PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (1) 79-84 Jan. 2025

Evaluating the Efficiency and Reliability of Fertilizer Subsidy Systems: The Role of Blockchain in Driving Enhancements in Tanzania

[*1]MBITA, OD; [2]NICHOLAUS, MR; [3]TWAHIR, RK

*[*1]Department of Information Systems and Technology, [2]Department of Computer Science and Engineering (CSE), [3]Department of Information Systems and Technology, College of Information and Communication Technology (CoICT), Mbeya University of Science and Technology, MUST Street, 53119, Mbeya -Tanzania,*

**Corresponding author Email: mgwetam@gmail.com*
[*]ORCID: https://orcid.org/0009-0000-0618-7716
[*]Tel: +255 764017794

Co-Author Email: twahirkazema@gmail.com; nicholausmrindoko@gmail.com

ABSTRACT: This paper aims to evaluate the efficiency and reliability of fertilizer subsidy systems in the Mbeya Region of Tanzania, while exploring the role of blockchain technology in driving enhancements to these systems. The research presents a blockchain-based e-voucher system as the innovative solution to these challenges, providing a robust framework that incorporates architectural design and algorithmic solutions to enhance efficiency within the distribution process. The findings demonstrate significant improvements in addressing the identified challenges, including streamlined application processing, voucher issuance and redemption, reimbursement procedures, and increased transparency and traceability. The proposed hybrid architecture integrates well-structured algorithms to improve operational efficiency and ensure a more secure and fair distribution system. These findings underscore the urgent need for novel approaches to improve agricultural productivity and food security, advocating for the widespread adoption of blockchain technology within the agricultural sector.

DOI: https://dx.doi.org/10.4314/jasem.v29i1.11

Cite this Article as: MBITA, O. D; NICHOLAUS, M. R; TWAHIR, R. K. (2025). Evaluating the Efficiency and Reliability of Fertilizer Subsidy Systems: The Role of Blockchain in Driving Enhancements in Tanzania. *J. Appl. Sci. Environ. Manage.* 29 (1) 79-84

Dates: Received: 22 October 2024; Revised: 20 November 2024; Accepted: 28 December 2024; Published: 31 January 2025

Keywords: Electronic Voucher; Subsidy Fertilizer; Blockchain Technology; Voucher System; Subsidy Systems

Fertilizer is crucial in modern agriculture because it enhances soil fertility and significantly increases crop yields (Lameck *et al.*, 2019). As global food demand rises, ensuring fertilizers' availability and proper distribution is vital to sustaining agricultural productivity, especially in regions where food security is critical (SDG.17 UN, 2015). With its predominantly agrarian economies, Sub-Saharan Africa faces unique challenges in achieving these goals, mainly due to the socio-economic constraints on smallholder farmers (Malhi *et al.*, 2021). However, access to fertilizers in Sub-Saharan Africa, particularly in Tanzania, remains a significant challenge for smallholder farmers. High costs and limited availability often hinder farmers from acquiring the quantities needed to improve their crop productivity (Lameck *et al.*, 2019). This lack of access perpetuates a cycle of low yields, economic instability, and food insecurity, particularly in resource-limited settings (Mwinuka, 2018). To address these challenges, several governments in Sub-Saharan Africa, including Tanzania, have implemented subsidy programs aimed at making fertilizers more affordable and accessible. These subsidy initiatives are vital for enhancing agricultural productivity by reducing the financial burden on

