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Time and frequency nexus among public debt, exchange rate, inflation, monetary policy rate and economic growth in Ghana

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ABSTRACT

The debate about the influence of public debt on an economy has gained long-standing attention among policy-makers, regulators and academic scholars. The excessive expansion of Ghana's public debt to GDP demands a fresh insight into the macroeconomic variables that are connected to economic growth. This study utilised wavelet techniques to investigate the nexus and effect of public debt, exchange rate, inflation rate, and monetary policy rate on economic growth in Ghana using monthly data from 2000 to 2022. Diks and Panchenko (2006) was used as a battery test for the wavelet results. We found a significant negative correlation between public debt and GDP at both short- and long-term frequencies, though there was no notable connection in the medium term. The causality analysis suggests a possibility of bidirectional causality between GDP and public debt in both the short and medium term. Interestingly, the COVID-19 pandemic had minimal impact on this relationship when comparing the pre-pandemic and during-pandemic periods. The only observed coherence (negative) between monetary policy and GDP occurred between 2000 and 2003, at low and medium frequencies. The WMCC results depicted that no variable was seen to lead or lag during the pandemic period however, GDP (exchange rate) reacted to shocks first (last) in the short run (long run) prior to the pandemic. The result of this research is crucial for policy implementation. The GDP-public debt negative nexus offers strong evidence for the government to make determined efforts to reduce external borrowing. The positive coherence of exchange rates and the public debt offers a strong incentive to the monetary authorities to make determined efforts to stop the rapid rise of exchange rates.

Introduction

Following the 2008 global financial crisis, the sustainability of high debt ratios became a significant concern for nations and governments, driven by a substantial rise in public debt levels worldwide. Ghana, akin to many other developing nations, has faced enduring challenges in managing external debt since independence. The report of the African Development Bank (AfDB) in February 2022 reveals that seven African countries were classified as being in debt distress while 16 more were at high risk of entering similar conditions. Ghana, since independence, has sought International Monetary Fund (IMF) assistance for an economic recovery

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programme 17 times [1]. The country has witnessed periods of economic growth interspersed with fiscal crises, prompting cycles of external borrowing and subsequent efforts to restructure its debts. Despite these interventions, the percentage of debt-GDP has continued to surge by approximately 80 %, rising from US$ 20.1 billion to US$ 36.2 billion between 2015 and 2021 [1].

The advent of the COVID-19 crisis ushered developing countries (Ghana) with weaker fiscal space to balloon their external borrowing in response to the adverse impacts of the crisis [2]. As indicated by the World Bank [3], the economic impact of the COVID-19 crisis created significant budget shortfalls in Ghana, amounting to 5.0 % of the GDP. To bridge these gaps, the country sought additional funding from various international financial institutions, including the IMF, World Bank, African Development Bank, and European Union. A circumstance, thus combining a severe economic shock with substantial foreign currency-denominated debt could potentially lead to a situation where the country might struggle to meet its debt obligations [4].

Theoretically, the Armey [5] inverted U-shape curve opined that a rising debt beyond a certain threshold results in a negative impact on the entire economy. Elmendorf and Mankiw's [6] traditional public debt theory supports this theory by the assertion that public debt positively influences economic growth in the short term but inversely impacts in the long term. Large amounts of debt escalate the likelihood of an economy facing elevated interest rates, placing pressure on monetary authorities to reduce rates. This approach not only impacts short-term interest rates but also, over time, can lead to higher inflation rates and stable real and nominal interest rates. Ultimately, these factors- higher inflation and interest rates result in a reduction in private investment, reducing GDP and slowing overall economic growth [7,8,9]. High and unpredictable inflation can distort economic decision-making, diminish purchasing power, and hinder long-term economic expansion [10]. In addition, the purchasing power parity (PPP) theory connects exchange rates with inflation and interest rates, highlighting how high inflation in a country can lead to the depreciation of its local currency. For example, exchange rate fluctuations can significantly impact a nation's economic growth by influencing the demand for imports and exports [11].

To regulate the growing inflation, the central bank uses monetary policy as a tool, which adversely affects the purchasing power and standard of living of people. The upward adjustment of the MPR serves as a benchmark for other interest rates in the economy, impacting savings and lending rates [12]. The recent ballooning of public debt coupled with a reduction in monetary rate, galloping inflation rate, continuous depreciation of the Ghana Cedis and unstable growth in the GDP (see Fig. 1) demand empirical investigation for deeper understanding and policy implementation regarding the dynamic interplay among these variables. It is evidenced from the foregoing discussion that studies regarding the nexus between public debt (PD), exchange rates (ER), inflation (IF), monetary policy (MP), and economic growth (GDP) in Ghana is urgent and paramount, especially in periods d of escalating public debt and an inflation rate of 43.1 % as of August 25, 2023 [13].

An escalating public debt like what the IMF [14] reports about Ghana can have a deteriorated impact on the economy. The report shows that public debt approached 76.1 % of GDP (GHS 291,614.5 billion) in 2020 up from 63.1 % in 2019 and 57.9 % in 2018. The rise in public debt (PD), galloping inflation rate, falling exchange rate and Cedis depreciation have raised concerns regarding debt sustainability and economic stability and their impact on livelihood in the country. While some research suggests that moderate levels of public debt can stimulate economic activity Awadzie, Garr and Tsoekeku [15], stress that excessive debt burdens may crowd out private investment and impede growth [16]. Fig. 1 depicts stylised fact about Ghana's public debt and other variables from January 2000 to January 2022.

Studies indicate that when countries default on their external debt, their real exchange rate often depreciates [4,17], implying that as a country's external debt burden grows its currency typically loses value relative to others. Chen [18] noted that countries with significant external debt are more vulnerable to capital outflows and fluctuations in exchange rates, which is tantamount to financial crises. Ghana's transition from an era of fixed exchange rate to a floating regime has been preceded by substantial variability in the value of the Ghana cedi. From 2019 to 2023, the cedi depreciated by >50 % against the US dollar [13], impacting inflation, trade balance, and overall economic stability. Though the exchange rate may adversely affect economic growth, a stable exchange rate is recognized for its positive effects on household incomes, consumption choices, as well as fiscal and monetary policies, and the trade

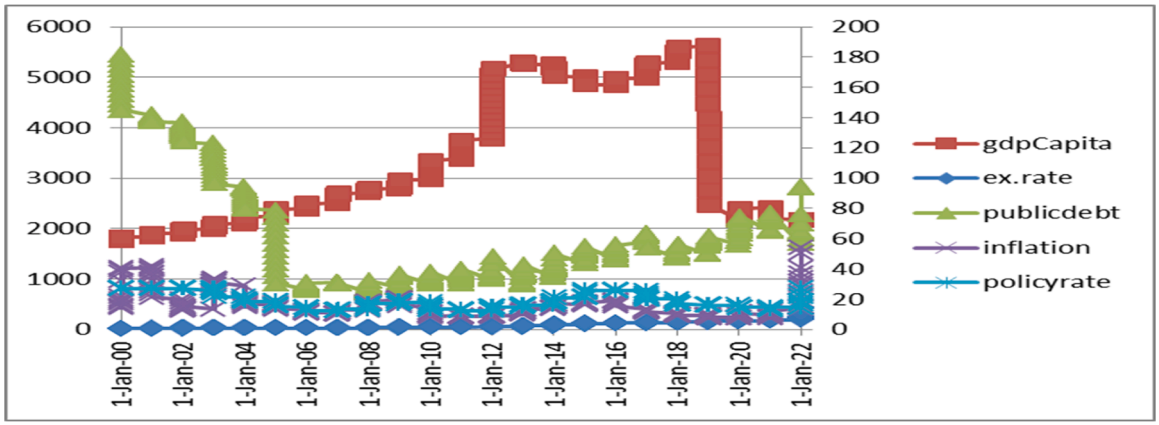


Fig. 1. External debt, exchange rate, inflation rate, monetary rate, and GDP per capita.

balance of governments [19].

Previous studies on GDP and related variables typically relied on annual data, overlooking the potential insights from high-frequency data. This study, however, utilises monthly data to explore the temporal and frequency dynamics among these variables. High-frequency data provides timely information crucial for policymaking [20], captures nuances in economic activities such as price dynamics, trading behaviour, and micro-structures [21,22,23], and enhances modelling accuracy [24]. Moreover, studies on public debt, inflation and exchange rate present contradictory findings. One school of thought contends that the level of public debt can influence both exchange rates and inflation rates. Conversely, another perspective argues that the causal relationship runs in the opposite direction, suggesting that fluctuations in inflation and exchange rates are what impact the level of public debt [25,26].

Prior studies have also examined these factors individually or in limited combinations [15,27–31], a comprehensive scrutiny for these variables interactions is lacking. The study that limits this paper is Nuhuman [32]. The annual dataset used for that study stemmed from 1980 to 2015 which does not capture current events. Also, the study focused on the impact of macroeconomic variables without considering monetary policy rate. The current paper captures the connectedness and causal impacts of public debt, exchange rate, monetary policy rate and inflation rate on economic growth in Ghana using monthly data from 2000 to 2022.

