ESP and the ICTEP, together with institutional ICT policies drawn from selected public universities, revealed policy frameworks shaped by national objectives and international development priorities. These documents reflect a growing convergence between institutional ambitions, national and international agendas, underscoring the importance of DT as a critical enabler of

education reform. Insights from international agencies, such as the World Bank, GIZ, and UNESCO, in addition to Ghana-specific ICT project initiatives such as the eTransform Ghana and the Ghana Accountability for Learning Outcomes Project (GALOP), further enrich the context for evaluation of goals, implementation progress, gaps, and outcomes of ICT interventions in Education throughout the country.

These documents consistently articulate goals aimed at leveraging ICT to improve the quality, equity, and relevance of education. At the national level, the ESP and the ICTEP identify digital technologies as essential instruments for fostering inclusive learning, enhancing teacher effectiveness, and increasing administrative efficiency (Ministry of Education, 2018; MoE, 2015). These priorities were highlighted in international assessments, where development partners such as UNESCO and the World Bank underscored the transformative role of digital education in addressing disparities, particularly in underserved and rural areas (UNESCO, 2022; World Bank, 2020). Institutional ICT strategies of selected public universities including UG, KNUST, University of Cape Coast (UCC), University of Development Studies (UDS), and University of Education, Winneba (UEW) also align with these national and international objectives. These materials underscore the need for advancement of digital learning environments, ICT-facilitated research, and enhanced access to virtual platforms in higher education.

Ghana's DT in education is being propelled largely by substantial external financial support. A flagship initiative in this regard is the World Bank-supported eTransform Ghana project, which has significantly enhanced ICT infrastructure and laid a solid foundation for the delivery of digital services across the education sector (World Bank, 2020). This project has been

instrumental in establishing platforms for e-learning and e-governance, enabling institutions to streamline administrative functions and improve access to digital education resources. Complementing this effort, GALOP has deployed digital training modules that have equipped thousands of teachers with essential ICT skills. Supported by the World Bank and other development partners, GALOP has implemented scalable digital innovations that revolutionized teacher training, enhanced student assessments, and refined education supervision in more than 10,000 basic schools across the country (World Bank, 2020). In parallel, the Ghana Digital Transformation Centre, supported by GIZ, also provided targeted technical expertise to strengthen institutional ICT capacities at both national and institutional levels (Adarkwah, 2020) thereby enhancing pedagogical effectiveness and digital literacy in the country.

At the tertiary level, the universities are implementing strategic digital initiatives to improve teaching, learning, and administrative work. These include the expansion of broadband connectivity, the deployment of Learning Management Systems (LMS), capacity building in digital pedagogy for academic staff, and the digitization of course content and student services. In response to the COVID-19 pandemic, universities such as UG and KNUST rapidly scaled up their digital infrastructure to support the widespread delivery of online and hybrid courses. Moreover, administrative functions such as student registration, academic records management, and faculty support services have been digitized, making them integral components of modern university operations. Ghana's institutional strategies, flagship programmes, and development-driven initiatives collectively underscore a strong commitment to DT within the education sector. These efforts reflect not only a growing recognition of ICT as a transformative tool for improving access to

quality education but also alignment between institutional and national development goals as well as international support systems. Through coordinated actions such as the eTransform Ghana project, GALOP, and the Ghana Digital Transformation Centre, stakeholders are working to embed digital technologies across all levels of education, purporting to foster an inclusive, efficient, and resilient learning environment.

Despite these efforts, the implementation of digital project initiatives continues to face persistent structural challenges. Key among these is the pronounced infrastructure disparity between urban and rural institutions, as highlighted in various institutional and international assessments reports (UNESCO, 2022; World Bank, 2020). Many schools targeted by GALOP and tertiary institutions located in remote areas lack reliable electricity, consistent internet connectivity, and modern digital infrastructural equipment. These deficiencies limit their capacity to fully participate in ongoing DT initiatives. Compounding these infrastructural challenges are financial constraints that threaten the sustainability of donor-funded projects and hinder the scaling up of institutional programmes.