**Corresponding author Email: mgwetam@gmail.com*
**ORCID: https://orcid.org/0009-0000-0618-7716*
**Tel: +255 764017794*

farmers (Lameck *et al.,* 2019). By lowering the cost of essential inputs, such programs empower farmers to boost their yields, supporting economic viability and food security. Historically, one of the most common approaches to delivering these subsidies has been through voucher systems. In Tanzania, for instance, the National Agricultural Input Voucher Scheme (NAIVS) in 2009 marked a shift towards a more structured and manageable fertilizer subsidy distribution (Wineman *et al.,* 2020). Paper vouchers were provided to farmers, allowing them to redeem a specific amount of fertilizer at designated dealers. However, while this method had benefits, it also encountered significant challenges. Issues such as fraud, mismanagement, and logistical complications in reaching rural areas limited its effectiveness, and the process of tracking and auditing paper-based transactions proved cumbersome and lacked transparency (Hepelwa *et al.,* 2013). In response, the Tanzanian government moved towards a more advanced solution in the 2022/2023 agricultural season by adopting an electronic voucher (e-voucher) system, utilizing Web2 technologies (MOA, 2022). Delivered via SMS or mobile apps, e-vouchers allowed for digital tracking, real-time monitoring, and a more efficient, streamlined distribution process. The rise in mobile phone usage among rural farmers further enhanced accessibility and convenience, offering a promising solution to the limitations of traditional voucher systems. Despite the improvements offered by e-voucher systems, challenges remained. Centralized databases and susceptibility to cybersecurity threats created new vulnerabilities while operational inefficiencies persisted (Bayan and Banach, 2023). As a result, attention has turned to the next phase of innovation, "blockchain technology."

With its decentralized, transparent, and secure framework, blockchain presents a new era for subsidy distribution across Sub-Saharan Africa. Blockchain could revolutionize the fertilizer subsidy landscape by eliminating many vulnerabilities associated with centralized systems and offering enhanced traceability (Bayan and Banach, 2023). In Tanzania, as in other parts of Sub-Saharan Africa, the adoption of blockchain technology promises to address persistent challenges, optimize subsidy distribution processes, and enhance agricultural productivity. The objective of this paper is to evaluate the efficiency and reliability of fertilizer subsidy systems in the Mbeya Region of Tanzania, while exploring the role of blockchain technology in driving enhancements to these systems.

MATERIALS AND METHODS

Research Design: This study employed a mixed-methods approach, combining quantitative and qualitative methodologies to evaluate the efficiency of subsidy fertilizer distribution in Tanzania. Quantitative data were gathered through structured questionnaires distributed to a random sample of stakeholders. In parallel, qualitative insights were obtained through in-depth interviews with these stakeholders to explore the challenges and operational complexities of the distribution system. Throughout the research, ethical considerations, including informed consent and confidentiality, were strictly adhered to ensuring the validity and reliability of the findings.

Data Collection: Random sampling was applied to the broader farmer population. The sample size was determined using the equation 1 to estimate proportions with a specified margin of error and confidence level (Verma, 2020).

$$\mathrm{N} = \frac{z^2 . p. (1 - p)}{E^2} \quad (1)$$

Preliminary data from TFRA indicated that 85,145 farmers in Mbeya were registered for the subsidy program for the 2023/2024 season. Based on this, the sample size was determined to be 384 farmers, who were selected from various districts including Mbeya Rural, Chunya, and Rungwe.

Data Analysis: the data were processed and analyzed using Python, with Anaconda serving as the development environment to manage dependencies. Jupyter Notebook was used for interactive data manipulation, analysis, and visualization. Python's libraries such as Pandas for data manipulation, NumPy for numerical analysis, and Matplotlib for visualizations enabled efficient handling of large datasets. These tools facilitated the application of statistical techniques.

Quantitative phase involved variable mapping, where key factors such as age, gender, farming experience, farm size, and primary income source were extracted from survey responses and encoded for analysis. Descriptive statistical analysis was then applied to summarize the frequency and proportion of distribution challenges, including trust issues, fraud, corruption, transparency, and other inefficiencies. The data was grouped based on demographic factors to facilitate comparisons and identify patterns of challenges experienced by different stakeholder groups. Cross-tabulation analyses examined the relationship between demographic variables and specific distribution challenges, with proportions

calculated to quantify the prevalence of these challenges. Visualizations were used to highlight key trends.

Qualitative phase involved in-depth interviews and open-ended survey questions were conducted with a subset of participants to capture farmers' nuanced experiences and perceptions regarding the fertilizer distribution process. Thematic coding was used to identify recurring themes related to distribution challenges, trust in the subsidy program, and the impact of fraud and corruption on farming practices. Detailed narratives were developed to illustrate the specific challenges faced by different demographic groups, such as those based on gender and farming experience. A comparative approach revealed distinct insights into how these challenges varied among stakeholders, emphasizing the need for tailored solutions to improve the effectiveness of the fertilizer subsidy distribution system.