Given these gaps, this paper seeks to provide answers to the following question: How are public debt, exchange rates, inflation rate, and monetary policy connected with GDP across time and frequency domains? How do these variables co-move among themselves and their influence on economic growth in Ghana? Did the COVID-19 pandemic have an exceptional impact on the nexus of the above? Understanding this complex nexus between these macroeconomic fundamentals in the time and frequency domain provides not only valuable information necessary for specific government policies but also scholarly insight for regulatory implementation and investment decisions in the Ghanaian economy.

This research makes several valuable contributions. It initially, presents deeper insight into time and frequency interconnectivity between PD, ER, IF, MP, and the growth of the Ghanaian economy. It utilises the wavelet technique to uncover lead-lag relationships between the studied variables. Secondly, this study provides fresh insight into intellectual discourse on the COVID-19 pandemic's influence on the nexus between PD, ER, IF, MP, and economic growth. Evidence regarding the Ghanaian economy can the vital to other African countries. Thirdly, by synchronising theoretical insight with empirical evidence from Ghana, this study enriches global discourse on the relationship and practical implications between these macroeconomic variables. The outcomes of this research can refine and extend existing theories on the relationship between PB, ER, IF, MP and GDP outcomes in developing economies as they may either support or challenge theoretical propositions in the specific context of Ghana, thereby contributing to a more nuanced understanding of monetary policy dynamics in developing economies. Finally, robust techniques are employed as battery tests for concrete empirical evidence. The paper will be useful for government and policymakers in policy formation. The findings will add to academic discourse for future studies.

We found a negative and significant co-movement between public debt and GDP in short- and long-term frequencies but no connectedness in the medium term. The coherence between the exchange rate and public debt was weak (strong) in the short (medium and long term) with positive signs within specific years. Interestingly, the pandemic had little to no significant impact on the co-movement. The only coherence (negative) that existed between monetary policy and GDP was in 2000–2003 at low and medium frequencies. The WMCC results show that prior to the pandemic, GDP (exchange rate) was noted to respond to shock first (last) in the short run (long run). No variable was noted to lead or lag during the pandemic.

The causal analysis indicated that bidirectional causality between GDP and public debt is possible in both the short and medium term. In Ghana, the correlation between the exchange rate and inflation was insignificant in the short term, but moderate in the medium term and post-2016. Additionally, a positive and significant relationship between the inflation rate and the monetary policy rate was identified across all frequencies, though this connection did not extend beyond the 2013 scales.

Literature review

This section of the paper considers theories that explain the connection between variables for computations. Theories such as the Armey curve, purchasing power parity theory, quantity theory of money, liquidity preference theory, and the conventional public debt theory of Elmendorf and Mankiw [6] were utilised to explore the interplay of the aforementioned variables. The other part of the review section focuses on empirical studies on the above variables.

Theoretical review

The present study applies the Armey [5] inverted U-shape curve to illustrate the public debt-economic growth associations. The curve posits an inverse U-shaped correlation between government size and the growth of an economy, suggesting that beneath some verge, a larger public debt positively influences growth, but beyond that point, it has a negative impact. The idea is grounded in the concept of diminishing returns, as initially formed by Armey in 1995, and explains what percentage of a nation's economic growth is allured by the public sector. The Armey in 1995 is affirmed by the traditional public debt theory. Elmendorf and Mankiw [6] assume that public debt can initially stimulate income, overall demand, and output. However, over the longer term, a rise in public debt may results in a reduction in GDP growth rates. The discussion on the sustainability of public debt often begins with the intertemporal budget limit concept, which implies that governments must maintain a stable level of debt over time [33]. In this framework, government borrowing at an interest rate denoted as r_t for a given time period t is crucial.

$$(1 + r_t)D_{t-1} + G_t = D_t + T_t \tag{1}$$

Here D_t signifies the total debt, G_t represents government expenditures, and T_t stands for tax income, it becomes essential to maintain the debt-GDP ratio [33,34] to ensure sustainability. The sustainability of the debt hinges on the government's ability to generate forthcoming primary surpluses, which are essential for covering future debts and accrued interest expenses.

A key criterion for ensuring debt sustainability, derived from this formula, stipulates that the percentage increase in interest rates should not surpass GDP growth rates. Assuming constant debt levels, sustainability requires that GDP growth rates exceed the interest rate ratio.

$$d_t = d_{t-1}\left(\frac{1+r_t}{1+y_t}\right) + c_t \tag{2}$$

c_t denotes the primary surplus as y_t signifies GDP growth rate, the responsiveness of the primary surplus to changes in debt levels is crucial for maintaining public debt stability. Controlling the stability of public debt is contingent upon how the fundamental surplus adjusts to shifts in debt.

The fundamental principle ensuring public debt sustainability is that the cumulative debt should ideally balance to zero over time. Continuously accumulating new debt to service accumulated debt is not prudent. Any deficit funded by borrowing must be offset by future surpluses. This critical criterion can be illustrated through the following model:

$$\sum_{t=0}^{\infty}\left(pc_t\prod_{p=1}^{t}\frac{1+rt}{1+gt}\right) + \ d_0 = 0 \tag{3}$$

Here, r_t represents interest rate as g_t signifies the growth rate in GDP, and d_0 stands for proportion of owning-to-GDP. In Albu and Albu [33], equilibrium occurs when the GDP growth approximates the interest rate.

As argued by Elmendorf and Mankiw [6], an increase in public debt can crowd out private investment by driving up interest rates, as governments compete with private borrowers for available funds in the financial markets. This study utilises the principles of the quantity theory of money and liquidity preference theory to scrutinise the influence of interest rate (monetary policy rate) on the Ghanaian economy. The roots of the policy rate can be traced back to classical economists, whose discussions laid the foundation for Irving Fisher's quantity theory of money (QTM) [35]. This theory links changes in the money supply directly to price levels and inflation, assuming velocity and output are stable. If governments finance debt by printing money, this leads to inflation as per Fisher's theory. Inflation, in turn, can depreciate the exchange rate, as the purchasing power of the currency declines. Fisher's theory underscores the importance of controlling the money supply to avoid inflationary pressures that arise from excessive public debt [36,37,38].

In contrast to the QTM, Merkl [39] posited that the growth of the money supply fails to substantially influence long-term economic growth, positing the concept of both immediate and future neutrality of money growth. Keynes challenged the foundations of QTM by questioning its assumptions, particularly the assumption of constant money velocity. Keynesian theory suggests that prices are relatively rigid in the short term and that adjustments in the money supply occur quickly [37]. Keynes proposed that the demand for money is not an independent variable but is closely linked to output levels and interest rates, as outlined in his influential liquidity preference theory [37]. Keynes' liquidity preference theory focuses on the inverse correlation between liquidity preference and interest rates [40]. According to this theory, interest rates represent the cost of holding money, and when interest rates are very low, the economy can enter a state known as a "liquidity trap". This happens when the short-term nominal interest rate falls below a certain lower limit [41].

From the theoretical perspective, high public debt can slow economic growth by increasing the cost of capital and reducing investment. It can also result in inflation when debt is paid with new printed money. Higher interest can reduce investment and productivity. However, in times of recession borrowing may stimulate demand if it is used for productive investments. An increase in borrowing can lead to a higher risk of inflation if the debt is monetised. This can weaken the currency, causing a depreciation of the exchange rate. Debt-financed spending may initially boost demand and output but can lead to inflationary pressures, reducing long-term growth if not managed properly.

Empirical review

Many government projects in developing countries rely heavily on substantial deficit financing. While this can stimulate domestic growth, nations with large debts may deter external investors [18]. This is because a substantial debt burden can lead to inflation, thereby reducing the value of future repayments in terms of the currency value. Adjei et al. [19] argued that in more dire circumstances, a government might resort to increasing the money supply as a partial solution to manage significant debt. However, this action inevitably results in inflation. Moreover, if a government cannot control its deficit through domestic measures such as sales of bonds in the domestic market or elevating the supply of money, it may need to issue more securities to foreign investors, potentially driving down their prices.

Albu and Albu [33] observed that public debt dynamically interacts with economic growth in European countries using wavelet analysis. Their research highlights an inverse association between high government debt and output, primarily due to concerns about debt sustainability. Chaudhry, Qamber, and Farooq [42] found that variations in Pakistan's real exchange rate impact the country's real gross domestic product over the long term.

A study by Klutse et al. [2] used a methodology to examine fiscal policies and assessed the sustainability of public debt. Their

findings corroborated that the COVID-19 pandemic significantly affected the debt situations in Ghana and Kenya.

Ramoni et al. [26] employed dynamic panel data and Generalized Autoregressive Conditional Heteroscedasticity models to assess the effect of exchange rate variability on economic growth while controlling for macroeconomic indicators such as government spending and trade openness. Their study revealed an inverse relationship in economic growth-exchange rate variability nexus. Ajayi and Aluko [43] investigated how government spending relates to the performance of Nigeria's economy, and found no significant correlation between these two variables.

Kaboro et al. [44] found GDP growth rate significantly and inversely affects exchange rate fluctuation within the EAC. This is consistent with the findings of Adjei [45] in Ghana, who utilised ARCH, GARCH models, and the Autoregressive Distributed Lag Approach. Similarly, Baidoo et al. [8] found, among other things, that economic growth is indirectly influenced by public debt in Ghana. Their study employed the Autoregressive Distributed Lag (ARDL) model for calculations. Allor [11] observes a temporary fall in the exchange rate due to contractionary policy rates in the short term, which aligns with the exchange rate puzzle. However, in the long term, the findings suggest a tendency for the exchange rate to appreciate in Ghana.

