ISSN (0): 3051-3006, ISSN (P): 3051-2999 2026, Volume 2, Issue 1, Page: 1-12.
WORLD JOURNAL OF ADVANCE MEDICINE
www.wjam.net

Research Article

BLOCKCHAIN TECHNOLOGY-BASED TRACEABILITY FOR COUNTERFEIT MEDICINE PREVENTION IN COMMUNITY PHARMACIES IN BAYELSA STATE, NIGERIA

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Article Info

Article Received: 05 July 2026,
Article Revised: 25 July 2026,
Published on: 01 August 2026.

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https://doi.org/10.5281/zenodo.21738827

How to cite this Article: *1Oraekeyi Anthony Uchenna, (2026). Blockchain Technology-Based Traceability For Counterfeit Medicine Prevention In Community Pharmacies In Bayelsa State, Nigeria. International Journal of Advance Healthcare Research, 2(1), 1-12.

ABSTRACT

Counterfeit and substandard medicines remain a major global public health threat, with the World Health Organization estimating that up to 10% of medicines in low- and middle-income countries are falsified or substandard, exceeding 20% for some therapeutic classes in sub-Saharan Africa. Blockchain technology, with its decentralised, immutable, and transparent digital ledger architecture, has been proposed as a promising solution for strengthening pharmaceutical supply chain traceability, yet little is known about the readiness of community pharmacies in Nigeria to adopt it. This study assessed the knowledge, current practices, and implementation readiness of blockchain-based traceability for counterfeit medicine prevention among community pharmacists in Bayelsa State, Nigeria, and examined the barriers and enablers influencing adoption. A descriptive cross-sectional survey design was employed, using a structured, validated questionnaire administered electronically through the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter. A total of 119 valid responses were obtained, exceeding the minimum sample size derived from Yamane's and Cochran's formulae, representing a 79.3% response rate. Data were analysed using descriptive and inferential statistics, including Chi-square tests. Findings revealed that although 71.4% of respondents had heard of blockchain technology, mean knowledge scores across core blockchain concepts were uniformly low (1.26-1.72 on a 5-point scale), reflecting a substantial awareness-comprehension gap. Authentication practices were overwhelmingly manual, with 77.3% relying on visual inspection of NAFDAC numbers and only 9.2% using digital scanning; 68.9% of pharmacists had encountered suspected counterfeit medicines in the past year. Implementation readiness was below average (Mean = 2.70/5.0), driven by strong training willingness (Mean = 3.74) but deficient infrastructure (Mean = 1.80). Resistance to change and high cost were the leading barriers, while user-friendly applications and mandatory regulation were the strongest enablers. The study concludes that community pharmacies in Bayelsa State are not yet structurally ready for blockchain-based traceability, although a receptive attitudinal environment and strong professional motivation exist to support a phased transition. It is recommended that NAFDAC and the Pharmacists Council of Nigeria develop a phased regulatory framework and integrate blockchain literacy into continuing professional development, that government prioritise infrastructure investment, and that technology developers design mobile-first, user-friendly, offline-capable systems, to enable a coordinated transition toward blockchain-enabled pharmaceutical traceability in Nigeria.

KEYWORDS: Blockchain technology, Traceability, Counterfeit medicines, Community pharmacy, Implementation readiness, Bayelsa State, Nigeria.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Counterfeit and substandard medications continue to represent one of the most significant and pressing public health crises on a global scale, particularly exacerbating the challenges faced by low- and middle-income countries (LMICs), with Nigeria standing as a notable example of this troubling trend. The World Health Organization (WHO) has estimated that roughly 10% of the pharmaceuticals available in developing regions are either substandard or intentionally falsified, a situation that carries dire consequences for treatment efficacy, contributes to the alarming rise of antimicrobial resistance, leads to preventable illnesses and deaths, and fundamentally undermines public trust in healthcare systems and institutions (WHO, 2017; WHO, 2019; Nayyar et al., 2019). More troubling still, evidence from sub-Saharan Africa suggests that the incidence of poor-quality medicines may surpass 20% within certain therapeutic categories, including antimalarials and antibiotics, a statistic that underscores the pervasive systemic deficiencies in pharmaceutical governance and the oversight of supply chains across the region (Bendavid et al., 2017; Akinyandenu, 2013; Ugochukwu & Onwujekwe, 2018).

The global burden of counterfeit pharmaceuticals is not merely a supply chain inconvenience; it constitutes a silent epidemic that erodes the very foundations upon which modern healthcare delivery is built. When patients receive medications that lack the appropriate active pharmaceutical ingredients, contain incorrect dosages, or harbour toxic contaminants, the consequences cascade throughout the health system. Treatment failures become commonplace, disease conditions that should be curable persist and worsen, and the emergence of drug-resistant strains of pathogens accelerates, creating long-term epidemiological threats that transcend national boundaries. The WHO's Global Surveillance and Monitoring System for Substandard and Falsified Medical Products has documented that cardiovascular medicines, antimicrobials, and anti-malarial drugs are among the most commonly falsified therapeutic categories, each representing critical treatment areas where pharmaceutical fraud can have immediately fatal consequences (WHO, 2023).

In the context of Nigeria specifically, the predicament posed by counterfeit and substandard pharmaceuticals assumes an especially severe character due to the intricate structural challenges inherent in the national pharmaceutical supply chain. This system is characterized by a heavy dependency on imports, which account for more than 70% of the country's finished pharmaceutical products, alongside fragmented distribution networks that involve multiple intermediaries between manufacturers and end-users, the operation of informal drug markets that exist largely outside regulatory scrutiny, porous national borders that facilitate cross-border smuggling of falsified products, and a distinct lack of coordinated regulatory efforts across the nation's borders (Yadav, 2015; OECD, 2020; Statista, 2023). Collectively, these vulnerabilities create an environment that is exceptionally conducive to the infiltration of falsified medicines into legitimate distribution channels, particularly at the community pharmacy level and within informal medicine outlets, where mechanisms for verification and validation of pharmaceutical products are frequently inadequate or altogether absent (Adebisi, Nwogu, & Alaran, 2020; Mackey & Nayyar, 2017).

The implications of counterfeit medications for public health extend far beyond the direct clinical damage they cause to individual patients. A growing body of research has established robust connections between the presence and prevalence of falsified medicines and a cascading series of adverse outcomes, including the escalation of healthcare expenses as patients require additional or alternative treatments, extended periods of illness and hospitalization, diminished economic productivity arising from prolonged morbidity, and a significant and often irreversible decline in public trust towards healthcare providers, pharmaceutical systems, and regulatory institutions (Nayyar et al., 2019; Mackey & Liang, 2019). During acute public health emergencies, such as the unprecedented COVID-19 pandemic that swept across the globe beginning in 2020, the prevalence of misinformation and fraudulent medical products exacerbated these pre-existing risks in sub-Saharan Africa, including Nigeria, thereby illuminating the complex and dangerous interplay between inadequate supply chain controls, compromised integrity of health information, and the overarching insecurity in public health systems that characterizes many developing nations (Adebisi et al., 2021; Chattu & Yaya, 2020).

In response to the magnitude and persistence of these challenges, Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) has taken decisive steps to enhance regulatory frameworks and deploy technological interventions aimed at bolstering the assurance of medicine quality across the country. Notable initiatives undertaken by the agency have included the implementation of comprehensive pharmaceutical product traceability guidelines, the introduction and nationwide rollout of the Mobile Authentication Service (MAS) which enables consumers to verify the authenticity of pharmaceutical products via text messaging, and sustained efforts to align national practices with international serialization and traceability standards promulgated by organizations such as GS1 and the International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH). These measures collectively represent a significant commitment to the fight against counterfeit medicines at the national level (NAFDAC, 2021; NAFDAC, 2023). However, despite these notable and commendable efforts, regulatory assessments and independent academic evaluations have consistently revealed ongoing enforcement gaps, a troubling lack of

interoperability among the various stakeholders within the pharmaceutical supply chain, and inconsistent adoption of sophisticated traceability technologies, particularly within the community pharmacy sector, which serves as the most immediate point of contact between the pharmaceutical system and the general public (Modum & Gustafsson, 2021; Shuchih & Rouse, 2019).

It is within this complex and challenging landscape that blockchain technology, broadly defined as a decentralized, immutable distributed ledger technology (DLT), has emerged as a potentially transformative digital innovation that could fundamentally revolutionize the governance of pharmaceutical supply chains worldwide. The inherent architectural capabilities of blockchain technology enable several critical functionalities that are directly relevant to the challenges of pharmaceutical traceability: comprehensive end-to-end tracking of products from the point of manufacture through every stage of distribution to the final point of dispensing, secure and tamper-resistant record-keeping that preserves data integrity across multiple nodes without reliance on a single trusted authority, cryptographic authentication measures that enable the verification of product identity and transaction legitimacy, and real-time verification of product provenance that allows any authorized stakeholder to confirm the authentic origin and handling history of a pharmaceutical product at any point along the supply chain (Casino et al., 2019; Kshetri, 2018; De Sousa Jabbour et al., 2018). Crucially, all of these capabilities can be executed across multiple independent stakeholders, including manufacturers, distributors, wholesalers, regulatory agencies, and pharmacies, without the necessity of a singular central governing authority or a unified database that could constitute a single point of failure or manipulation (Tseng et al., 2018; Toyoda et al., 2017; Zou, Zhang, & Wang, 2022).

Beyond its core ledger functionalities, blockchain technology possesses the remarkable ability to significantly enhance various aspects of data integrity, accountability, and trustworthiness in digital transactions, particularly within the context of healthcare and pharmaceutical operations. Blockchain does not operate in isolation; rather, it serves to complement and augment existing traceability technologies, such as barcoding systems, radio-frequency identification (RFID) tagging, and the established GS1 data standards for product identification and serialization. By providing an immutable and shared data layer that integrates information from these diverse technological inputs, blockchain creates a unified and auditable record of the pharmaceutical supply chain that is resistant to tampering, retroactive modification, or selective data deletion (Medina & Rufin, 2020; Sunny et al., 2020). Furthermore, the integration of blockchain technology with smart contracts, which are self-executing digital agreements encoded with predefined rules and conditions, can facilitate the automation of critical supply chain governance processes, including compliance verification checks against regulatory standards, automated triggers for product recall procedures when safety thresholds are breached, and streamlined regulatory reporting obligations that reduce the administrative burden on both pharmaceutical operators and regulatory agencies. The cumulative effect of these capabilities is a substantially bolstered framework for regulatory oversight and significantly improved patient safety outcomes across the pharmaceutical ecosystem (Singh et al., 2020; Iqbal & Matulevičius, 2021).

Nevertheless, despite the extensive range of potential advantages that blockchain technology could confer upon pharmaceutical supply chain governance, the actual adoption of such innovative solutions within healthcare supply chains, especially in low- and middle-income countries (LMICs), continues to be characterized by significant limitations and formidable challenges. Numerous studies conducted across different geographical and institutional contexts have identified a variety of key barriers that impede the widespread implementation of blockchain technology in the pharmaceutical sector. These barriers include, but are not limited to, the high costs associated with the initial acquisition, deployment, and ongoing maintenance of blockchain systems; the inherent complexity of the technology itself, which requires specialized technical knowledge for implementation and management; insufficient digital infrastructure, including unreliable internet connectivity and inconsistent electricity supply in many developing regions; uncertainty in regulatory frameworks regarding the legal status, governance, and compliance requirements for blockchain-based systems; growing concerns surrounding data privacy and the management of sensitive health information on distributed networks; and a pervasive lack of readiness among various stakeholders, including pharmacists, distributors, and regulators, to embrace these fundamentally new technological paradigms (Queiroz & Fosso Wamba, 2019; Moubarak & Filali, 2022; Attaran, 2020). In the specific context of Nigeria, there exists a particularly notable deficiency in empirical evidence regarding the preparedness of community pharmacies, which serve as the most numerous and accessible point of pharmaceutical service delivery, to adopt blockchain technology for traceability purposes. This deficiency gives rise to a substantial knowledge gap concerning stakeholders' awareness and understanding of blockchain concepts, the current traceability methods and authentication practices employed at the community pharmacy level, and the overall organizational, infrastructural, and human-capacity preparedness of these pharmacies to transition to blockchain-based traceability solutions.

1.2 Statement of the Problem

The ongoing prevalence of counterfeit and substandard medicines continues to jeopardize the quality, safety, and overall effectiveness of healthcare delivery systems in Nigeria, with community pharmacies representing a

particularly vulnerable and critical node within the intricate network of the national pharmaceutical supply chain. Community pharmacies occupy a unique and strategically important position within the healthcare architecture of Nigeria: they serve as the most accessible point of contact between the pharmaceutical system and the general population, particularly in underserved areas where hospital facilities and government health centres are either distant, overburdened, or inadequately stocked. Consequently, the integrity of medicines dispensed through community pharmacies has a direct and measurable impact on population health outcomes, making these establishments a priority target for counterfeit medicine prevention interventions (Adebisi et al., 2020; NAFDAC, 2023).

While national regulatory initiatives, most notably those spearheaded by NAFDAC and aimed at enhancing traceability and combating counterfeit products, have demonstrated an institutional commitment to addressing this pressing challenge, existing evidence consistently suggests that there remain significant and persistent gaps in technology awareness, structured practices for medicine traceability, and the institutional readiness of frontline pharmaceutical stakeholders to adopt advanced digital solutions. The regulatory interventions deployed to date, including the Mobile Authentication Service (MAS), have achieved only partial penetration, with many community pharmacies continuing to rely on rudimentary manual verification processes that offer limited protection against increasingly sophisticated counterfeiting operations (Adebisi et al., 2020; NAFDAC, 2023).

Traditional pharmaceutical traceability systems, which typically rely on barcode-based verification processes, paper-based documentation, and radio-frequency identification (RFID) technology, are often characterized by a centralized and inherently fragmented structure that renders them susceptible to data manipulation, unauthorized alterations, and a general lack of transparency across the multiple nodes of the supply chain. These systems typically operate in silos, with each stakeholder, whether manufacturer, distributor, wholesaler, or pharmacy, maintaining independent records that are difficult to cross-reference, verify, or audit in real time. Such fragmentation not only undermines the overall effectiveness of traceability in managing complex supply chains involving multiple actors but also creates exploitable gaps through which counterfeit products can enter and persist within legitimate distribution channels (Kumar, Liu, & Shan, 2020; Modum & Gustafsson, 2021).

These limitations become even more pronounced in environments that are marked by weak infrastructural capabilities, informal and poorly regulated distribution networks, and challenging geographical conditions, such as those found in Bayelsa State, Nigeria. The state's unique riverine geography, characterized by dispersed settlements connected predominantly by waterways, fragmented logistics infrastructure, and significant "last-mile" delivery challenges, means that achieving real-time verification of pharmaceutical products and ensuring comprehensive end-to-end visibility across the supply chain poses considerable and often insurmountable challenges for conventional traceability systems. Furthermore, the humid tropical climate of the Niger Delta region creates additional pressures on pharmaceutical product integrity, as improper storage conditions exacerbated by unreliable cold chain infrastructure can compromise the quality of genuine medicines, making it even more difficult to distinguish between authentic products that have degraded and deliberately falsified ones.

Blockchain technology presents a fundamentally distinct architectural framework that is predicated on the principles of decentralized consensus, robust cryptographic security measures, and immutable audit trails, which could substantially enhance the traceability of pharmaceuticals and contribute meaningfully to the prevention of counterfeit product infiltration. However, the degree to which community pharmacies in Nigeria, and in Bayelsa State specifically, possess the necessary knowledge of blockchain concepts, the operational capabilities to integrate blockchain into existing workflows, and the overall organizational readiness to successfully implement and sustain blockchain-based traceability systems remains, for the most part, undocumented and critically under-researched. The absence of empirical evidence at both the sub-national and practical levels severely constrains informed policymaking, the design of targeted capacity-building initiatives, the allocation of resources for digital infrastructure development, and the effective deployment of technological solutions that could meaningfully reduce the burden of counterfeit medicines.

Consequently, this study seeks to address this critical evidence gap by systematically and rigorously examining the levels of knowledge, current operational practices, and the overall readiness for implementation of blockchain technology-based traceability systems among community pharmacies situated in Bayelsa State, Nigeria. By situating the assessment of blockchain adoption within the broader framework of counterfeit medicine prevention and public health protection, this study aspires to generate actionable evidence that can effectively inform regulatory strategies, enhance professional pharmaceutical practices, guide technology design decisions, and ultimately contribute to the sustainable digital transformation of the pharmaceutical supply chain in Nigeria.

1.3 Research Questions

The following research questions were formulated to guide this investigation:

i. What is the level of knowledge of blockchain-based traceability among community pharmacists in Bayelsa State?

ii. What are the current practices used by community pharmacies for medicine authentication and traceability?
iii. What is the level of implementation readiness for blockchain technology-based traceability systems among stakeholders in community pharmacies in Bayelsa State?
iv. What barriers and enablers exist for adopting blockchain traceability within pharmaceutical supply chains in Bayelsa State?

1.4 Research Objectives

Aim: To assess the knowledge, current practices, and implementation readiness of blockchain technology-based traceability for counterfeit medicine prevention in community pharmacies in Bayelsa State, Nigeria.

Specific Objectives

i. To determine the level of awareness and understanding of blockchain-based traceability among community pharmacists in Bayelsa State.
ii. To investigate the current practices used by community pharmacies for medicine authentication and traceability.
iii. To assess the implementation readiness for blockchain technology-based traceability systems among stakeholders in community pharmacies in Bayelsa State.
iv. To evaluate the barriers and enablers for adopting blockchain traceability within pharmaceutical supply chains in Bayelsa State.

1.5 Significance of the Study

The significance of this study is multi-dimensional, spanning implications for pharmacy practice, regulatory policy, technology development, and public health protection. Each dimension represents a distinct yet interconnected contribution to the broader discourse on pharmaceutical supply chain integrity and digital health innovation in Nigeria and comparable contexts.

Significance for Pharmacy Practitioners and Healthcare Organizations: The findings of this study offer valuable and directly applicable insights for pharmacy practitioners and healthcare organizations by systematically identifying the structural, technical, and human-capacity enablers and barriers that influence the adoption of blockchain-based traceability in community pharmacy settings. These insights are intended to guide strategic investment decisions regarding the acquisition and deployment of digital traceability systems, to inform the design of workforce training initiatives that address identified knowledge and skill gaps, and to shape system design choices that prioritize usability, interoperability, and alignment with existing pharmaceutical workflows. Enhanced traceability, when effectively implemented, has the potential to significantly reduce the circulation of substandard and falsified medicines within community pharmacies, thereby improving therapeutic outcomes for patients, reducing the incidence of treatment failures attributable to fake medicines, and reinforcing public trust in community pharmacy services as reliable and safe sources of authentic pharmaceutical products.

Significance for Regulators and Policymakers: This study bridges critical gaps at the intersection of health informatics, pharmacy practice, and technology adoption science, generating empirical evidence that is directly relevant to the operational mandates of key regulatory bodies, including the Pharmacists Council of Nigeria (PCN) and the National Agency for Food and Drug Administration and Control (NAFDAC). The findings illuminate the current state of readiness among community pharmacies for blockchain traceability adoption, identify the specific dimensions in which readiness is lacking, and articulate the conditions under which adoption is most likely to succeed. These insights can assist regulators in designing phased implementation roadmaps, compliance frameworks that account for the diverse operational realities of community pharmacies, and incentive structures, whether regulatory, financial, or professional, that facilitate the responsible and equitable integration of blockchain technologies into the national drug supply chain system. Furthermore, the study's findings on barriers and enablers provide an evidence base for policymakers seeking to craft targeted interventions that address the root causes of adoption resistance, infrastructure deficits, and knowledge gaps within the community pharmacy sector.

Significance for Technology Developers and Digital Health Innovators: The study holds strategic significance for technology developers and digital health innovators by articulating the contextual requirements, operational constraints, and user expectations that characterize pharmacy practice in Bayelsa State and, by extension, in comparable resource-limited settings across Nigeria and the broader West African region. Understanding these contextual dynamics is essential for the design of blockchain platforms and traceability applications that are genuinely responsive to local realities, including infrastructural constraints such as intermittent internet connectivity and unreliable power supply, regulatory expectations regarding data standards and compliance reporting, and the digital literacy levels and technology adoption attitudes of end-users. Blockchain solutions designed without regard for these contextual factors are unlikely to achieve sustainable adoption and long-term impact, regardless of their technical sophistication. By providing this contextual intelligence, the study contributes to the development of more appropriate, user-centred, and contextually sensitive blockchain solutions for pharmaceutical supply chain management.

