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Geospatial Application for Sustainable Cold Chain Logistics Infrastructure in Urban Development in Nigeria

Michael Moses Apeh[1,2], Susanna Ibrahim Zego[1,3], Zuhra Junaida Binti IR Mohamad Husny Hamid[1]

[1] Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia

[2]Department of Cartography, Federal Polytechnic, Idah, Kogi State, Nigeria

[3]Nigerian Institute of Transport Technology, Zaria, Kaduna State, Nigeria

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ABSTRACT

The global demand for perishable goods, including food and pharmaceuticals, underscores the critical importance of an efficient and reliable cold chain infrastructure. Sustainable cold chain logistics infrastructure refers to systems designed to maintain the integrity of temperature-sensitive products throughout the supply chain while minimizing environmental impact. This paper explores the various components and technologies integral to a sustainable cold chain logistics operation, including energy-efficient refrigeration, renewable energy integration, advanced insulation materials, and real-time monitoring systems. Additionally, it examines the economic, environmental, and social benefits of adopting sustainable practices, such as reducing greenhouse gas emissions, decreasing operational costs, and enhancing food security. By highlighting case studies and innovations in cold chain logistics, this study aims to provide a comprehensive understanding of how sustainable cold chain logistics infrastructure can contribute to global sustainability goals and support the transition to a greener economy.

Keywords: Cold chain infrastructure, Sustainability, Energy-efficient refrigeration, Supply chain, Geospatial.

INTRODUCTION

The cold chain logistics operation, a temperature-controlled supply chain operation, is essential for preserving and transporting perishable goods such as fresh food, pharmaceuticals, and biotechnological products (Turan & Ozturkoglu, 2021). As the global population grows and consumer demands for fresh and high-quality products increase, the cold chain logistics industry faces significant challenges in maintaining product integrity while addressing environmental sustainability (Aigbavboa & Mbohwa, 2020; Chukwu et al., 2018). Further, Peng (2019) argued that traditional cold chain systems are energy-intensive and heavily reliant on fossil fuels, contributing to greenhouse gas emissions and climate change. Therefore, it is important to consider the impact of genetic algorithms on optimizing cold chain logistics transportation routes to reduce costs, improve efficiency, and enhance the economic benefits for businesses operating in this field. Zhang et al. (2022) argued that traditional cold chain logistics face significant challenges, including centralized data storage, low data reliability, vulnerability to data tampering, and difficulty in identifying accountability, all of which undermine the protection of consumer rights. Thus, by incorporating both consortium and private blockchains, there will be a balance between transparency and the necessary levels of privacy and security.

Su et al. (2022) opined that sustainable cold chain logistics operations create an atmosphere for marketing innovation services such as comparative advantage, compatibility, complexity, trialability, and observability, which each have a significant impact on consumers' participation in express packaging recycling infrastructure emerging as a solution to these challenges, aiming to balance the need for efficient temperature control with environmental responsibility. Furthermore, Castelein, Geerlings, & van Duin (2020) argued that policy measures can be implemented by port authorities to better attract and facilitate the transportation of refrigerated containers,

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

as the refrigerated or 'reefer' containers are a fast-growing segment in the container shipping market. Therefore, sustainable cold chains can reduce carbon footprints, lower operational costs, and improve efficiency by incorporating energy-efficient refrigeration technologies, renewable energy sources, advanced insulation materials, and real-time monitoring systems. Moreover, sustainable practices in the cold chain are crucial for enhancing food security, reducing waste, and ensuring the safe delivery of life-saving fruits and vegetables.

Although there are different perspectives on cold chain logistics sustainability, this paper delves into the principles and components of sustainable cold chain logistics infrastructure, analyzing the latest innovations and technologies driving this transformation through a geospatial view. It explores the economic, environmental, and social impacts of sustainable cold chains, supported by case studies and practical examples. By understanding the importance and implementation of sustainable practices in cold chain logistics operations, stakeholders can make informed decisions that align with global sustainability goals and contribute to a more resilient and eco-friendlier. Thus, this paper's objective is to explore the current challenges of cold chain logistics in Nigeria and explore how geospatial technology can be integrated into cold chain logistics sustainable infrastructure development as depicted in Figure 1.