Another critical barrier is the limited digital literacy among educators, which remains a major obstacle to the effective integration of ICT in teaching and learning. (UNESCO 2022) notes that the absence of structured and continuous professional development in digital skills slows adoption and diminishes the pedagogical impact of technology in the classroom. In addition, weak monitoring and evaluation systems continue to undermine policy responsiveness. Although many policy documents include provisions for evaluation, the implementation of such frameworks is inconsistent, often lacking the robust feedback mechanisms necessary for adaptive learning and evidence-based decision-making.

Furthermore, the absence of coordinated inter-institutional collaboration remains a key impediment to progress. Many educational institutions function in isolation, resulting in fragmented efforts, resource duplication, and lost opportunities for synergy, innovation sharing, and system-wide learning. While sustainability is often emphasized in strategic discourse, few programmes incorporate long-term plans for financing, infrastructure maintenance, or digital project lifecycle management.

These findings highlight the urgent need for an integrated and equity-focused approach that goes beyond merely addressing infrastructure and capacity gaps. Ghana must invest in both digital infrastructure and human resource while fostering a coherent policy environment that supports interoperability, cross-sector collaboration, and strong governance. To ensure lasting impact, digital education strategies must embed sustainability and inclusivity at their core, guided by clear action plans and accountability mechanisms. Equally important should be a commitment to evidence-based practice and meaningful stakeholder engagement. These elements will ensure that ICT integration is not only effective but also responsive to the diverse needs of educators and learners. By aligning policy, investment, and practice, Ghana can unlock the full potential of digital technologies to enhance learning outcomes and support national development.

Comparative Analysis of PMM in Ghana's Education Sector

To effectively implement any ICT project, it is essential to select a suitable PMM. This section provides comparative analysis of three (3) main PMMs: Agile, Waterfall, and Hybrid. Their attributes, benefits, and drawbacks were examined to determine their suitability for Ghana's education sector. The analysis employs international PM standards and insights derived from ICT projects at the universities and government-

led educational reform programs. Table 1 presents a summary of the results.

Table 1: Summary of Comparative Analysis of PMM in Ghana's Education Sector

Criteria	Agile	Waterfall	Hybrid
Planning	Adaptive & incremental; Minimal upfront planning	Rigid and upfront; All phases defined before execution	Mix of upfront & iterative planning
Flexibility	High - responds quickly to change	Low - difficult to accommodate changes once the project starts	Medium – High: flexible in Agile components, structured in others
Stakeholder Input	Continuous throughout sprints and reviews	Minimal after initial planning phase	Phased and flexible - input varies by component and phase
Documentation	Light - often informal or evolving	Comprehensive. Detailed at each stage	Moderate and tailored: varies by component and compliance need
Risk Management	Reactive: addressed as issues arise	Predictive: risks identified and mitigated in planning phase	Balanced: combines proactive risk planning and adaptive responses
Governance & Accountability	Decentralized and team-driven: relies on transparency through sprints and retrospectives	Centralized and hierarchical: based on milestones, contracts, and formal oversight	Mixed model: centralized for structured phases, decentralized for adaptive parts; requires strong coordination
Suitability (Ghana)	High for innovation, pilots, LMS customization: less for bureaucratic settings	High for infrastructure and procurement-heavy projects	Best fit for mixed-scope ICT4E projects involving both fixed infrastructure and iterative components
Scalability	High for modular, small-scale digital solutions	High for large, well-defined infrastructure projects	Moderate – high: scalable with strong coordination and skilled project leadership

The table above, indicates that Ghana's educational landscape, where donor funding, public procurement, and institutional hierarchy shape digital project implementation realities, no single methodology fits all project types. Agile offers benefits in small-scale, user-centric initiatives but lacks the structure needed for large public programs. Waterfall aligns with government protocols but is less adaptable to changing digital needs within the sector. The Hybrid model stands out as the most contextually appropriate, allowing institutions to align with formal structures while embracing innovation in critical areas. As ICT in education continues to expand, capacity-building for PM and

institutional adoption of tailored hybrid frameworks will be essential to achieving scalable and sustainable DT in the education sector in Ghana.