Proposed Framework Architecture for Blockchain-Based e-Voucher System: The proposed framework for a Blockchain-Based e-Voucher System employs a hybrid architecture integrating N-tier and microservices architectures, enhancing modularity, scalability, and maintainability. The framework consists of several key layers, each with distinct roles, enabling efficient management of the complex processes involved in fertilizer distribution (Horn *et al.*, 2022). Fig.1 illustrates this architecture, showcasing how the integration of N-tier and microservices optimizes the system by breaking down functions into smaller, manageable services while maintaining a tiered structure for better control and organization of data flow and interactions. The user interface Layer includes web and mobile applications, offering user friendly interaction for farmers, suppliers, and government officials, with seamless processes like registration, voucher issuance, and redemption. It connects with dedicated microservices for responsiveness and scalability. The application layer contains five core algorithms: user registration and authentication, voucher issuance, voucher redemption, supplier reimbursement, and the smart contract algorithm, which enforces automated transaction terms via blockchain, ensuring security and scalability. The business logic layer handles core functionalities like user data management, voucher lifecycle events, and reimbursement processing, interacting with microservices to maintain consistency and reduce redundancy. The data access layer manages efficient and secure data storage and retrieval, supporting modular data interactions with traditional databases and blockchain networks. Lastly, the blockchain layer provides a decentralized, secure framework for voucher transactions, ensuring transparency, traceability, and immutability, thus enhancing trust, minimizing fraud, and improving the overall efficiency of the fertilizer subsidy system.

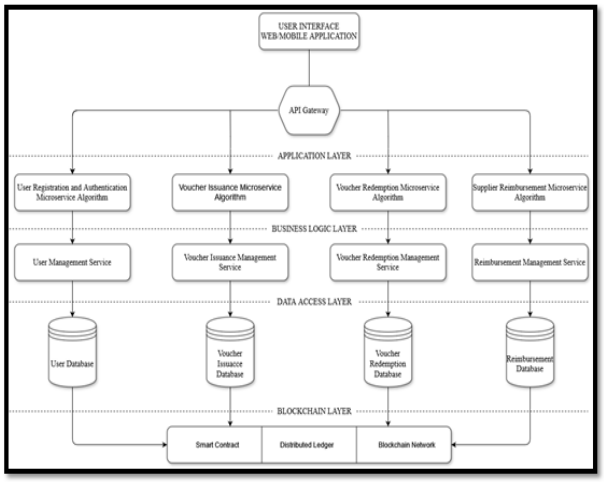

Fig.1: proposed framework architecture

Proposed Framework Algorithms for blockchain based e-voucher system: Developing the core algorithms in the Application Layer is crucial to the framework's overall functionality and efficiency. Each algorithm addresses tasks within the fertilizer distribution system, ensuring that user registration, voucher issuance, redemption, supplier reimbursement, and contract enforcement are handled securely and efficiently. These algorithms operate as independent microservices, allowing for modularity and scalability, and are integrated with the system through APIs to ensure smooth data exchange and process automation. Below is a detailed explanation of each algorithm and its role in the system.

User Registration and Authentication Microservice Algorithm: This algorithm registers and authenticates farmers and suppliers using their National Identification Number (NIDA) to generate a Digital Identity (DID), cryptographic keys (public and private), and a recovery phrase, which is later used for authentication and account recovery. Fig.2 illustrates this process, detailing how NIDA is utilized to generate a secure DID and cryptographic keys, ensuring both identity verification and data protection. The figure also highlights how the recovery phrase plays a crucial role in account recovery, enhancing the system's security and user accessibility.