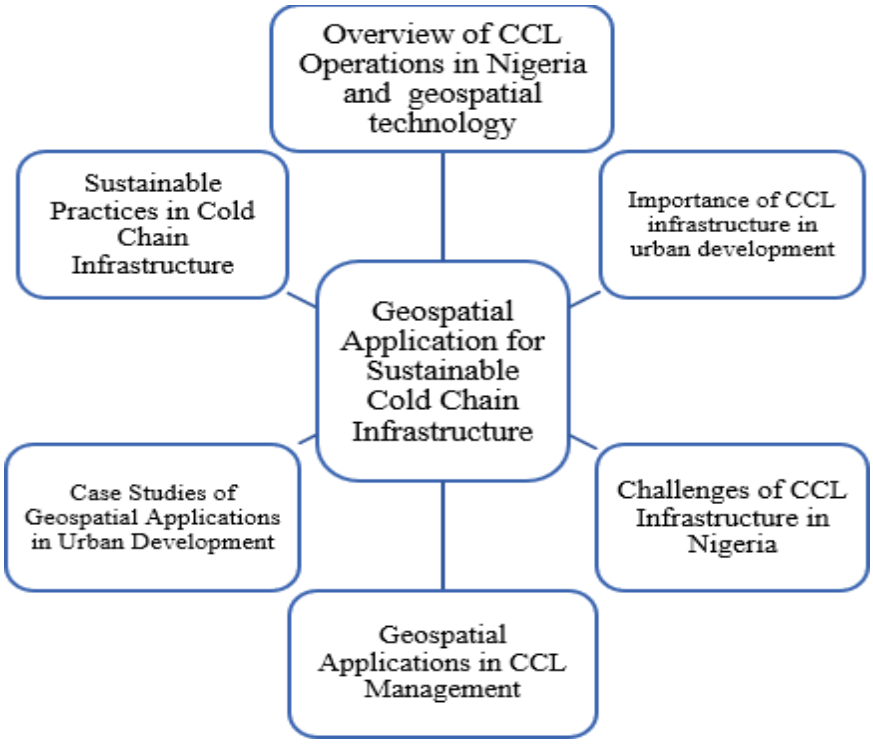

Figure 1. conceptual framework

Overview of Cold Chain Logistics Operations in Nigeria and Geospatial Technology

Cold chain logistics operations in Nigeria are private sector driven and are faced with a lot of operating challenges bordering from infrastructure deficit, distribution challenges, storage challenges absence of government policy, financial constraint(Babatunde et al., 2020; Chukwu & Nnogo, 2021). These challenges plague their overall system performance and this has led to a series of broken chain operations(Cassou et al., 2020; Zego & Hamid 2024). It can therefore be said that cold chain logistics in Nigeria is still evolving in Nigeria are still evolving is in the pursuit of sustainable urban progress, the significance of geospatial technology, especially in improving Nigeria's cold chain infrastructure, cannot be overstated. The integration of geospatial technology with sustainable urban development strategies presents a promising avenue for enhancing Nigeria's cold chain infrastructure, particularly in rapidly growing urban centres. This intersection of fields offers valuable opportunities to optimize resource allocation, improve logistics, and ultimately strengthen the efficiency and resilience of cold storage systems across Nigerian cities.

Geospatial tools enable urban planners and policymakers to conduct sophisticated spatial analyses, facilitating data-driven decision-making in the placement and management of cold storage facilities. By leveraging

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

geographical information systems (GIS) and remote sensing technologies, stakeholders can gain a comprehensive understanding of the spatial distribution of existing infrastructure, identify gaps in coverage, and strategically plan for future expansion (Adeyemi et al., 2021). Further, the application of geospatial analysis to cold chain logistics can significantly enhance the transportation and distribution of perishable goods within urban areas. By optimizing routing and facility locations based on population density, transportation networks, and other relevant factors, cities can reduce spoilage, minimize energy consumption, and improve overall supply chain efficiency (Olanrewaju et al., 2019). Furthermore, the integration of e-governance platforms with geospatial technologies can promote transparency and accessibility in urban service delivery. By providing citizens with user-friendly interfaces to access spatial information and services related to cold chain infrastructure, cities can foster greater public engagement and trust in urban development processes (Nwosu and Onyenechere, 2022). Additionally, the adoption of qualitative spatial analysis methods, in conjunction with quantitative GIS techniques, can provide a more nuanced understanding of the socio-economic factors influencing cold chain development in Nigerian cities. This holistic approach can help identify potential barriers to implementation and inform targeted interventions to address community needs (Abubakar et al., 2020).

As Nigerian cities continue to grow and evolve, the strategic application of geospatial technologies in cold chain management will be crucial for ensuring food security, reducing waste, and supporting economic development. By embracing these innovative tools and methodologies, urban planners and policymakers can work towards creating more sustainable, resilient, and efficient urban environments that are better equipped to meet the challenges of rapid urbanization and climate change (Oluwatayo and Ojo, 2018). The convergence of geospatial technology and sustainable urban development offers a powerful framework for enhancing Nigeria's cold chain systems.

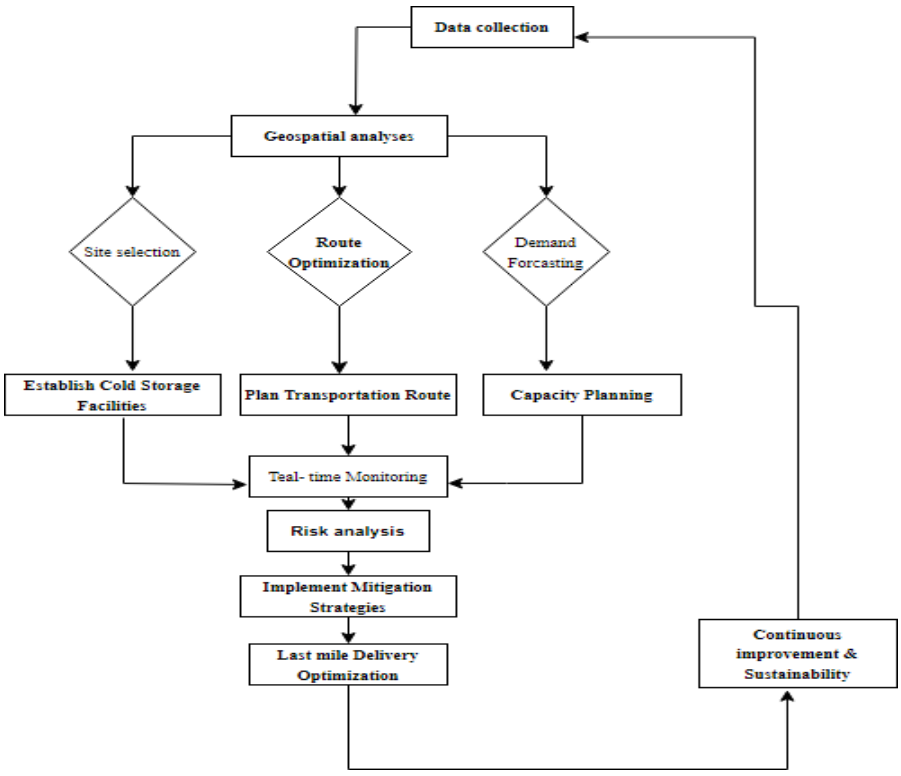

Figure 2. Cyclical process of using geospatial tools in cold chain logistics

The process begins with comprehensive data collection, gathering relevant geospatial and cold chain information as illustrated in Figure 2. This data undergoes thorough geospatial analysis, informing crucial decisions on cold storage site selection, transportation route optimization, and demand forecasting for capacity planning. Based on these insights, cold storage facilities are established, and transportation routes are planned. Once operational, the system enters a phase of continuous real-time monitoring and risk analysis, allowing for the implementation of timely mitigation strategies. Last-mile delivery is optimized, with a focus on navigating urban environments

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

efficiently. The cycle concludes with a continuous improvement phase, where lessons learned and new data are integrated back into the process, initiating the next iteration of data collection and analysis. This cyclical approach ensures that the cold chain logistics system remains dynamic, efficient, and responsive to evolving conditions, ultimately preserving food quality throughout the transportation and storage process.

METHODOLOGY

The study combines qualitative research and geospatial analysis to develop sustainable cold chain logistics in urban areas of Nigeria. It includes 13 focus group discussions with 78 participants in Kano state and uses geospatial techniques to propose efficient and sustainable cold chain logistics solutions tailored to Nigeria's urban development needs.