SWOT Analysis of the Adoption of Hybrid PMM in Ghana's Education Sector

As Ghana's education sector increasingly adopts digital tools for education, there is a pressing need for adaptable PM frameworks that can accommodate both bureaucratic requirements and technological innovation. The Hybrid PMM, which combine structured (Waterfall) and adaptive (Agile) approaches offer a promising model. The SWOT analysis shown in table 2 evaluates

the strengths, weaknesses, opportunities, and threats associated with adopting hybrid PMs in the Ghanaian educational context.

Table 2: SWOT Analysis of Hybrid PMM in Ghana's Education Sector

Strengths	Weaknesses
Flexible adaptation to structured and iterative phases	Requires skilled project managers and coordination
Aligns with public procurement and donor frameworks	Inconsistent adoption across departments
Supports incremental innovation and early feedback	Capacity gaps in Agile and hybrid execution
Enables phased stakeholder engagement	Scope creep risks due to evolving demands
Opportunities	Threats
Accelerates institutional digital transformation	Institutional resistance to adaptive structures
Aligns with global donor preferences (World Bank, GIZ, UNESCO)	Fragmented policy environments
Enables low-risk piloting of ICT innovations	Budget rigidity limits financial flexibility
Enhances system-wide ICT policy coherence	Risk of unsustainability post-donor funding

The strengths of hybrid methodologies lie in their ability to offer contextual flexibility while preserving the structure required by public institutions. For example, in ICT infrastructure procurement and classroom digitization projects, the Waterfall model ensures compliance and accountability. Conversely, the Agile components allow for user feedback and iterative improvement in areas such as e-learning module implementation and teacher ICT training. The hybrid model thus enables institutions to balance compliance with creativity. However, the adoption of hybrid approaches is not without challenges. The sector lacks a deep pool of project managers trained in both Agile and traditional methods, making it difficult to coordinate dual processes. Additionally, institutional fragmentation and hierarchical management structures can reduce the effectiveness of hybrid teams and dilute project ownership. If not well-integrated into a broader project governance framework, hybrid approaches risk becoming inconsistent or misunderstood.

On the opportunities front, Ghana's strong partnerships with international development organizations such as the World Bank, UNESCO, and GIZ provide avenues for funding and technical support aligned with

hybrid execution models. These agencies advocate for flexible, outcome-based planning, which matches the hybrid methodology's philosophy. Moreover, Ghana's long-term ESP encourages innovation and equity, both of which can be advanced through hybrid-managed digital projects. However, several threats exist. Organizational resistance to change, limited flexibility in public budgeting, and inadequate long-term planning could undermine hybrid project sustainability. There is also a danger that hybrid methods may become overly donor-dependent, with insufficient local ownership or institutionalization post-project.

Nonetheless, Hybrid PMM provide an effective approach for overseeing the intricate, multi-stakeholder, and dynamic characteristics of ICT-based project initiatives in education in Ghana. They integrate the advantages of both Agile and Waterfall methodologies, enabling educational institutions to adhere to regulatory requirements while innovating adaptively. To maximize their potential, Ghana's education sector must invest in training, policy alignment, and sustainable implementation frameworks that incorporate hybrid techniques into institutional norms and national strategies.

Triangulated Analysis: Adoption of Hybrid PMMs in Ghana's Education Sector

This section synthesizes the areas of convergence and divergence across the various data sources, drawing attention to how the evidence either reinforces or contests prevailing assumptions. In doing so, it strengthens the credibility and reliability of the findings while offering deeper explanatory power on the dynamics shaping hybrid PMM adoption. Beyond confirming consistency across perspectives, the triangulated approach uncovers nuanced opportunities and constraints that may not be visible through single-source analysis.