Adaramola and Dada [46], using the ARDL model, found that the performance of Nigeria's economy is negatively affected by inflation and the real exchange rate. Conversely, both interest rates and money supply were identified as factors positively and significantly impacting economic growth. Mandeya and Ho [47] discovered that inflation negatively impacts the short and long terms growth of the South African economy. However, they noted that uncertainty related to inflation affects the short term only and does not influence the long-term perspective.

Aderemi et al. [28] analysed the external debt-exchange rate volatility connectedness in Nigeria and found, among other things, debt other than domestic, impacts changes in the exchange rate. Adjei et al. [19], using Ordinary Least Squares and Simple Linear Regression techniques, investigated factors determining the real exchange rate and its performance in Ghana. Their study revealed, among other findings, that public debt has a statistically insignificant repercussion on the real exchange rate. Insah and Chiaraah [48] aimed to uncover the causes of exchange rate fluctuations in Ghana, utilising the Autoregressive Distributed Lag (ADL) Model. Their results indicated an inverse relation between public debt and real exchange rate volatility in Ghana.

Nortey, Ngoh, Doku-Amponsah, and Ofori-Boateng [49] constructed models using multivariate GARCH DCC and BEKK models with data from Ghana. Their findings suggested that when the Ghanaian cedi strengthens in the foreign exchange market, both inflation rates and interest rates respond positively and eventually stabilise over a longer period.

Olatunbode, Adegbemi, and Odutola [50] found a significant long-term negative relationship between external public debt and the exchange rate. Ali [7] concluded that economic performance was a determinant of ER variability and public debt in South Asia, within the study period, with a negative correlation observed between external debt and economic growth. Using ARDL and Vector Error Correction models, Mohammed, Mohammed, and Nketiah-Amponsah [51] found in the long term results that factors such as inflation, central bank policy, and money supply influence exchange rate fluctuations. Conversely, the short term model showed that exchange rate volatility was notably affected by the central bank's policy rate and past values.

Methodology

The existing literature on the interplay between public debt (PD), economic growth (GDP), and exchange rates (ER) has utilised various methodologies such as OLS [19], ARDL models [28], and Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models [26]. However, these models have drawbacks that may not be suitable for the current study. Some significant drawbacks of the OLS model are its susceptibility to outliers, assumption of homoscedasticity and symmetric error distribution, which can bias estimated coefficients and distort outcomes. This can lead to inefficient and inconsistent parameter estimates [52].

The ARDL model does not require variables to have the same integration order as it allows for the inclusion of both I(0) and I(1) variables in a single estimation [53,54]. When dealing with variables of different integration orders, the ARDL approach may produce spurious regression results [55]. One of the most significant advantages of the Wavelet technique is its ability to perform multi-resolution analysis, which allows researchers to decompose a time series into different frequency components. This capability is particularly useful for capturing both short term and long term dynamics within the same dataset. In contrast, the ADRL model typically focuses on linear relationships without explicitly accounting for variations at different time scales [56].

Wavelet techniques are adept at modelling nonlinear relationships and capturing abrupt changes or structural breaks in time series data. This flexibility allows for a more nuanced understanding of the relationships between variables, especially in dynamic systems where nonlinearities are prevalent. The techniques are effective in noise reduction through the process of thresholding, allowing for clearer identification of underlying patterns in the data. This feature is beneficial in economic and financial time series analysis, where noise can obscure important signals [57,58,59]. Unlike GARCH models other models, which are primarily used for analysing and forecasting economic and financial time series data with volatility clustering, wavelet transforms excel in capturing time-frequency information, essential for discerning patterns across different scales [60]. This makes them better suited for examining non-stationary financial data by capturing both immediate and future term variability. Besides, the bi-wavelet transform is effective in denoising financial time series data by separating noise from the underlying signal. Noise can obscure critical signals and lead to unreliable model estimates [61].

In this study, wavelet methods including cross-wavelet transform, cross-wavelet coherency, and wavelet multiple, as described in Owusu Junior et al. [61] are deployed. The bi-wavelet method examines the frequency and time domain relationships between variables under study and detects any lead-lag associations among them. To thoroughly investigate the interconnectedness among these variables, we employ wavelet multiple techniques. The paper is a novel one that utilizes wavelet techniques to examine lead-lag connectedness, degree of integration and interdependency between ER, PD, IF, MP and GDP nexus in Ghana using high frequency data.

A recent paper that used wavelet approaches in a similar study used annual data [62].

Bi-wavelet

In this section, we initiate our examination by assessing the interactions between pairs of variables individually. We explore the convergence between exchange rate-economic growth, public debt-economic growth, and exchange rate-public debt. Following this, we delve into the associations between public debt and the remaining variables, aiming to understand the impact of one element on another.

Continuous wavelet transform (CWT)

Wavelet calculations are defined by two main components: location/time (i) and scale (s), see Eqn. (1)

$$\text{⋔!s}\,(\text{t}) = \sqrt{s}^{-1}\,\text{⋔}(\text{t}-\text{i})(s^{-1}),\ \ \text{⋔}(.)\in\ L^2\text{®} \tag{4}$$

where $\sqrt{s}^{-1}$ illustrates the standardised component that assures the unit dispersion of the wavelet

|| ⋔!s(t)||^2=1; i || stands for the time element that determines this wavelet's specified position, while the scale dilatation factor, represented by s, characterises wavelet expansion. The Morlet wavelet can be written in the second equation.

$$\varnothing^M(t) = \ \pi^{-\frac{1}{4}} e^{ivot} e^{-t^{\frac{1}{2}}} \tag{5}$$

Here the wavelet prevalence frequency is denoted by vo. vo is gauged at 6 [61]. A time series, denoted as x(t), is disassembled using a chosen mother wavelet, as demonstrated in Li et al. [58] and Owusu et al. [59]:

$$Wx(i,s) = \int_{-\infty}^{\infty} x\ (t)\sqrt{s}^{-1}\ \text{⋔}\left(\frac{t-i}{s}\right)dt \tag{6}$$

By applying a specified wavelet ⋔ (·) to a specific series, we arrive at *Ws(i,s)*. The significant benefit of Continuous Wavelet Transform is seen in its potential to breakdown into components and restores the function $x(t)\in L^2(R)$ as

$$x(t) = \frac{1}{C_{\emptyset}}\int_{-\infty}^{\infty}\left[\int_0^{\infty} Wx\ (i,\ s)\ \text{⋔i,s}\ (\text{t})\text{di}\right]\frac{ds}{s^2}, s>0 \tag{7}$$

Wavelet transform coherence (WTC)

The Wavelet Transform Coherence (WTC) technique entails standardising the squared magnitude of one wavelet cross-spectrum to create a unified wavelet power spectrum. This approach was first introduced in 1998 by Torrence and Compo. As a result, the squared wavelet coefficient is derived from this normalization process.

$$R^2(x,y) = \frac{|\ p(s{-}1\ Wxy\ (i,\ s))|2}{p(\text{s}-1\ |Wx\ (i,\ s)|2)p(s{-}1|Wy\ (i,s)|2)} \tag{8}$$

p harmonises resolution and significance; $0 \le R^2_{xy}(i,s) \le 1$. It also serves as a smoothing parameter. A numerical value near 0 indicates a weak connection, while a value near 1 signifies a strong correlation. To assess the statistical significance of these relationships, the Monte Carlo method, first introduced by Torrence and Compo [63], is employed. This method is selected because the theoretical distribution of the cross-wavelet transform coefficient is unknown.

WTC phase difference

The phase difference extracted from the wavelet transform coherence signifies the perturbations observed in the fluctuations within the time series. The phase distinctness betwixt x(t) and y(t) can be articulated below as

$$\phi_{xy}(,s) = tan^{-1}\left(\frac{\zeta\{\delta(\text{ß}^{\text{-}1}6_{\Gamma}\eta\ (i,\text{ß}))\}}{\Re\{S(s^{\text{-}1}W_{\text{xy}}(i,s)\ )\}}\right) \tag{9}$$

In the wavelet connectedness map, the dimensional-phase marking illustrates the effects obtained from wavelet convergence differentiation, and ζ (ℜ) represent the imaginary (real operators). Different dimensional arrows are used to distinguish various phase patterns.

Wavelet multiple correlation (WMC)

To offer a comprehensive perspective on the frequency-dependent lead-lag relations, we subsequently apply the Wavelet Multiple Cross-Correlation (WMCC) within the context of this study. This technique is employed because the bi-wavelet technique alone is insufficient for examining integration among multiple variables simultaneously [57,61].