Importance of Cold Chain Logistics Infrastructure in Urban Development

It is evident that the Nigeria's perishable food loses about 40-50% perishable food products due to poor preservation , storage practices and also due to challenges of transportation(Cassou et al., 2020; Zego & Mohamad Husny, 2023; Zego & Mohamad 2024). Hence, in cities undergoing swift expansion like Nigeria, where quickening urbanization and an increasing populace demand effective supply lines for food, the role of cold chain infrastructure in civic growth is immensely critical. With the broadening of urban zones, establishing dependable and enduring systems for cold chains becomes increasingly vital to safeguard the transit and preservation of goods that spoil easily. The evolution within food distribution networks in emerging nations such as India serves to illuminate how modern logistical companies alongside niche market distributors play a pivotal part in refining the flow of food products (Minten et al.). Amidst environmental uncertainties jeopardizing farm outputs in Tanzania, funnelling resources into climate-resilient farming methods stands out as key for diminishing these hurdles while bolstering toughness amongst farmers with small landholdings, thereby spotlighting the importance of versatile and sturdy cold chain setups in maintaining alimentary reliability (Begasha et al., 2020). Hence, it is essential to weave geographic information system tools into crafting sustainable frameworks for cold chains within Nigerian metropolises; this approach not only aids in judiciously managing resources but also decreases wastage of edibles and propels economic advancement on a broader scale.

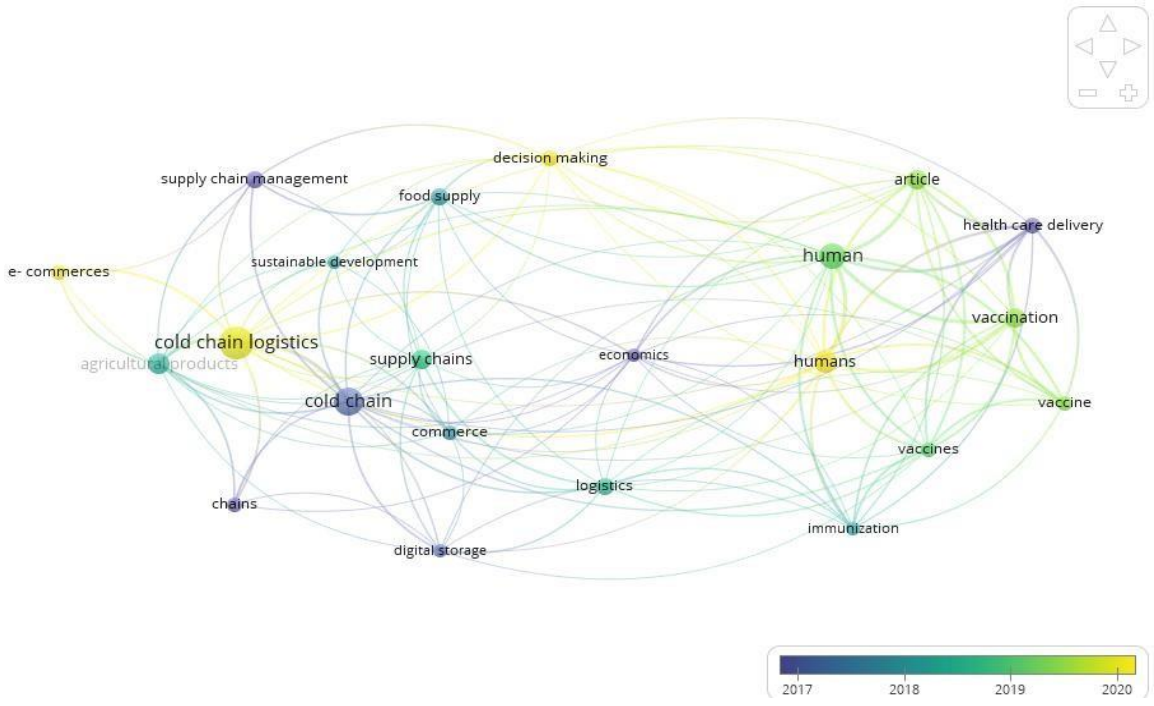

Figure 3. Network visualization

Figure 3 shows the network visualization of the different aspects of cold chain logistics over time. The figure depicts that the darker the colour the more saturated studies of cold chain were carried out in the field of research the lighter the colour the greyer the studies is and this need to be further explored by more scholars.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

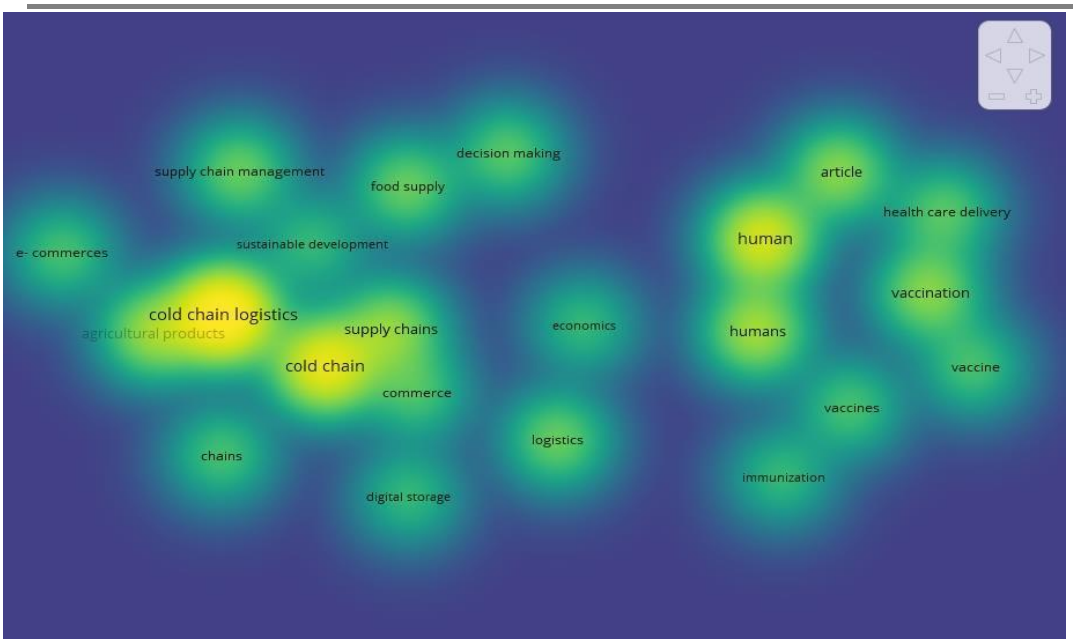

Figure 4. Density visualization

Figure 4 shows the bibliometric density visualization. This gives a clear depiction of the field of studies in cold chain logistics over time. The more pronounced the colour the more impact of cold chain studies in the area of specialization.