Significance for Academic Research and Knowledge Advancement: From an academic perspective, this study contributes to the expanding body of literature on blockchain technology adoption in healthcare settings within developing countries. It addresses a notable gap in empirical research by providing sub-national data from a specific geographical and operational context, Bayelsa State, that has not been previously studied in relation to blockchain readiness. The study's integration of multiple

theoretical frameworks, including the Diffusion of Innovations theory, the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, and the Technology-Organization-Environment framework, among others, demonstrates a comprehensive analytical approach that can serve as a model for future research endeavours examining technology adoption in similar healthcare contexts across Africa and other developing regions.

1.6 Rationale and Justification of the Study

The rationale underpinning this scholarly investigation is firmly anchored in the observable and well-documented disintegration of centralized, manual, and institutionally segmented regulatory frameworks that have been tasked with the critical responsibility of safeguarding the concluding phases of pharmaceutical distribution, particularly within resource-limited contexts such as the Niger Delta region of Nigeria. Despite the ongoing and persistent regulatory efforts orchestrated by Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC), which encompass various initiatives including the implementation of the Mobile Authentication Service (MAS) and the introduction of pharmaceutical product traceability guidelines, the alarming and widespread circulation of substandard and falsified medications continues to be a pressing issue that cannot be overlooked or minimized. This troubling persistence of counterfeit pharmaceuticals within the supply chain indicates not merely a failure in enforcement mechanisms but rather points to a deeper, more systemic inadequacy within the existing regulatory and technological framework: the current systems in place are predominantly reactive in nature, necessitating verification of product authenticity only after the point of purchase has occurred, which ultimately shifts the burden of quality assurance onto consumers themselves, thereby exposing them to unacceptable levels of risk. The present study is therefore articulated as a necessary scholarly response to the urgent need for a paradigm transition from the prevailing reactive model of post hoc verification to a forward-thinking paradigm of proactive immutability, wherein the integrity of pharmaceutical data is maintained continuously and cannot be subjected to retroactive alteration at any point along the distribution continuum.

Bayelsa State serves as a particularly apposite and instructive illustration of this overarching systemic fragility and vulnerability. The unique riverine geography of the region, characterized by its dispersed settlements separated by an intricate network of waterways, fragmented logistics and transportation infrastructure, and the significant challenges associated with last-mile delivery in a predominantly aquatic environment, creates persistent regulatory blind spots where the efficacy of centralized oversight diminishes dramatically. In such conditions, pharmaceutical products may pass through numerous unregulated intermediaries before reaching the community pharmacy, with each transfer point representing a potential vulnerability for counterfeit infiltration. Centralized databases, which are inherently reliant on stable and consistent network connectivity, hierarchical trust dynamics, and institutional integrity, become particularly vulnerable to single points of failure, administrative corruption, and operational discontinuities under these challenging geographical and infrastructural conditions. In stark contrast, the introduction of a decentralized ledger architecture, as embodied by blockchain technology, offers a transformative paradigm shift by establishing a distributed trust protocol that is not tethered to any singular geographic location or institutional entity. The justification for this research is therefore predicated, in part, on its potential to elucidate how blockchain technology can fundamentally reconfigure the architecture of trust within pharmaceutical supply chains, transforming trust from an organizational promise, dependent on the integrity and capacity of individual institutions, into a systemic property that is enforced cryptographically and maintained immutably across a distributed network, thereby substantially enhancing the reliability and verifiability of pharmaceutical transactions.

Equally essential to consider is the acknowledgement that the theoretical soundness of a technology does not necessarily guarantee its practical applicability or successful adoption in real-world settings, particularly within the complex socio-technical environments characteristic of developing healthcare systems. A considerable portion of the existing scholarly literature surrounding blockchain technology in healthcare remains largely confined to discussions focused on algorithmic design, cryptographic protocols, or abstract conceptual frameworks, offering minimal practical insights into the nuances of real-world adoption, the challenges of user acceptance, the constraints imposed by existing infrastructure, or the institutional dynamics that shape technology implementation in low-resource environments. This study endeavours to address this significant empirical lacuna by foregrounding implementation readiness as a pivotal analytical concern that warrants rigorous and context-sensitive examination. Specifically, the study delves into what may be characterized as the "human-in-the-loop" dimension of blockchain adoption, posing critical inquiries into whether licensed community pharmacists operating in urban and semi-urban centres within Bayelsa State, such as Yenagoa, possess the requisite levels of digital literacy, enjoy access to the necessary digital infrastructure, and are supported by appropriate institutional incentives to meaningfully engage with and effectively utilize a disruptive ledger-based traceability system. Therefore, the justification for this study emerges not merely as a technological inquiry concerning the capabilities of blockchain but as a comprehensive socio-technical evaluation that examines the complex interplay among technological feasibility, human agency and capacity, organizational readiness, and the alignment of existing institutional frameworks with innovative digital practices.

1.7 Scope of the Study

The scope of this study has been carefully and intentionally delineated to ensure analytical depth over mere descriptive breadth, allowing for a nuanced and rigorous exploration of the subject matter. The investigation is thematically confined to three interrelated dimensions that are deemed central to the process of technology adoption within the context of regulated health systems, each of which captures a distinct yet complementary facet of the adoption landscape.

The Cognitive Dimension: The first dimension, characterized as the cognitive dimension, seeks to examine the knowledge base and conceptual understanding that community pharmacists in Bayelsa State possess regarding distributed ledger technologies and their application to pharmaceutical traceability. This dimension assesses whether blockchain is perceived by pharmacists as a comprehensible and potentially useful tool that could enhance their practice, or merely as an abstract and technically inaccessible imposition that bears little relevance to their operational realities. The cognitive dimension encompasses both awareness, whether pharmacists have encountered the concept of blockchain in professional or general discourse, and understanding, the depth to which they comprehend specific blockchain concepts such as decentralization, cryptographic immutability, smart contracts, and end-to-end traceability.

The Praxeological Dimension: The second dimension, referred to as the praxeological dimension, focuses on the existing practices surrounding the procurement, storage, authentication, and verification of pharmaceutical products within community pharmacies. This dimension systematically identifies the operational methods currently employed by pharmacists to verify the authenticity of medicines upon receipt, the inventory tracking systems in use, and the frequency with which suspected counterfeit products are encountered. By mapping these current practices, the study identifies the operational "friction points" at which counterfeit medicines have a tendency to infiltrate legitimate supply chains and assesses the extent to which existing practices could be enhanced, complemented, or replaced by blockchain-based traceability solutions.

The Structural Dimension: The third dimension, designated as the structural dimension, evaluates implementation readiness by examining the infrastructural, organizational, and attitudinal foundations that would support or constrain the adoption of blockchain-based traceability systems. This includes an assessment of infrastructural reliability, particularly the availability and stability of internet connectivity and electrical power supply, which are essential prerequisites for the operation of any digital system. It also encompasses organizational factors, including management willingness to invest in new technologies, staff digital literacy levels, and the broader organizational culture, particularly attitudes toward data sharing, transparency, digital transformation, and inter-institutional collaboration.

Geographically, the study is strictly confined to Bayelsa State, Nigeria, encompassing its eight Local Government Areas (LGAs): Nembe, Ekeremor, Ogbia, Brass, Yenagoa, Kolokuma/Opokuma, Sagbama, and Southern Ijaw. This spatial delimitation is not merely an administrative convenience but carries significant analytical purpose. Bayelsa State's unique characteristics, including its riverine topography, dispersed settlement patterns, high humidity, challenging transportation infrastructure, and the relative concentration of pharmaceutical services in the state capital Yenagoa, create a distinctive operational context that enables a rich and contextualized examination of how geographical, climatic, and logistical conditions affect both the physical integrity of medicines and the digital continuity of traceability records.

The population of interest is limited to licensed community pharmacists, specifically superintendent pharmacists, who function as the principal gatekeepers of public access to medicines within the state and who bear legal responsibility for the regulatory compliance and operational decisions of community pharmacies. While hospitals, patent medicine vendors, and other pharmaceutical distribution actors remain relevant stakeholders within the broader medicine supply chain ecosystem, community pharmacies constitute the most consistent and decentralized interface between regulatory systems and the general public in Bayelsa State, making them the most appropriate and analytically productive unit of analysis for this inquiry.

Importantly, this study does not seek to design, develop, or propose a novel blockchain protocol or platform. Rather, its focus is confined to the application layer of established blockchain frameworks, such as Hyperledger Fabric or Ethereum-based private sidechains, and to the assessment of stakeholder readiness to engage with such systems. The analytical emphasis is placed on traceability-relevant data, including batch identifiers, expiry dates, chain-of-custody records, and authentication outcomes, rather than on financial transactions, cryptocurrency mechanisms, or the technical implementation details of blockchain consensus algorithms. This deliberate scoping ensures that the study remains grounded in the practical realities of pharmaceutical practice and regulatory compliance, rather than venturing into speculative technological territory.

1.8 Operational Definition of Key Terms

Blockchain Technology: A decentralized, distributed, and immutable digital ledger system that records transactions across a network of computers in a manner that makes the records resistant to retroactive modification. In this study, blockchain technology refers specifically to its application as a traceability tool for tracking pharmaceutical products across supply chain nodes.

Traceability: The ability to track and trace the movement, origin, processing, and distribution of a pharmaceutical product through all stages of the supply chain, from manufacturing to final dispensing. Traceability encompasses both forward tracking (from manufacturer to patient) and backward tracking (from patient to manufacturer) of pharmaceutical products.

Counterfeit Medicines: Pharmaceutical products that are deliberately and fraudulently mislabelled with respect to identity, composition, source, or origin. This includes products with no active ingredient, incorrect active ingredient, incorrect dosage, or that are repackaged expired medicines. The term is used interchangeably with "falsified medicines" and "substandard and falsified (SF) medicines" in this study.

Community Pharmacy: A retail pharmacy premises registered with the Pharmacists Council of Nigeria (PCN) and operated under the supervision of a licensed pharmacist (superintendent pharmacist), providing pharmaceutical services including the dispensing of prescription and over-the-counter medicines to the general public.

Implementation Readiness: The degree to which an organization and its personnel possess the necessary infrastructure, knowledge, skills, financial resources, and institutional willingness to adopt and effectively utilize a new technology. In this study, implementation readiness specifically refers to the preparedness of community pharmacies to adopt blockchain-based traceability systems.

Smart Contracts: Self-executing digital agreements with the terms of the agreement directly written into code on a blockchain network. In the pharmaceutical context, smart contracts can automate supply chain processes such as compliance verification, temperature monitoring alerts, and product recall triggers.

Distributed Ledger Technology (DLT): A digital system for recording, sharing, and synchronizing data across multiple sites, institutions, or geographies without the need for a centralized administrator. Blockchain is the most prominent form of DLT.

Cryptographic Security: The use of mathematical algorithms and protocols to secure data, ensure the integrity of transactions, and verify the identity of participants within a blockchain network. Cryptographic security ensures that records on the blockchain cannot be altered without detection.

CHAPTER TWO: LITERATURE REVIEW

2.1 Counterfeit Medicines: A Global Public Health Crisis

Counterfeit medications represent a category of pharmaceutical products that have been intentionally and fraudulently altered, mislabelled, or manufactured in a manner that renders them substandard, whether through the deliberate absence of active pharmaceutical ingredients (APIs), the inclusion of erroneous dosages, the substitution of harmful or inactive compounds, or the inappropriate labelling of product identity, composition, or origin. These products significantly elevate the risks associated with treatment failures, contribute directly to the global escalation of antimicrobial resistance, and ultimately lead to increased morbidity and mortality among populations that depend on pharmaceutical interventions for the management of acute and chronic health conditions (World Health Organization, 2017; 2023). The World Health Organization's Global Surveillance and Monitoring System for Substandard and Falsified Medical Products has documented that this phenomenon is not confined to any single region or therapeutic category; rather, it represents a pervasive and systemic global challenge that transcends national boundaries, regulatory jurisdictions, and levels of economic development, though its consequences are disproportionately borne by populations in low- and middle-income countries (LMICs) where regulatory enforcement capacity and supply chain visibility are frequently limited (Mackey & Nayyar, 2017; Ozawa et al., 2018).

The global magnitude of the counterfeit medicine crisis is staggering in both its scale and its implications. The World Health Organization has estimated that approximately 10.5% of medicines circulating in low- and middle-income countries are substandard or falsified, a figure that translates to hundreds of millions of individual dosage units reaching patients in compromised form each year (WHO, 2017). The Pharmaceutical Security Institute (PSI), which maintains one of the most comprehensive global databases of pharmaceutical counterfeiting incidents, reported a sustained increase in the number of detected counterfeiting cases over the past decade, with incidents documented across every inhabited continent and involving virtually every major therapeutic category, from antimalarials and antibiotics to cardiovascular medications, oncology drugs, and vaccines (PSI, 2023). The economic dimensions of this crisis are equally alarming: estimates suggest that the global trade in counterfeit pharmaceuticals generates between USD 75 billion and USD 200 billion in annual revenue, making it one of the most profitable forms of transnational organized crime, surpassing even the illicit drug trade in certain product categories (WHO, 2017; OECD, 2020). These figures underscore the reality that pharmaceutical counterfeiting is not merely a public health concern but a complex criminal enterprise that is sustained by weak governance structures, insufficient regulatory capacity, and the enormous profit margins available to counterfeiters who operate with relative impunity in many jurisdictions.

2.1.1 The Global Landscape: Prevalence and Impact across Regions

The Global Picture: The prevalence of counterfeit medicines varies considerably across regions, shaped by the interplay of regulatory strength, supply chain complexity, economic conditions, and the capacity of health systems to detect and respond to pharmaceutical fraud. The World Health Organization's landmark 2017 study estimated that 1 in 10 medical products in developing countries is substandard or falsified, with the problem most acute in sub-Saharan Africa and parts of Southeast Asia. Antimalarial medicines, antibiotics, and medicines for chronic conditions such as hypertension and diabetes are among the most frequently falsified categories globally, reflecting the intersection of high demand, limited supply, and the chronic underfunding of pharmaceutical quality assurance systems in many developing regions (WHO, 2017; Nayyar et al., 2019). The COVID-19 pandemic further exposed and exacerbated the vulnerability of global pharmaceutical supply chains, with Interpol's Operation Pangea reporting significant seizures of falsified COVID-19 vaccines, test kits, and therapeutic agents across multiple countries during 2020 and 2021, demonstrating that even high-income countries are not immune to pharmaceutical fraud during periods of supply chain disruption and heightened public anxiety (Interpol, 2021; Hamilton et al., 2016).

The American Context: In the Americas, particularly the United States, the challenge of counterfeit medicines has been addressed through a robust legislative and technological framework, though the problem persists in modified forms. The United States Drug Supply Chain Security Act (DSCSA) of 2013 established a comprehensive framework for the electronic, interoperable tracing of prescription drug products through the pharmaceutical distribution supply chain, with full implementation mandated by 2023 (FDA, 2019; 2023). The DSCSA represents one of the most ambitious national serialization and traceability programmes globally, requiring every package and case of prescription drugs to carry a unique product identifier that enables electronic tracking from manufacturer to dispenser. Despite this legislative framework, the United States continues to face challenges related to the infiltration of counterfeit products through online pharmacies, international mail shipments, and the grey market for specialty and high-cost drugs. The Partnership for Safe Medicines has documented numerous cases of counterfeit oncology drugs, HIV antiretrovirals, and cardiovascular medications entering the US supply chain, often through sophisticated parallel importation schemes that exploit regulatory gaps between jurisdictions (Brechtelsbauer et al., 2016; FDA, 2023). In Latin America, the challenge is more acute, with studies in countries such as Brazil, Mexico, and Argentina documenting counterfeit medicine prevalence rates ranging from 10% to 30% in certain therapeutic categories, driven by fragmented regulatory frameworks, the dominance of open drug markets, and the limited capacity of national regulatory agencies to enforce quality standards across complex and geographically dispersed supply chains (Pan American Health Organization, 2019).

The European Context: The European Union has implemented one of the most sophisticated regulatory frameworks for combating counterfeit medicines through the EU Falsified Medicines Directive (FMD) 2011/62/EU, which became fully operational in February 2019. This directive mandates end-to-end serialization and verification of prescription medicines across all EU member states through the European Medicines Verification System (EMVS), requiring that every pack of prescription medicine carries a unique identifier and an anti-tampering device that must be verified at the point of dispensing. The European Medicines Verification Organisation (EMVO) coordinates this system across a network of national medicines verification organisations in each member state, creating a continent-wide infrastructure for pharmaceutical authentication that represents the largest operational medicines verification system in the world (European Commission, 2019; EMVO, 2022). Despite this advanced framework, challenges remain, particularly regarding cross-border pharmaceutical commerce within the single market, the growth of online pharmacy sales, and the emergence of falsified medicines entering Europe through third-country imports. The European Medicines Agency (EMA) has reported that falsified medicines detected in the EU are increasingly sophisticated, with counterfeits that closely replicate legitimate packaging, holograms, and even batch numbers, necessitating continuous technological innovation to stay ahead of counterfeiters (EMA, 2022).

The African Context: Sub-Saharan Africa bears a disproportionate burden of the global counterfeit medicine crisis. The WHO has estimated that in some African countries, up to 30-40% of medicines in circulation may be substandard or falsified, with antimalarials and antibiotics being the most frequently compromised categories (WHO, 2017; Ozawa et al., 2018). The African Union Development Agency-New Partnership for Africa's Development (AUDA-NEPAD) has identified pharmaceutical counterfeiting as one of the most critical threats to health security on the continent, with an estimated 122,000 deaths annually in sub-Saharan Africa attributed to falsified antimalarials alone (Renschler et al., 2015). The proliferation of counterfeit medicines across Africa is driven by a complex web of interrelated factors: the dominance of informal and poorly regulated pharmaceutical markets, the heavy dependence of most African countries on pharmaceutical imports, chronic underfunding of national regulatory agencies, porous borders that facilitate cross-border trafficking of falsified products, and the existence of vast informal distribution networks that operate beyond effective regulatory reach (Khadem Broojerdi et al., 2020). The African Medicines Regulatory Harmonisation (AMRH) initiative and the establishment of the African Medicines Agency (AMA) represent continental efforts to strengthen

regulatory capacity, but implementation remains nascent and uneven across the 55 member states of the African Union.

The Nigerian Context: In Nigeria, the challenge of counterfeit and substandard pharmaceuticals assumes an especially severe and complex character. Nigeria is the largest pharmaceutical market in sub-Saharan Africa by both volume and value, yet the country relies on imports for more than 70% of its finished pharmaceutical products, creating a supply chain of extraordinary complexity and vulnerability (Statista, 2023; OECD, 2020). The National Agency for Food and Drug Administration and Control (NAFDAC) has estimated that at various points in the country's recent history, counterfeit medicines have constituted between 16.7% and 40% of medicines in circulation, depending on the region, therapeutic category, and market channel surveyed (NAFDAC, 2022; Akinyandenu, 2013). The Nigerian pharmaceutical supply chain is characterized by fragmented distribution networks involving multiple layers of importers, major distributors, sub-distributors, and retail outlets; the operation of large informal drug markets, most notably the Idumota and Iweka drug markets in Lagos and Onitsha respectively, which handle enormous volumes of pharmaceutical products with limited regulatory oversight; porous national borders, particularly in the north and along maritime routes, that facilitate the entry of falsified products from China, India, and other source countries; and a general lack of coordinated regulatory efforts across the country's 36 states and Federal Capital Territory (Adebisi, Nwogu, & Alaran, 2020; Mackey & Nayyar, 2017). NAFDAC has deployed several interventions to combat this challenge, including the Mobile Authentication Service (MAS), the Truscan portable spectrometer programme for field verification of medicine quality, and the implementation of pharmaceutical product traceability guidelines aligned with international GS1 standards (NAFDAC, 2021; 2023). However, these interventions have achieved only partial coverage and penetration, particularly in the southern states where community pharmacies serve as the primary point of medicine access for the general population.