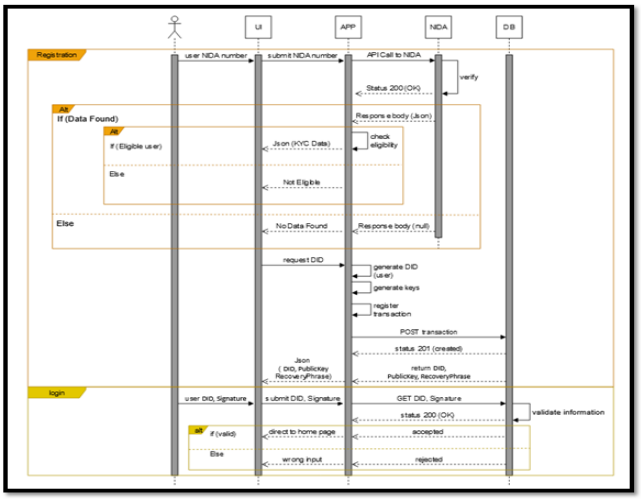

Fig.2: user registration and authentication microservice algorithm

Voucher Issuance Microservice Algorithm: This algorithm issues vouchers to eligible farmers by verifying their identity, checking for duplicates, and ensuring eligibility criteria are met. Once validated, the algorithm generates a smart contract linked to the voucher, distributed via a secure blockchain network. The voucher and associated smart contract details are returned to the requesting farmer in JSON format, ensuring a safe and transparent voucher issuance process. If the farmer is ineligible or has a duplicate entry, the system responds with an error message, preventing duplicate or unauthorized voucher issuance. Fig.3 illustrates this process, showing the identity verification, duplication check, smart contract generation, and the secure distribution of the voucher via blockchain. It also highlights the error handling mechanism for ineligible or duplicate entries, ensuring the integrity and fairness of the voucher system.

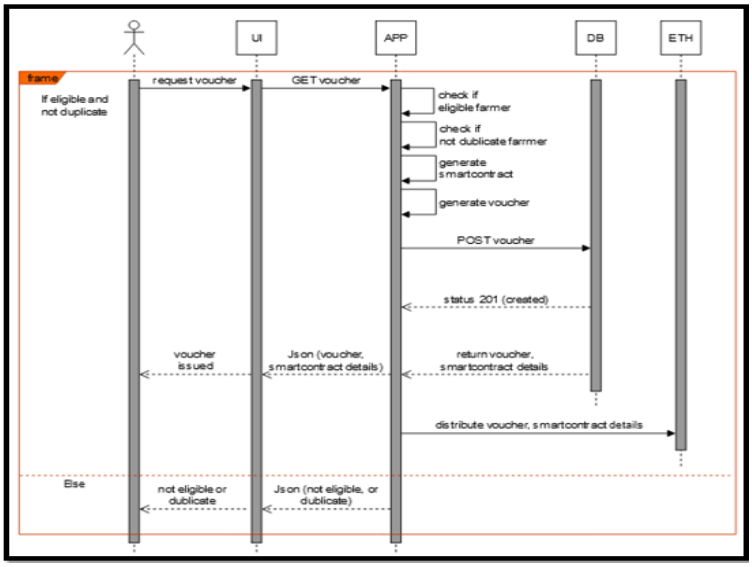

Fig.3: voucher issuance microservice algorithm

Voucher Redemption Microservice Algorithm: This algorithm facilitates the redemption of vouchers by validating their authenticity and ensuring they have not been previously redeemed. The voucher is cross-checked against the system to confirm its validity and status upon submission. If valid, the algorithm redeems the voucher and logs the transaction details into the database, including the farmer, supplier, and inputs. The transaction is confirmed with a "201 Created" response, and the redeemed voucher details are returned in JSON format. In cases where the voucher is invalid or has already been redeemed, the algorithm promptly responds with an error message, ensuring secure and accurate voucher redemption. Fig.4 illustrates this process, showing how the system verifies the voucher, logs the transaction, and responds with either a success message or an error, depending on the voucher's status, ensuring reliability and transparency in the redemption process.