A bibliometric analysis was carried to demonstrate the relationship between cold chain logistics growth and development on environmental sustainability. To achieve this 92 articles and conference papers where mapped from Scopus. Clearly, the result of the analysis shows both the network visualization and density visualization. The analysis unequivocally proves that while studies on cold chain logistics in the perishable food industry began to gain a lot of attention in 2017, there remains significant room for further research on cold chain logistics operations, applications, and sustainability, in different aspects of the business environment which are constantly evolving. Furthermore, the analysis shows that 5 minimum number of occurrence of keywords out of 1015 keywords meet the threshold. 22 key words were selected. further 2 clusters as represented by the mapping colours emerged. the darker the colour the more then the study in that area, the lighter the colour the less is the study in that area.

Challenges of Cold Chain Infrastructure in Nigeria

Obstacles in the cold storage networks within Nigeria create a substantial blockade against the effective spread of vital commodities, such as the perishable foods that spoil quickly(Adebimpe & Adeoye, 2021). Thus, given the extensive benefits for economic growth and health advancements that robust cold storage infrastructure could offer, overcoming these obstacles is crucial. Inefficient storage solutions, lacking capacity, and sparse technological adoption are major impediments to refining the cold chain logistics. Furthermore, the inadequate education of personnel working in the cold chain adds to the system's inefficiency. The predicament worsens considering specific preservation needs for products such as fruits , vegetables and pharmaceutical products such as vaccines and also the transportation needs (Cassou et al., 2020; Chukwu & Adibe, 2022; GAIN, 2018). Through restructuring its distribution framework, improving employee training programs, and pouring resources into broadening infrastructure capabilities, Nigeria can alleviate adverse outcomes stemming from its insufficient cold chain operations. Such transformation is imperative not merely for disseminating vaccines but equally critical for augmenting sectors like agriculture where losses post-harvest due to subpar cold storage systems remain a significant hurdle across the nation. Packaging infrastructure

Storage Infrastructure

According to Li et al., (2020), storage is a very critical requirement in every cold chain logistics operation. storage preserves the product and extends the shelf and make the products health for consumption. the storage

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process commences from product harvest to precooling and consistent temperature monitoring and control to the market environment. Hence ,Without adequate storage products are exposed to harsh weather conditions and speeds up the product decaying process causing a lot of product waste(Ani et al., 2022; Cassou et al., 2020).

Figure 5. Different Methods Used for Preserving Tomato Products

Figure 5 shows the different methods used for preserving tomato products by locals and distribution channel members during haulage operation, where the product is just loaded in open trucks without any form of cooling available. Also, when these products are not sold, they are dried up in the drier which are insufficient thus not meeting the required capacity of the needs of the distribution members. Hence, regularly, the most used method for drying tomato products is the method of pouring them on the bear sandy ground, which is not hygienic at all.

Transportation infrastructure

Transportation is the movement of product from the source of origin to their destination in a safe manner. majorly on the value stream the road transport is the main predominant means of transport being utilized for freighting products from their source of origin to their destination markets in Lagos due to the absence of other means of transport. Although there are other multimodal transport options available like the rail and air however, their operations are highly expensive and not reliable, hence the large depency on road transport. However, due to long distance travel covering about 1,244 kilometter it an average of 4 to 5 days most times for products to arrive at their desired market destination in Lagos. There is scarcity of sufficient trucks for conveying products to the markets as a result on ethical practices of over loading and loading of trucks in discriminated trucks like fuel tankers is now being accepted as the normal norm. Hence to to the limited insufficient availability of trucks most product end up not being transhipped and get wasted. Figure 6 shows transportation risk along the route from Kano to Lagos.

Table 1: showing the hotspot along the Kano – Lagos route.

S/No	State	Hotspot Areas
1	Kano	Nil
2	Kaduna	Tashan Yari, Olam, Jere (Potholes, insecurity challenges, banditry)
3	Abuja	Abaji, Kwali (Potholes)
4	Niger	Dikko Juction, Bidda, Mokwa trailer park, Garatu, Lambata (Potholes, traffic congestion, sharp bends, delay spot, accident black spot)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

5	Kogi	Gadar Murtala, Kabba (Potholes, single lane route)
6	Kwara	Luru (Potholes)
7	Benin	Benin City (Robbers)
8	Ogun	Oguse, Elesha (Traffic congestion)
9	Osun	Ikare (Potholes)
10	Oyo	Ogbomoso express, Oyo Alaka, Akinyele (Potholes)

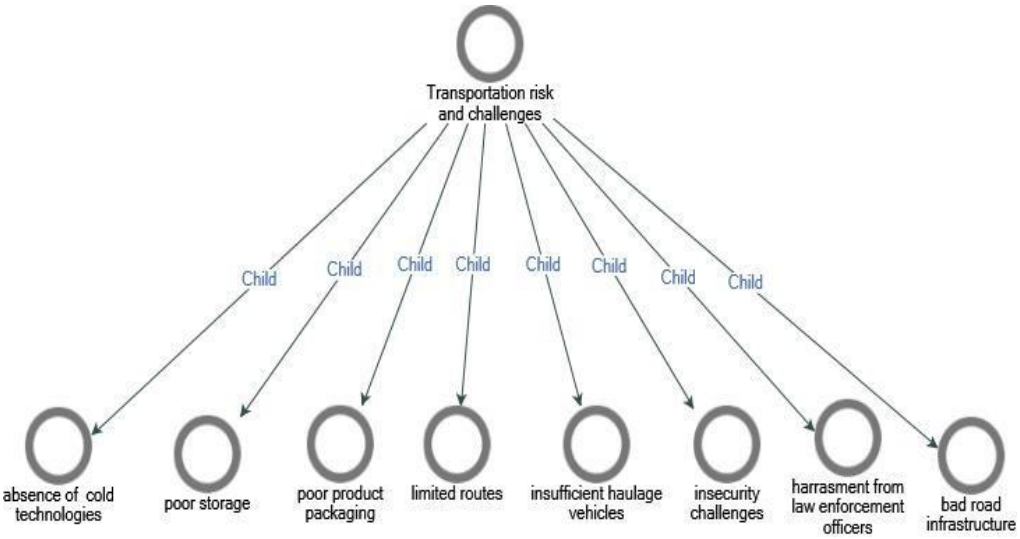

Figure 6. Transportation risk

Figure 6 shows the transportation risk along the Kano -Lagos route when conveying tomato products. This risk operations inefficiencies and hinder cold chain logistics growth and development.