The Bayelsa State Context: Bayelsa State, situated in the heart of the Niger Delta region, presents a particularly instructive case study for understanding the challenges of pharmaceutical supply chain integrity in a resource-constrained environment. The state's unique riverine geography, characterized by dispersed settlements connected predominantly by waterways, fragmented transportation infrastructure, high humidity and temperature conditions that challenge pharmaceutical storage and stability, and the concentration of the majority of formal pharmaceutical services in the state capital Yenagoa, creates conditions that amplify every vulnerability present in the broader Nigerian pharmaceutical supply chain. Community pharmacies in Bayelsa State frequently receive pharmaceutical products that have passed through multiple intermediaries, often from major distribution hubs in Lagos, Port Harcourt, or Onitsha, with each transfer point representing a potential vulnerability for counterfeit infiltration or product degradation. The limited presence of NAFDAC inspection and enforcement personnel in the state, the challenges of accessing remote riverine communities for regulatory oversight, and the general underdevelopment of digital infrastructure further compound the difficulty of ensuring medicine quality at the point of dispensing. While no comprehensive prevalence study specific to Bayelsa State has been published, the state's structural characteristics strongly suggest that it is among the more vulnerable locations within Nigeria's pharmaceutical landscape, making it an analytically important site for investigating the potential of blockchain-based traceability as a countermeasure against pharmaceutical fraud.

2.2 Traditional versus Technological Tracking Methods in Pharmaceutical Supply Chains

The traceability of pharmaceutical products through supply chains has historically relied on a combination of manual and semi-automated mechanisms that, while representing incremental improvements over time, continue to exhibit fundamental limitations that undermine their effectiveness in combating counterfeit medicine infiltration. Understanding the evolution, capabilities, and constraints of these traditional methods is essential context for evaluating the transformative potential of blockchain-based alternatives.

Paper-Based Documentation: The oldest and most rudimentary form of pharmaceutical traceability relies on paper-based documentation, including invoices, delivery notes, batch records, and stock registers maintained manually at each node of the supply chain. While paper records remain in widespread use, particularly in developing countries and smaller pharmacy operations, they are inherently limited by their vulnerability to human error, physical deterioration, deliberate falsification, and the impossibility of conducting real-time cross-referencing or auditing across multiple supply chain nodes. Paper-based systems create information silos at each point of the supply chain, meaning that no single stakeholder possesses complete visibility of a product's journey from manufacturer to patient. In the context of Bayelsa State, where the majority of community pharmacies continue to rely on manual paper ledgers for inventory tracking, these limitations are not theoretical abstractions but daily operational realities that directly affect the capacity of pharmacists to detect and prevent counterfeit medicine infiltration (Boehm & Peschke, 2022; Mackey & Nayyar, 2017).

Barcode and RFID Systems: The introduction of barcode technology and subsequently radio-frequency identification (RFID) systems represented significant advances in pharmaceutical traceability by enabling automated data capture, faster inventory management,

and the association of individual products or batches with digital records. Barcode systems, including one-dimensional (1D) barcodes, two-dimensional (2D) matrix codes such as Data Matrix and QR codes, and the GS1 DataBar standard specifically designed for healthcare applications, allow for the rapid scanning and identification of products at various points in the supply chain. RFID technology extends this capability by enabling non-contact, non-line-of-sight reading of product identifiers, which facilitates faster processing at warehouses and distribution centres. However, both barcode and RFID systems are fundamentally limited by their centralized data architecture: the information associated with a scanned code is stored in proprietary databases maintained by individual companies or supply chain actors, meaning that the data is vulnerable to manipulation, unauthorized modification, or selective deletion by any party with administrative access. Furthermore, these systems lack inherent mechanisms for ensuring data immutability or for providing transparent, shared access to supply chain information across organizational boundaries (Boehm & Peschke, 2022; Kshetri, 2018). The sophistication of modern counterfeiting operations means that barcodes and even RFID tags can be duplicated or cloned, rendering these technologies insufficient as standalone authentication tools.

Mobile Authentication Services (MAS): In Nigeria specifically, NAFDAC's Mobile Authentication Service represents an innovative attempt to empower consumers to verify the authenticity of pharmaceutical products through a simple text message-based system. Under MAS, pharmaceutical products carry a unique scratch-off code that consumers can send via SMS to receive an immediate confirmation of authenticity. While MAS has achieved notable success in raising consumer awareness and enabling point-of-purchase verification, the system has inherent limitations: it is reactive rather than proactive, relying on consumer action after purchase rather than preventing counterfeit products from entering the supply chain in the first place; it operates on a centralized database architecture that represents a potential single point of failure or compromise; and its effectiveness is dependent on consumer awareness and willingness to engage with the verification process, which field studies suggest remains inconsistent, particularly in rural and semi-urban areas (NAFDAC, 2021; Adebisi et al., 2020).

Blockchain Technology as a Paradigm Shift: In stark contrast to these traditional and semi-digital approaches, blockchain technology introduces a fundamentally different architectural framework for pharmaceutical traceability. As a decentralized and immutable distributed ledger, blockchain enables the real-time, transparent, and tamper-resistant recording of every transaction occurring within the pharmaceutical supply chain, from the sourcing of raw materials through manufacturing, packaging, distribution, and final dispensing to the patient. Unlike centralized databases, blockchain ensures that once transaction data are inscribed onto the ledger, they cannot be modified, deleted, or retroactively altered without achieving consensus across the network of participating nodes, thereby eliminating the possibility of unilateral data manipulation by any single actor (Casino et al., 2019; Treiblmaier, 2018). This consensus-based immutability represents a paradigmatic shift from trust in institutions to trust in cryptographic protocols, with profound implications for environments where institutional trust is weak or compromised. Comparative analyses across multiple studies consistently demonstrate that blockchain technology surpasses traditional traceability mechanisms in data integrity, transparency, interoperability, auditability, and the provision of genuine end-to-end visibility within the pharmaceutical supply chain (Boehm & Peschke, 2022; Kshetri, 2018; Casino et al., 2019).

2.3 Blockchain Technology: Architecture, Mechanisms, and Pharmaceutical Applications

Blockchain technology, at its foundational level, is a distributed database technology that maintains a continuously growing list of data records, organized into blocks, that are secured using cryptographic techniques and linked in a chronological chain. Each block contains a cryptographic hash of the previous block, a timestamp, and a set of transaction data, creating an append-only structure in which any attempt to alter historical records would require the simultaneous modification of all subsequent blocks across a majority of network nodes, a computational feat that is practically infeasible in properly designed blockchain networks. The technology was originally conceptualized by Satoshi Nakamoto in 2008 as the underlying infrastructure for Bitcoin, the first decentralized cryptocurrency, but its potential applications have since expanded dramatically across sectors including healthcare, supply chain management, government administration, intellectual property protection, and identity management (Nakamoto, 2008; Casino et al., 2019).

Within the pharmaceutical sector, blockchain technology can be deployed through several architectural configurations, each offering different trade-offs between decentralization, transaction throughput, data privacy, and governance complexity. Public blockchains, such as Ethereum, offer maximum transparency and decentralization but may raise concerns regarding data privacy and transaction speed in high-volume pharmaceutical supply chain applications. Private or permissioned blockchains, such as Hyperledger Fabric, restrict network participation to authorized entities, enabling faster transaction processing, enhanced data privacy controls, and governance structures more compatible with existing pharmaceutical regulatory frameworks. Consortium blockchains, which distribute governance authority across a defined group of organizations such as manufacturers, regulators, and major distributors, offer a middle ground that is

increasingly regarded as the most appropriate architecture for pharmaceutical supply chain applications (Dutta et al., 2020; Queiroz et al., 2020).

The application of blockchain in pharmaceutical supply chains serves several interrelated objectives. First, it enables comprehensive end-to-end traceability by creating an immutable digital record of every custody transfer, location change, and handling event that a pharmaceutical product undergoes from manufacture to dispensing. Second, it facilitates provenance verification by enabling any authorized participant in the supply chain to instantly trace the origin, manufacturing conditions, and complete chain-of-custody history of a pharmaceutical product by querying the blockchain. Third, the integration of smart contracts, which are self-executing agreements encoded directly onto the blockchain, enables the automation of critical governance processes including compliance verification, temperature excursion alerts, expiry date monitoring, and automated regulatory reporting (Saberi et al., 2019; Yadav & Singh, 2020; Onik et al., 2019). Empirical studies and systematic reviews consistently confirm that blockchain-enabled traceability significantly enhances supply chain resilience, operational transparency, and stakeholder trust across the pharmaceutical value chain (Min, 2019; Benyamini et al., 2023; Shetty et al., 2022).

Several real-world implementations and pilot projects have demonstrated the practical feasibility of blockchain-based pharmaceutical traceability. MediLedger, a US-based consortium blockchain project involving major pharmaceutical companies and distributors, has successfully demonstrated blockchain-based product verification and returns processing compliant with the US DSCSA requirements. In Europe, the Novartis-IBM blockchain partnership explored the use of distributed ledger technology for tracking clinical trial drug supplies across multiple countries and sites. In India, the partnership between the government of Andhra Pradesh and various technology providers has piloted blockchain-based tracking of pharmaceutical products from manufacturing facilities to rural healthcare centres. In Africa, several pilot initiatives, including the Novartis-Merck blockchain pilot in East Africa and various NGO-supported projects, have explored the application of blockchain to track antimalarial and antiretroviral medications through complex and often informal distribution networks (Musamih et al., 2021; Tseng et al., 2018; Soman & Ramanathan, 2021). While these projects vary in scale, maturity, and governance structure, they collectively provide a growing evidence base for the feasibility and utility of blockchain-based traceability in diverse pharmaceutical supply chain contexts.

2.4 Theoretical Framework

The adoption of blockchain technology for pharmaceutical traceability is a complex socio-technical phenomenon that cannot be adequately explained by any single theoretical perspective. This study therefore draws upon a multi-theoretical framework that integrates eight complementary theories, each of which illuminates a distinct dimension of the adoption landscape. The rationale for this integrative approach is rooted in the recognition that blockchain adoption in community pharmacies is simultaneously an individual cognitive decision (requiring awareness and acceptance), a social process (shaped by peer influence and regulatory pressure), an organizational capability challenge (dependent on resources, infrastructure, and management capacity), and an institutional phenomenon (driven by legitimacy concerns and regulatory compliance). No single theory captures all of these dimensions; hence, the multi-theoretical framework provides the analytical breadth and depth necessary for a comprehensive investigation.

2.4.1 Diffusion of Innovations (DOI) Theory

Rogers' (1962) Diffusion of Innovations theory provides the foundational macro-micro lens through which to comprehend the mechanisms by which blockchain traceability disseminates and gains traction within the pharmaceutical ecosystem. DOI conceptualizes the adoption of new technologies as a complex social process, emphasizing the critical roles played by communication channels, the temporal dynamics of adoption, and the characteristics of the social system in which adoption occurs. The theory posits that the diffusion of an innovation through a social system follows a characteristic S-shaped adoption curve, with adopters categorized as innovators, early adopters, early majority, late majority, and laggards based on their temporal position in the adoption process.

When applied to the context of community pharmacies in Bayelsa State, DOI reveals that blockchain traceability transcends its status as a mere technical artifact; rather, it constitutes a socially negotiated innovation whose adoption requires consensus and collaboration among multiple stakeholders within the healthcare ecosystem. The progression of pharmacists through the sequential stages of knowledge acquisition, persuasion, decision-making, implementation, and confirmation is significantly influenced by peer interactions, the involvement of professional associations such as the Pharmaceutical Society of Nigeria (PSN), regulatory messaging from NAFDAC and the Pharmacists Council of Nigeria (PCN), and the experiential learning that pharmacists accumulate through engagement with existing and emerging technologies (Al-Kubaisi et al., 2023; Ugboma et al., 2024; Ogholuwarami et al., 2024; Chukwu, 2024). Rogers' five perceived attributes of innovations, namely relative advantage, compatibility, complexity, trialability, and observability, offer a structured analytical framework for assessing the likelihood that community pharmacists will perceive blockchain traceability favourably enough to proceed through the adoption decision process.

DOI is particularly valuable for this study in its capacity to elucidate the heterogeneous patterns of adoption

observable within the pharmacy sector, specifically the question of why certain pharmacies or pharmacists emerge as early adopters while others remain resistant despite facing similar risks from counterfeit products. However, the theory has recognized limitations: it tends to assume a relatively rational and information-driven adoption process, thereby underplaying the structural constraints such as inadequate digital infrastructure, financial limitations, and power asymmetries that characterize many community pharmacies in Bayelsa State. Consequently, while DOI provides essential insight into the social dynamics of technology diffusion, it requires complementation by theories that address individual cognition, organizational capacity, and environmental pressures.

2.4.2 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), established by Davis (1989) and subsequently refined through numerous empirical applications across diverse technological and geographical contexts, significantly advances the analysis of blockchain adoption by focusing on the individual-level cognitive determinants that influence technology acceptance decisions. TAM posits that the adoption of a new technology by an individual user is primarily determined by two foundational constructs: perceived usefulness (PU), defined as the degree to which a person believes that using a particular system would enhance their job performance or outcomes, and perceived ease of use (PEOU), defined as the degree to which a person believes that using the system would be free from effort. These constructs, individually and in combination, shape the user's attitude toward the technology, which in turn influences their behavioural intention to adopt it.

Within the community pharmacy context in Bayelsa State, the willingness of pharmacists to embrace blockchain traceability systems is contingent upon whether they perceive these systems as genuinely useful for their practice, encompassing benefits such as improved detection of counterfeit products, enhanced regulatory compliance, better inventory management, and stronger supplier accountability, and whether they perceive the systems as sufficiently simple, intuitive, and non-disruptive to integrate into their existing daily workflows without imposing excessive cognitive or operational burden. TAM is particularly relevant in the Nigerian pharmacy context, where pervasive scepticism toward new technological implementations often stems from prior negative experiences with health information systems that were poorly designed, inadequately supported, or prematurely imposed without sufficient training and institutional preparation. Pharmacists may resist blockchain adoption not because they lack appreciation for its conceptual merits, but because they harbour legitimate concerns regarding system complexity, potential disruption to established routines, and the reliability of digital infrastructure required to support the technology.

TAM's strength lies in its parsimony and its extensive empirical validation across diverse contexts. However, its primary limitation is its individualistic focus: TAM explains technology acceptance as a primarily cognitive process driven by individual perceptions, without adequately accounting for the organizational, environmental, and social factors that profoundly influence adoption decisions in institutionally embedded settings such as community pharmacies. Therefore, TAM must be situated within broader socio-organizational frameworks to avoid the risk of technological reductionism and to capture the full complexity of blockchain adoption dynamics in the study context.

2.4.3 Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT), formulated by Venkatesh, Morris, Davis, and Davis (2003), represents a significant theoretical synthesis that integrates elements from eight prior technology acceptance models, including TAM, DOI, the Theory of Planned Behaviour, and the Social Cognitive Theory, into a unified framework with superior predictive validity. UTAUT identifies four primary constructs that directly influence technology use behaviour: performance expectancy (the degree to which using the technology is expected to provide benefits in job performance), effort expectancy (the perceived ease of using the technology), social influence (the degree to which an individual perceives that important others believe they should use the technology), and facilitating conditions (the degree to which an individual believes that organizational and technical infrastructure exists to support use of the technology). These constructs are moderated by individual difference variables including age, gender, experience, and voluntariness of use.

In the context of Bayelsa State, UTAUT's inclusion of social influence as a primary determinant of technology use is particularly salient. The authority of regulatory bodies such as NAFDAC and PCN, the normative influence of professional associations, and the peer dynamics among pharmacists within the relatively tight-knit professional community of Bayelsa State collectively exert substantial pressure on individual adoption decisions. Pharmacists may adopt or resist blockchain traceability not solely based on personal cognitive assessment of the technology's usefulness or ease of use, but in significant part based on the perceived expectations of regulatory authorities, the adoption behaviour of peer pharmacies, and the professional norms communicated through formal and informal channels within the pharmaceutical community. Furthermore, UTAUT's facilitating conditions construct directly addresses the infrastructure concerns, including internet connectivity, power supply reliability, and access to technical support, that are among the most critical constraints facing community pharmacies in the state.

2.4.4 Technology-Organization-Environment (TOE) Framework

The Technology-Organization-Environment (TOE) framework, conceptualized by Tornatzky and Fleischer (1990), introduces a meso-level organizational perspective that is essential for understanding why different community pharmacies exhibit varying levels of implementation readiness for blockchain-based traceability. Unlike the individual-focused TAM and UTAUT, the TOE framework situates adoption decisions within the broader context of three interacting domains: the technological context, encompassing the characteristics of the technology itself and the existing technological infrastructure of the organization; the organizational context, including firm size, management structure, communication processes, human resource quality, and available financial resources; and the environmental context, comprising the competitive landscape, regulatory environment, industry characteristics, and external pressures facing the organization.

The TOE framework is particularly valuable for this study because it explicitly acknowledges that blockchain adoption in community pharmacies is not solely a function of pharmacists' individual attitudes or the inherent qualities of blockchain technology; rather, it is profoundly shaped by organizational realities such as pharmacy size, revenue capacity, management orientation toward innovation, staff digital literacy, and the availability of IT infrastructure, as well as environmental factors including the intensity of regulatory pressure from NAFDAC, competitive dynamics among pharmacies, the perceived severity of the counterfeit medicine threat, and the availability of external technical support and training resources. In the specific context of Bayelsa State, environmental pressures arising from regulatory scrutiny and escalating public health concerns may exert greater influence on adoption decisions than the internal readiness of individual pharmacies, potentially compelling pharmacies to pursue blockchain adoption even when they are resource-constrained, a phenomenon that the TOE framework is uniquely equipped to analyze and explain (Oliveira et al., 2014).

2.4.5 Institutional Theory

Institutional theory, as propounded by Meyer and Rowan (1977) and subsequently developed by DiMaggio and Powell (1983), offers a distinct and complementary analytical lens by reconceptualizing the adoption of blockchain technology not primarily as a rational efficiency-seeking decision but as an endeavour oriented toward achieving organizational legitimacy within an institutionally structured field. The theory identifies three mechanisms through which institutional pressures influence organizational behaviour: coercive isomorphism, arising from regulatory mandates and compliance requirements; normative isomorphism, driven by professional standards, training, and the influence of professional associations; and mimetic isomorphism, occurring when organizations imitate the practices of successful or prestigious peers in conditions of uncertainty.

In the Nigerian health sector, where the legitimacy conferred by regulatory bodies such as NAFDAC and PCN is often a decisive factor in determining organizational survival, institutional pressures can have profound coercive and normative impacts on pharmacy behaviour. Community pharmacies may choose to adopt blockchain traceability not because they have conducted a careful cost-benefit analysis demonstrating operational advantages, but because adoption signals compliance with regulatory expectations, alignment with global pharmaceutical standards, and commitment to professional excellence. Conversely, the absence of clear regulatory mandates or frameworks for blockchain adoption may impede uptake, as pharmacies lack the institutional pressure and legitimacy incentive to invest in an unproven technology. This perspective is crucial for the current study because it highlights the potential for ceremonial or symbolic adoption, wherein pharmacies implement blockchain systems to satisfy external expectations without fully integrating them into daily operations, a risk that must be addressed through complementary capacity-building and genuine engagement strategies.

2.4.6 Stakeholder Theory

Stakeholder Theory, established by Freeman (1984) and subsequently elaborated through extensive scholarship in business ethics and corporate governance, situates blockchain traceability within a framework that emphasizes the moral and governance obligations of pharmaceutical organizations to the multiple constituencies they serve. The theory posits that organizations should not be managed solely in the interest of shareholders or owners, but should balance the legitimate interests and expectations of all stakeholders who are affected by or can affect the organization's activities, including patients, regulatory authorities, suppliers, employees, the broader community, and society at large.

In the context of pharmaceutical supply chains, the issue of counterfeit medicines represents a profound stakeholder concern: patients have a right to receive authentic and efficacious medications; regulators have a mandate to ensure pharmaceutical quality and safety; suppliers have an interest in protecting their brand integrity and market reputation; and society has a collective interest in maintaining trust in the healthcare system. The transparency and trust that blockchain technology promises resonate powerfully with these stakeholder expectations. Consequently, Stakeholder

Theory justifies the adoption of blockchain traceability on ethical and governance grounds that transcend narrow

profitability calculations, embedding adoption within the broader context of public health responsibilities and professional obligations. However, the theory's limitation lies in its operationalization: while it elucidates the ethical imperative for adoption, it provides limited guidance on the practical mechanisms, resources, and processes through which adoption can be achieved and sustained.

2.4.7 Resource Dependency Theory (RDT)

Resource Dependency Theory (RDT), as posited by Pfeffer and Salancik (1978), introduces a critical materialist perspective that is frequently overlooked in technology adoption studies dominated by cognitive and institutional theories. RDT posits that organizations are fundamentally dependent on resources from their external environment, and that this dependence shapes organizational behaviour, strategic choices, and inter-organizational relationships. The readiness of community pharmacies to adopt blockchain technology is significantly constrained by their dependence on external resources, including capital investment for system acquisition and deployment, reliable internet connectivity and electricity supply, access to skilled technical personnel for implementation and maintenance, ongoing vendor support for software updates and troubleshooting, and the availability of training programmes for pharmacy staff.