Consider a multivariate stochastic process denoted as $X_t = x_{1t},\ x_{2t}, \ldots,\ x_{nt}$ and let $W_{it} = \ w_{it},\ w_{it}, \ldots,\ w_{njt}$ represent the wavelet coefficients obtained through the Maximal Overlap Discrete Wavelet Transform (MODWT). The concept of Wavelet Multiple Coherence (WMC) denoted as $\widetilde{\mathrm{X}}^{'}(\lambda_j)$ was introduced by Fernández-Macho [64]. This collection of multiscale coherence is derived from X_t using the following method. It involves calculating the $\sqrt{R^2}$ by combining w_{ijt} linearly. Where $i = 1, 2, \ldots,\ n$ variables, and it is determined at each wavelet scale λ_j. Previous research has established that there is no need to run auxiliary regressions because the R^2 resulting from element $\mathrm{z_i}$ on a collection of predicting elements $\{z_t,\ k \neq i\}$ is expressed in the form $R_i^2 = 1 - p^{-ii}$; p^{ii} represents the i^{th} diagonal element of the reverse comprehensive correlation matrix P. In effect, Eq. (10) captures WMC.

$$\widetilde{\mathrm{O}}^{'}\mathrm{X}(\lambda_{\mathrm{j}}) = \left(1 - \frac{1}{maxdiagP_{\mathrm{j}}^{-1})}\right)^{1/2} \tag{10}$$

where P_j is the (n x n) connectedness matrix of W_{jt}

Concerning regression theory and z_i predicted values as z_t, WC is written in the form

$$\acute{\mathrm{O}}\mathrm{X}(\lambda_j) = Corr(w_{ijt}\grave{w}_{ijt}) = \frac{Corr(\mathrm{w}_{ijt},\grave{w}_{ijt})}{(\mathrm{Var}(\mathrm{w}_{ijt})\mathrm{Var}(\grave{w}_{ijt}))^{1/2}} \tag{11}$$

where w_{ijt} is chosen to maximize $\widetilde{\mathrm{O}}^{'}\mathrm{X}(\lambda_j$ and $\grave{W}_{ijt}$ constitute the predicted values in the regression of w_{ij} on the remaining wavelet coefficients at scale λ_j. WMCC is generated in this paper by permitting a lag τ betwixt observed and predicted values at each horizon λ_j as

$$\acute{\mathrm{O}}\mathrm{X},\tau(\lambda_j) = Corr(w_{ijt}, \grave{w}_{ijt+\tau}) = \frac{Cov(\grave{w}_{ijt},\ \grave{w}_{ijt+\tau})}{(\mathrm{Var}(\mathrm{w}_{ijt})\mathrm{Var}(\grave{w}_{ijt}+\tau))} \tag{12}$$

There is coherence between WMC and WMCC, and the standardised wavelet correlation and cross-correlation, where $n = 2$. To calculate WMC and WMCC, this paper gauge the achievement of the multi-variable random process X_t to

$t = 1, 2, \ldots,\ T$ represent $X = \{X_1,\ X_2,\ \ldots, X_T\}$. Relating MODWT order J to each one of the one-dimension time series $\{X_{1i},\ \ldots, X_{iT}\}$, for $i = 1, 2, \ldots, n$, this J length $-T$ vector of parameters of MODWT $\widetilde{\mathrm{V}}_j = \widetilde{\mathrm{V}}_{j1},\ \widetilde{\mathrm{V}}_{j2}, \ldots,\ V\widetilde{\mathrm{V}}_{j,\ T-1}$ for $j = 0, 1, \ldots, j$ is attained.

From Eq. (12), a nonlinear equation of all $m(m-1)/2$ wavelet correlations of scale λ_j and a st estimator of wavelet correlation from the MODWT is written

$$\widehat{\mathrm{Z}}\mathrm{X}\ (\lambda_j) = \left(1 - \frac{1}{maxdiagP_j^{-1}}\right)^{\frac{1}{2}} = Corr\left(\overline{w}_{ijt},\ \widehat{w}_{ijt}\right)\frac{Cov\left(\overline{w}_{ijt},\ \widehat{w}_{ijt}\right)}{\left(Var\left(\overline{w}_{ijt}\right)\ Var\left(\widehat{w}_{ijt}\right)\right)^{\frac{1}{2}}} \tag{13}$$

We note that the covariance and variances of the wavelet can be expressed as

$$Cov\left(\overline{w}_{ijt},\ \widehat{w}_{ijt}\right) = \overline{\gamma}_j = \frac{1}{\overline{T}_j}\sum_{t=L_j-1}^{T-1}\overline{w}_{ijt},\ \widehat{w}_{ijt} \tag{14}$$

$$Var\left(\overline{w}_{ijt}\right) = \overline{\delta}_j^2 = \frac{1}{\overline{T}_j}\sum_{t=L_j-1}^{T-1} w_{ijt}^2 \tag{15}$$

$$Var\left(\widehat{w}_{\mathrm{ijt}}\right) = \overline{\xi}_j^2 = \frac{1}{\overline{T}_j}\sum_{t=L_j-1}^{T-1}\widehat{w}_{ijt}^2 \tag{16}$$

where $\overline{w}_{ij}$: the regression of the identical set of independent variables $\{\overline{w}_{kj},\ k \neq i\}$ reduces the $R^2, \widehat{w}_{ij}$ represents conforming predicted values, and $L_j = \left(2^j - 1\right)(L-1)$ indicates the values of wavelet coefficients that the border conditions related with wavelet filter of length L and scale λ_j affect, but $\overline{T} = L_j + 1$ is wavelet coefficient values that border conditions have no impact.

Similarly, a consistent estimator of the WMCC is express as

$$\widehat{\mathrm{Z}}\mathrm{X},\tau\left(\lambda_j\right) = \frac{Corr\left(\overline{w}_{ijt},\ \widehat{w}_{ijt+\tau}\right)\ Cov\left(\overline{w}_{ijt},\ \widehat{w}_{ijt+\tau}\right)}{\left(Var\left(\overline{w}_{ijt}\right)\ Var(ijt+\tau)\right)^{\frac{1}{2}}} \tag{17}$$

To establish a reliable confidence interval (CI) for WMC, the article applies a transformation denoted as arctan h(r), where arctan h (.) represents a reverse hyperbolic tangent equation [64,65]. The CI is established on the hypothesis that X is realised in the estimation of both WMC and Wavelet Multiple Cross-Correlation, and similarly for $\widehat{\mathrm{Z}}X(\lambda_j)$ in equation (17), the $\widetilde{z}_j \sim F\left(\widetilde{z}_j, \left(\frac{T}{2j}\right) - - 3^{-1}\right)$, here $z = \arctan h(ZX(\lambda_j))$, $\widetilde{z}_j = \arctan h(\widehat{\mathrm{Z}}X(\lambda_j))$, and *F*signifies the folded symmetric distribution -an estimate$(1 - - a)$ *CI* can be

$$CI(1-a)(ZX(\lambda_j)) = tanh\left[\widetilde{z}_j - \frac{C_2}{\left(\frac{T}{2j} - 3\right)1/2}; \widetilde{z}_j + \frac{C_1}{\left(\frac{T}{2j} - 3\right)1/2}\right] \tag{18}$$

Where the *FII* critical values C_1, C_2 are $Z(C_1) + Z(C_1 - 2z^0) = 1 - a/2$ and $Z(C_2) + Z(C_1 - 2z^0) = 2 - a/2$ with Z(.) being the standard symmetric distribution while $\tanh(z^0) = Z_x^0(\lambda)$ serving as the value of some WMC formed in relations to a null hypothesis of no connectedness.

Data, descriptive and preliminary analysis

Data description

Monthly time series data from January 2000 to December 2022 constituting 753 observations was used for the estimations. Data on public debt, real exchange rate, inflation, monetary policy rate and economic growth were extracted from the websites of the Ministry of Finance (https://mofep.gov.gh/public-debt/debt-data) and the Bank of Ghana (www.bog.gov.gh) [66]. Annual data on GDP per capita was obtained from Ministry of Finance and was converted to monthly data with the help of EViews software. EViews uses frequency conversion in this process (Eview.com). The returns of data used were computed as $lnr_t = lnP_t - lnP_{t-1}$ where r_t is continuous compound return, P_t is the current price and P_{t-1} is the previous price.