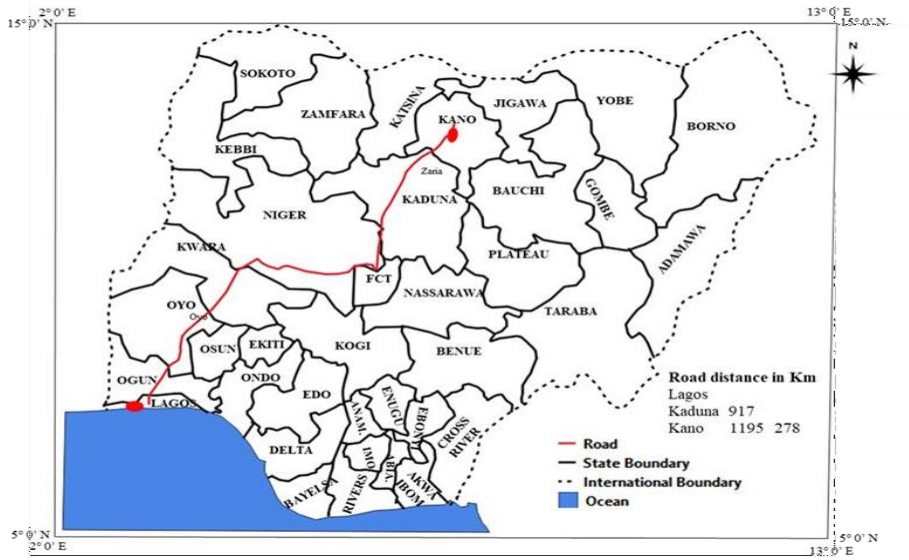

Figure 7 shows the main and major route utilized by motorist for haulage of products from kano to Lagos.

Geospatial Applications in Cold Chain Logistics Management

In the realm of urban progress within Nigeria, applications grounded in geospatial science are pivotal for boosting the management of cold chains. The fusion of technologies like spatial analysis and remote sensing into

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planning stages for cold chain infrastructures enables key players to refine how temperature dependent products are stored and distributed, promoting economic stability and food safety. Utilizing data centred on geographical nuances such as population patterns or terrain uses aids in pinpointing prime spots for facilities dedicated to cold storage alongside efficient paths for transportation. Such a strategy is essential in curbing losses of perishable goods, thereby fortifying urban endurance against challenges. Additionally, this geospatial schema assists in tracking the repercussions stemming from human-induced factors including modifications to land utilization or climatic shifts on operations tied to cold chains, thus better preparing strategies that lean towards sustainable progress. By marrying principles core to managing cold chains with the prowess of geospatial tech, Nigeria stands poised to propel its agenda focused on urban advancement while maintaining an infrastructure resilient enough to support effective cold chain systems.

Case Studies of Geospatial Applications in Urban Development

Geospatial technologies in urban cold chain logistics significantly improve efficiency, reduce waste, and enhance sustainability. In Mumbai, India, GIS-based modeling addressed COVID-19 vaccine distribution challenges in a densely populated city. By optimizing vaccine distribution centre locations and delivery routes, and enabling real-time shipment tracking, the initiative achieved a 30% reduction in vaccine wastage and improved immunization coverage, demonstrating the effectiveness of geospatial tools in public health logistics (Tripathi et al., 2022). So also, European cities have also utilized geospatial technologies for cold chain enhancements. In Rotterdam, the integration of IoT sensors with GIS platforms created a smart cold chain management system for Europe's largest seaport. This allowed for real-time temperature monitoring of perishables, predictive maintenance of refrigeration units, and a blockchain-enabled traceability system. The result was a 25% reduction in cold chain breaches and improved energy efficiency in refrigerated container handling (van Duin et al., 2019). Furthermore, In Nairobi, Kenya, the last-mile delivery challenges for perishables in rapidly expanding urban areas were tackled through a mobile app featuring GPS for real-time order tracking and GIS-based demand forecasting. Spatial analysis optimized micro-fulfilment centre locations, leading to a 40% reduction in delivery times and a 20% decrease in food wastage, showcasing geospatial technologies' role in enhancing food distribution in developing economies (Onyango et al., 2021). Additionally, Asian cities, too, have employed geospatial tools for cold chain infrastructure planning. Shanghai, China, utilized remote sensing to identify sites for new cold storage facilities, applying spatial multi-criteria analysis. Incorporating 3D city modeling allowed for assessing new facilities' urban impact, resulting in the strategic placement of 15 cold storage sites and a 35% improvement in cold chain coverage (Li et al., 2020). In South America, São Paulo, Brazil, used geospatial technologies to support an urban farming initiative aimed at food security. The initiative involved mapping urban farm locations and local markets, establishing community cold storage units, and optimizing transportation routes between farms and markets. This led to a 45% reduction in post-harvest losses and greater fresh produce availability in urban food deserts, illustrating geospatial tools' support for localized food systems (Santos et al., 2023). North American cities focus on geospatial technologies to enhance cold chain sustainability. Toronto, Canada, employed GIS-based carbon footprint modeling, spatial analysis for transitioning to electric refrigerated vehicles, and green corridor mapping to prioritize low-emission routes. These efforts achieved a 30% reduction in cold chain-related emissions and improved air quality in key urban areas, highlighting geospatial tools' role in aligning cold chain operations with urban sustainability goals (Ahmed et al., 2022).

Collectively, these case studies illustrate the diverse applications of geospatial technologies in optimizing cold chain logistics in urban environments. From enhancing vaccine distribution and port operations to supporting urban farming and driving sustainability initiatives, these tools are essential in addressing the unique challenges of urban cold chain management. As cities grow and logistical complexities increase, the importance of geospatial technologies in developing efficient, sustainable, and resilient cold chain systems will likely continue to rise.