In the specific context of Bayelsa State, where community pharmacies typically operate as small-to-medium enterprises with limited capital reserves and where digital infrastructure remains underdeveloped compared to more urbanized states, RDT illuminates the structural power dynamics that shape adoption trajectories. Pharmacies with limited resources may find themselves in a position of dependency on external technology providers, potentially adopting proprietary blockchain platforms that offer limited autonomy, data ownership, or interoperability with other systems. Resource

Dependency Theory therefore brings to light the important risk that blockchain adoption, if not managed equitably, could inadvertently reinforce existing inequalities within the pharmaceutical sector, creating a digital divide between well-resourced pharmacies capable of full engagement with blockchain systems and smaller, resource-constrained pharmacies that are marginalized by the technology transition.

2.4.8 Task-Technology Fit (TTF) Framework

The Task-Technology Fit (TTF) framework, developed by Goodhue and Thompson (1995), enhances the theoretical landscape by emphasizing the importance of functional alignment between the characteristics of a technology and the requirements of the tasks it is intended to support. TTF posits that technology is most likely to have a positive impact on individual or organizational performance when there is a strong correspondence between the capabilities provided by the technology and the demands of the tasks users need to perform. When the fit is high, the technology enables more efficient and effective task completion; when the fit is low, the technology may be rejected, underutilized, or work around rather than through.

In the pharmaceutical traceability context, the intrinsic characteristics of blockchain technology, including its immutability, distributed architecture, cryptographic security, auditability, and capacity for smart contract automation, align effectively with the core task requirements associated with tracking drug provenance, verifying product authenticity, maintaining chain-of-custody records, and detecting the infiltration of counterfeit products. This suggests that blockchain technology exhibits a high degree of task-technology fit for pharmaceutical traceability applications. However, TTF theory also cautions that high fit at the functional level does not necessarily guarantee user acceptance or organizational adoption if the technology imposes excessive demands on usability, if adequate training is not provided, or if the supporting infrastructure is insufficient. This caveat is directly relevant to the Bayelsa State context, where the functional fit between blockchain capabilities and traceability tasks may be high, but the enabling conditions for effective utilization, including digital literacy, infrastructure, and institutional support, may be inadequate to realize the technology's potential.

Collectively, these eight theoretical perspectives provide a comprehensive, multi-level analytical framework for understanding blockchain adoption in community pharmacies. The integration of individual-level theories (TAM), social process theories (DOI, UTAUT), organizational theories (TOE, RDT), institutional theories (Institutional Theory), ethical frameworks (Stakeholder Theory), and functional alignment theories (TTF) enables this study to capture the full complexity of the adoption landscape, from individual pharmacist cognition to organizational capacity, regulatory environment, and broader socio-technical dynamics.

2.5 Blockchain-Based Traceability of Counterfeited Drugs

Counterfeit and substandard medications represent one of the most enduring and multifaceted obstacles confronting global healthcare systems, particularly in regions classified as low- and middle-income countries where the ramifications are felt most acutely. These medications are not merely misrepresented by accident; they are deliberately and fraudulently mischaracterized in terms of their identity, composition, or source of origin, frequently manufactured with the primary intention of generating financial profit rather than providing therapeutic efficacy. Counterfeited pharmaceuticals may completely lack any active pharmaceutical ingredient (API), contain an incorrect dosage of the API, include harmful or toxic substances, or consist of repackaged expired medications deceptively relabelled to appear as authentic products (Rai, 2022). The presence of such products poses severe risks to patient safety, leading to treatment failures, the

emergence of antimicrobial resistance, organ damage, and mortality.

The increasing and rapid growth of global pharmaceutical demand over recent decades has further exacerbated this critical challenge. Population growth, expanding chronic disease burdens, and heightened dependence on pharmaceutical interventions have collectively produced extensive cross-border drug trade and complex multi-tiered supply chains. Musamih et al. (2021) observed that this complexity, coupled with profit-driven distribution practices, creates structural vulnerabilities actively exploited by counterfeiters. Illicit actors infiltrate legitimate supply chains through informal distribution networks, parallel imports, and poorly regulated wholesale and retail markets.

Drug traceability has therefore emerged as an essential pillar of modern pharmaceutical supply chain management. It encompasses the ability to track and trace a pharmaceutical product through all supply chain stages, from raw material sourcing and manufacturing through distribution, dispensing, and final consumption. Effective traceability systems authenticate origin, movement, and handling conditions, enabling stakeholders to verify product integrity (Conti et al., 2018). However, traditional traceability systems remain fragmented, centralized, and susceptible to manipulation, with information asymmetry, data silos, and lack of interoperability severely undermining transparency. Ahmad et al. (2021) argued that conventional systems frequently fall short of providing end-to-end visibility and real-time verification, weakening accountability and creating opportunities for falsified products to infiltrate legitimate channels undetected.

Blockchain technology offers a fundamentally different approach: a decentralized, immutable, and transparent ledger that records every supply chain transaction. Each drug unit or batch can be assigned a unique digital identity, enabling stakeholders to verify authenticity at any distribution point. Unlike centralized databases, blockchain reduces reliance on institutional trust by embedding trust within cryptographic protocols and consensus mechanisms. In pharmaceutical traceability, blockchain facilitates tamper-proof documentation, real-time data sharing, and auditable transaction histories. These capabilities make it exceedingly difficult for malicious actors to manipulate records, introduce fraudulent products, or conceal illicit activities without detection. Blockchain-based traceability systems thus not only improve operational efficiency but restore and enhance the confidence of patients, healthcare providers, regulators, and manufacturers in the integrity of the pharmaceutical system.

2.5.1 The Impact of Blockchain in the Pharmaceutical Supply Chain

The impact of blockchain technology on pharmaceutical supply chains operates across multiple dimensions: traceability enhancement, transparency improvement, regulatory compliance automation, operational efficiency gains, and patient empowerment. At the most fundamental level, blockchain introduces a shared distributed ledger in which every supply chain transaction, from manufacturing and packaging to shipment and dispensing, is permanently documented and time-stamped in an immutable manner. This creates an unbroken and verifiable audit trail that is accessible to all authorized participants while being resistant to unilateral manipulation by any single party.

One of the most significant impacts is the enhancement of end-to-end traceability. Each pharmaceutical item can be tracked at unit, batch, or pallet level through serialization techniques and cryptographic identifiers linked to the blockchain. This capability empowers regulators and supply chain participants to instantly verify the authenticity, source, and complete movement history of pharmaceutical products. When counterfeit suspicion arises or quality failures are detected, blockchain enables rapid identification of affected products, supports targeted recall operations, and facilitates thorough root-cause analysis, all within timeframes that would be impossible with conventional traceability systems (Brechtelsbauer et al., 2016; Shetty et al., 2022).

Blockchain also fosters increased transparency and trust among supply chain stakeholders. Traditional supply chains are plagued by information asymmetry, with no single entity possessing complete visibility across the system. Blockchain mitigates this challenge by granting authorized participants synchronized access to a shared repository of verified data, reducing disputes, minimizing fraud opportunities, and strengthening collaboration among manufacturers, distributors, pharmacies, and regulatory authorities. From a regulatory standpoint, blockchain facilitates compliance automation through smart contracts that enforce requirements such as temperature controls, licensing verification, and expiry date checks, ensuring that pharmaceuticals are handled in accordance with established standards. For instance, a smart contract can automatically flag or prevent the distribution of a drug batch that fails to meet storage conditions or lacks regulatory approval (Saberi et al., 2019; Yadav & Singh, 2020).

However, notwithstanding these benefits, the deployment of blockchain in pharmaceutical supply chains presents important challenges including data privacy concerns, regulatory uncertainty regarding blockchain's legal status, organizational preparedness, scalability limitations, and interoperability with existing systems. For blockchain to achieve systemic impact rather than remaining at the pilot or experimental stage, institutional frameworks, stakeholder incentives, and technological capabilities must

be aligned. Governance frameworks, capacity-building programmes, and supportive policy environments are essential preconditions for successful implementation (Dutta et al., 2020; Kshetri, 2018; NAFDAC, 2022).

2.5.2 Knowledge and Practice Gaps among Healthcare Providers

Community pharmacists occupy a vital frontline role within healthcare systems, particularly in the critical processes of detecting, reporting, and preventing the proliferation of counterfeit medicines. As the last professional checkpoint before medicines reach patients, pharmacists bear a unique responsibility for ensuring that the products they dispense are authentic, properly stored, and within their expiry dates. However, empirical research across multiple contexts has revealed a concerning degree of variability in the levels of knowledge, awareness, and practical engagement that pharmacists demonstrate with respect to advanced digital traceability technologies (Mackey & Nayyar, 2017; Benyamini et al., 2023).

Studies conducted in the American context have found that while pharmacists in the United States are generally aware of the DSCSA requirements and the concept of pharmaceutical serialization, their understanding of the specific role of blockchain technology in enhancing traceability beyond conventional systems remains limited, even among practitioners in hospital and institutional pharmacy settings where technological sophistication is generally higher (FDA, 2023). In Europe, despite the operational maturity of the EU Falsified Medicines Directive verification system, surveys of community pharmacists across several member states have indicated that awareness of blockchain as a specific technology applicable to pharmaceutical traceability remains relatively low, with pharmacists generally viewing verification as a scanning and compliance activity rather than understanding the underlying data architecture that supports it (EMVO, 2022).

In African contexts, the knowledge gap is considerably more pronounced. Studies conducted in countries including Nigeria, Kenya, Ghana, and South Africa have consistently found that the majority of community pharmacists have limited or no awareness of blockchain technology and its potential applications in pharmaceutical supply chain management (Adebisi et al., 2021; Khadem Broojerdi et al., 2020). In Nigeria specifically, pharmacists' engagement with medicine authentication remains predominantly manual, with the majority relying on visual inspection of NAFDAC registration numbers, physical examination of packaging characteristics, and trust in established supplier relationships rather than leveraging technology-enabled verification methods. This reliance on subjective and manual methods is inherently limited in its capacity to detect sophisticated counterfeits that closely replicate the visual characteristics of genuine products.

This pronounced gap between the potential offered by blockchain technology and the actual knowledge and practices observed in real-world pharmacy settings underscores the critical need for comprehensive assessment of knowledge levels, current practices, and implementation readiness among community pharmacy stakeholders. Multiple studies confirm that without sufficient training, robust institutional support, compelling regulatory incentives, and adequate infrastructure, blockchain-based traceability systems are likely to remain underutilized even where their deployment is technically feasible and operationally beneficial (Onik et al., 2019; Adebisi et al., 2021). The evaluation of pharmacist knowledge, practices, and readiness therefore emerges as an essential prerequisite for informed policy development, effective capacity-building programme design, and the formulation of sustainable anti-counterfeiting strategies tailored to the specific conditions and constraints of the Nigerian and Bayelsa State context.

2.6 Summary of the Literature Review

The literature reviewed in this chapter establishes several critical findings that frame the present study. First, counterfeit medicines represent a global public health crisis of enormous scale and consequence, with sub-Saharan Africa and Nigeria bearing a disproportionate burden due to structural vulnerabilities in pharmaceutical supply chains, regulatory capacity limitations, and the prevalence of informal distribution networks. Second, traditional traceability mechanisms, including paper-based documentation, barcode and RFID systems, and mobile authentication services, while representing incremental improvements, exhibit fundamental limitations in data integrity, interoperability, and resistance to manipulation that constrain their effectiveness against increasingly sophisticated counterfeiting operations. Third, blockchain technology offers a paradigmatically different approach to pharmaceutical traceability, with inherent capabilities in immutability, decentralization, transparency, and smart contract automation that address many of the shortcomings of conventional systems. Fourth, the adoption of blockchain in healthcare settings is a complex socio-technical phenomenon best understood through a multi-theoretical lens that integrates perspectives on individual cognition, social influence, organizational capacity, institutional pressure, ethical obligation, resource dependency, and task-technology alignment. Fifth, significant knowledge and practice gaps exist among community pharmacists globally, and particularly in African and Nigerian contexts, regarding blockchain technology and its pharmaceutical applications.

These gaps, combined with infrastructure deficits and the absence of clear regulatory frameworks, represent substantial barriers to adoption that must be empirically characterized as a prerequisite for effective intervention design. The present study contributes to addressing these gaps by providing the first empirical assessment of blockchain knowledge, current traceability practices,

implementation readiness, and adoption barriers and enablers among community pharmacists in Bayelsa State, Nigeria.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter presents a comprehensive and detailed account of the research methodology employed in this study. It systematically describes the research design, the study area, the study population, the sampling technique and sample size determination, the data collection instrument and procedure, the methods of data analysis, and the ethical considerations that guided the entire research process. The methodological choices documented in this chapter are grounded in established research principles and are specifically designed to ensure that the study's objectives, which encompass the assessment of knowledge, current practices, implementation readiness, and barriers and enablers related to blockchain-based traceability among community pharmacists in Bayelsa State, Nigeria, are addressed with appropriate rigour, validity, and reliability. Each methodological decision is justified with reference to the relevant scholarly literature and is aligned with the specific contextual realities of the study setting.

3.2 Research Design

This study employs a descriptive cross-sectional survey design. The descriptive survey design is a research approach that seeks to systematically describe the characteristics, behaviours, attitudes, and experiences of a defined population at a specific point in time, without manipulating any variables or establishing causal relationships (Creswell & Creswell, 2018; Saunders, Lewis, & Thornhill, 2019). The cross-sectional component of the design indicates that data were collected from respondents at a single point in time, capturing a snapshot of the prevailing levels of knowledge, current practices, and implementation readiness among community pharmacists as they existed during the period of data collection, rather than tracking changes over an extended period.

The selection of a descriptive cross-sectional survey design for this study is justified on several methodological grounds. First, the study's primary objectives are descriptive and exploratory in nature: to determine knowledge levels, to investigate current practices, to assess implementation readiness, and to evaluate barriers and enablers. These objectives do not require the establishment of causal relationships or the manipulation of independent variables, which would necessitate experimental or quasi-experimental designs. Second, the cross-sectional design is particularly appropriate for studies that aim to assess the prevalence and distribution of specific characteristics, attitudes, or behaviours within a defined population, as it enables the efficient collection of data from a large number of respondents within a compressed timeframe (Bryman, 2016; Sekaran & Bougie, 2020). Third, the cross-sectional survey design is well-suited to the practical constraints of the study context, including the geographical dispersion of community pharmacies across Bayelsa State, the professional schedules of practising pharmacists, and the need to collect data through a remote digital instrument that minimises disruption to respondents' work activities.

The descriptive cross-sectional design also facilitates the application of inferential statistical techniques, such as Chi-square tests of association and correlation analysis, which enable the examination of relationships between demographic variables and key outcome variables including blockchain awareness, knowledge scores, perceived barriers, and readiness levels (Field, 2018; Hair et al., 2019). This analytical capability is essential for addressing the study's research questions, which seek not only to describe the current state of knowledge and practice but also to identify the demographic and organisational factors that influence these outcomes.

The choice of this design is further substantiated by its extensive use in previous studies investigating technology adoption, blockchain readiness, and pharmaceutical supply chain practices in comparable contexts. Studies by Abbas et al. (2021), Kamble, Gunasekaran, and Arha (2019), and Knaflic and Tomic (2020) have successfully employed cross-sectional survey designs to examine blockchain adoption readiness, technology acceptance, and supply chain traceability practices among healthcare and pharmaceutical professionals in developing and emerging economies, establishing a robust methodological precedent for the present investigation.

3.3 Study Area

The geographical focus of this study is Bayelsa State, one of the 36 states of the Federal Republic of Nigeria, situated in the South-South geopolitical zone within the ecologically distinctive Niger Delta region. Bayelsa State was created on the 1st of October, 1996, carved out of the former Rivers State, and has its capital and administrative centre in Yenagoa, which also serves as the principal commercial hub and the primary location of formal pharmaceutical services within the state. The state is bordered by Delta State to the north and west, Rivers State to the east, and the Atlantic Ocean to the south, giving it a significant coastline and extensive riverine geography that profoundly shapes its settlement patterns, transportation infrastructure, economic activities, and the logistics of service delivery across all sectors, including healthcare and pharmaceutical distribution.

Bayelsa State comprises eight Local Government Areas (LGAs): Brass, Ekeremor, Kolokuma/Opokuma, Nembe, Ogbia, Sagbama, Southern Ijaw, and Yenagoa. The state's population, estimated at approximately 2.3 million persons based on projections from the 2006 National Population Census, is distributed unevenly across these LGAs, with a significant concentration in the Yenagoa metropolitan area and smaller populations in the more

remote riverine communities that characterise the other LGAs. The riverine topography of the state, characterised by an intricate network of creeks, rivers, and mangrove swamps, presents unique challenges for the distribution and supply of pharmaceutical products, as many communities are accessible only by waterway transportation, which is subject to seasonal variations, safety risks, and logistical unpredictability. These geographical realities directly affect the pharmaceutical supply chain by increasing the number of intermediaries involved in product distribution, extending transit times during which product integrity may be compromised, and creating regulatory blind spots in areas that are difficult for NAFDAC and PCN inspection teams to access regularly..

The pharmaceutical service landscape in Bayelsa State reflects the broader pattern observed across many Nigerian states: formal pharmaceutical services are concentrated in the state capital and a few larger towns, while the majority of the population in semi-urban and rural areas depends on a combination of community pharmacies, patent medicine vendors, and informal medicine sellers for access to pharmaceutical products. Community pharmacies in Bayelsa State are registered with and regulated by the Pharmacists Council of Nigeria (PCN), with each premises required to operate under the supervision of a licensed superintendent pharmacist who bears legal responsibility for the quality and authenticity of all medicines dispensed. According to the records of the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter, there are approximately 150 registered community pharmacies operating within the state, the overwhelming majority of which are located in Yenagoa Local Government Area, with significantly fewer premises in the other seven LGAs.

Bayelsa State was selected as the study area for several analytically significant reasons. First, the state's unique combination of geographic challenges, infrastructural limitations, and concentration of pharmaceutical services creates a distinctive context for investigating the feasibility and readiness for blockchain-based traceability, as the conditions that prevail in Bayelsa State represent an important subset of the broader challenges facing pharmaceutical supply chain management in Nigeria's Niger Delta region and in comparable resource-constrained environments globally. Second, the relatively defined and enumerable nature of the community pharmacy population in Bayelsa State, comprising approximately 150 registered premises, creates a manageable study population that permits both comprehensive coverage and meaningful statistical analysis. Third, the existence of an active ACPN chapter in the state provides an organised professional platform through which community pharmacists can be accessed for research purposes, facilitating the data collection process.

3.4 Study Population

The target population for this study comprises all licensed community pharmacists practising within registered community pharmacies in Bayelsa State, Nigeria. Specifically, the study targets superintendent pharmacists, who are the licensed pharmacists legally responsible for the operation, regulatory compliance, and pharmaceutical service delivery of community pharmacy premises under the Pharmacists Council of Nigeria (PCN) regulations. Superintendent pharmacists were selected as the study population because they occupy the primary decision-making authority within community pharmacies: they are responsible for medicine procurement decisions, supplier selection, inventory management, quality assurance protocols, regulatory compliance, staff supervision, and the adoption of new technologies and operational systems. Consequently, their knowledge of blockchain technology, their current traceability practices, their assessment of implementation readiness, and their perceptions of barriers and enablers are the most strategically relevant data points for informing policy, practice, and technology design interventions aimed at enhancing pharmaceutical traceability in community pharmacy settings.

Based on the records of the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter, the estimated total population of registered community pharmacies in Bayelsa State is approximately 150 premises, each operated by at least one superintendent pharmacist. This figure of 150 was adopted as the study's total population (N = 150) for the purpose of sample size determination and statistical analysis. It is acknowledged that the actual number of operational community pharmacies may fluctuate due to new registrations, closures, or changes in licensing status; however, the figure of 150 represents the best available estimate at the time of the study and is consistent with the membership records maintained by the ACPN Bayelsa State Chapter.

3.5 Sample Size Determination

The determination of an appropriate sample size is a critical methodological consideration in survey-based research, as it directly influences the statistical power, precision, and generalisability of the study's findings. For this study, the sample size was calculated using two complementary approaches to ensure robustness: the Yamane (1967) simplified formula and the Cochran (1977) formula for finite populations.