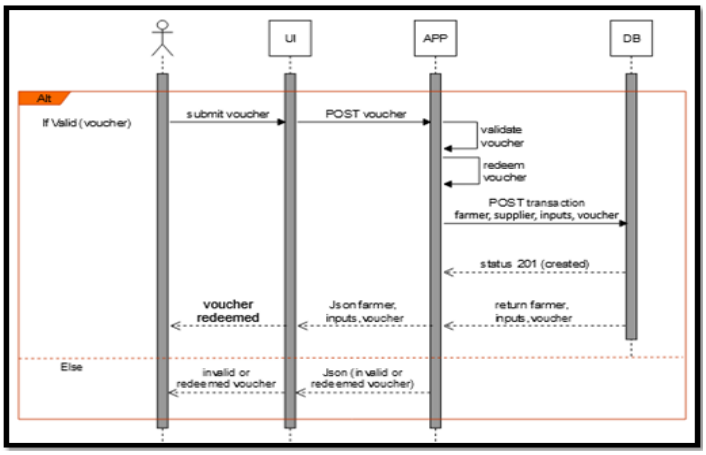

Fig.4: voucher redemption microservice algorithm

Supplier Reimbursement Microservice Algorithm: This algorithm manages the reimbursement process for suppliers by validating redeemed vouchers and generating smart contracts for reimbursement. When a supplier submits a redeemed voucher, the algorithm verifies its validity and ensures the voucher has been correctly redeemed. Upon successful validation, the algorithm creates a reimbursement smart contract and logs the reimbursement details to the database and blockchain network. The system then confirms the transaction with a "201 Created" status and returns the reimbursement details, including smart contract information, to the supplier. In cases where validation fails or the voucher is deemed invalid, the algorithm promptly denies reimbursement and provides an error response, ensuring transparency and accuracy throughout the reimbursement process. Fig.5 illustrates this flow, from voucher validation and smart contract generation to transaction logging and reimbursement confirmation, while also showcasing the error-handling mechanism for failed validations.

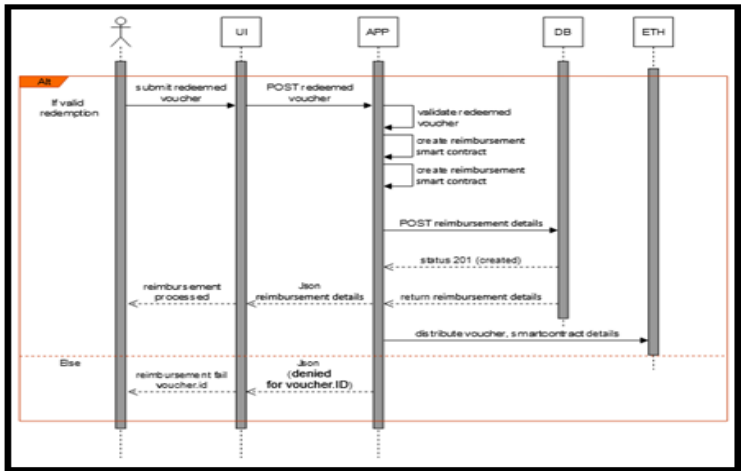

Fig.5: supplier reimbursement microservice algorithm

RESULTS AND DISCUSSION

Quantitative analysis has revealed distinct patterns in adopting subsidized fertilizers across different age groups. Among respondents aged 18 to 30 years, 81.2% reported using subsidized fertilizers, while 18.8% did not. In the 31 to 45 age group, 82.7% were users, with 17.3% identifying as nonusers. A slight decline was noted in the 46 to 60 age range, where 76.6% adopted the fertilizers compared to 23.4% who chose not to. Interestingly, respondents over 60 years demonstrated the highest adoption rate at 95%, despite constituting the smallest demographic segment. These findings indicate strong overall adoption rates but highlight the need to investigate and address potential barriers faced by younger farmers to ensure consistent participation across all age groups.

The impact of fertilizer usage on agricultural productivity varied significantly among respondents. A notable 38.8% reported significant positive outcomes, indicating that subsidized fertilizers effectively improve crop yields. Furthermore, 28.7% experienced moderate enhancements, while 28.1% observed no substantial effect, suggesting variability in results likely influenced by factors such as soil quality, climate conditions, or farming practices. Additionally, 4.4% of respondents reported negative impacts, highlighting the need for improved monitoring and support systems to mitigate adverse effects and optimize the program's benefits. These findings emphasize the importance of refining subsidy distribution frameworks to achieve maximum effectiveness and equitable outcomes.