Sustainable Practices in Cold Chain logistics Infrastructure

Within the sphere of metropolitan enlargement in Nigeria, the deployment of enduring methodologies in frigid chain setups is crucial for facilitating the effective and eco-aware conveyance of perishable (Chen, 2020; He & Yin, 2021; Ndraha et al., 2019) The employment of spatial technologies presents an optimistic path for ameliorating the durability of cold chain networks through enhancing routing efficiency and diminishing power

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

use. Nevertheless, the triumph of such strategies greatly leans on tackling systemic barriers that impede investment prospects in fisheries within developing nations, as depicted by Wilderness Markets' evaluations (2016). Acknowledging the synergy amongst data handling, market segregation, and infrastructural progress allows city designers to plot towards nurturing a holistic method that marries economic gain with societal well-being and preservation aims(Li et al., 2022). In addition, revelations from investigations into sea produce trade routes in Indonesia (2015) emphasize the necessity to craft investable bodies alongside solid monetary structures backing sustainable chilly chain project initiatives. As such, grasping these limitations and openings thoroughly becomes essential for moulding policies and actions encouraging geospatial tool incorporation for driving durable cold chain methods across Nigeria's urban terrains.

Sustainability is described as the development that meets the needs of the present generation without causing disruption that will hinder future generation from achieving their own desires successfully (Sahore & Verma, 2017). It centers on the integration of social, economic and environmental activities businesses in order to gain economic, social environmental benefits which result in achieving competitive advantage according to Elkington in Sahore &Verma, (2017). Similarly, Pagell and Wu (2009), also agreed that sustainability integrates, social, economic, and environmental responsibilities. However, Bové & Swartz (2016) argue that supply chain management activities have 90% percent effect on natural resources, such as; air, soil and land and that over 80% percent of greenhouse-gas emissions for fast moving consumer-goods products occur in the supply chains. Therefore, since cold chain service providers' activities affect the environment directly it is very essential for these service providers to ensure that their activities and practices are done ethically in conformity with global best practices to protect the environment (Mani et al., 2020). Thus, the triple bottom line sustainability approach is focus on promoting ethical supply chain practices which are basis for quality service attainment in cold chain operations (Gogou et al., 2015). The Triple bottom line activities are shown in the fig.8 below as thus.

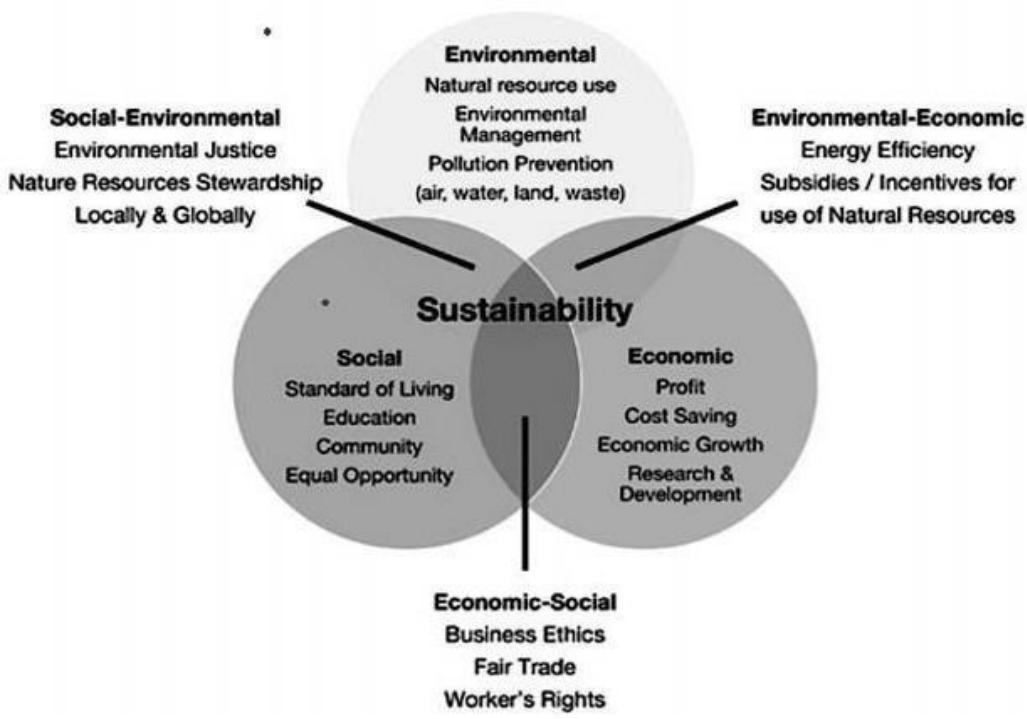

Figure 8. Triple Bottom Line Sustainability

The above Figure 8 shows how the "Triple Bottom Line Sustainability" approach creates balance in the supply chain by ensuring that there is synergy between economic, social and environmental performance. It also shows that cold chains can achieve sustainable reforms in their value systems through the integration of social, economic and environmental activities. The triple bottom line sustainability approach also promotes business ethics and service transparency and workers right (Zak, 2016). Furthermore, (Hussain *et al.*, (2016) opined that sustainable supply chains which includes cold chains must have a sustainable framework that focus on environmental management, social responsibility, customer management, health, safety and risk management which are very crucial to its operations effectiveness. This is depicted in Figure 9 as thus;

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

Figure 9. Cold Supply Chain Sustainability Framework (Hussain et al., 2016)

Figure 9 shows the cold supply chain sustainable framework which according to Hussain *et al*. (2016), promotes quality service delivery and customer satisfaction in the cold chain logistics value stream. This is achieved through the attainment of environmental management, social responsibility, health safety, risk management and customer management.

Sustainable Cold Chains Logistics Operations Effect on Energy Efficiency

Energy efficiency has become a critical energy policy goal in the functioning of global supply chains, as well as an important aspect of the cold chain logistics industry (Bányai, 2018). Similarly, according to Polzot *et al*., (2017) sustainable cold chain (SCC) logistics operations depend on how much energy is being used and how much CO2 is emitted as a result of transportation operations.. However, according to (Zhang,(2017), the existing cold chains, waste too much energy and cannot ensure ideal food quality due to a lack of understanding of microcosmic energy and mass transfer mechanisms, which is detrimental to environmental sustainability (Bányai, 2018). Thus, according to Liu *et al.*,(2021)the optimization of the cold chain logistics industry's carbon emission structure is a high priority for assuring the logistics industry's long-term viability. Similarly, Bányai, (2018) further opined that from the institutions that develop energy efficient measures to everyone in society, energy efficiency is a critical aspect for economic and social progress in cold chain logistics operations. Thus, according to Qiao,(2019), cold chain logistics operation is focused on achieving a rapid, effective method of product and service flow between suppliers and buyers in order to meet consumer demand while maintaining a low-temperature environment, in order to overcome space, time, and temperature impediments.