3.5.1 Yamane's (1967) Formula

Yamane's simplified formula for proportional sample size determination from a finite population is one of the most widely used methods in social science and health research. The formula is expressed as:

$$\mathbf{n = N / [1 + N(e)^2]}$$

Where:

n = required sample size

N = total population size (150)

e = margin of error or level of precision (0.05, corresponding to 95% confidence level)
Substituting the values:
$n = 150 / [1 + 150(0.05)^2]$
$n = 150 / [1 + 150(0.0025)]$
$n = 150 / [1 + 0.375]$
$n = 150 / 1.375$
$n = 109.09 \approx 110$ respondents

Based on Yamane's formula, the minimum required sample size for this study is approximately 110 respondents. This calculation indicates that a sample of 110 or more respondents drawn from the population of 150 community pharmacists in Bayelsa State would provide statistically valid and generalisable findings at a 95% confidence level with a 5% margin of error.

3.5.2 Cochran's (1977) Formula for Finite Populations

As a complementary validation, the Cochran (1977) sample size formula for finite populations was also applied. Cochran's formula first calculates an initial sample size assuming an infinite population, then applies a finite population correction factor:
Step 1: Initial sample size (n_0) for infinite population:
$n_0 = Z^2 \times p \times q / e^2$
Where:
Z = Z-value for 95% confidence level (1.96)
p = estimated proportion of the population with the attribute of interest (0.5, used for maximum variability when no prior estimate is available)
q = 1 - p = 0.5
e = desired margin of error (0.05)
$n_0 = (1.96)^2 \times 0.5 \times 0.5 / (0.05)^2$
$n_0 = 3.8416 \times 0.25 / 0.0025$
$n_0 = 0.9604 / 0.0025$
$n_0 = 384.16 \approx 385$

Step 2: Finite population correction:
$n = n_0 / [1 + (n_0 - 1) / N]$
$n = 385 / [1 + (385 - 1) / 150]$
$n = 385 / [1 + 384/150]$
$n = 385 / [1 + 2.56]$
$n = 385 / 3.56$
$n = 108.15 \approx 109$ respondents

Cochran's formula with finite population correction yields a minimum required sample size of approximately 109 respondents, which is consistent with the Yamane calculation of 110. Both formulae converge on a minimum sample size requirement of approximately 109-110 respondents for the study to achieve statistical validity at the 95% confidence level with a 5% margin of error.

3.5.3 Achieved Sample Size

A total of 119 valid responses were received during the data collection period. This achieved sample size of 119 exceeds both the Yamane-derived minimum of 110 and the Cochran-derived minimum of 109, representing a response rate of approximately 79.3% (119 out of the estimated 150 community pharmacists in Bayelsa State). This response rate is considered very good for web-based survey research, where typical response rates range between 30% and 60% (Nulty, 2008; Baruch & Holtom, 2008). The achieved sample size of 119 provides adequate statistical power for the descriptive and inferential analyses employed in this study and ensures that the findings are representative of the community pharmacist population within Bayelsa State at the specified confidence and precision levels.

Table 3.1 Summary of Sample Size Determination.

Parameter	Yamane (1967)	Cochran (1977)
Total Population (N)	150	150
Confidence Level	95%	95%
Margin of Error (e)	0.05	0.05
Computed Minimum Sample	110	109
Achieved Sample Size	**119**	**119**
Response Rate	**79.3%**	**79.3%**

As shown in Table 3.1, the achieved sample size of 119 respondents satisfies the minimum sample size requirements derived from both Yamane's and Cochran's formulae, confirming the statistical adequacy of the study sample.

3.6 Sampling Technique

This study employed a purposive convenience sampling technique to recruit community pharmacists within Bayelsa State. Purposive sampling is a non-probability sampling method in which participants are selected based on specific characteristics that are relevant to the research objectives (Etikan, Musa, & Alkassim, 2016; Palinkas et al., 2015). In this study, the inclusion criteria required that respondents be licensed community pharmacists currently practising in Bayelsa State, specifically superintendent pharmacists who hold legal responsibility for community pharmacy premises. This criterion ensured that the data collected reflects the perspectives of the individuals who are most directly involved in medicine procurement, authentication, inventory management, and operational decision-making within community pharmacies, and who would be the primary users of any blockchain-based traceability system implemented at the community pharmacy level.

The convenience element of the sampling strategy reflects the practical approach used to reach respondents. Rather than attempting a census or a random selection process, which would have been logistically challenging given the geographical dispersion of pharmacies across the eight LGAs of Bayelsa State and the absence of a comprehensive digital contact database, the study leveraged the existing professional communication infrastructure of the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter. The structured questionnaire was distributed electronically through the ACPN Bayelsa State Chapter's official WhatsApp platforms, which serve as the primary digital communication channel through which the state chapter disseminates professional information, regulatory updates, and continuing professional development materials to its members. This distribution strategy was selected for several reasons: WhatsApp is the most widely used digital communication platform among pharmacists in Nigeria, the ACPN WhatsApp groups provide access to a substantial proportion of practising community pharmacists in the state, and electronic distribution enables efficient data collection across geographically dispersed respondents without the logistical and financial constraints of physical questionnaire distribution.

It is acknowledged that the use of purposive convenience sampling through professional association platforms introduces the possibility of self-selection bias, as pharmacists who are more digitally active, professionally engaged, or personally interested in the subject matter may be more likely to respond. However, this potential limitation is mitigated by several factors: the ACPN WhatsApp platforms represent the most comprehensive accessible sampling frame for community pharmacists in Bayelsa State; the achieved response rate of 79.3% is substantially higher than typical rates for online surveys, suggesting broad participation across the membership; and the study's descriptive objectives, which focus on characterising the current state of knowledge, practices, and readiness rather than establishing causal relationships, are appropriately served by this sampling approach (Bryman, 2016; Saunders et al., 2019).

3.7 Data Collection Instrument

The primary data collection instrument for this study was a structured, self-administered questionnaire designed to systematically capture quantitative data across the four domains corresponding to the study's research objectives. The questionnaire was developed based on a thorough review of existing scholarly literature on blockchain technology adoption, pharmaceutical supply chain traceability, technology readiness assessment, and digital health innovation in developing contexts (Abbas et al., 2021; Kamble et al., 2019; Knaflic & Tomic, 2020; Venkatesh et al., 2003). The instrument was designed and hosted on Google Forms, a widely used and accessible web-based survey platform that enables efficient electronic distribution, automated response collection, and structured data export for subsequent statistical analysis.

The questionnaire comprised 20 structured items organised into five distinct sections, each corresponding to a specific analytical domain of the study:

Section A: Socio-Demographic Characteristics (5 items). This section collected background information about respondents including gender, Local Government Area (LGA) of practice, years of practice experience, highest academic qualification, and current position in pharmacy practice. These variables were included to enable the demographic profiling of the study sample and to facilitate inferential analyses examining the association between demographic characteristics and key outcome variables such as blockchain awareness, knowledge levels, and readiness scores.

Section B: Knowledge of Blockchain-Based Traceability (5 items). This section assessed respondents' awareness of and knowledge about blockchain technology in the context of healthcare and pharmaceutical traceability. It included a dichotomous (Yes/No) item assessing prior awareness of blockchain technology, four Likert-scale items measuring self-reported understanding of specific blockchain concepts (Decentralised Ledger, Cryptographic Security, Smart Contracts, and Real-time End-to-End Traceability) on a 5-point scale ranging from 1 (No Knowledge) to 5 (Expert Knowledge), and a categorical item assessing respondents' belief in blockchain's capacity to distinguish genuine from counterfeit medicines. This section directly addresses Research Objective 1.

Section C: Current Practices for Medicine Authentication and Traceability (3 items). This section investigated the methods currently employed by community pharmacists for verifying medicine authenticity, the inventory tracking systems in use, and the frequency with which suspected counterfeit medicines were encountered within the preceding 12 months. Response options were developed based on the range of authentication methods and inventory systems documented in the Nigerian community pharmacy literature and validated through the pilot testing process. This section directly addresses Research Objective 2.

Section D: Implementation Readiness (4 items). This section assessed organisational and infrastructural readiness for blockchain adoption using four Likert-scale items measured on a 5-point agreement scale (1 = Strongly Disagree to 5 = Strongly Agree). The four statements assessed were: (i) the availability of stable internet and power supply to support digital tools, (ii) willingness to undergo training to use blockchain-based software, (iii) management willingness to invest in new traceability technologies, and (iv) sufficiency of staff digital literacy to

adopt new technologies. This section directly addresses Research Objective 3.

Section E: Barriers and Enablers of Adoption (2 items). This section identified perceived barriers to and enablers of blockchain adoption through two multiple-response items. For barriers, respondents were asked to select all applicable options from a list including: high cost of implementation, lack of technical expertise or training, poor internet connectivity, absence of a clear government/NAFDAC regulatory framework, and resistance to change from traditional methods. For enablers, options included: government subsidies for technology acquisition, mandatory regulatory requirements by PCN/NAFDAC, evidence of increased profit and reduced financial losses, and user-friendly mobile or web-based applications. This section directly addresses Research Objective 4.

Table 3.2 Structure of the Research Questionnaire.

Section	Domain	Items	Scale Type	Research Objective
A	Socio-Demographics	5	Categorical	Profiling
B	Blockchain Knowledge	5	Likert / Binary	Objective 1
C	Current Practices	3	Categorical	Objective 2
D	Implementation Readiness	4	5-point Likert	Objective 3
E	Barriers and Enablers	2	Multiple Response	Objective 4
	Total	**19**		

3.8 Validity and Reliability of the Instrument

3.8.1 Validity

The validity of the research instrument was established through a combination of content validity and face validity procedures. Content validity, which refers to the extent to which the items in the questionnaire adequately cover the full domain of the constructs being measured, was ensured through a systematic process of item development guided by extensive literature review and expert consultation. The questionnaire items were developed based on validated constructs and measurement approaches documented in the existing scholarly literature on blockchain technology adoption (Abbas et al., 2021; Kamble et al., 2019), technology acceptance and readiness (Venkatesh et al., 2003; Davis, 1989), pharmaceutical supply chain traceability (Mackey & Nayyar, 2017; Boehm & Peschke, 2022), and health technology assessment in developing contexts (Knaflic & Tomic, 2020).

Prior to deployment, the draft questionnaire was submitted for review by a panel of experts comprising academic faculty members with expertise in pharmacy practice and health informatics, practising community pharmacists with operational knowledge of traceability practices in Bayelsa State, and a researcher with experience in technology adoption studies. The expert reviewers assessed the instrument for clarity and comprehensibility of item wording, relevance and appropriateness of items to the study's objectives, logical sequencing of sections and items, adequacy of response options, and the overall completeness of domain coverage. Feedback from the expert review process was incorporated into the final version of the questionnaire, resulting in refinements to item wording, the addition of response options for certain categorical items, and the reordering of selected items to improve logical flow.

Face validity was additionally established through a pilot administration of the questionnaire to a small group of 5 community pharmacists who were asked to complete the instrument and provide feedback on the clarity, relevance, and ease of completion of each item. The pilot respondents confirmed that the questionnaire items were clearly worded, relevant to their professional experience, and could be completed within a reasonable timeframe of approximately 8-12 minutes. Minor adjustments to item phrasing were made based on pilot feedback prior to the main data collection.

3.8.2 Reliability

The reliability of the research instrument, which refers to the consistency and stability of measurement across items, respondents, and occasions, was assessed using Cronbach's Alpha coefficient, the most widely accepted measure of internal consistency reliability for Likert-scale and multi-item survey instruments (Nunnally & Bernstein, 1994; Tavakol & Dennick, 2011). Cronbach's Alpha was computed separately for each multi-item construct in the questionnaire and for the overall instrument. A Cronbach's Alpha coefficient of 0.70 or above was considered the threshold for acceptable internal consistency, in accordance with widely accepted psychometric standards (Nunnally & Bernstein, 1994; Hair et al., 2019). The detailed reliability results, including Cronbach's Alpha values for each construct and the overall instrument, are presented in Chapter Four (Table 4.1), where all constructs achieved alpha values above 0.70, confirming the reliability and internal consistency of the instrument.

3.9 Data Collection Procedure

Data collection was conducted over a 10-day period from the 1st to the 10th of February, 2026. The structured questionnaire, hosted on Google Forms, was distributed electronically to community pharmacists in Bayelsa State through the official WhatsApp platforms of the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter. The ACPN WhatsApp groups serve as the primary digital communication infrastructure for the

community pharmacy profession in the state, providing a direct and efficient channel for reaching the target population of superintendent pharmacists.

The data collection procedure followed a structured protocol. First, the researcher obtained formal permission from the ACPN Bayelsa State Chapter leadership to distribute the survey instrument through the association's official WhatsApp platforms. Second, a brief introductory message was posted on the platforms explaining the purpose and objectives of the study, the voluntary nature of participation, the estimated time required to complete the questionnaire (approximately 10 minutes), the assurance of anonymity and confidentiality, and a direct hyperlink to the Google Forms questionnaire. Third, follow-up reminder messages were posted at intervals during the data collection period to encourage participation and improve response rates, a strategy recommended in the survey methodology literature to mitigate non-response bias in web-based surveys (Dillman, Smyth, & Christian, 2014). Fourth, the Google Forms platform automatically recorded responses in a structured spreadsheet format, with each submission timestamped, facilitating data management, quality assurance, and subsequent export for statistical analysis.

The use of Google Forms as the data collection platform offered several methodological and practical advantages for this study. Google Forms is freely accessible, widely familiar to Nigerian professionals, compatible with both smartphones and computers, and provides built-in features for response validation, skip logic, and automatic data organization. Importantly, Google Forms allows the researcher to collect responses anonymously, as no email addresses or personal identifying information were required for submission, thereby enhancing respondent anonymity and encouraging candid responses on potentially sensitive topics such as counterfeit medicine encounters and infrastructure deficiencies. At the close of the data collection period on 10th February, 2026, a total of 119 valid responses had been received and were exported from Google Forms as a structured Microsoft Excel spreadsheet for subsequent data cleaning, coding, and statistical analysis.

3.10 Method of Data Analysis

The quantitative data collected through the structured questionnaire were subjected to a comprehensive analysis employing both descriptive and inferential statistical techniques. All statistical analyses were conducted using the IBM Statistical Package for Social Sciences (SPSS) software, Version 26.0, following established analytical protocols and conventions for health and social science survey research (Field, 2018; Hair et al., 2019; Pallant, 2020).

3.10.1 Descriptive Statistics

Descriptive statistics were employed as the primary analytical approach for summarising and characterising the distribution of responses across all sections of the questionnaire. For categorical variables, including gender, LGA of practice, years of experience, qualification, current position, blockchain awareness, authentication methods, inventory tracking systems, counterfeit encounter frequency, and barrier and enabler selections, frequencies and percentages were computed and presented in tabular and graphical formats. For continuous and ordinal variables, including the Likert-scale knowledge ratings and readiness scores, measures of central tendency (means) and dispersion (standard deviations) were calculated to characterise the distribution of responses. Cross-tabulations were generated to examine the distribution of key outcome variables across demographic categories. Results are presented using frequency distribution tables, bar charts, and pie charts to enhance visual clarity and facilitate interpretation.

3.10.2 Inferential Statistics

Inferential statistical techniques were employed to examine the statistical significance of associations between demographic variables and key outcome variables, thereby enabling the identification of factors that influence blockchain awareness, knowledge, perceived barriers, and implementation readiness among community pharmacists.

Chi-Square Test of Association (χ^2): The Pearson Chi-square test was used to examine the statistical significance of associations between categorical variables, including: years of practice experience versus blockchain awareness, educational qualification versus blockchain knowledge score category, inventory system type versus counterfeit detection, and years of practice experience versus perceived barriers. The Chi-square test is appropriate for examining relationships between two categorical variables measured at the nominal or ordinal level and tests whether the observed distribution of frequencies differs significantly from the distribution expected under the null hypothesis of independence (Field, 2018). A significance threshold of $p < 0.05$ was applied for all Chi-square tests.

Pearson Correlation Analysis: Pearson product-moment correlation coefficients were computed to examine the strength and direction of linear relationships among continuous readiness variables, including staff digital literacy, management support, and overall adoption readiness scores. Correlation analysis was used to identify which readiness factors are most strongly associated with overall preparedness for blockchain adoption, thereby informing the identification of priority intervention areas.

Table 3.3 Summary of Data Analysis Methods by Research Objective.

Research Objective	Variables	Analytical Method
Objective 1: Knowledge	Awareness, knowledge scores, demographics	Frequencies, means, SD, Chi-square
Objective 2: Practices	Authentication methods, inventory systems, counterfeit encounters	Frequencies, percentages, Chi-square
Objective 3: Readiness	Readiness indicators, literacy, management support	Means, SD, Pearson correlation
Objective 4: Barriers/Enablers	Barrier selections, enabler selections, demographics	Frequencies, percentages, Chi-square

3.11 Ethical Considerations

The conduct of this research was guided by established ethical principles for research involving human participants, as articulated in the Declaration of Helsinki (World Medical Association, 2013), the Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979), and the ethical guidelines of the National Health Research Ethics Committee of Nigeria (NHREC). The following specific ethical safeguards were implemented throughout the research process:

Ethical Approval: Prior to the commencement of data collection, ethical approval was sought and obtained from the relevant institutional review board, ensuring that the study protocol, data collection instruments, and informed consent procedures were reviewed and approved by an independent ethics committee with the authority and competence to evaluate the ethical dimensions of the proposed research.

Informed Consent: All potential participants were provided with clear and comprehensive information about the purpose, objectives, and procedures of the study before they were asked to participate. The introductory section of the Google Forms questionnaire included a detailed informed consent statement that explained the study's aims, the voluntary nature of participation, the types of data being collected, the measures in place to protect confidentiality and anonymity, the estimated time required for completion, the absence of any risks or direct benefits associated with participation, and the respondent's right to withdraw at any point. By proceeding to complete the questionnaire, respondents indicated their informed consent to participate in the study.

Anonymity and Confidentiality: The questionnaire was designed to collect responses anonymously, with no items requesting personally identifiable information such as names, email addresses, phone numbers, or pharmacy names. The Google Forms platform was configured to not collect respondent email addresses, ensuring that no digital identifier could be linked to individual responses. All collected data were stored securely on password-protected devices accessible only to the researcher, and data were analysed and reported only in aggregate form, ensuring that no individual respondent can be identified from the published findings.

Voluntary Participation: Participation in the study was entirely voluntary. No inducements, incentives, or coercive pressures were applied to encourage participation. The introductory message on the ACPN WhatsApp platforms clearly stated that participation was optional and that non-participation would carry no professional, regulatory, or personal consequences. Respondents were free to discontinue completion of the questionnaire at any stage without providing a reason and without any adverse repercussions.

Beneficence and Non-Maleficence: The study was designed to pose minimal risk to participants. The questionnaire items did not address sensitive personal topics and were confined to professional knowledge, practices, and opinions. The potential benefits of the study, including the generation of evidence to inform policy, practice, and technology interventions aimed at improving pharmaceutical supply chain integrity, were assessed as significantly outweighing any minimal inconvenience associated with questionnaire completion.

Data Storage and Management: All electronic data files were stored on encrypted, password-protected devices. Access to the raw data was restricted to the principal researcher and the supervising academic. Data will be retained in secure storage for a period consistent with institutional and regulatory requirements, after which they will be securely deleted in accordance with data protection best practices.

3.12 Limitations of the Methodology

Several methodological limitations are acknowledged and should be considered in the interpretation of the study's findings. First, the use of a cross-sectional design captures data at a single point in time and does not permit the assessment of changes in knowledge, practices, or readiness over time, nor the establishment of causal relationships between variables. Longitudinal or experimental designs would be required to address these questions.

Second, the reliance on self-reported data introduces the possibility of social desirability bias, whereby respondents may overstate their knowledge, underreport their use of manual or informal practices, or express greater willingness to adopt new technologies than their actual behaviour would reflect. However, the anonymity of the

data collection process is expected to mitigate this bias to a considerable extent.

Third, the purposive convenience sampling strategy, while offering practical advantages and yielding a strong response rate, does not constitute probability sampling and therefore limits the strict statistical generalisability of findings beyond the study population. The concentration of responses from Yenagoa LGA reflects the actual distribution of community pharmacies in the state but means that the perspectives of pharmacists in the more remote riverine LGAs may be underrepresented..

Fourth, the use of an electronic questionnaire distributed through WhatsApp platforms introduces a digital access bias, as pharmacists without smartphones, stable internet access, or active participation in ACPN WhatsApp groups would be excluded from the sampling frame. However, given the near-universal smartphone ownership among licensed pharmacists in Nigeria and the comprehensive membership coverage of the ACPN WhatsApp platforms, this limitation is considered to have minimal practical impact on the representativeness of the sample.