An evaluation of the fertilizer application process revealed varied perceptions regarding its efficiency and accessibility. While 20.2% of respondents rated the application process as very good and 14.8% as good, a significant 33.4% expressed dissatisfaction, citing challenges that detracted from their overall experience. Gender-specific challenges were also apparent, with 79.6% of female respondents reporting difficulties in accessing subsidies compared to 70.9% of male respondents, highlighting systemic barriers that disproportionately affect women.

Furthermore, an analysis of application speed uncovered considerable inefficiencies that may impede productivity. Only 12% of respondents perceived the application process as very fast, with an additional 13.5% describing it as fast, suggesting that streamlined systems benefit only a small portion of users. A moderate 22.1% rated the process as average, while 34.4% characterized it as slow, and 18% as very slow. These findings underscore critical bottlenecks in the application process, emphasizing the urgent need for reforms to enhance efficiency and improve user satisfaction, particularly for underserved groups.

The qualitative analysis consisted of in-depth interviews and open-ended survey questions conducted with a subset of participants from Tanzania's fertilizer subsidy program. The aim of this qualitative phase was to capture the nuanced experiences and perceptions of farmers regarding the fertilizer distribution process. Initially, thematic coding was utilized to identify recurring themes related to distribution challenges, trust in the subsidy program, and the influence of fraud and corruption on farming practices. Following this, detailed narratives were crafted to illustrate the specific challenges faced by different demographic groups, such as those based on gender and farming experience. By employing a comparative approach, the analysis unearthed distinct insights into how these challenges differ among stakeholders, highlighting the necessity for tailored solutions to enhance the effectiveness of the fertilizer subsidy distribution system. Table.1 summarizes the key themes and insights derived from this qualitative analysis.

Table 1: themes and insights from qualitative analysis of fertilizer distribution experiences

Theme	Subtheme	Participants	% Male	% Female	Examples
Trust Issues	Distrust in Stakeholders (Suppliers and Officials)	82	60% (49)	40% (33)	I do not believe in suppliers and LGA officials.
Corruption	Bribery	173	70% (121)	30% (52)	Farmers with large farms feel that paying a bribe is the only way to get fertilizer.
	Nepotism	19	84% (16)	16% (03)	It's all about who you know in this system
Fraud	Misrepresentation of Resources	114	55% (63)	45% (51)	Some people sell us fake fertilizers, claiming they are genuine.
Transparent	Lack of Clarity in Processes	56	50% (28)	50% (28)	We need clearer guidelines on how to apply for subsidies
Distribution Challenges	Access Issues	224	65% (146)	35% (78)	It's difficult to find fertilizers if you do not buy them earlier
	Bureaucratic Delays	33	45% (15)	55% (18)	The application process takes too long, and by then, it's too late

System Development: The development of the Subsidy Fertilizer Voucher System, utilizing blockchain technology, marks a significant advancement in the efficiency, security, and transparency of agricultural subsidy management. By incorporating Ethereum's decentralized and immutable blockchain, this system ensures that only verified farmers and suppliers are involved, with all transactions securely recorded to eliminate the risks of tampering and fraud. The platform employs microservices for voucher issuance, redemption, and supplier reimbursement, built with AngularJS for an intuitive user interface, Node.js for backend operations, and Solidity smart contracts for Ethereum-based transactions. This integration guarantees a decentralized and tamper-proof infrastructure, facilitating seamless interactions among all stakeholders.

The registration process utilizes Tanzania's National ID (NIDA) to authenticate users and issue Decentralized Identifiers (DIDs) along with recovery phrases, ensuring secure logins and maintaining data privacy. Farmers are provided with a comprehensive dashboard that streamlines voucher issuance, farm registration, and fertilizer tracking. The processes for voucher issuance and redemption are made efficient, allowing farmers to easily select their farms, preferred fertilizer types, and suppliers. Supplier reimbursements are managed through blockchain-validated smart contracts, which guarantee transparent and reliable disbursements. The backend is powered by Node.js, enabling real-time operations and scalability while effectively handling thousands of requests without sacrificing performance, making it well suited for largescale agricultural initiatives.