Han *et al*. (2021) opined that there is need for sustainable energy efficiency in cold chain operation to promote low-carbon solutions and smart innovation which are crucial in addressing environmental issues as well as the market's shifting needs. However, according to Liu *et al*. (2021), the existing cold chain logistics business is plagued by issues such as outdated equipment, inefficient refrigeration technology, and irrational distribution management, all of which increase energy consumption and have substantial environmental consequences. Thus, designing a reasonable and efficient distribution route layout can not only minimize distribution time, operational costs, and corporate efficiency, but also improve customer service (Qiao, 2019). Similarly, according to Bányai (2018), the use of technology will allow for real-time processing of open tasks in a network of package delivery service providers, which reduces order fulfillment time and reduce carbon emission issues. Furthermore, according to Liu *et al*. (2021) by improving the cold chain logistics distribution channel, the entire supply chain system's carbon emissions can be efficiently reduced, satisfying the objectives of sustainable development. Hence, according to Zhang (2017), sustainable energy efficiency is a critical component of a long-term cold chain logistics operation that can be achieved through super cold chain logistics activities, which are multiscale, multiphase, and multicomponent systems focused on understanding the mechanics of energy, mass movement, and quality control at all times, starting at the micro level. The super cold chain logistics operations reduce

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

energy consumption while also promoting sustainable development, both of which have important environmental consequences. The super cold chain logistics operations meet future expectations for energy conservation, emissions reduction, and ecologically friendly development.

Sustainable Cold Chain Logistics Impact on Food Safety

In today's global economy, sustainable Cold chain logistics operations and practices are very relevant in promoting food safety and security (Wang, 2021). According to Shashi (2021), every year 30% of the world's entire food production is wasted and this equates to 1.3 billion tonnes of food, US$1 trillion in economic expenditures, US$700 billion in environmental costs, and US$900 billion in social costs. Most of these food losses occur as a result of poor and efficient cold chain logistics operations in place (Cassou et al 2020). In fact, the decay of perishable food items has a negative impact on both the pricing and availability of the product as well as the health of the consumer (Shashi, 2021). Thus, the targets of the 2030 sustainable development agenda is to reduce global food waste at the production levels: end hunger and the harmful effects of food waste on the supply chain, retail, and consumers. Hence, there is need to ensure that the right infrastructure, expertise, material handling, storage, packaging, distribution and delivery methods are utilized for cold chain products operations at all times (Cassou *et al* 2020). Furthermore, this will also preserve the products shelf life, increase their durability and reliability (Firous *et al*., 2021).

Principle of SDG2

The focus of the second sustainable development goal (SDG2) is to "end hunger, achieve food security, improve nutrition and promote sustainable agriculture," by 2030 (Barthel *et al*., 2019: UNICEF et al., 2019). According to Hansen et al. (2022), despite significant progress in many countries, around two billion people, which is 25% of the world's population, still experience moderate to severe food insecurity. Additionally, 47 million children under the age of five are classified as wasted, meaning they are acutely malnourished, and 144 million are classified as stunted, meaning they are chronically malnourished. An estimated two billion people also lack essential micronutrients. Chen et al. (2020) reported that globally, two billion people suffer from nutritional deficiencies, and approximately 800 million people still endure hunger due to poverty and poorly developed food systems. Barthel et al. (2019) emphasize that the loss of local production capability poses a threat to the resilience of nations that rely heavily on imported food, particularly due to the volatility of global food prices. This volatility can be influenced by various factors, including social instability in the region. In addition, reducing food waste can contribute positively to multiple sustainable development goals (SDG2) (Chen et al., 2020). Cassou et al. (2020) suggest that cold chain logistics operations can help reduce food loss and waste of perishable products, such as tomatoes, within the perishable food value chain and fast-moving consumer goods (FMCG) industry in Nigeria.

Integrating SDG2, 12 and 13

The Sustainable Development Goal (SDG) 2 aims to eliminate hunger, while SDG 12 focuses on promoting responsible consumption and production, and SDG 13 addresses climate action. The COVID-19 pandemic has significantly impacted these goals, especially SDG 12. The increased use of disposable materials to prevent the spread of the virus has led to a rise in waste generation (Bianchet et al., 2021). Sylvester (2024) argued that food loss and waste contribute to environmental degradation, affecting SDG 12's objective of responsible production and consumption. Furthermore, climate change poses a threat to achieving the SDGs, and challenges in implementing climate actions hinder progress towards SDG 13 (Owusu-Sekyere et al., 2024). Despite these challenges, experts unanimously agree that artificial intelligence has the potential to significantly impact various Sustainable Development Goals (SDGs), especially those related to hunger, consumption, and climate action. Consequently, addressing these issues requires a comprehensive approach that integrates technological advancements, sustainable practices, and global cooperation.

Integration of Geospatial Technology for Sustainable Cold Chain Infrastructure

In the realm of ensuring the growth of cold chain logistics infrastructure critical for sustainable advancement, especially within city landscapes such as Nigeria, the fusion of geospatial technologies is pivotal. As underscored

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by (Carlo et al., 2016), it's paramount that there exists a seamless circulation of commodities, amenities, and intel to bolster economic robustness. This underscores an urgency in cultivating strategies geared towards the prolonged revitalization and reintegration of city domains with overarching national logistics frameworks reliant on interconnected vital infrastructures. Concurrently, employing geospatial intelligence to dissect and model intricate relationships amongst essential system infrastructures like transport aids significantly in strategizing and making informed choices. Moreover, (Adeleke A. et al., 2022) sheds light on how embracing composite tech modalities can bridge developmental voids faced under limited resource scenarios especially concerning agrarian outputs.

