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Cloud Computing Attack Resilience and its Implication for Public Institutions in Zambia: A Review and Adaptive Security Framework Proposal

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***Abstract* - This research systematically examines the cybersecurity challenges facing public institutions in Zambia within the context of heterogeneous cloud networks. By reviewing recent literature (2016–2024) and conducting expert interviews, the study highlights the complexities of cloud adoption in resource-constrained environments. Key findings reveal vulnerabilities stemming from inconsistent cloud service policies, inadequate infrastructure, and limited technical expertise. To address these issues, the research proposes an Adaptive Security Framework that integrates continuous monitoring, real-time threat detection, dynamic policy adjustments, and Distributed Ledger Technologies (DLTs) to enhance data integrity and confidentiality. This framework aims to improve Zambia's cloud security resilience while providing practical policy recommendations to strengthen cloud security in public institutions. The study is built on over 50 scholarly references and offers a roadmap for enhancing cloud security management in Zambia's public sector.**

Keywords: Cloud Computing, Public Institutions, Heterogeneous Cloud Networks, Cybersecurity Challenges, Attack Resilience, Data Breaches, ICT Infrastructure.

I. INTRODUCTION

A. Background.

Cloud computing has evolved into a crucial asset for public institutions, offering operational flexibility, scalability, and cost savings. However, integrating heterogeneous cloud networks, public, private, and hybrid presents cybersecurity challenges. The rapid adoption of cloud services in Zambia is no exception, as public institutions aim to leverage these services while contending with cyber threats and limited technical resources [1][2].

Public institutions in Zambia face specific challenges due to the inconsistent application of security protocols, which can lead to vulnerabilities such as data breaches and unauthorized access [3]. These challenges are exacerbated by the lack of technical expertise and inadequate regulatory frameworks that govern cloud computing in the region [4][5].

B. Problem Statement

The use of heterogeneous cloud services in Zambia's public institutions is essential for achieving efficient service delivery, but this also exposes these institutions to considerable cybersecurity risks. The primary issue lies in the inconsistency of security practices across different cloud platforms. This inconsistency results in an increased risk of data breaches and poor incident response management, further exacerbated by a lack of financial resources and trained IT personnel [6][7][8][9].

C. Research Aim and Objectives

This research aims to develop an adaptive security framework designed to address the cybersecurity challenges that arise from the use of heterogeneous cloud networks in Zambia's public institutions. The specific objectives include:

- Analyzing the current cybersecurity challenges faced by public institutions in Zambia.
- Reviewing existing adaptive security models for cloud computing.
- Proposing a comprehensive, adaptive security framework that addresses cloud-specific vulnerabilities.
- Offering policy recommendations for strengthening cloud security in Zambia.

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II. LITERATURE REVIEW

A. Search Inclusion Criteria

The literature review adhered to the PRISMA guidelines for systematic reviews. The databases used for this review included IEEE Xplore, ScienceDirect, SpringerLink, and local Zambian publications. Only peer-reviewed papers published between 2016 and 2024 were considered. Keywords such as "cloud computing," "heterogeneous cloud networks," "cybersecurity," "adaptive security frameworks," and "Zambia public institutions" were used to filter the results. This review yielded 54 relevant articles after screening for quality and relevance.

B. Search Exclusion Criteria

The Papers which did not have full-text availability and papers that were not written in the English language were not included during the search. In addition, studies such as editorials, summaries of keynotes, workshops, tutorials and book chapters were not included in the search for literature.

C. Cloud Computing in Public Institutions

Cloud computing enables public institutions to improve service delivery while reducing operational costs. It offers a scalable and flexible IT infrastructure that can adapt to changing demands [10][11]. However, public institutions in developing countries, including Zambia, face significant challenges when adopting cloud technologies, such as inadequate internet connectivity, limited technical expertise, and insufficient financial resources [12][13].

Studies have highlighted that public institutions in Zambia benefit from cloud adoption but face considerable obstacles in ensuring data security [14][15]. Furthermore, the lack of standardized security protocols exacerbates the risks associated with heterogeneous cloud networks [16]. Research suggests that cloud computing adoption in Africa is growing, but many public institutions struggle to implement secure systems due to these challenges [17].