Consensus Across Sources

- i. **Flexibility and Adaptability are Essential:** There is strong agreement that ICT projects for education in Ghana require adaptive planning mechanisms. National documents such as the ESP (2018–2030) and institutional ICT strategies from public universities recognize the need for flexibility in project execution especially, the implementation of digital platforms, staff training, and infrastructure upgrade. International agencies such as the World Bank and GIZ emphasize the value of iterative implementation cycles in managing technology-driven interventions in developing countries.
- ii. **Alignment with Bureaucratic Structures is Necessary:** Across all sources, there is a shared recognition that PMMs in the Ghanaian context must conform to public sector planning, procurement, and reporting processes. Hybrid models are widely seen as a practical solution, with the Waterfall component ensuring regulatory compliance. Both national and donor-driven projects emphasize the need for structured planning phases, especially when public funds or

state accountability mechanisms are involved.

- iii. **Institutional Capacity is a Core Limitation:** Weak PM expertise especially in Agile methodologies is identified consistently as a constraint to successful DT initiatives in the education sector in Ghana. ICT strategy documents of public universities highlight significant skill gaps among both IT personnel and academic staff (Adarkwah, 2020; World Bank, 2020; GIZ, 2021). The UNESCO ICT Competency Framework similarly stresses that successful adoption of technology requires both technical and PM skills - areas where many education institutions in Ghana remain under-resourced (UNESCO, 2018).

Divergence Across Sources

- i. **Stakeholder Engagement Expectations:** While Ghana's national and tertiary-level ICT strategies tend to view stakeholder engagement as episodic, international organizations like UNESCO and the World Bank advocate for continuous, user-centred engagement, as promoted in Agile methodologies. This reflects a divergence in philosophical orientation: institutional frameworks often favour top-down decision-making, while international standards encourage participatory design and real-time feedback.
- ii. **Monitoring and Evaluation Practices:** National documents, such as the ESP and ICTEP, emphasize output-based monitoring (e.g., number of computers distributed, training sessions held), whereas development partners promote outcome-based evaluations, focusing on actual learning improvements, behavioural changes, or user satisfaction. This difference impacts how project success is defined and managed under different methodological frameworks.
- iii. **Risk Tolerance and Innovation:** Hybrid PMM often support controlled innovation through iterative processes.

However, Ghana's public institutions, as noted in both national policy and ICT strategies of public universities, show a low tolerance for risk, especially regarding budget variability and procurement adjustments. Development agencies, by contrast, encourage experimentation and piloting, even if it means revising scope or timelines - suggesting a divergence in risk management culture.

Validation and Credibility through Triangulation

The credibility of the findings is reinforced by a clear convergence of evidence across multiple sources on several critical themes. These include the imperative for flexible and adaptive planning, persistent challenges in institutional capacity, and the growing consensus around the viability of hybrid PMMs to reconcile structural rigidity with the demands of digital innovation. Such cross-cutting issues highlights areas of strategic alignment and sector-wide concern.

This synthesis draws on a broad base of inputs, including policy-level directives such as the ESP and the ICTEP, institutional strategies from public universities as well as empirical findings and best practices from international development partners like the World Bank, UNESCO, and GIZ. By integrating these sources, the analysis captured both macro-level policy aspirations and micro-level implementation realities, offering a holistic and context-sensitive understanding of PM approaches in Ghana's DT in education. This ensures that the recommendations are grounded in practical realities, international standards, and institutional capabilities.

Triangulated Insight on Hybrid PMM

Triangulation confirms that hybrid PMM are contextually suitable for Ghana's educational landscape. There is broad consensus on their potential to balance control and adaptability, particularly in ICT projects in education that span

infrastructure, digital content, and training. However, divergences in stakeholder engagement models, evaluation practices, and innovation culture highlight areas where institutional transformation and mindset shifts are required. To close these gaps, Ghana must invest in PM capacity-building to reorient ICT project implementation culture to embrace a more participatory, evidence-driven, and flexible PM environment.