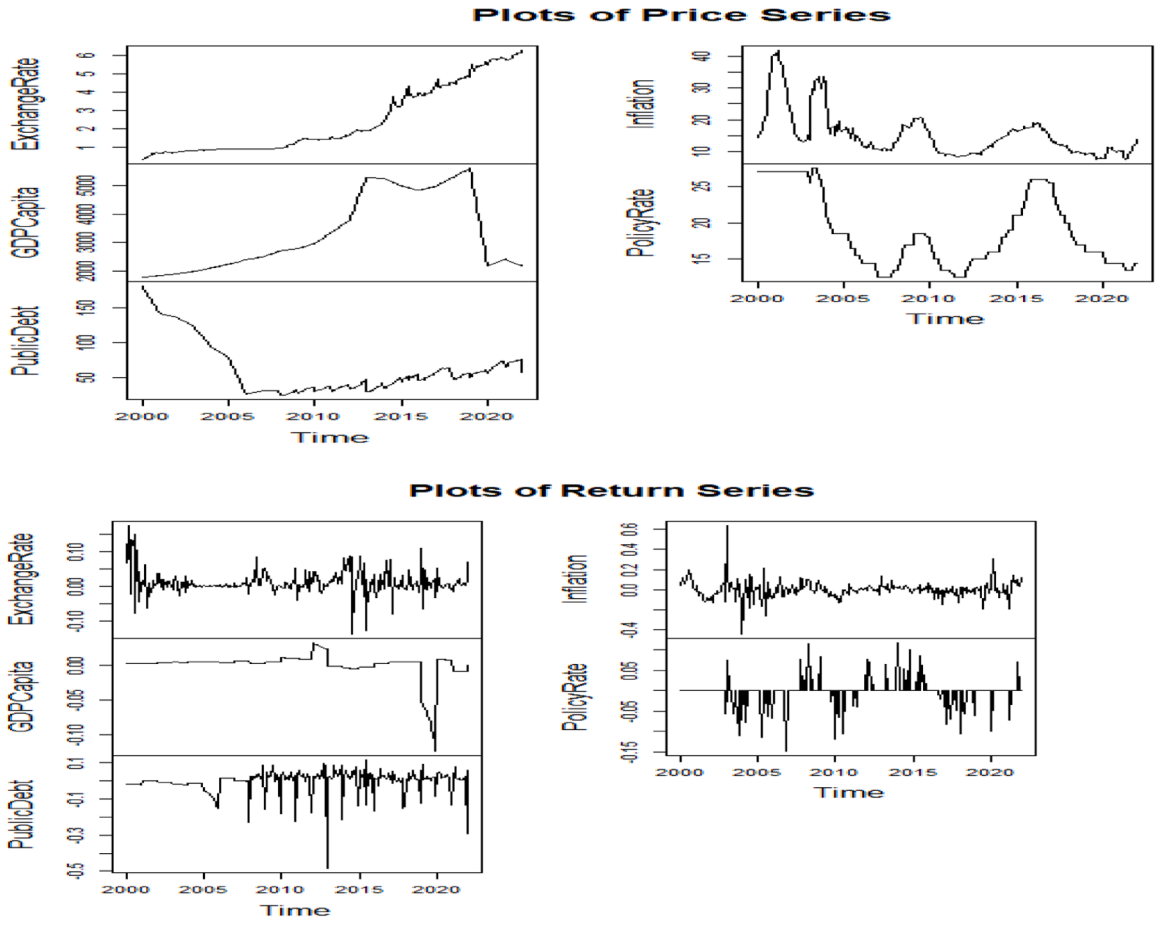


Fig. 2. Graphical representation of monthly exchange rate, GDP per capita, public debt, monetary policy, and inflation at price level (left) and at returns level (right).

Graphical representation

Understanding the pattern of real exchange rate, public debt, inflation rate, monetary policy rate and GDP per capita at price series and returns during the study period is paramount. Therefore, the analysis of the data commences by examining the statistical distribution of the returns series to provide an overview of these movements. Fig. 2 displays the graphical depictions of the monthly frequencies of variables at the series level and their corresponding log returns. A quick glance at the plots reveals real exchange rate and GDP series depict an upward trend from 2000 to 2022, but GDP experienced a sharp fall at the end of 2019 and continued to the end of 2022. This may be attributed to the impact of the COVID-19. Generally, PD, MP and IF demonstrate upward and downward movements within the study period. The pattern of the series influences the behaviour of their corresponding returns.

Descriptive statistics of ER, PD, MP, IF and GDP are also provided in Table 1. The mean among variables is not far from one another as public debt assumes the lowest mean and monetary policy rate exhibits the highest in the distribution. A similar pattern is seen in the variance. Returns of real exchange rate, public debt and GDP are skewed to the left while inflation rate and monetary policy rate are skewed to the right, yet the entire variables are leptokurtic. The paper detects deviations from normality at specified levels of significance, with distributions skewed to the left and right showing flatness in their tails. The coefficients representing the trends show significance across standard levels, underscoring the existence of trends within the dataset. This consequently provides validation for employing the statistical method.

Additionally, the returns series indicate some degree of stationarity, which was statistically confirmed using two different approaches: the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller [67] and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. The test showed that the series achieved stationarity at the first difference. The detailed results of these tests can be found in Table 2. In addition to the unit root test, Table 1 provides the descriptive statistics of the monthly returns for selected variables. The Jarque-Bera statistics indicate that all the return series deviate from a symmetric distribution. Despite this departure from normality, the mean returns for all variables were positive except public debt (PD), albeit close to zero throughout the study period. This pattern of nearly zero mean returns was consistent with the fluctuations observed in the returns over time. Furthermore, ADF and KPSS tests confirm that the various return series exhibit stationarity properties at the first difference.

Empirical results and discussion

The research introduces the bi-wavelet approach, which is used to evaluate the presence of one-way relationships between two variables within the context of time-frequency analysis. This method also helps uncover the degree of simultaneous variations joining the two elements across both time and frequency domains. The horizontal axis represents the time domain, while the vertical axis signifies the frequency domain (measured in intrinsic time or time horizons). These axes jointly establish the framework of the time-frequency scales. The analytical methodology and statistical exposition used in this study were derived from Owusu Junior et al. [61].

To enhance clarity in understanding the data, right- and left-pointing arrows are used to indicate instances when variables exhibit in-phase (moving in the identical path) and anti-phase (moving in the inverse path) relationships, respectively. When the first variable leads, upward right-pointing arrows/downward left-pointing arrows are used, while the second variable leading is denoted by upward left-pointing arrows/downward right-pointing arrows.

Cross-wavelet coherence (WTC)

Cross-wavelet coherence reveals the time-frequency bands where variables exhibit concurrent variations. In this paper, we focus on the time intervals and frequency ranges where variables display coherence. The degree of coherence existing in the two returns is represented by the colour of the surface and the corresponding colour scheme. A red shade within the white contour at the lower part of the plots indicates a strong co-movement at low frequencies, while a red colour within the white contours on the left side signifies a strong co-movement at the beginning of the analysed period. Arrows convey the phase difference between the two returns, with the order of the returns corresponding to their placement on top of the plots [57,61]. The cone of influence (COI) displayed in the bi-wavelet graphs outlines the area in which wavelet outcomes are considered statistically significant. Findings beyond the bounds of the COI are considered insignificant, as they fall beyond the 95 % significant level.

Fig. 3. exhibits the cross-wavelet coherency of monthly returns of variables in Ghana. Results reveal a strong positive interconnectedness between exchange rate and GDP per capita across all frequencies within 2000–2003, and in the short-run (0–4 months) between 2004 and 2007. A strong in-phase in the long-run (32–64 months) corresponds to 2009–2013. In the medium-term, during COVID-19 (2020–2022), GDP led as ER lagged. This supports the findings of Ramoni et al. [26] and Kaboro et al. [44] who found a

Table 1
Descriptive statistics.

Variab	Obs	Min	Max	Mean	Std. Deviation	Skewness	Kurtosis	ADF	Jarque B	KPSS
Exchange	275	−3.7E-01	3.0E-01	1.2E-02	4.5E-02	−0.753	25.230	−7.269***	7045.8***	0.085***
GDP per	275	−1.2E-01	3.3E-02	7.5E-04	1.9E-02	−3.978	18.869	−4.289***	4641.3***	0.695***
Public D	275	−4.9E-01	2.1E-01	−2.4E-03	6.3E-02	−2.899	16.124	−6.082***	3245.2***	0.770***
Inflation	275	−4.4E-01	6.4E-01	4.8E-03	8.6E-02	1.062	13.093	−4.612***	1938.6***	0.211***
Monetary	275	−1.5E-01	1.6E-01	7.0E-19	3.5E-02	0.314	6.371	−3.357*	449.77***	0.368***

***, **, and * Significant at 1, 5, and 10 percent confidence level.

Table 2
Summary of non-parametric causality test.

Variables	Original	D1	D2	D3	D4	D5
ER/GDP	2.245**	−1.985	1.456*	1.701**	1.051	−1.375
GDP/ER	1.501*	0.831	1.001	−1.511	0.579	1.522*
ER/PD	2.245**	−0.294	1.173	1.318*	1.157	1.983**
PD/ER	1.501*	0.933	1.432*	1.045	1.754**	1.411*
ER/IF	0.257	−0.775	0.925	1.272	1.944**	2.177**
IF/ER	0.814	−0.209	−1.694	−1.744	0.984	1.598*
ER/MP	0.257	−0.035	−0.959	0.761	1.518*	1.261
MP/ER	0.814	1.168	1.397*	−0.094	0.363	1.364*
PD/GDP	−1	1.114	1.845**	3.098***	1.443*	−0.368
GDP/PD	−1	1.545*	1.362*	2.271***	−0.07	1.201
PD/IF	−0.278	−0.349	−0.513	0.619	1.281	1.396*
IF/PD	1.766	−3.862	−1.307	−1.212	0.656	1.432*
PD/MP	−0.278	−0.099	1.400*	0.422	1.437*	0.595
MP/PD	1.766	1.782**	0.716	0.642	1.162	0.258
GDP/IF	−0.278	0.055	−0.718	−1.255	−0.931	1.356*
IF/GDP	1.766	−2.001	−0.311	−0.367	0.105	0.532
GDP/MP	−0.278	0.185	0.185	0.593	0.532	1.641**
MP/GDP	1.766**	−0.86	−0.86	−0.698	0.772	−0.087
IF/MP	−1	−1.759	−1.759	0.706	2.864***	2.621***
MP/IF	−1	1.924**	1.924**	0.03	1.334*	0.747

Note: ***, ** and * denote 0.001, 0.05 and 0.10 significant level, respectively.

negative relationship between exchange rate and economic growth. A weak inverse correlation exists between ER and PD in the short and medium-term in 2010 as exchange rate leads and public debt. The findings agree with the findings of Augustine and Kumar [68] in India but contradict the findings of Chaudhry et al. [42] in Pakistan. Within 2001 and 2002, a moderate coherency existed in the ER-PD nexus in the middle-term. Contrary, a weak positive nexus existed for 24–34 months in 2012–2017. Interestingly, no dependency was revealed during COVID-19 time.