Despite these limitations, the study's methodological design is considered appropriate and adequate for achieving its stated objectives, and the findings provide a robust empirical foundation for understanding the current state of blockchain knowledge, traceability practices, implementation readiness, and adoption dynamics among community pharmacists in Bayelsa State, Nigeria.

CHAPTER FOUR: RESULTS AND DATA ANALYSIS

4.1 Introduction

This chapter presents the results and analysis of data collected from 119 community pharmacists in Bayelsa State, Nigeria. The analysis is structured to align sequentially with the four research objectives: (1) knowledge of blockchain-based traceability, (2) current authentication and traceability practices, (3) implementation readiness, and (4) barriers and enablers of adoption. Both descriptive and inferential statistical techniques are employed.

4.2 Validity and Reliability of the Research Instrument

Table 4.1 Cronbach's Alpha Reliability Statistics.

Construct	No. of Items	Cronbach's Alpha
Knowledge of Blockchain Traceability	5	0.81
Current Authentication Practices	3	0.78
Implementation Readiness	4	0.84
Barriers and Enablers	2	0.79
Overall Questionnaire	**14**	**0.85**

All constructs recorded Cronbach's Alpha values above the 0.70 threshold, indicating good internal consistency. The overall questionnaire achieved a coefficient of 0.85, confirming instrument reliability.

4.3 Socio-Demographic Characteristics of Respondents

Table 4.2 Socio-Demographic Characteristics (n = 119).

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	103	86.6
	Female	16	13.4
Years of Experience	Less than 5 years	19	16.0
	5-10 years	59	49.6
	11-20 years	41	34.5
Qualification	B.Pharm / PharmD	53	44.5
	M.Sc. / MPH	66	55.5
Position	Superintendent Pharmacist	119	100.0

Table 4.2 presents the socio-demographic profile of the 119 community pharmacists surveyed. The sample is predominantly male (86.6%), with the largest experience cohort being 5-10 years (49.6%), followed by 11-20 years (34.5%). The majority hold M.Sc./MPH qualifications (55.5%), with 44.5% holding B.Pharm/PharmD degrees. All respondents are Superintendent Pharmacists, representing the principal decision-makers within community pharmacy operations.

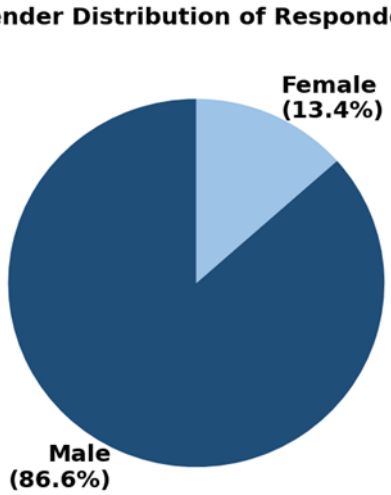

Figure 4.1: Gender Distribution of Respondents.

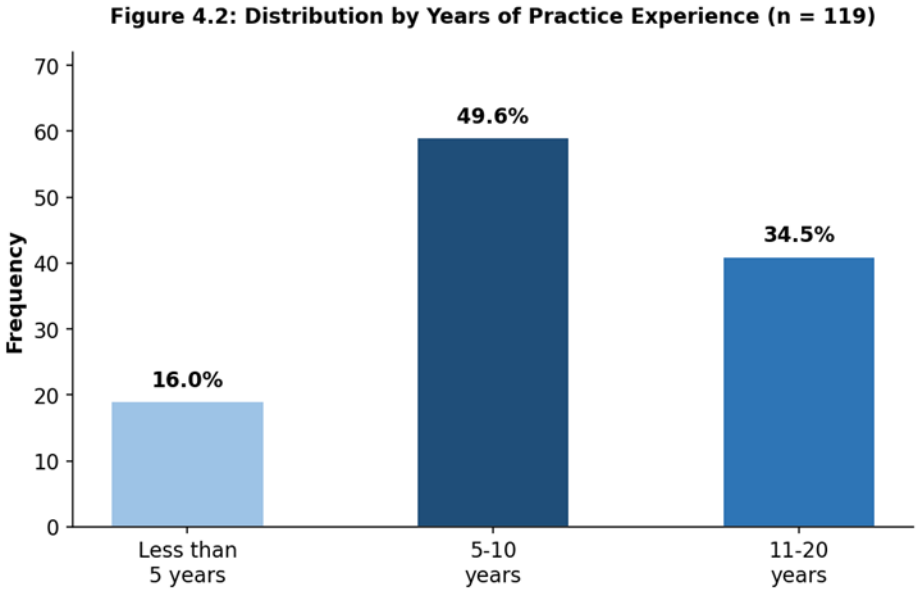

Figure 4.2: Years of Practice Experience of Respondents.

4.4 Research Objective 1: Knowledge of Blockchain-Based Traceability

This section addresses Research Question 1: What is the level of knowledge of blockchain-based traceability among community pharmacists in Bayelsa State?

Table 4.3 Awareness of Blockchain Technology in Healthcare (n = 119).

Response	Frequency (n)	Percentage (%)
Yes	85	71.4
No	34	28.6
Total	**119**	**100.0**

Table 4.3 shows that 71.4% of respondents (85 pharmacists) reported prior awareness of blockchain technology in the context of healthcare, while 28.6% (34 respondents) had no prior awareness. While the majority have heard of blockchain, subsequent analysis of knowledge scores reveals important limitations in the depth of understanding.

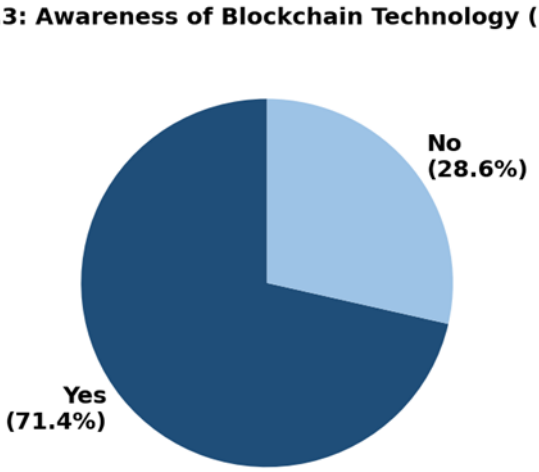

Figure 4.3: Awareness of Blockchain Technology among Respondents.

Table 4.4 Mean Knowledge Scores of Blockchain Concepts (n = 119).

Blockchain Concept	N	Mean	Std. Dev.
Real-time end-to-end traceability	119	1.26	0.44
Decentralized ledger (shared database)	119	1.56	0.93
Smart contracts (automated verification)	119	1.72	0.90
Cryptographic security (immutability)	119	1.72	0.90

Table 4.4 presents mean knowledge scores on a scale of 1 (No Knowledge) to 5 (Expert Knowledge). All four concepts scored between 1.26 and 1.72, indicating uniformly low understanding at the "No Knowledge" to "Basic Awareness" level. Real-time traceability recorded the lowest mean (1.26, SD = 0.44), while smart contracts and cryptographic security both scored 1.72 (SD = 0.90). Despite 71.4% having heard of blockchain, actual technical understanding remains minimal, revealing a significant gap between superficial awareness and functional comprehension.

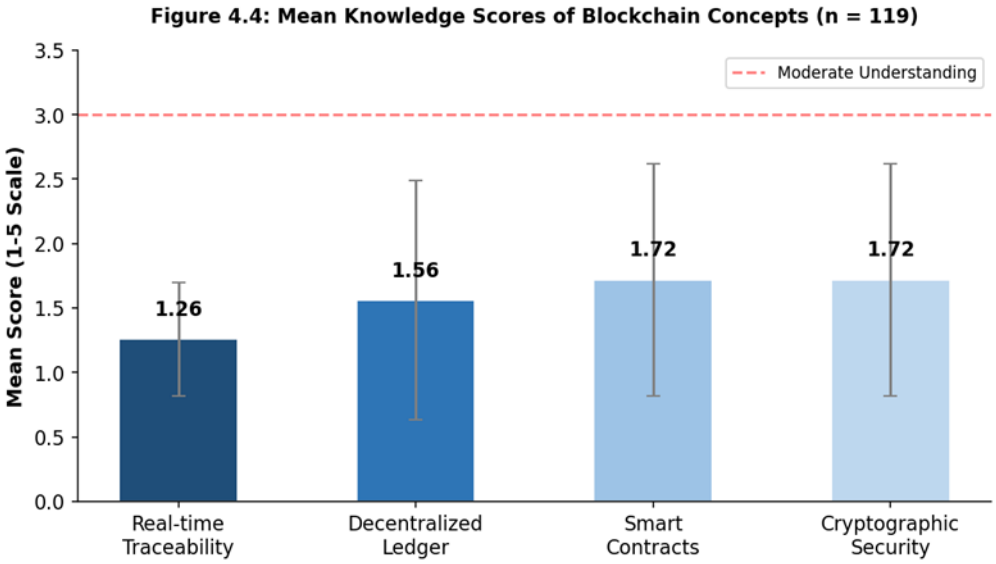

Figure 4.4: Mean Knowledge Scores of Blockchain Concepts.

Table 4.5 Belief in Blockchain's Ability to Distinguish Genuine from Counterfeit Medicines (n = 119).

Response	Frequency (n)	Percentage (%)
Yes	85	71.4
Not sure	34	28.6
Total	**119**	**100.0**

Of the respondents, 71.4% believe blockchain can distinguish genuine from counterfeit medicines, while 28.6% were unsure. Notably, no respondent answered "No", suggesting the absence of outright scepticism. The proportion expressing uncertainty aligns with those who reported no prior awareness, indicating that lack of knowledge rather than rejection drives uncertainty.

Table 4.6 Association between Demographics and Blockchain Awareness.

Variable	Chi-Square	df	p-value
Years of Experience vs. Awareness	10.27	2	0.006*
Qualification vs. Knowledge Score	17.94	1	<0.001**

**p < 0.05; **p < 0.01*

Years of practice experience is significantly associated with blockchain awareness (Chi-square = 10.27, p = 0.006), while educational qualification shows an even stronger association with knowledge scores (Chi-square = 17.94, p < 0.001). Pharmacists with postgraduate qualifications demonstrate significantly better conceptual understanding.

4.5 Research Objective 2: Current Practices for Medicine Authentication and Traceability

This section addresses Research Question 2: What are the current practices used by community pharmacies for medicine authentication and traceability?

Table 4.7 Primary Methods Used to Verify Medicine Authenticity (n = 119).

Authentication Method	Frequency (n)	Percentage (%)
Visual inspection of NAFDAC registration numbers	92	77.3
Physical inspection (packaging, labels)	16	13.4
Barcode or QR code scanning	11	9.2
Total	**119**	**100.0**

Table 4.7 reveals overwhelming reliance on manual authentication. The vast majority (77.3%) depend on visual inspection of NAFDAC numbers, 13.4% use broader physical inspection, and only 9.2% use barcode/QR scanning. This distribution confirms that medicine verification in Bayelsa State remains heavily dependent on human observation, which is inherently vulnerable to sophisticated counterfeiting. The near-absence of digital authentication represents a critical gap.

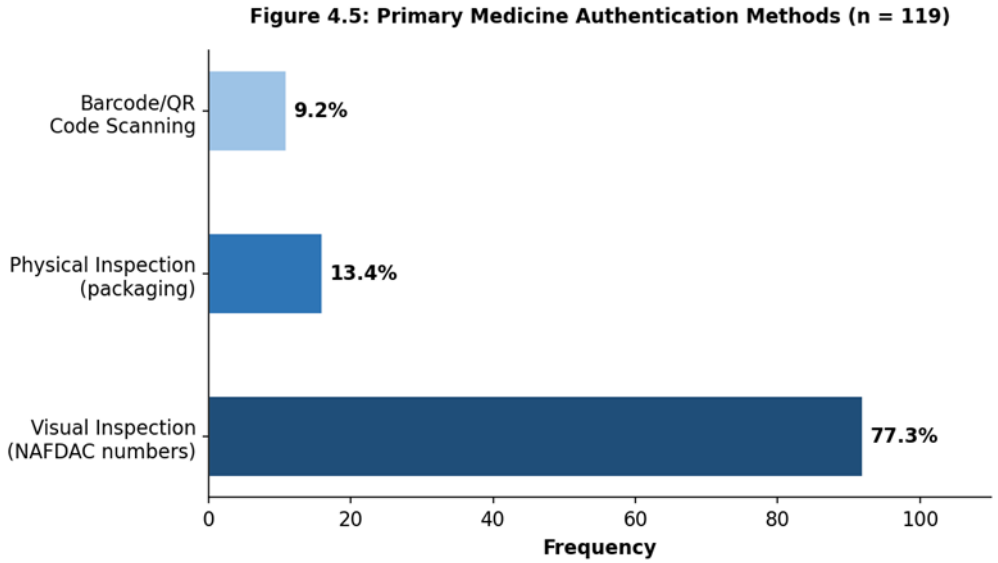

Figure 4.5: Primary Methods Used to Verify Medicine Authenticity.

Table 4.8 Inventory Tracking Systems Currently Used (n = 119).

Inventory Tracking System	Frequency (n)	Percentage (%)
Manual paper ledger	66	55.5
No formal tracking system	42	35.3
Integrated cloud-based system	11	9.2
Total	**119**	**100.0**

A majority of pharmacies (55.5%) rely on manual paper ledgers, while 35.3% operate without any formal tracking system. Only 9.2% use integrated cloud-based systems. Over 90% of pharmacies lack the digital infrastructure required for blockchain implementation, representing a fundamental structural barrier.

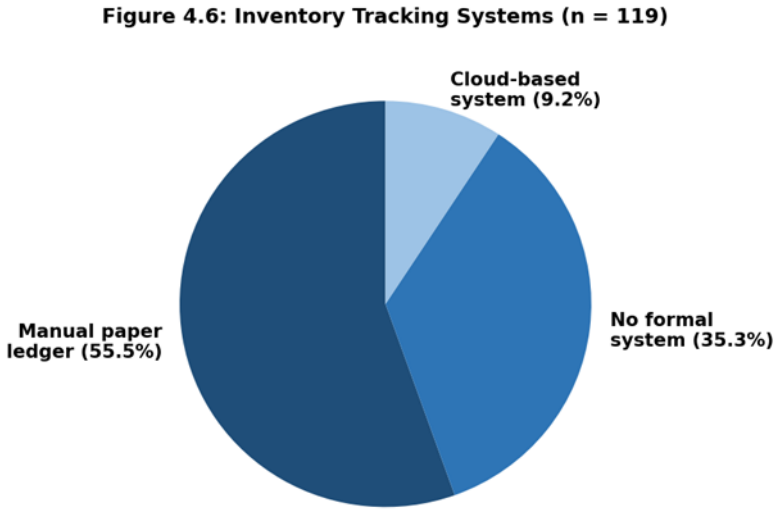

Figure 4.6: Inventory Tracking Systems Currently Used.

Table 4.9 Frequency of Encountering Suspected Counterfeit Medicines (n = 119).

Frequency	Respondents (n)	Percentage (%)
Never	37	31.1
1-5 times	70	58.8
More than 10 times	12	10.1
Total	**119**	**100.0**

A significant 68.9% of pharmacists encountered suspected counterfeit medicines at least once in the past 12 months. The largest group (58.8%) reported 1-5 encounters, while 10.1% reported more than 10. These findings provide empirical evidence that counterfeit medicines remain a persistent problem in Bayelsa State's pharmaceutical supply chain.

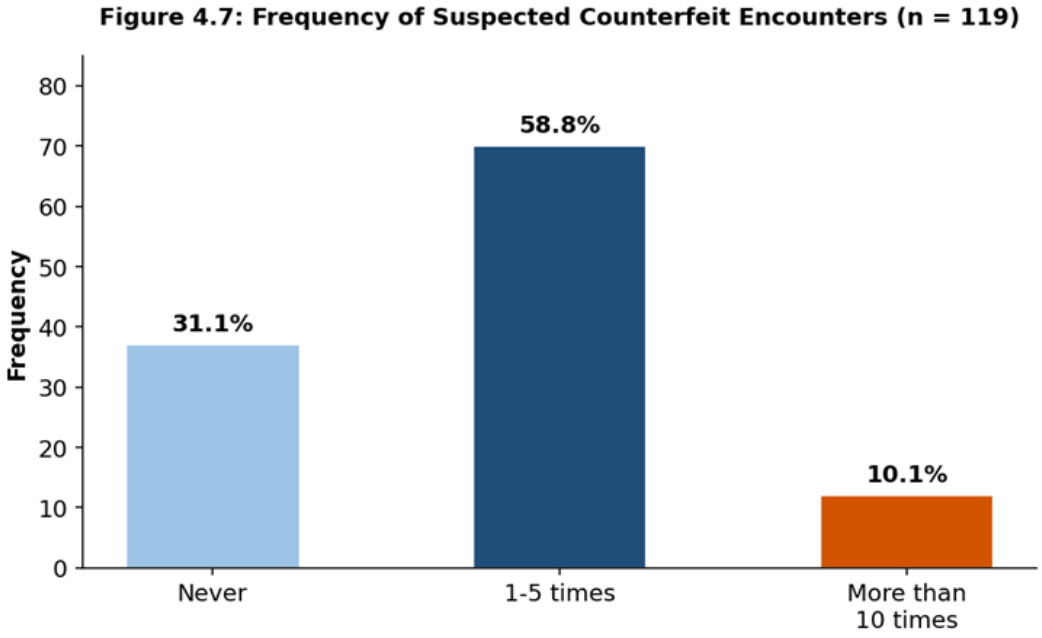

Figure 4.7: Frequency of Encountering Suspected Counterfeit Medicines.

Table 4.10 Association between Inventory System and Counterfeit Detection.

Statistic	Value	df	p-value
Pearson Chi-Square	13.21	2	0.001**
N of Valid Cases	119		

***p < 0.01*

A statistically significant association exists between inventory system type and counterfeit detection (Chi-square = 13.21, p = 0.001). Pharmacies with digital systems are more likely to detect suspected counterfeits, supporting the role of digital infrastructure as a foundational enabler of supply chain vigilance.

4.6 Research Objective 3: Implementation Readiness for Blockchain-Based Traceability

This section addresses Research Question 3: What is the level of implementation readiness for blockchain technology-based traceability systems among stakeholders in community pharmacies?

Table 4.11 Implementation Readiness Indicators (n = 119).

Statement	Mean	Std. Dev.
Stable internet and power supply	1.80	0.88
Willingness to undergo training	3.74	1.53
Management willingness to invest	2.93	1.51
Staff digital literacy	2.34	1.34
Overall Readiness	**2.70**	**0.84**

The overall readiness score of 2.70 (SD = 0.84) indicates below-average readiness for blockchain adoption. Willingness to undergo training is the highest indicator (Mean = 3.74, SD = 1.53), suggesting strong human motivation. However, infrastructure readiness is critically weak: stable internet/power scored only 1.80 (SD = 0.88), while staff digital literacy scored 2.34 (SD = 1.34). Management investment willingness is ambivalent at 2.93 (SD = 1.51). These results reveal a critical tension: strong human willingness but severely underdeveloped structural and infrastructural foundations.

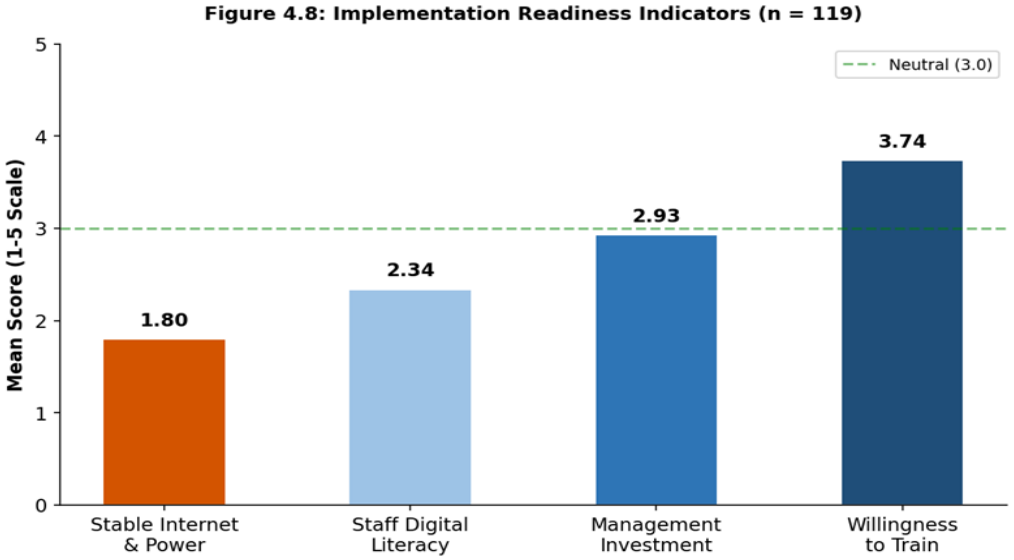

Figure 4.8: Implementation Readiness Indicators.