D. Security Issues in Heterogeneous Cloud Networks

Heterogeneous cloud networks, which integrate public, private, and hybrid clouds, present unique security challenges. The integration of multiple cloud service models complicates the implementation of uniform security protocols, resulting in inconsistent encryption, monitoring, and access control practices [18][19]. Public institutions in Zambia, which often operate under resource constraints, are particularly vulnerable to these challenges [20][21]. Adaptive security frameworks have emerged as a solution to these problems. These frameworks allow institutions to continuously monitor and adjust security policies in real-time based on evolving threats. Research shows that adaptive security models are critical for securing heterogeneous cloud environments, particularly in dynamic and resource-limited settings [22][23].

E. Local Research: Zambia's Cybersecurity Landscape

Local research on cybersecurity in Zambia reveals several key challenges facing public institutions as they adopt cloud technologies. Studies show that Zambian public institutions are particularly vulnerable to cyber-attacks due to limited cybersecurity expertise, outdated infrastructure, and a lack of comprehensive regulatory frameworks [24][25][26]. The Zambia Information and Communications Technology Authority (ZICTA) has called for improved cybersecurity measures to protect sensitive government data, but progress has been slow [27].

Local experts have emphasized the need for tailored cybersecurity solutions that address Zambia's unique challenges, including the need for capacity building and regulatory reform [28]. Recent studies suggest that investment in training IT professionals and developing localized cybersecurity policies could significantly improve the resilience of Zambia's public institutions [29][30].

F. Distributed Ledger Technologies (DLTs) for Cloud Security

Distributed Ledger Technologies (DLTs), such as blockchain, offer a promising solution for enhancing security in cloud environments. DLTs provide a decentralized, tamper-proof record of transactions, ensuring data integrity and confidentiality [31][32]. In cloud networks, DLTs can be used to secure sensitive data and prevent unauthorized access by creating immutable audit trails [33].

Research has shown that DLTs are particularly useful in environments where traditional cybersecurity measures are limited, making them ideal for adoption in Zambia's public institutions [34]. However, the practical implementation of DLTs in Zambia remains limited due to financial and technical constraints, highlighting the need for further research and investment in this area [35].

III. METHODOLOGY

A. Research Design

This study adopts a mixed-methods approach, combining a systematic literature review with qualitative data collection through expert interviews and surveys. The literature review provided the foundation for identifying key cybersecurity challenges, while the interviews provided practical insights into the current state of cloud security in Zambia's public institutions [36][37]. The population of 100 participants from public institutions of Zambia were targeted.

B. Data Collection

Surveys were conducted with 86 ICT professionals, cybersecurity experts, and policymakers from Zambia's public institutions. The questionnaires were provided to participants that explored the security challenges faced by

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these institutions, the adequacy of existing security measures, and potential solutions for improving cloud security. The responses were recorded, transcribed, and analyzed using Excel software.

C. Data Analysis

The data collected from surveys was analyzed using thematic analysis to identify recurring themes and challenges related to cloud security. These themes were then compared with the findings from the literature review to provide a comprehensive understanding of the security issues facing Zambia's public institutions.

IV. FINDINGS

A. Literature Sources Summary

TABLE 1: Literature sources

Data Source	No. of Articles reviewed	Papers Used	Focus Area
IEEE Xplore	48	22	Cloud computing, cybersecurity, DLTs, and adaptive security frameworks
ScienceDirect	35	12	Heterogeneous cloud networks and cloud security
Local Zambian Journals	30	10	Cybersecurity challenges in Zambia's public institutions
SpringerLink	15	5	Comparative studies from sub-Saharan Africa
Google Scholar	38	5	Broader studies on cloud adoption in developing countries
Totals	**166**	**54**	

B. Cybersecurity Challenges in Zambia's Public Institutions

The literature review and surveys identified several key challenges facing Zambia's public institutions in managing cloud security, including:

Inconsistent Security Policies: Many institutions struggle to implement uniform security measures across diverse cloud environments, leading to gaps in encryption and access control [38][39].