The Proposed Context-Specific Hybrid PM Framework for Ghana's Education Sector

To address the unique challenges of ICT project implementation in Ghana's education sector, a context-specific hybrid PM framework is proposed. This framework integrates the rigorous structure of Waterfall with the adaptive and participatory strengths of Agile, enabling phased delivery while ensuring compliance with public sector protocols. Table 3 present the summary of the proposed hybrid PM for Ghana's education sector.

Foundation Phase: Waterfall-Oriented (Strategic Planning and Compliance)

Purpose: Ensure alignment with national policy, budget structures, and donor or procurement requirements.

The key Activities are to:

- i. Define project scope, objectives, and key deliverables.
- ii. Secure approvals from GES, MoE, or the Academic board.
- iii. Develop budget, procurement timelines, and compliance documentation.

Tools: Project charter, logical framework, risk register, procurement plan.

Stakeholders Involved: Ministry officials, university leadership, legal/procurement teams.

Outputs:

- i. Approved project initiation plan.
- ii. Signed-off budget and resource schedule.

Rationale: Aligns with public sector requirements and build institutional legitimacy.

Design Phase: Transitional (Stakeholder Engagement and Co-Creation)

Purpose: Translate strategic intent into functional requirements through collaborative planning.

Key Activities:

- i. Conduct participatory needs assessments (teachers/lecturers, students, ICT staff/admin. staff).
- ii. Co-develop user stories, feature lists, and learning objectives.
- iii. Identify technology and capacity-building needs.

Tools: Stakeholder mapping, user personas, storyboarding, Gantt charts (for fixed components).

Stakeholders Involved: Project teams, users, donor reps, ICT service providers.

Outputs:

- i. Functional specifications (for software/tools).
- ii. Stakeholder-informed design blueprint.

Rationale: Encourages ownership, contextualization, and relevance in project design

Implementation Phase: Agile-Oriented (Iterative Delivery)

Purpose: Deliver working components through short cycles with embedded feedback.

Key Activities:

- i. Break down implementation into sprints (2–4 weeks each).
- ii. Develop/test content modules, features, or digital tools.
- iii. Host feedback loops with users at the end of each sprint.

Tools: Kanban boards, sprint backlogs, demo reviews, digital M&E dashboards.

Stakeholders Involved: Agile team (including developers, teachers/lecturers, content creators), end users.

Outputs: Incremental releases of working digital systems, content, or services.

Rationale: Facilitates rapid learning, user alignment, and correction.

Integration Phase: Waterfall-Oriented (System Rollout and Institutional Embedding)

Purpose: Consolidate outputs into the wider institutional system with support structures.

Key Activities:

- i. Train trainers and institutional ICT leads.
- ii. Finalize integrations with institutional MIS, academic calendars, or national databases.
- iii. Standardize policies, manuals, and support protocols.

Tools: SOPs, checklists, training evaluations, integration plans.

Stakeholders Involved: Implementation teams, faculties/directorates, IT units.

Outputs:

- i. Operational systems and trained user base.
- ii. Institutional policies aligned with new practices.

Rationale: Embeds innovations within stable systems and enables long-term sustainability.

Evaluation and Adaptation Phase: Agile + Waterfall (Dual Monitoring Loop)

Purpose: Ensure accountability, learning, and readiness for scale or replication.

Key Activities:

- i. Conduct structured evaluations against original KPIs.
- ii. Use real-time data to assess usability, adoption, and educational impact.
- iii. Host reflection sessions with stakeholders; adapt future phases accordingly.

Tools: Balanced scorecards, surveys, focus groups, iterative learning reviews.

Stakeholders Involved: M&E officers, end users, funders, project managers.

Outputs:

- i. Final evaluation report.
- ii. Lessons-learned repository.

Rationale: Combines formal accountability with adaptive learning for future application.