Table 4.12 Readiness Response Distribution (n = 119).

Statement	SD (1)	D (2)	N (3)	A (4)	SA (5)
Stable internet/power	48 (40.3%)	59 (49.6%)	0	12 (10.1%)	0
Training willingness	23 (19.3%)	0	20 (16.8%)	18 (15.1%)	58 (48.7%)
Management invest	37 (31.1%)	0	43 (36.1%)	12 (10.1%)	27 (22.7%)
Digital literacy	57 (47.9%)	0	27 (22.7%)	35 (29.4%)	0

The detailed distribution confirms that 89.9% of respondents disagree or strongly disagree about having stable internet/power, while 63.8% agree or strongly agree about training willingness. Management investment shows polarized views. Digital literacy shows 47.9% strongly disagreeing, with 29.4% agreeing.

Table 4.13 Correlation Matrix of Readiness Factors.

Variable	Staff Literacy	Mgmt Support	Adoption Readiness
Staff Digital Literacy	1.00	0.30*	0.45**
Management Support	0.30*	1.00	0.41**
Adoption Readiness	0.45**	0.41**	1.00

*$p < 0.05$; **$p < 0.01$*

Staff digital literacy correlates moderately with adoption readiness ($r = 0.45$, $p < 0.01$), while management support shows a similar relationship ($r = 0.41$, $p < 0.01$). The literacy-management correlation ($r = 0.30$, $p < 0.05$) suggests that digitally competent staff reinforce managerial willingness to adopt innovation.

4.7 Research Objective 4: Barriers and Enablers of Blockchain Adoption

This section addresses Research Question 4: What barriers and enablers exist for adopting blockchain traceability within pharmaceutical supply chains in Bayelsa State?

Table 4.14 Perceived Barriers to Blockchain Adoption (n = 119, multiple response).

Barrier	Frequency (n)	Percentage (%)
Resistance to change from traditional methods	51	42.9
High cost of implementation	42	35.3
Lack of technical expertise or training	32	26.9
Poor internet connectivity	30	25.2
Absence of NAFDAC/PCN regulatory framework	12	10.1

Resistance to change (42.9%) is the most cited barrier, followed by high cost (35.3%), lack of technical expertise (26.9%), poor internet connectivity (25.2%), and absence of regulatory framework (10.1%). These findings suggest that attitudinal and financial barriers outweigh purely technical or regulatory obstacles.

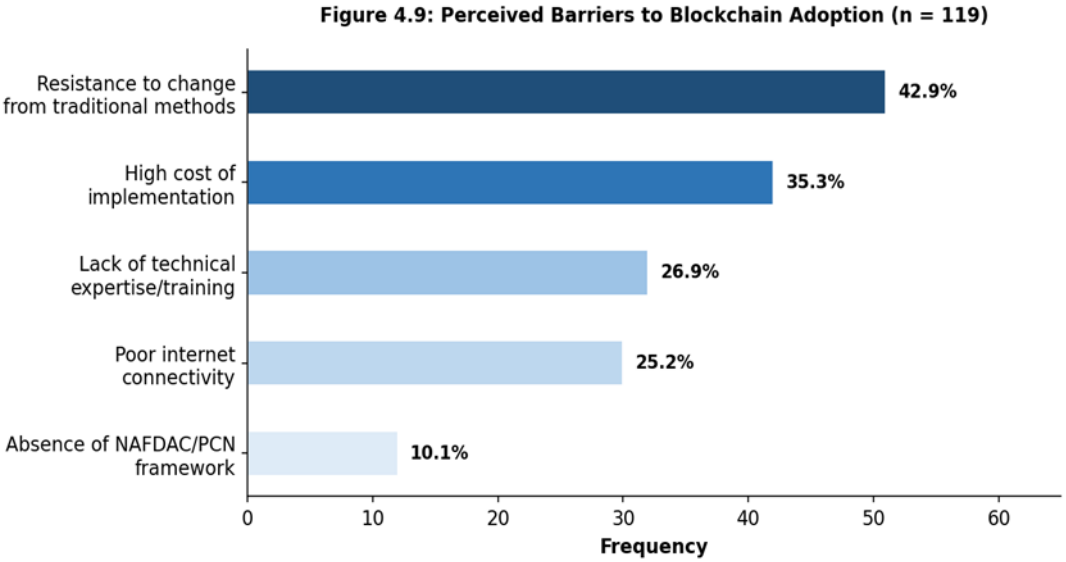

Figure 4.9: Perceived Barriers to Blockchain Adoption.

Table 4.15 Perceived Enablers of Blockchain Adoption (n = 119, multiple response).

Enabler	Frequency (n)	Percentage (%)
User-friendly mobile/web applications	51	42.9
Mandatory regulatory requirements (PCN/NAFDAC)	43	36.1
Government subsidies for technology acquisition	31	26.1
Evidence of increased profit/reduced losses	12	10.1

User-friendly applications (42.9%) emerged as the strongest enabler, confirming that usability is paramount. Mandatory regulatory requirements (36.1%) suggest that policy mandates would significantly accelerate adoption. Government subsidies (26.1%) address the cost barrier, while evidence of economic benefit (10.1%) is secondary to usability and regulatory direction.

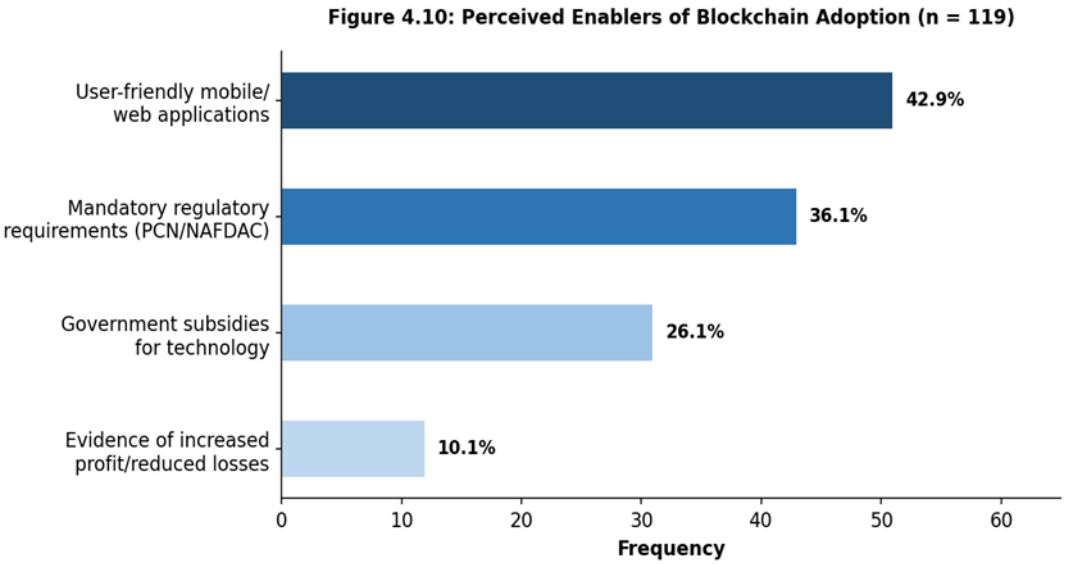

Figure 4.10: Perceived Enablers of Blockchain Adoption.

Table 4.16 Association between Years of Practice and Perceived Barriers.

Variable	Chi-Square	df	p-value
Years of Practice vs. High-Cost Barrier	10.94	2	0.004*
Years of Practice vs. Lack of Expertise	12.67	2	0.002**

*$p < 0.05$; **$p < 0.01$*

Statistically significant associations exist between practice experience and both the cost barrier (Chi-square = 10.94, p = 0.004) and technical expertise gap (Chi-square = 12.67, p = 0.002), indicating that barrier perceptions vary by career stage.

4.8 Summary of Key Findings

Research Objective 1 (Knowledge): While 71.4% have heard of blockchain, mean knowledge scores range from 1.26 to 1.72 on a 5-point scale, indicating minimal technical understanding. Educational qualification is significantly associated with knowledge ($p < 0.001$), and 71.4% believe blockchain can distinguish genuine from counterfeit medicines, though this appears based on general awareness rather than comprehension.

Research Objective 2 (Current Practices): Authentication is overwhelmingly manual (77.3% visual inspection), with only 9.2% using digital scanning. Inventory systems are paper-based (55.5%) or non-existent (35.3%). Critically, 68.9% encountered suspected counterfeit medicines in the past year, and inventory system type significantly predicts detection capability ($p = 0.001$).

Research Objective 3 (Implementation Readiness): Overall readiness is below average (Mean = 2.70/5.0). Training willingness is the strongest indicator (Mean = 3.74), but infrastructure readiness is critically deficient (Mean = 1.80). Staff digital literacy ($r = 0.45$) and management support ($r = 0.41$) significantly correlate with adoption readiness.

Research Objective 4 (Barriers and Enablers): Resistance to change (42.9%) and high cost (35.3%) lead barriers, while user-friendly applications (42.9%) and mandatory regulatory requirements (36.1%) are the strongest enablers. Practice experience significantly influences barrier perceptions ($p < 0.01$).

CHAPTER FIVE
DISCUSSION, CONCLUSION, PUBLIC HEALTH IMPLICATIONS, AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the discussion, conclusion, and recommendations arising from the findings of this study, which investigated blockchain technology-based traceability for counterfeit medicine prevention in community pharmacies in Bayelsa State, Nigeria, with specific focus on knowledge, current practices, and implementation readiness. The discussion is structured to correspond sequentially with the four research objectives of the study, interpreting the findings within the context of the existing literature reviewed in Chapter Two and the multi-theoretical framework underpinning the investigation. The chapter subsequently presents the conclusion, which synthesises the principal findings and their implications, followed by a discussion of the public health implications of the study and specific recommendations for policy, practice, and future research. The contributions to knowledge are articulated, and the limitations of the study are acknowledged to contextualise the scope and applicability of the findings.

5.2 Discussion of Key Findings

5.2.1 Knowledge of Blockchain-Based Traceability among Community Pharmacists

The first research objective sought to determine the level of awareness and understanding of blockchain-based traceability among community pharmacists in Bayelsa State. The findings reveal a paradoxical pattern: while a substantial majority of respondents (71.4%) reported having heard of blockchain technology in the context of healthcare, the actual depth of technical understanding, as measured by mean knowledge scores across four core blockchain concepts, was uniformly low, ranging from 1.26 to 1.72 on a 5-point scale. This disparity between surface-level awareness and functional comprehension represents one of the most significant findings of the study and carries important implications for the design of capacity-building interventions.

The finding that 71.4% of community pharmacists have heard of blockchain technology is notable and exceeds what might be expected in a resource-constrained sub-national context. This relatively high awareness rate likely reflects the growing visibility of blockchain in public discourse, including media coverage of cryptocurrency, the increasing attention to blockchain applications in health informatics literature, and the dissemination of information through professional development channels within the pharmacy profession. However, the extremely low mean knowledge scores for specific blockchain concepts, particularly real-time end-to-end traceability (Mean = 1.26, SD = 0.44) and decentralised ledger architecture (Mean = 1.56, SD = 0.93), indicate that this awareness is largely superficial and does not extend to the technical mechanisms that differentiate blockchain from conventional database technologies. Pharmacists appear to recognise blockchain as a broadly relevant innovation without understanding the specific architectural features, namely decentralisation, cryptographic immutability, consensus mechanisms, and smart contract automation, that constitute its distinctive value proposition for pharmaceutical traceability.

This finding aligns with the broader pattern documented in the international literature. Studies conducted across diverse contexts, including the United States (FDA, 2023), Europe (EMVO, 2022), and several African countries (Adebisi et al., 2021; Khadem Broojerdi et al., 2020), have consistently reported that while healthcare professionals may be generally aware of blockchain as a concept, their functional understanding of its technical architecture and specific applications to pharmaceutical supply chain management remains limited. The awareness-comprehension gap observed in Bayelsa State is therefore not an anomaly but rather a manifestation of a global pattern, albeit one that is amplified by the relative scarcity of blockchain-specific training and educational resources within the Nigerian pharmacy education curriculum and continuing professional development framework.

The statistically significant association between educational qualification and blockchain knowledge scores (Chi-square = 17.94, $p < 0.001$) is particularly instructive. Pharmacists holding postgraduate qualifications (M.Sc./MPH) demonstrated significantly stronger conceptual understanding than those with first degrees (B.Pharm/PharmD) alone. This finding is consistent with the Diffusion of Innovations theory (Rogers, 1962), which posits that educational attainment and exposure to diverse information channels are among the key characteristics that distinguish earlier adopters from later adopters of innovations. Postgraduate education likely exposes pharmacists to a broader range of digital health and health informatics concepts, cultivates stronger research literacy skills that facilitate engagement with emerging technologies, and promotes a more receptive attitude toward innovation. This finding has direct implications for the design of blockchain awareness and training programmes, suggesting that educational level should be considered as a stratifying variable when tailoring the content, depth, and delivery format of capacity-building interventions.

Similarly, the significant association between years of practice experience and blockchain awareness (Chi-square = 10.27, $p = 0.006$) suggests that the diffusion of blockchain knowledge within the pharmacy profession is not uniform across career stages. Mid-career pharmacists, who constitute the largest demographic cohort in the sample (49.6% with 5-10 years of experience), may represent the segment most amenable to engagement with blockchain concepts, as they combine sufficient professional maturity to appreciate the practical value of enhanced traceability with enough career trajectory remaining to justify the investment in learning new technological competencies. This interpretation is consistent with the UTAUT framework (Venkatesh et al., 2003), which identifies age and experience as key moderating variables in technology acceptance.

The finding that 71.4% of respondents believe blockchain can distinguish genuine from counterfeit medicines, with no respondent expressing outright disbelief, suggests a receptive attitudinal environment that could be leveraged for adoption. This optimistic perception, even among those with limited technical knowledge, may reflect a general openness to technological solutions for the counterfeit medicine problem, driven by the lived experience of encountering suspected counterfeit products in daily practice (68.9% of respondents reported at least one such encounter in the past year). From a Stakeholder Theory perspective (Freeman, 1984), this finding indicates that pharmacists recognise the ethical and professional imperative for improved traceability and are predisposed to view blockchain favourably, even if their understanding of the technology's mechanisms remains incomplete.

5.2.2 Current Practices for Medicine Authentication and Traceability

The second research objective investigated the current practices used by community pharmacies for medicine authentication and traceability. The findings paint a picture of a predominantly manual, observation-dependent, and digitally under-equipped operational environment that is fundamentally misaligned with the requirements of blockchain-based traceability.

The finding that 77.3% of community pharmacists rely on visual inspection of NAFDAC registration numbers as their primary method of verifying medicine authenticity represents both a practical reality and a significant vulnerability. Visual inspection, while the most accessible and cost-free verification method available, is inherently limited in its capacity to detect sophisticated counterfeits that faithfully replicate the visual characteristics of genuine products, including NAFDAC registration numbers, holographic seals, and packaging designs. Modern pharmaceutical counterfeiting operations, particularly those originating from large-scale illicit manufacturing facilities in Asia and other regions, have achieved remarkable levels of visual fidelity, producing counterfeit products that are virtually indistinguishable from genuine products through visual examination alone (WHO, 2023; OECD, 2020). The overwhelming reliance on visual inspection therefore represents a significant detection gap that leaves the pharmaceutical supply chain in Bayelsa State exposed to precisely the type of sophisticated counterfeiting that poses the greatest threat to patient safety.

The additional finding that only 9.2% of pharmacists use barcode or QR code scanning for medicine authentication is particularly concerning, as these digital scanning technologies represent the foundational interface through which pharmaceutical products would interact with a blockchain-based traceability system. The near-absence of digital scanning infrastructure at the community pharmacy level means that even if a blockchain traceability platform were deployed at the national or state level, the vast majority of community pharmacies in Bayelsa State would lack the basic technological capability to participate as end-point verification nodes, which is precisely the role that community pharmacies must fulfil for any traceability system to achieve comprehensive last-mile coverage. This finding aligns with the Task-Technology Fit framework (Goodhue & Thompson, 1995), which predicts that technology adoption will fail or underperform when there is a significant mismatch between the technology's requirements and the user's operational infrastructure.

The inventory tracking data further compounds this concern. The finding that 55.5% of pharmacies rely on manual paper ledgers and a further 35.3% operate without any formal inventory tracking system means that over 90% of community pharmacies in Bayelsa State lack the digital data infrastructure that blockchain integration would require as a prerequisite. Blockchain-based traceability is fundamentally a digital system that requires digital inputs; it cannot integrate with or enhance practices that exist exclusively in analogue form. The transition from manual or non-existent tracking systems to blockchain-enabled traceability therefore represents not merely a technology upgrade but a fundamental operational transformation that encompasses digitisation of inventory records, acquisition of digital scanning hardware, establishment of reliable internet connectivity, and retraining of staff in digital workflow processes. The magnitude of this transformation is a critical contextual factor that must be recognised in any realistic assessment of blockchain adoption timelines and requirements for the community pharmacy sector in Bayelsa State.

The statistically significant association between inventory system type and counterfeit detection capability (Chi-square = 13.21, $p = 0.001$) provides important empirical support for the proposition that digital infrastructure is not merely a technical prerequisite for blockchain adoption but also a direct contributor to improved pharmaceutical supply chain vigilance under current conditions. Pharmacies using integrated cloud-based systems demonstrated significantly higher rates of suspected counterfeit detection, suggesting that the systematic data recording, cross-referencing, and anomaly identification capabilities of digital systems enhance the capacity of pharmacists to identify irregularities that may indicate counterfeit infiltration. This finding is consistent with the TOE framework (Tornatzky & Fleischer, 1990), which identifies technological infrastructure as a foundational determinant of technology adoption and organisational performance, and provides evidence-based justification for prioritising the digitisation of pharmacy operations as a necessary precursor to blockchain implementation.

The finding that 68.9% of community pharmacists encountered suspected counterfeit medicines at least once in the preceding 12 months, with 10.1% reporting more than 10 encounters, provides compelling empirical confirmation of the persistence and severity of the counterfeit medicine problem in Bayelsa State's pharmaceutical supply chain. This high encounter rate establishes the practical urgency that underlies the theoretical case for blockchain-based traceability: the problem that the technology is proposed to address is not hypothetical but is a routine reality of community pharmacy practice in the state. From a Resource Dependency Theory perspective (Pfeffer & Salancik, 1978), this finding also highlights the vulnerability of community pharmacies to supply chain integrity failures that originate beyond their operational control, reinforcing the need for systemic, technology-enabled solutions that extend traceability beyond the boundaries of individual pharmacy premises.

5.2.3 Implementation Readiness for Blockchain-Based Traceability

The third research objective assessed the implementation readiness for blockchain technology-based traceability systems among stakeholders in community pharmacies. The findings reveal a complex and internally contradictory readiness profile, characterised by strong human motivation coexisting with severe infrastructural and organisational deficits.

The overall readiness score of 2.70 on a 5-point scale (SD = 0.84) falls below the neutral midpoint of 3.0, indicating that community pharmacies in Bayelsa State are, on aggregate, not yet ready for blockchain adoption. However, this aggregate score conceals a critical internal tension that has important strategic implications. The highest-scoring readiness indicator, willingness to undergo training (Mean = 3.74, SD = 1.53), represents the human capital dimension and indicates that pharmacists are personally motivated to learn about and engage with blockchain-based systems. This finding is encouraging and suggests that resistance to change, while identified as a barrier by 42.9% of respondents, does not reflect an entrenched or universal opposition to technological innovation but rather a more nuanced stance in which pharmacists are willing to adapt if appropriate support is provided. This interpretation is consistent with the Technology Acceptance Model (Davis, 1989), which identifies perceived ease of use as a critical determinant of adoption: pharmacists who express willingness to undergo training are implicitly acknowledging that they do not currently find blockchain easy to use but are open to acquiring the competencies that would reduce this barrier.