Correction between PD and GDP showed a moderate (strong) anti-phase within short- (medium-) terms in 2000–2021, and within 2012–2013 (2015–2019) in the short run (long-term). Results debunk the argument that a rise in Ghana's public debt from 58.66 % in 2019 to 93.51 % in 2020 is associated with the COVID-19 pandemic since results during the pandemic showed insignificant co-movement. It rather suggests that higher government spending reflects economic growth in short- and medium-terms in 2000–2021, and within 2012–2013 (2015–2019) in the short run (long-term). Also, the outcome partly supports the Keynesian hypothesis that government expenditure serves as an exogenous policy instrument to influence economic growth. Instead, agrees with Armey's [5] Curve theory and previous studies that government expenditure beyond a certain threshold leads to an economic downturn [43,33].

There exists a weak negative interconnectivity between MP and GDP in the short- and medium-run frequencies in 2000–2002 but no significant correlation exists in the long-run and other horizons and their corresponding frequencies. The results indicate that the continuous decrease of monetary policy from 2016 to 2021 by the policy committee in Ghana did not result in economic growth. The findings support Keynesian liquidity trap theory which argues that lowering interest rate, becomes ineffective in stimulating economic activity. In the case of GDP and inflation, positive and moderate correlations were portrayed in 2013 in the medium-term. Nonetheless, a moderate negative correlation was seen beyond 2020 within the short- and medium-term. Results depict non-linear relationship between inflation rate and economic growth, and it supports the findings of Dammak and Helali [69].

Correlation in ER-IF nexus unveiled insignificant nexus across all horizons except after 2019 (during COVID-19) where co-movement (positive) strengthened from short to long-term. Between ER and MP, a moderate in-phase correlation was exhibited in the medium-run in 2015, while strong positive co-movement was shown beyond 2019 in the long-run. Findings suggest that ER and MP influence each other at different frequencies. The positive correlation between variables in the long-run is in line with the findings of Nortey et al. [49] and Ahiabor [70].

The PD-MP coherency showed a strong positive co-movement in the short- and medium-term (medium-term) in 2000–2003 (2016–2019). Negative (weak) (strong) interdependence existed in the short-term (medium-term) in 2003 (2013). PD-IF nexus revealed weak to no correlation between short to long-term frequencies. However, public debt predicted inflation in the extreme long-run (beyond 64 months). A moderate to strong in-phase interconnectedness was uncovered in the IF-MP nexus in the short- and medium-term bands in 2003–2004, 2004–2005 and 2010–2013. A strong positive correlation was found in the extreme long-run, where inflation predicted monetary policy rate. The findings do not support Ahiabor [70] whose results unveiled an inverse relation between interest rate and inflation in Ghana.

Wavelet bivariate correlation matrix

The paper deploys multiple wavelet correlations to examine the associations and correlations among multiple sets of the data in both time and frequency domains. In the application of this technique, the time series data undergo an initial decomposition into distinct frequency components using wavelet transforms. The utilisation of wavelet transforms enables the inspection of data across

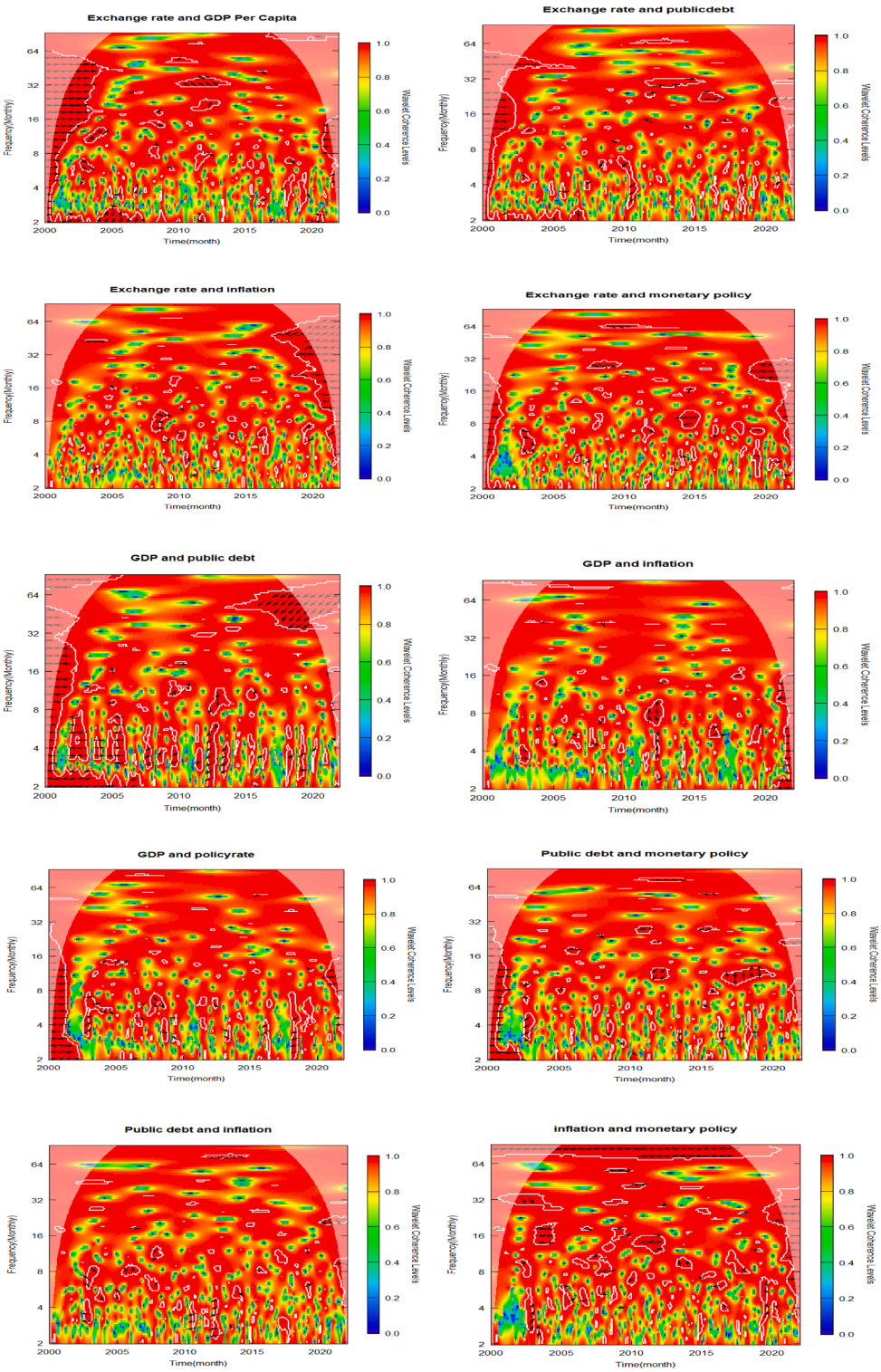


Fig. 3. Cross-wavelet transform - pair-wise.

various scales, thereby enabling the detection of correlations that may remain concealed when employing conventional correlation analysis.

The variables in Figs. 4 and 5 are represented as follows: exchange rate (C1), GDP per capita (C2), public debt (C3), inflation rate (C4), and monetary policy rate (C5). When computing wavelet correlation coefficients, the horizontal axis illustrates potential

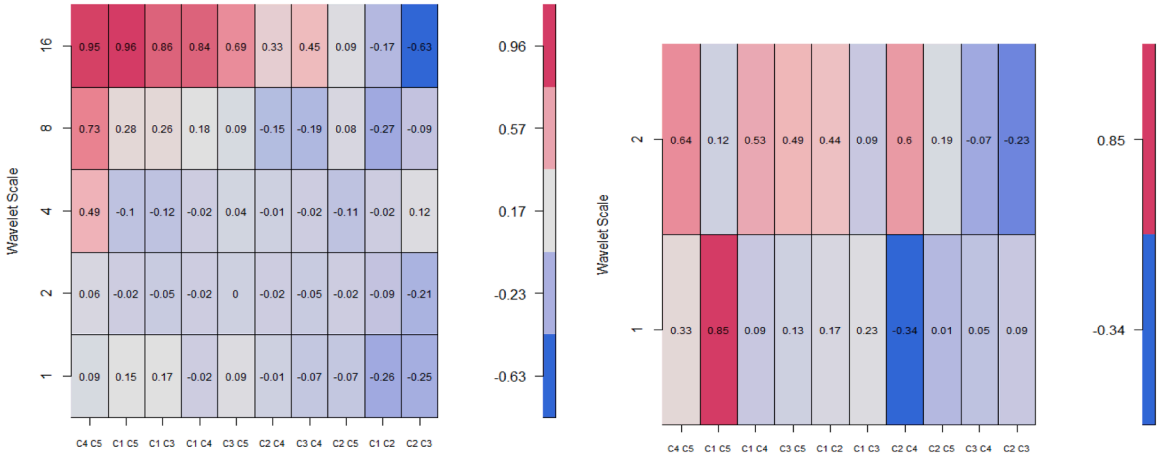


Fig. 4. Bivariate wavelet correlation before (left) (2000/01/01–2020/03/12) and during COVID-19 (right) (2020/03/12–2022/12/30).