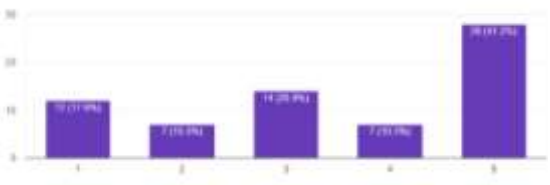

Figure 1: Difficulty in managing security policies

Figure 1 above shows that out of the total of 68 responses we got on the aspect of 'difficulty of managing security policies', the highest number (28) representing 41.2% indicated that many public institutions in Zambia have difficulty in practicing uniform security measures across various cloud environments.

Limited Technical Expertise: A significant barrier to effective cloud security is the lack of trained IT personnel within Zambia's public institutions, which often rely on external cloud service providers for security [40][41].

Figure 2 below, shows that out of 68 responses received from participants on the aspect of 'limited technical expertise', the highest number (23) that represented 33%, said that public institutions in Zambia lack experts to handle cloud computing that led to Cloud security vulnerability.

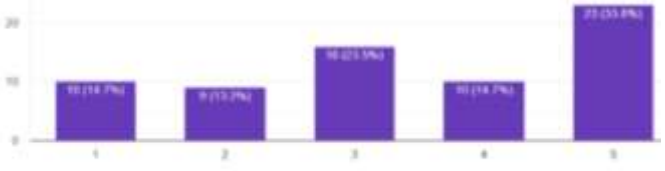

Figure 2: Technical expertise

Regulatory Gaps: Zambia's cybersecurity regulations are outdated and do not adequately address the security challenges posed by heterogeneous cloud networks [42][43]. Figure 3 below shows that a high number, represented by 27.7% in the pie chart, of responders said that Zambia's cybersecurity policies are outdated and do not adequately resolve the security challenges posed by heterogeneous cloud networks.

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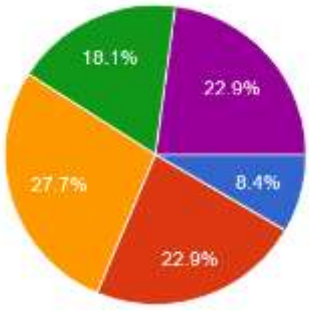

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Figure 3: Non-Regulatory compliance – 27.7%

D. Adaptive Cybersecurity Framework.

Based on the findings, this study proposes an Adaptive Security Framework tailored to Zambia's public institutions. This framework incorporates continuous monitoring, real-time threat detection, and dynamic policy adjustment to respond to evolving cyber threats. Additionally, it integrates DLTs to secure sensitive data and ensure tamper-proof records of transactions [44][45]. The following framework in figure 4 is proposed.

Figure 4: Adaptive Framework

V. DISCUSSION

E. Enhancing Cybersecurity in Heterogeneous Cloud Networks.

To address the identified challenges, Zambia's public institutions must adopt a multi-layered security strategy that includes:

Continuous Monitoring and Threat Detection: Real-time monitoring is essential for detecting and mitigating cyber threats as they arise [46][47][48].

Capacity Building: Investment in training IT staff and building technical capacity is critical to improving cloud security management [49][50].

Regulatory Reform: Policymakers should develop updated cybersecurity regulations that address the specific challenges posed by cloud computing in public institutions [51][52].

F. The Role of DLTs in Enhancing Cloud Security.

The integration of DLTs into Zambia's public cloud infrastructure could significantly enhance data integrity and resilience against cyber-attacks. DLTs offer a decentralized, tamper-proof solution for managing sensitive data in cloud environments, ensuring that information remains secure even with limited technical resources [53][54].

VI. CONCLUSION

This study systematically analyzes the cybersecurity challenges facing Zambia's public institutions in managing heterogeneous cloud networks. By combining a thorough literature review with expert interviews, the research identifies key vulnerabilities and offers practical solutions for enhancing cloud security. The proposed adaptive security framework, incorporating DLTs, offers a clear path forward for improving the security of Zambia's cloud infrastructure. Future research should focus on the practical implementation of this framework and its scalability to other developing countries.

VII. RECOMMENDATIONS

The following recommendations are suggested:

 Adopt Adaptive Security Frameworks: Public institutions should implement flexible security frameworks that can adapt to evolving threats in real-time.

Invest in Capacity Building: Training IT professionals and building technical capacity are essential for addressing Zambia's cloud security challenges.

Develop Comprehensive Cybersecurity Regulations: Policymakers should prioritize the development of updated regulations that address the unique challenges posed by heterogeneous cloud networks.

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