Table 3 Summarized Ghana-Specific Hybrid PM Framework

Phase	Orientation	Purpose	Main Outputs
Foundation	Waterfall	Planning, compliance, budgeting	Approved scope, budget, risk plan
Design	Mixed	User needs integration	Context-driven technical and content design
Implementation	Agile	Iterative delivery & feedback	Working components, tested outputs
Integration	Waterfall	Rollout and institutionalization	Trained staff, embedded systems
Evaluation & Adaptation	Mixed	Learning and accountability	Evaluation report, adaptation strategy

Strategic Enablers for Successful Adoption

To operationalize this hybrid model within Ghana's education system, the following enablers are necessary. They are:

- i. Capacity Building: Targeted training in hybrid PMMs for education project leads and ICT directorate staff.
- ii. Policy Alignment: Develop national guidelines that endorse and regulate hybrid project approaches.
- iii. Digital M&E Tools: Invest in tools for real-time monitoring and iterative learning (e.g., dashboards, mobile feedback apps).
- iv. Change Management Structures: Deploy champions and steering committees within institutions to manage transitions.
- v. Sustainability Planning: Include lifecycle budgeting, vendor support, and community-based maintenance models.

This tailored hybrid framework offers a strategic and culturally responsive approach to project delivery in Ghana's education sector. By recognizing the dual demands of public sector structure and technological adaptability, the proposed framework supports both policy compliance and innovation readiness. If systematically implemented, it can enhance the success and sustainability of ICT projects in education

and DT initiatives across all levels of Ghana's educational landscape.

Discussion

This study contributes to the evolving discourse on DT in education by presenting a context-specific hybrid PM framework tailored to the governance, infrastructural, and capacity conditions in Ghana's education sector. The triangulated analysis confirms that while Ghana's education policy environment strongly advocates for digital innovation, effective implementation is often hindered by structural rigidity, weak institutional capacity, and fragmented project oversight. These findings reinforce the argument by Aubry and Hobbs (2010) that successful project outcomes are contingent not only on the choice of methodology but also on the fit between PM structures and organizational context.

The hybrid framework proposed in this study responds directly to the dual challenge of maintaining bureaucratic accountability while fostering agile responsiveness. Drawing on project governance theory (Joslin & Müller, 2016), the model incorporates elements of centralized control (via Waterfall) and decentralized innovation (via Agile), enabling institutions to align digital interventions with national policy mandates without sacrificing adaptability. This dual approach echoes best practices in global ICT4E initiatives where flexible, user-centred implementation is nested

within structured delivery systems (UNESCO, 2022).

Importantly, the study validates hybrid PMM as the most contextually suitable approach for Ghana's education sector, as it balances the need for policy compliance, particularly in procurement and funding with the iterative experimentation required for successful deployment of educational technology. The capacity for phased stakeholder engagement and iterative rollout, as embedded in the Agile components, supports improved user alignment, rapid feedback loops, and more sustainable digital adoption. This aligns with findings from international development projects where hybrid methods have been linked to improved project agility, user satisfaction, and implementation success in complex environments (PMI, 2021; GIZ, 2021).

From a practical perspective, this study highlights the importance of equipping education-sector project managers with dual competencies in Agile and traditional methods. It also emphasizes the need to institutionalize hybrid frameworks through policy reforms, capacity building, and national guidelines. The Ghanaian government and tertiary institutions must invest in training programs and change management structures that promote iterative learning, risk tolerance, and adaptive planning. Development partners such as the World Bank, UNESCO, and GIZ can play a catalytic role by aligning their support with hybrid implementation models that reinforce institutional capacity while maintaining project discipline.

At the policy level, the findings suggest an urgent need to standardize M&E systems across education projects, shifting from purely output-based metrics to outcome-focused indicators that capture learning effectiveness, system resilience, and user satisfaction. Embedding real-time feedback mechanisms and agile evaluation loops into

national ICT and education strategies will allow Ghana to better track and respond to evolving needs during project implementation.