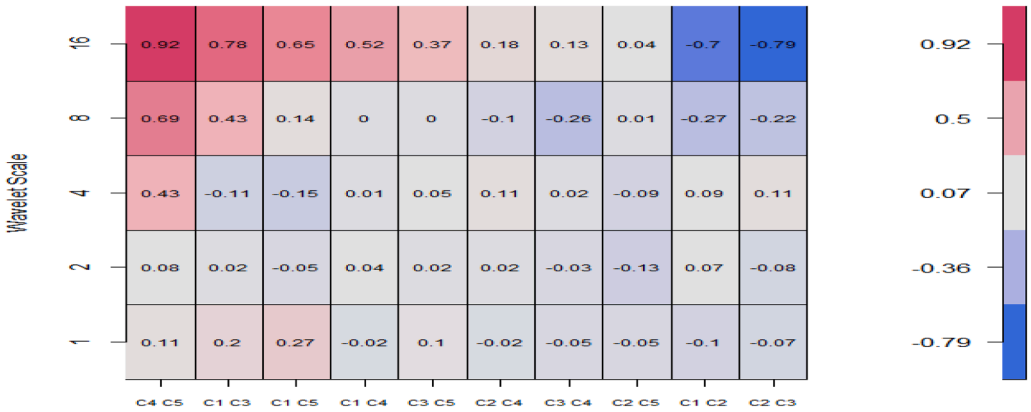


Fig. 5. Wavelet bivariate correlations matrix (full sample period: 2000/01/12–2022/01/12).

combinations. The transition from left to right indicates a decreasing degree of similarity between pairs of ER, GDP, PD, IF, and MP connections. On the vertical axis, wavelet scales represent different frequencies. Consequently, the bivariate contemporary connectedness matrix is influenced by frequency and combines characteristics from both time and frequency scales [57].

The variables are encoded as Exchange rate (C1), GDP per capita (C2), Public debt (C3), Inflation rate (C4) and Monetary policy rate (C5).

We present a wavelet correlation matrix for the returns related to the selected variables, considering five different wavelet scales for pre-, during-COVID-19, and full sample period; two scales for during the COVID-19 era. Interestingly, the results are almost like those obtained through bivariate analysis. Within these findings, a mix of positive and negative relationships is observed among the pairs of variables. Notably, monetary rate-inflation displayed the highest levels of co-movement before (0.96) and during (0.85) COVID-19 periods, with coefficients varying between 0.15 and 0.96 (before) and 0.85 and 0.12 (during COVID-19) across various time scales. These coefficient values suggest that the positive correlation between MP and the IF increases in strength from the 4th month to the 16th month (before the COVID-19 sample period), and remains asymmetrical across all the wavelet scales. During COVID-19, the correlation was strong in the 1st month but weakened beyond that month. This is accompanied by nexuses of ER-PD, and ER-IF and ended with PD-GDP for both pre- and during COVID-19 sample periods.

Significant co-movements were found between IF-MP, ER-PD, ER-MP and GDP-MP at the 16th wavelet scales pre-COVID-19, implying that the interdependency between these variables is significant in the long run. This observation aligns with the findings of Chaudhry et al. [42] and Olatunbode et al. [50]. During the COVID-19 period, moderate co-movements were portrayed in IF-MP, ER-MP, PD-MP and ER-GDP in the short-term (2nd month).

Throughout the wavelet scale, GDP per capita and other variables nexus show a very weak negative and positive connectedness in different scales. Thus, changes in other variables have little influence on GDP per capita in Ghana. The argument is supported by previous studies: Albu and Albu [33], Adaramola and Dada [46], Baidoo et al. [8], Ramoni et al. [26] (negative connectedness), and Kaboro et al. [44] (positive connectedness).

Wavelet multiple correlations (WMC)

Figs. 6a and 6b depict the WMC for return series of GDP per capita, exchange rate volatility, public debt, inflation rate, and monetary policy rate, which have been localised by frequency using the MODWT method [64]. Figs. 6a and 6b are designed to assess the level of interconnections among the examined variables across various time scales, spanning from short-term to long-term dynamics. They do not explicitly specify which variable leads or lags but offer insights into the overall co-movements among the variables. Monthly return series exhibit a comparatively higher level of interconnectedness approaching 98 % (pre- and full sample period) and 92 % during the COVID-19 crisis for the wavelet multiple correlations, 98 % for the lower panel, and 99 % for the upper panel for pre-COVID-19, 65 % (lower) and 99 % (upper) panel during COVID and 90 % (lower) and 99 % (upper) for the full sample period.

This indicates that numerous correlations are consistently strengthening over time. Consequently, the monthly returns of a single variable can be explained to a significant extent by the other four variables, accounting for approximately 98 % (92 %) of interdependence on a monthly basis, extending up to scale 16 (2). These findings align with existing literature [57,61,65].

WMCC

Figs. 7a and 7b present the wavelet multiple cross-correlation coefficients, encompassing five different wavelet scales (pre-COVID-19 and full sample period) and two scales (During COVID-19). As discussed earlier in the exploration of multiple wavelet analysis, the scales on the y-axis carry similar meanings. However, the vertical axis depicts the series' time lag, covering a range of 6 months (pre- and during COVID-19) and 20 months (full sample period) for both direct and inverse lags. The inclusion of both direct and indirect lags is crucial for confirming potential leading and lagging variables. Specifically, positive lag positions indicate variables that lag, while negative lag positions indicate variables that lead at the corresponding scales. When the localisation coincides with the zero-lag (as indicated by dashed lines), it implies neither leading nor lagging behaviour. Localisation points to the highest figures in the non-curve combination of all elements at the wavelet scales, and these are marked with dashed lines in the dotted lines at all lags.

When a variable is listed on a scale, it signifies that it has the highest coefficient in the straight combination of all the variables at that specific scale. If a dashed line accompanies a listed variable in the heat map, it indicates an existing lead/lag. In practical terms, the economic significance of wavelet multiple cross-correlations (WMCC) lies in its capacity to reveal the extent of interdependence between variables. It also aids in identifying the most prevailing element at a specific wavelet scale, indicating whether it acts as a leading variable (the first to respond to shocks) or a lagging variable (responding to shocks after the other variables have reacted). The pre-COVID-19 period depicts GDP responding first to shocks within a 1–3 scale at lags −3 and −1 in the short-run. In the medium-term, policy rate responses to shocks after all variables have a lag of 1 between 3 and 5 months. Exchange rate responses to shocks last in the long run at lag 1 beyond scale 12 (12 months). No variable was noted to lead or lag during COVID-19 times. From the full sample, the only notable scene is the monetary policy rate lagging within 3.5–4.5 on the scale representing four months and two weeks (at lag 9) within the medium-term.

Wavelet-based non-causality test

This research utilised the wavelet-centred causality test to assess the reliability of the cross-wavelet analysis findings. This non-parametric causality test, employing MODWT, allows for the evaluation of causal relationships between observed variables across various frequency ranges [71,72]. Diks and Panchenko [73] argue that unlike conventional causality tests, this method mitigates issues such as excessive rejection of the null hypothesis due to structural changes in the data and addresses the sensitivity to fluctuations in vector distributions. In this analysis, the null hypothesis assumes the absence of nonlinear causal relationships. Most results from the root series indicated a bidirectional causality existed between exchange rate and economic growth, and exchange rate and public debt

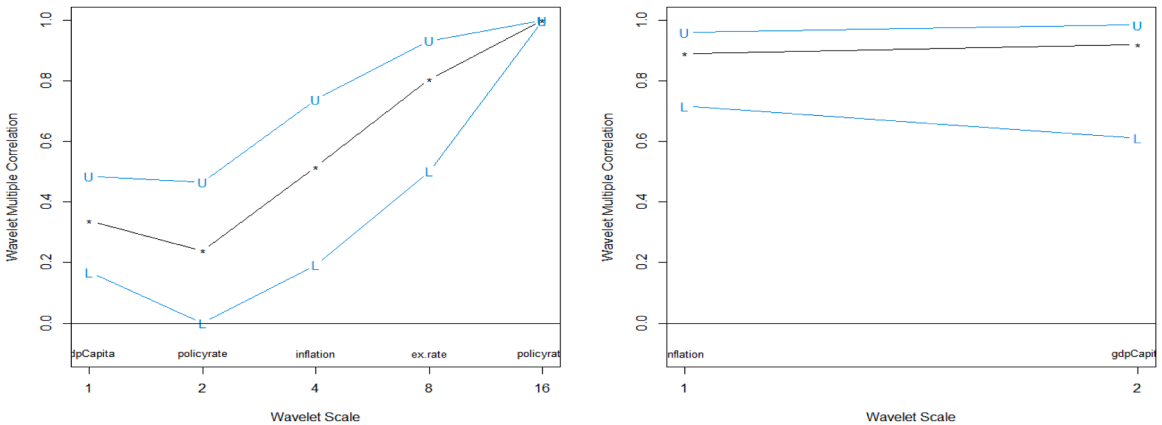


Fig. 6a. Wavelet Multiple Correlation pre-(left) and during COVID-19 (right).