Declarations of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the first author.

REFERENCES

Ahmed, S; Islam, M. E; Hosen, M. T; aHasan, M. H. (2020). BlockChain based fertilizer distribution system: Bangladesh perspective. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3377049.3377116

Bayan, T; Banach, R. (2023). Exploring the Privacy Concerns in Permissionless Blockchain Networks and Potential Solutions. *SIST 2023 - 2023 IEEE International Conference on Smart Information Systems and Technologies, Proceedings*. https://doi.org/10.1109/SIST58284.2023.10223536

Cagigas, D; Clifton, J; Diaz-Fuentes, D; Fernandez-Gutierrez, M. (2021). Blockchain for Public Services: A Systematic Literature Review. *IEEE Access*, *9*, 13904–13921. https://doi.org/10.1109/ACCESS.2021.3052019

Hepelwa, A. S; Selejio, O; Mduma, J. K. (2013). The Voucher System and the Agricultural Production in Tanzania: Is the model adopted effective? Evidence from the Panel Data analysis. *Environment for Development*, *August*.

Horn, A; Fard, H. M; Wolf, F. (2022). Multi-objective Hybrid Autoscaling of Microservices in Kubernetes Clusters. In J. Cano and P. Trinder (Eds.), *Euro-Par 2022: Parallel Processing*. 13440: 233–250. https://doi.org/10.1007/978-3-031-12597-3_15

Kamilaris, A; Fonts, A; Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends. Food Sci. Technol.* 91: 640–652. https://doi.org/10.1016/j.tifs.2019.07.034

Lameck, C; Mwanjombe, K; Scheer, S. (2019). The Influence of an Agricultural Subsidy Extension Program on Smallholder Maize Farmers in Tanzania. *Journal of International Agricultural and Extension Education*, *26*(1). https://doi.org/10.5191/jiaee.2019.26102

Malhi, G. S; Kaur, M; Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability (Switzerland)*, *13*(3). https://doi.org/10.3390/su13031318

Mirabelli, G; Solina, V. (2020). Blockchain and agricultural supply chains traceability: Research trends and future challenges. *Procedia Manufacturing*, *42*. https://doi.org/10.1016/j.promfg.2020.02.054

MOA, T. (2022). *Mwongozo Wa Utekelezaji Wa Mpango Wa Ruzuku Ya Mbolea Kwa Msimu Wa 2022/2023*. https://www.kilimo.go.tz/resources/view/mwongozo-wa-utekelezaji-wa-mpango-wa-ruzuku-ya-mbolea-kwa-misimu-wa-2022-2023

Mwinuka, L. (2018). Fostering Fertilizer Use and Welfare Distribution in Tanzania: Implications for Policy and Practice. In *Soil Productivity Enhancement*. https://doi.org/10.5772/intechopen.78043

SDG.17 UN. (2015). Transforming Our World: The 2030 Agenda For Sustainable Development United Nations United Nations Transforming Our World: *The 2030 Agenda For Sustainable Development*.

Tende, I. G; Aburada, K; Yamaba, H; Katayama, T; Okazaki, N. (2022). Proposal for a blockchain based agricultural input voucher system. *Artificial Life. Robo.* *27*(3), 461–471. https://doi.org/10.1007/s10015-021-00724-9

Verma, J. P; Verma, P. (2020). Understanding Concepts in Estimating Sample Size in Survey Studies. In J. P. Verma and P. Verma. *Determ. Samp. Size. Power. Res. Stud.* 29–40. https://doi.org/10.1007/978-981-15-5204-5_3

Wineman, A; Jayne, T. S; Isinika Modamba, E; Kray, H. (2020). The changing face of agriculture in Tanzania: Indicators of transformation. *Develop. Policy Rev.* *38*(6). https://doi.org/10.1111/dpr.12491