In stark contrast, the lowest-scoring readiness indicator, stable internet and power supply (Mean = 1.80, SD = 0.88), with 89.9% of respondents disagreeing or strongly disagreeing that they have reliable digital infrastructure, represents a fundamental structural constraint that cannot be addressed through training or attitudinal change alone. This finding has profound implications for blockchain adoption strategy in Bayelsa State: even if every pharmacist were fully trained, enthusiastically supportive, and technologically literate, the absence of reliable internet connectivity and electrical power would render blockchain-based traceability systems inoperable in the vast majority of community pharmacies. This infrastructure deficit is consistent with the broader challenges documented across the Niger Delta region and many parts of Nigeria, where the reliability of public utilities remains a persistent barrier to digital transformation across all sectors (Nkengasong & Tambo, 2019).

The moderate score for staff digital literacy (Mean = 2.34, SD = 1.34), with 47.9% of respondents strongly disagreeing that staff possess sufficient digital literacy, identifies a second critical capacity gap. Digital literacy encompasses not merely the ability to use smartphones or computers but the broader competency to interact with digital systems, interpret digital information, troubleshoot basic technical problems, and adapt to new digital workflows. The finding that nearly half of respondents assess their staff's digital literacy as critically insufficient indicates that even where infrastructure challenges are addressed, a substantial investment in digital skills development will be required before blockchain-based systems can be effectively operationalised at the pharmacy level.

The significant positive correlations between staff digital literacy and adoption readiness ($r = 0.45$, $p < 0.01$) and between management support and adoption readiness ($r = 0.41$, $p < 0.01$) provide empirical evidence of the interdependencies among readiness factors that the UTAUT framework (Venkatesh et al., 2003) would predict. These correlations suggest that adoption readiness is not determined by any single factor but emerges from the interaction of multiple enabling conditions, each of which must reach a threshold level for the system as a whole to achieve adoption readiness. The additional correlation between staff digital literacy and management support ($r = 0.30$, $p < 0.05$) introduces a further dynamic: pharmacies with more digitally literate staff may cultivate more innovation-receptive management cultures, creating a virtuous cycle that accelerates readiness development. Conversely, pharmacies where both staff literacy and management support are low may become trapped in a low-readiness equilibrium from which escape is difficult without external intervention.

5.2.4 Barriers and Enablers of Blockchain Adoption

The fourth research objective evaluated the barriers and enablers for adopting blockchain traceability within pharmaceutical supply chains in Bayelsa State. The findings provide a nuanced understanding of the adoption landscape, revealing that attitudinal, financial, and technical barriers interact in complex ways, while enablers are oriented toward regulation, usability, and financial support.

The identification of resistance to change from traditional methods as the most frequently cited barrier (42.9%) is a significant finding that merits careful interpretation. This resistance should not be understood as a simple unwillingness to modernise or an irrational attachment to outdated practices. Rather, in the context of community pharmacy operations in Bayelsa State, resistance to change likely reflects a rational assessment by pharmacists of the risks and uncertainties associated with adopting a technology that they do not fully understand, that requires infrastructure they do not currently possess, and that carries costs they may not be able to bear. Institutional Theory (Meyer & Rowan, 1977; DiMaggio & Powell, 1983) provides a useful interpretive lens here: in the absence of clear institutional signals, whether regulatory mandates from NAFDAC, professional standards from PCN, or visible adoption by respected peer pharmacies, individual

pharmacists face a high-uncertainty decision environment in which the rational response is to maintain existing practices until the institutional landscape clarifies. The finding that mandatory regulatory requirements (36.1%) emerged as the second-strongest enabler supports this interpretation: pharmacists are indicating that they would adopt blockchain if the institutional environment made adoption a clear expectation rather than an uncertain option.

The high cost of implementation, cited by 35.3% of respondents, represents a tangible economic barrier that is consistent with the community pharmacy operating environment in Bayelsa State and across Nigeria more broadly. Community pharmacies typically operate as small-to-medium enterprises with modest revenue margins, limited access to business credit, and significant operational cost pressures from rent, staff salaries, inventory acquisition, and utility expenses. The additional capital expenditure required for blockchain implementation, encompassing hardware acquisition (scanners, computers), software licensing or subscription fees, internet connectivity establishment and maintenance, and staff training, represents a substantial financial commitment relative to the typical pharmacy operating budget. Resource Dependency Theory (Pfeffer & Salancik, 1978) illuminates the structural dimension of this barrier: community pharmacies are resource-dependent organisations whose investment capacity is constrained by their revenue model, and the adoption of capital-intensive technology requires either enhanced revenue, external financial support, or a regulatory mandate that transforms adoption from an optional investment into a compliance cost that is factored into standard operating expenses.

The emergence of user-friendly mobile or web-based applications as the strongest perceived enabler (42.9%) is a critically important finding that has direct implications for the design of blockchain-based traceability solutions for the community pharmacy context. This finding resonates powerfully with the Technology Acceptance Model (Davis, 1989), which identifies perceived ease of use as a primary determinant of technology adoption: pharmacists are communicating that they are most likely to adopt blockchain traceability if the system is presented through familiar, intuitive, and accessible digital interfaces, specifically mobile applications or web-based platforms, rather than through complex, specialised software that requires extensive technical training. This insight should guide technology developers and policymakers: blockchain solutions designed for community pharmacy adoption in contexts similar to Bayelsa State should prioritise front-end simplicity and mobile-first design, abstracting the technical complexity of the underlying blockchain architecture behind user-friendly interfaces that integrate seamlessly into existing pharmacy workflows.

The statistically significant associations between years of practice experience and both cost perceptions (Chi-square = 10.94, p = 0.004) and technical expertise gaps (Chi-square = 12.67, p = 0.002) indicate that barrier perceptions are not uniform across the professional demographic spectrum but vary systematically by career stage. This finding suggests that intervention strategies should be segmented by career stage: earlier-career pharmacists may benefit most from technical training and mentorship programmes that build confidence in engaging with digital systems, while more established practitioners may require financial support mechanisms and clear demonstrations of return on investment to overcome cost-related hesitations. This career-stage differentiation is consistent with both the DOI theory's adopter categories (Rogers, 1962) and UTAUT's identification of experience as a moderating variable (Venkatesh et al., 2003).

5.3 CONCLUSION

This study set out to assess the knowledge, current practices, and implementation readiness of blockchain technology-based traceability for counterfeit medicine prevention in community pharmacies in Bayelsa State, Nigeria. Based on the analysis of data collected from 119 community pharmacists, the study arrives at the following conclusions:

First, community pharmacists in Bayelsa State possess a high level of surface awareness of blockchain technology (71.4%) but an extremely low level of functional understanding of the technical concepts that constitute blockchain's distinctive value for pharmaceutical traceability. Mean knowledge scores ranging from 1.26 to 1.72 on a 5-point scale indicate that the pharmacy workforce is at the "No Knowledge" to "Basic Awareness" level, with a significant awareness-comprehension gap that must be bridged before any meaningful engagement with blockchain-based systems can occur. Educational qualification is a significant predictor of knowledge depth, suggesting that postgraduate-educated pharmacists represent the most knowledge-ready segment of the professional community.

Second, current medicine authentication and traceability practices in community pharmacies in Bayelsa State are overwhelmingly manual and observation-dependent, with 77.3% of pharmacists relying on visual inspection of NAFDAC numbers, 55.5% using paper-based inventory records, and 35.3% operating without any formal inventory tracking system. Only 9.2% of pharmacies possess the digital scanning or cloud-based infrastructure that would constitute the minimum technological prerequisite for participation in a blockchain-based traceability network. Despite these limitations, 68.9% of pharmacists encountered suspected counterfeit medicines in the past year, and digital inventory systems are significantly associated with higher detection rates, establishing both the practical urgency for improved traceability and the empirical case for digitisation as a foundational intervention.

Third, the overall implementation readiness of community pharmacies for blockchain-based traceability is below average (Mean = 2.70/5.0), characterised by a critical tension between strong human willingness to engage with the technology (training willingness Mean = 3.74) and severely deficient structural foundations, most critically the near-universal absence of reliable internet and power infrastructure (Mean = 1.80). Staff digital literacy and management support are significantly correlated with overall readiness, indicating that capacity-building interventions targeting these factors would yield the most direct improvements in adoption preparedness.

Fourth, the adoption landscape is shaped by a complex interplay of attitudinal barriers (resistance to change, 42.9%), financial constraints (high cost, 35.3%), capacity deficits (lack of expertise, 26.9%), and infrastructure limitations (poor connectivity, 25.2%), while the most powerful enablers are system usability (user-friendly applications, 42.9%), regulatory direction (mandatory requirements, 36.1%), and financial support (government subsidies, 26.1%). These findings collectively indicate that blockchain adoption in community pharmacies in Bayelsa State cannot be achieved through a single intervention but requires a coordinated, multi-stakeholder strategy that simultaneously addresses infrastructure, capacity, regulation, and technology design.

In synthesis, this study concludes that community pharmacies in Bayelsa State are not currently ready for blockchain-based traceability adoption, but that the attitudinal environment is receptive and the professional motivation exists to support a phased transition toward digital traceability if the requisite enabling conditions, particularly infrastructure development, capacity building, regulatory clarity, and user-centred system design, are systematically addressed.

5.4 Public Health Implications of the Study

Beyond its methodological and theoretical contributions, this study carries direct implications for public health protection in Bayelsa State and comparable resource-constrained settings. The finding that 68.9% of community pharmacists encountered suspected counterfeit medicines in the preceding year, set against an environment in which 77.3% of authentication decisions rely on unaided visual inspection, indicates that a substantial volume of falsified or substandard medicines is likely reaching patients undetected at the point of dispensing. Given that community pharmacies function as the first, and frequently the only, point of contact with the formal health system for a large proportion of the population in the Niger Delta region, particularly for the management of highly prevalent conditions such as malaria, bacterial infections, hypertension, and diabetes, the practical consequence of this traceability gap is a continuing risk of treatment failure, prolonged illness, avoidable morbidity, and, in severe cases, mortality among patients who have no means of independently verifying the authenticity of the medicines they receive.

The public health stakes are heightened by the specific therapeutic categories most vulnerable to counterfeiting internationally, namely antimalarials and antimicrobials (WHO, 2017; Bendavid et al., 2017), both of which are heavily prescribed and dispensed within Bayelsa State's disease burden profile. Undetected substandard or falsified antimalarials and antibiotics do not merely fail to treat the individual patient; sub-therapeutic dosing of these agents is a recognised driver of antimicrobial and antimalarial drug resistance, a slow-moving but consequential public health threat with implications that extend beyond the individual patient to the wider community and health system. In this sense, the traceability gap identified in this study is not only a patient-safety issue but a population-level health security issue, with the low technological readiness of community pharmacies in Bayelsa State representing a structural vulnerability in the state's broader defence against drug resistance.

The findings also carry implications for equity in public health protection. Bayelsa State's relatively under-resourced health infrastructure, evidenced in this study by the near-universal deficiency in reliable internet and power supply (Mean = 1.80/5.0) and the low penetration of digital inventory systems (9.2%), mirrors patterns observed across much of the Niger Delta and other resource-constrained regions of Nigeria. This suggests that, absent deliberate intervention, the benefits of blockchain-enabled traceability are likely to be realised first, and perhaps only, in better-resourced urban centres, while patients in states such as Bayelsa remain disproportionately exposed to counterfeit medicine risk. Addressing this gap is therefore not simply a matter of technological modernisation but a matter of equitable public health protection, requiring policy attention to ensure that traceability innovations do not bypass the populations that stand to benefit from them most.

Finally, the study underscores that interim, non-blockchain-dependent public health measures remain essential while the structural and human-capacity foundations for blockchain adoption are being built. The strong training willingness expressed by pharmacists (Mean = 3.74/5.0), despite the current knowledge and infrastructure deficits, represents an immediately actionable public health asset: targeted, low-cost capacity-building interventions, such as structured continuing professional development on counterfeit detection and reporting, strengthened utilisation of the existing Mobile Authentication Service, and reinforced collaboration between community pharmacists and NAFDAC's pharmacovigilance and post-marketing surveillance systems, can yield meaningful public health protection in the short term, even as the longer-term transition toward blockchain-based traceability is pursued.

5.5 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed for policy, practice, and technology development:

5.5.1 Recommendations for Regulatory Bodies (NAFDAC, PCN)

i. NAFDAC and PCN should develop and disseminate a clear, phased regulatory framework for the adoption of blockchain-based traceability in community pharmacies, providing institutional clarity that addresses the uncertainty currently inhibiting adoption. The framework should articulate timelines, compliance milestones, minimum technical requirements, and the relationship between blockchain traceability and existing regulatory mechanisms such as the Mobile Authentication Service (MAS).

ii. The Pharmacists Council of Nigeria should integrate blockchain technology and digital health literacy modules into the mandatory Continuing Professional Development (CPD) curriculum for community pharmacists, ensuring that all practising pharmacists have access to structured, professionally accredited training that bridges the awareness-comprehension gap identified in this study.

iii. NAFDAC should consider establishing pilot blockchain traceability programmes in selected states, including Bayelsa State, to generate implementation experience, identify operational challenges, and build an evidence base for national scale-up. These pilots should be designed in partnership with community pharmacy stakeholders to ensure contextual relevance and professional buy-in.

5.5.2 Recommendations for Government and Infrastructure Development

iv. The Bayelsa State Government, in collaboration with federal agencies and telecommunications providers, should prioritise the expansion of reliable broadband internet infrastructure and stable electricity supply to areas where community pharmacies operate, recognising that digital infrastructure is a prerequisite not only for blockchain adoption but for the broader digital transformation of healthcare service delivery in the state.

v. Government at both state and federal levels should establish dedicated funding mechanisms, whether through subsidies, tax incentives, low-interest technology loans, or grant programmes, to support community pharmacies in acquiring the digital hardware, software, and connectivity required for participation in blockchain-based traceability networks. The 35.3% of respondents who identified high cost as a barrier indicates that financial support is essential for equitable adoption, particularly among smaller and resource-constrained pharmacy operations.

5.5.3 Recommendations for Technology Developers and Digital Health Innovators

vi. Blockchain-based traceability solutions designed for community pharmacy deployment in Nigeria and comparable contexts should prioritise mobile-first, user-friendly interface design that abstracts the technical complexity of the underlying blockchain architecture. The finding that user-friendly applications are the strongest perceived enabler (42.9%) indicates that system usability will be the single most important determinant of pharmacist adoption and sustained engagement.

vii. Technology developers should design blockchain traceability systems that are interoperable with existing NAFDAC systems (including MAS) and compatible with the GS1 standards already endorsed by the Nigerian regulatory framework, ensuring that blockchain implementation complements rather than disrupts established verification workflows.

viii. Blockchain platforms for the community pharmacy sector should be designed to function effectively in low-bandwidth environments and should incorporate offline-capable functionality that permits core traceability operations to continue during periods of internet or power disruption, with automatic synchronisation when connectivity is restored. This design consideration is essential given the infrastructure realities documented in this study.

5.5.4 Recommendations for Professional Associations (ACPN, PSN)

ix. The Association of Community Pharmacists of Nigeria (ACPN) and the Pharmaceutical Society of Nigeria (PSN) should organise awareness campaigns, workshops, and peer learning initiatives focused on blockchain technology and its applications to pharmaceutical traceability, leveraging existing professional communication channels including WhatsApp platforms, state chapter meetings, and annual conferences.

x. Professional associations should identify and support blockchain "champions" or early adopters within the community pharmacy profession who can serve as peer educators, demonstrate practical applications of the technology, and provide evidence of its benefits from first-hand experience, leveraging the social influence mechanisms identified in the UTAUT framework and the peer diffusion dynamics described in Rogers' DOI theory.

5.5.5 Recommendations for Academic Institutions and Pharmacy Education

xi. Pharmacy training institutions, including the Faculty of Pharmacy at Niger Delta University and other pharmacy schools in the region, should integrate blockchain technology, health informatics, and digital supply chain management into undergraduate and postgraduate pharmacy curricula, ensuring that future pharmacists

graduate with foundational knowledge of emerging digital health technologies.

xii. Academic researchers should be encouraged and supported to conduct further empirical studies on blockchain adoption in pharmaceutical supply chains, including implementation science research, user experience studies, and cost-effectiveness analyses that can inform evidence-based policy and investment decisions.

5.6 Contributions to Knowledge

This study makes several contributions to the existing body of knowledge on blockchain technology adoption in pharmaceutical supply chains within developing country contexts:

First, the study provides the first empirical assessment of blockchain knowledge, current traceability practices, implementation readiness, and adoption barriers and enablers among community pharmacists in Bayelsa State, Nigeria, contributing sub-national data from a previously unstudied context to the growing international literature on blockchain adoption in healthcare.

Second, the study identifies and quantifies the awareness-comprehension gap in blockchain knowledge among community pharmacists, demonstrating empirically that high surface awareness (71.4%) can coexist with extremely low functional understanding (Mean scores 1.26-1.72/5.0), a finding that has implications for how blockchain awareness is measured and interpreted in technology adoption research.

Third, the study provides empirical evidence of the critical tension between human readiness (strong training willingness) and structural readiness (critically deficient infrastructure) in the community pharmacy sector, contributing to theoretical understanding of the multi-dimensional nature of technology readiness in resource-constrained healthcare settings.

Fourth, the study generates context-specific evidence on the hierarchy of barriers and enablers for blockchain adoption in Nigerian community pharmacies, demonstrating that attitudinal resistance and cost constraints outweigh technical barriers, while system usability and regulatory mandates are stronger motivators than economic incentives alone.

Fifth, the study validates the utility of a multi-theoretical framework integrating DOI, TAM, UTAUT, TOE, Institutional Theory, Stakeholder Theory, RDT, and TTF for analysing blockchain adoption dynamics in community pharmacy settings, demonstrating that no single theory adequately captures the full complexity of the adoption landscape and that integrative approaches yield richer analytical insight.

5.7 Suggestions for Further Research

Based on the findings and limitations of this study, the following areas are recommended for future research investigation:

i. A multi-state comparative study should be conducted to examine whether the knowledge, practice, and readiness patterns identified in Bayelsa State are consistent across other states in the Niger Delta region and beyond, enabling the development of nationally representative baseline data for blockchain adoption planning.

ii. Qualitative research, employing in-depth interviews and focus group discussions with community pharmacists, regulatory officials, technology developers, and pharmaceutical distributors, should be conducted to generate deeper contextual understanding of the motivations, concerns, and decision-making processes that underlie the quantitative patterns documented in this study.

iii. Implementation science research should be conducted to design, deploy, and evaluate pilot blockchain traceability interventions in selected community pharmacies in Bayelsa State, generating real-world evidence on the feasibility, usability, acceptance, and effectiveness of blockchain-based systems under actual operating conditions.

iv. Cost-effectiveness and return-on-investment analyses should be conducted to quantify the economic implications of blockchain adoption for community pharmacies, including the costs of implementation, the potential savings from reduced counterfeit infiltration and associated losses, and the long-term financial sustainability of blockchain-based traceability systems in the Nigerian community pharmacy context.

v. Longitudinal studies should be undertaken to track changes in blockchain knowledge, readiness, and adoption behaviour over time, particularly in response to regulatory developments, infrastructure improvements, and the implementation of training and awareness programmes, enabling the assessment of the temporal dynamics of blockchain diffusion within the community pharmacy profession.

vi. Research should be conducted on the design and evaluation of blockchain-based traceability user interfaces specifically optimised for community pharmacy settings in Nigeria, employing user-centred design methodologies and usability testing with pharmacist end-users to ensure that technology solutions are responsive to the needs, preferences, and constraints documented in this study.

ACKNOWLEDGEMENTS

First and foremost, I give glory to God Almighty for the strength, wisdom, and perseverance granted throughout this study. Without His guidance, this work would not have been possible.

I express my profound gratitude to my supervisor, Prof Peter. A. Owonaro, for the invaluable guidance, constructive criticism, and consistent encouragement provided throughout the course of this research.

I am equally grateful to the Head of Department, Dr Sounyo Adebukula, and all academic staff of the department of Clinical pharmacy and pharmacy practice, Niger Delta University, for their support and scholarly direction during my postgraduate programme.

My gratitude goes to Prof Diepreye Ere for his mentorship and support.

My sincere appreciation goes to the community pharmacists of Bayelsa State, recruited through the Association of Community Pharmacists of Nigeria (ACPN), Bayelsa State Chapter, who participated in this study. Your willingness to share your knowledge, practices, and perspectives made this research possible.

I also extend my thanks to the leadership of the ACPN Bayelsa State Chapter, and to colleagues and friends especially Pharm Kenneth .E. Nisiama and Pharm Henry Messiah TMT who supported and encouraged me throughout this research.

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