However, the study is not without limitations. First, the analysis is based entirely on secondary data. While triangulation enhances the credibility of the findings, the absence of primary data from project implementers or end-users limits the depth of insight into lived implementation experiences. Second, the study's scope is geographically confined to Ghana, which, while providing rich context-specific insights, limits the generalizability of the proposed hybrid framework to other national or regional contexts without further adaptation.

Future research should focus on empirical testing of the proposed framework through pilot projects, stakeholder interviews, and cross-country comparative studies. Such efforts would validate the practical applicability of the model, refine its phases, and generate actionable lessons for DT in similar governance environments across sub-Saharan Africa.

In sum, this study affirms the potential of hybrid PMMs in bridging the structural and adaptive demands of DT in Ghana's education sector. By anchoring innovation within robust institutional frameworks, Ghana can chart a more effective, inclusive, and sustainable path toward its digital educational goals.

Conclusion and Recommendations

This study examined the applicability of PMMs in advancing DT in Ghana's education sector. Drawing on a triangulated analysis of national policy documents, institutional strategies, and international development reports, the study established that while both Agile and Waterfall methodologies offer distinct benefits, each in isolation is insufficient to meet the complex demands of educational reform in

a highly structured public sector environment. This study also contributes to project management and digital transformation literature by operationalizing Adaptive Governance Theory through a novel Ghana-specific hybrid framework that reconciles Waterfall compliance with Agile adaptability in bureaucratic education systems. Agile's flexibility, adaptability, and iterative nature are critical for innovation and user engagement, but its application is constrained by procurement rules, hierarchical governance, and low familiarity among institutional actors. Conversely, the Waterfall model offers structure and accountability, aligning well with bureaucratic expectations, but lacks the responsiveness needed for real-time digital adaptation.

Considering these findings, the study reaffirms the value of a context-specific hybrid PMM that strategically integrates Agile and Waterfall principles. The proposed hybrid framework, comprising five interlinked phases (Foundation, Design, Implementation, Integration, and Evaluation/Adaptation) offers a structured yet flexible pathway for planning, executing, and scaling digital education projects. It accommodates compliance-driven processes while enabling iterative learning, phased stakeholder engagement, and adaptive feedback loops, making it uniquely suited to Ghana's institutional realities.

To operationalize this framework and unlock the full potential of DT in Ghana's education sector, the following recommendations are proposed:

- For Policymakers:
 - i. Institutionalize hybrid PMMs within national ICT and education policy frameworks by developing guidelines, standards, and regulatory protocols that endorse mixed-method approaches.
 - ii. Strengthen governance structures by embedding agile monitoring and evaluation systems within the

education sector, ensuring projects are assessed based on both outcomes and adaptability.

- iii. Promote policy coherence and inter-agency collaboration to avoid duplication and fragmentation across digital initiatives and foster shared ownership and accountability.

- For Educational Institutions:

- i. Invest in capacity building to develop institutional expertise in both Agile and traditional PMMs, targeting project leads, ICT units, and academic management staff.
- i. Adopt the hybrid PMM framework in the design and delivery of digital initiatives, particularly in projects involving e-learning systems, ICT training, and digital content deployment.
- ii. Establish change management teams or steering committees to support institutional transitions, manage stakeholder engagement, and ensure the sustainability of digital projects.

- For Development Partners and Researchers:

- ii. Align funding and technical support with hybrid implementation models that balance structure with innovation and prioritize institutional capacity development over project-level delivery.
- iii. Support pilot testing of the hybrid framework in selected institutions or education sub-sectors, with clear evaluation metrics to assess scalability and impact.
- iv. Conduct further empirical research through case studies, interviews, and longitudinal assessments to refine the framework and examine its applicability in other low- and middle-income country contexts.

In conclusion, this paper presents a grounded and adaptable approach to PM that aligns with Ghana's strategic vision for

DT in education. By adopting a hybrid PMM tailored to national realities and institutional structures, stakeholders can improve the effectiveness, inclusivity, and

sustainability of digital initiatives, thereby contributing meaningfully to the realization of SDG 4 and national development goals.

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