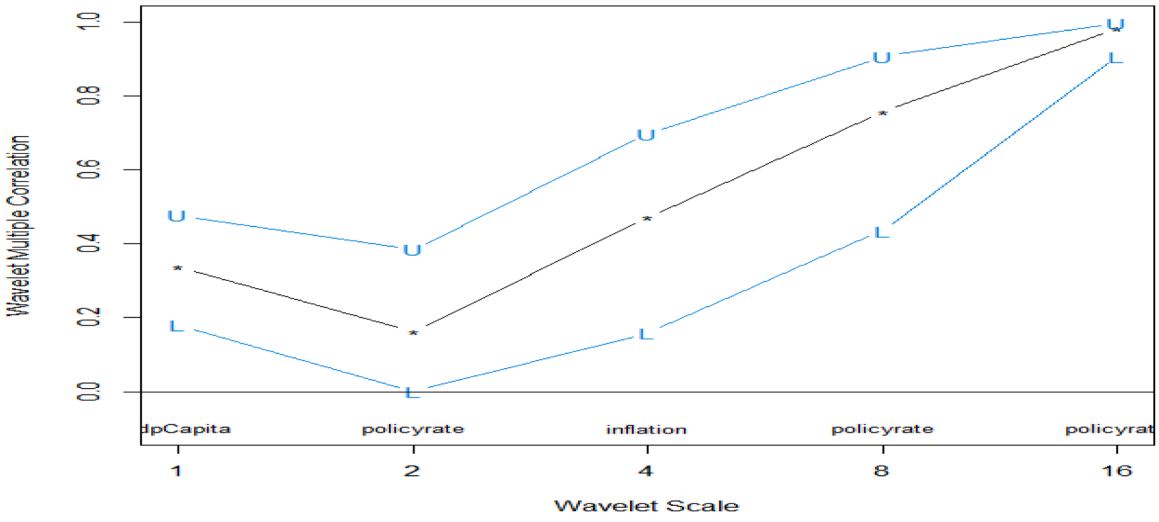


Fig. 6b. Wavelet Multiple Correlation (2000/01/12–2022/01/12).

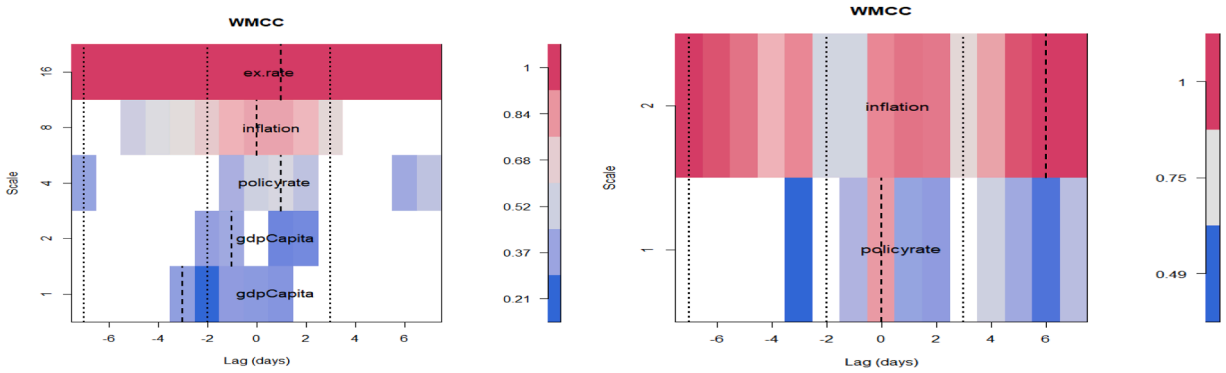


Fig. 7a. WMCC before (left), and during COVID-19 (right).

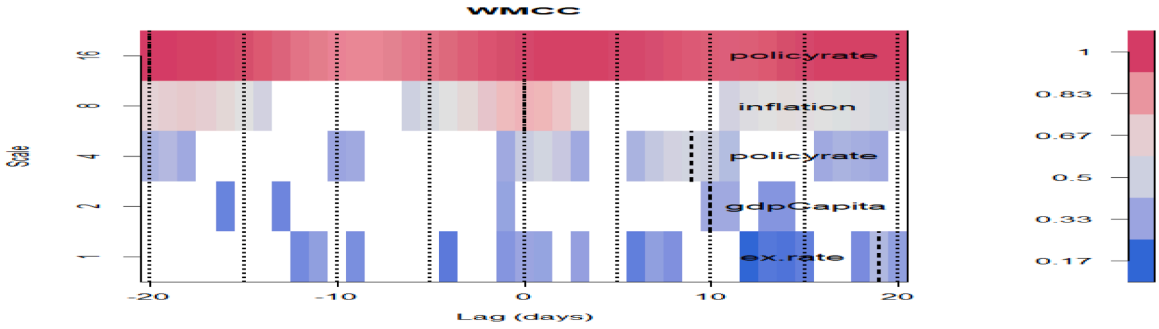


Fig. 7b. Wavelet multiple cross-correlation before and during COVID-19.

at 5 % and 10 % significant levels. Contrary, a unidirectional causal effect was revealed between monetary policy and economic output at a 5% level. These findings agree with the WCA's findings and are further supported by the disintegrated series, indicating ER, PD, IF, MP and GD influence each other at different frequencies. These results validate the findings of the WCA and offer significant insights for policymakers and investors in Ghana. Detailed results can be found in Table 2 for both the original and frequency-based data series.

Conclusion

This paper investigated the connectedness between exchange rate volatility, public debt, monetary rate, inflation and economic

growth in Ghana using monthly data from 2000 to 2022. Analysis initially divided the data into before COVID-19 and during COVID-19 and subsequently used the full dataset. The understanding of the nexus of these variables is crucial in government fiscal and monetary policy adjustment, especially in times when the country's external debt is ballooning against national income with unfavourable country risk ratings from international rating agencies.

The article utilised Continuous Morlet Transform, wavelet coherency and multiple wavelet correlation with their generally accepted features. The methods' strength lies in their resilience against established indicators of shared movement, achieved by focusing on specific time-frequency domains. Additionally, wavelet technique excels in tracking the progression of the connection over time and differentiating between occurrences at high and low frequencies.

Findings show a moderate co-movement between public debt and GDP in the short- and long-run but no significant connectedness was found in the medium-term. A strong positive co-movement was observed between ER and economic performance across all frequencies. The coherence between exchange rate and public debt within the study period shows a nonlinear relationship as weak negative coherencies existed in the medium, weak positive in the short-run and strong positive in the long-run. In the case of the inflation rate and GDP per capita, insignificant connectedness was found in the short- and long-run while moderate and positive coherence existed in the medium-run. There exists an anti-phase between monetary policy and GDP in the short-run and medium-run frequencies, but a weak relationship in the long-run scale.

A weak positive co-movement existed between the exchange rate-public debt nexus in the short-run while negative (positive) moderate (weak) coherence existed in the medium- (long-run) frequencies. The correlation between the exchange rate and the inflation rate in Ghana was insignificant in the short-run but significant in the medium and long term beyond 2016. Between ER and MP, a significant connectedness was revealed during the COVID-19 era, predominantly in the medium term. A positive and significant connectedness was uncovered between the inflation rate and monetary policy rate across all frequencies but not beyond the 2013 scales. The results from the full data, before COVID-19 and during COVID-19 support one another as they all exhibit similar findings.

The results imply that government borrowings between 2000 and 2022 do not correspond to GDP growth. This suggests that the government's purpose of borrowing (especially) from external sources has shifted from investment in engine blocks of the economy to other purposes, which might not have the capability to resolve the rising debt in the country. The consequences of such actions show the likelihood of a perpetual elevation in PD in the country if urgent attention is not shifted to fiscal policies. The real exchange rate influences public debt in the medium- and long-run. ER and economic growth co-move moderately in the medium-term suggesting that depreciations in the Cedis do not correlate with GDP growth in the short- and long-run. This might not be healthy for the economy in the long-run as the correlation between variables weakens. The changes in inflation are dominantly induced by the ER in the long-run indicating a decline in the Cedis with a ripple effect on the prices in the country. The increase or decrease of MP does not drive economic performance.

It is recommended that government borrowing should be channelled directly into economic activities such as infrastructural development, education, health facilities, and research and development to enhance economic growth. Besides, the government of Ghana should exercise caution when considering increases in public (domestic) debt to mitigate potential fluctuations in inflation and the associated risks to the economy. The study suggests that relying solely on monetary policy may not be sufficient to manage inflation effectively, and it is recommended that the adoption of stringent fiscal and other non-monetary measures is necessary and efficient to achieve sustainable and inclusive growth. Private borrowing must be directed toward productive activities for economic growth. Regulators must implement policies that would enhance the stability and appreciation of the cedis against major trading currencies.

Future studies can focus on institutional quality, public debt and economic growth in Ghana. Besides, studies on the connectedness of credit rating, exchange rate volatility, public debt and economic growth in Ghana can be helpful to literature and policymakers.

CRediT authorship contribution statement

Absalom Odoom: Conceptualization, Writing – original draft, Project administration, Methodology, Supervision. **Peterson Owusu Junior:** Conceptualization, Software, Validation, Supervision. **Anthony Adu-Asare Idun:** Conceptualization, Supervision. **Patrick Kwashie Akorsu:** Supervision, Formal analysis, Visualization.

Declaration of interests

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

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