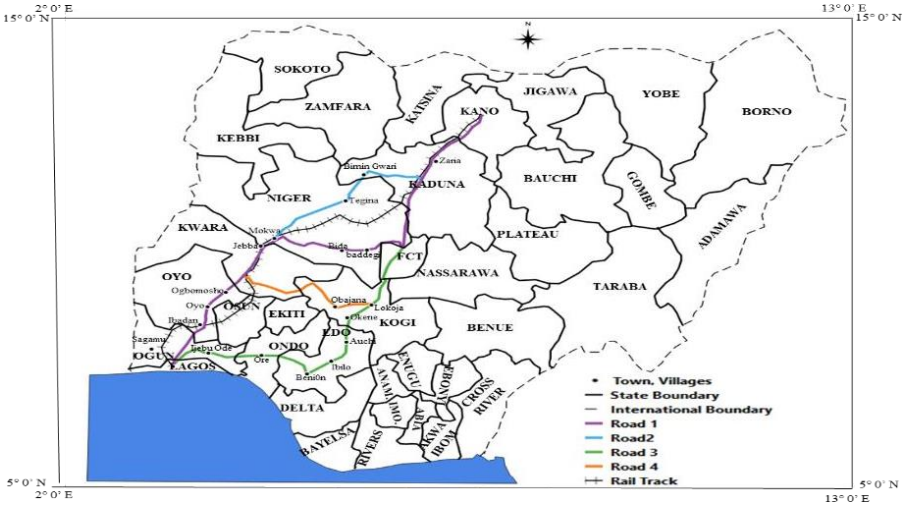

Figure 10. Geospatial Analysis showing Different Road Network to Cold Chain Logistics Locations Sure, here is the revised text:

For example, Figure 10 shows the analysis of different routes leading to the cold chain locations. While other routes such as orange, green, and blue are possible, the purple route is the most commonly used. Integrating geospatial technology solutions into the coordination of climate dynamics, water resource management, integration of renewable energy sources, and agricultural development offers a strong foundation for new business models that support the improvement of cold chain infrastructure in urban areas and help reduce greenhouse gas emissions (Qiu et al., 2020). This comprehensive approach aligns with the broader goal of leveraging spatial data advancements to promote sustainable urban development while enhancing cold transportation, distribution, and storage networks across Nigeria. Policy Implications for Cold Chain Infrastructure Development in Nigeria

It is crucial to develop a cold chain logistics infrastructure policy in Nigeria, particularly in the fast-moving consumer goods industry, in order to improve the efficiency and durability of urban development procedures (Chukwu et al., 2018). Utilizing geospatial technology applications can provide valuable insights into enhancing the logistics of cold chains within city landscapes. Digital innovations throughout agricultural supply chains, supported by CTA's efforts to promote digitally enhanced and inclusive agricultural changes (Addom et al., 2019), present an opportunity for Nigeria to support small-scale cultivators and business innovators in gaining market access and improving livelihoods. Recognizing the crucial role of policy frameworks in facilitating the adoption of digital solutions for cold chain systems can help Nigeria create a supportive ecosystem conducive to innovation and financial investments in this important area. IFAD's approval for disseminating relevant research from bodies such as the alliance of biodiversity International and CIAT (Garrett et al., 2020) emphasizes the need for collaborative efforts aimed at promoting sustainable developmental achievements through knowledge exchange and partnerships. Therefore, directing policy guidance towards embracing geographical information technologies and digital advancements could lead to lasting developments in cold chain infrastructures across Nigeria, ultimately enhancing urban community resilience and progress.

Socio-Economic Impact of Improved Cold Chain Infrastructure

In urbanizing Nigeria, the advancement of better cold chain facilities carries profound consequences for the

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region's socio-economic fabric. By boosting both the dependability and efficiency of food distribution networks, this enhanced infrastructure can have a direct effect on enhancing food security, spurring economic expansion, and improving community health. As underscored in (Carpenter et al.), it is vital to merge cutting-edge technological solutions with thoughtful planning within agricultural frameworks to tackle challenges related to food security while pushing towards sustainable growth(Babatunde et al., 2020; Ndraha et al., 2019; Ogboghodo et al., 2017) Moreover, (Angela Wardell-Johnson et al.) underlines the importance of adopting holistic methods that meticulously assess how economic dynamics interact with social and environmental aspects within agricultural adjustment tactics. Henceforth, employing a geospatially enlightened tactic toward evolving sustainable cold storage network enhancements in Nigeria aids not just in augmenting urban development but also strengthens local alimentation systems' robustness alongside fostering financial constancy. The all-encompassing evaluation of impacts pertaining to socioeconomics together with technological progress is indispensable for amplifying the success rate of initiatives aimed at bolstering cold chain infrastructure and endorsing lasting city progression within Nigeria.

State of cold chain infrastructure in Nigeria

Currently, the cold chain logistics operations in Nigeria is in dire need of storage infrastructure that is required to boost the preservation of the temperature sensitive products that require consistent quality temperature control (Cassou et al., 2020; Zego & Mohamad Husny, 2023). However, According to (Chukwu et al., 2018) opined that the eminent absence of cold chain infrastructure sustainable electric power sustenance and absence of policy regulation have contributed to the scarcity and inefficient performance of cold chain infrastructure especially meant for storage(Chukwu et al., 2018).

RESULTS AND DISCUSSION

The results of the research findings shows that cold chain logistics operations in Nigeria is insufficient in meeting the current market demand. Given the fact that the population is growing by the day and consumers are becoming more health conscious. Hence, there is a growing demand for cold chain products like fruits, vegetables and also pharmaceutical products. However, the inefficiencies of cold chain logistics operations presently is causing a lot of system failures leading to huge product losses of 50% alone in the perishable food industry. The absence of cold reefer containers and facilities for storage in most farming communities has also led huge product losses. Hence, as a result of limited access of farmers to the dynamic product market environment most product after harvest end up being left without proper precooling and cooling but with a free exposure to the natural free air which affects their freshness, durability and shelf life. Hence, this practice hastens the decaying process for products and also diminishes the product shelf life, ultimately leading to early decay and waste.

The study results further shows that cold chain logistics operations in Nigeria are mainly private sector driven and they face numerous challenges such as infrastructure deficits, distribution and storage issues, lack of government policy, and financial constraints. These challenges have resulted in inefficient systems which are characterised with frequent breakdowns in cold chain logistics operations and ultimately affects the overall cold value chain performance in Nigeria. To address these obstacles, the use of geospatial technology is seen as a strategic solution for optimizing cold chain infrastructure, particularly in rapidly growing urban centres.

Geospatial analysis also plays a key role in improving transportation routes and facility placement, reducing the spoilage of perishable goods, minimizing energy consumption, and maximizing supply chain efficiency. By considering factors such as population density, transportation networks, and real-time traffic data, cold chain logistics can better adapt to the complexities of urban environments.

Critically too, the high reliance on the road transport as the only means of transport being utilized in the value stream for most products transhipment and distribution has further limited the access of products to potential viable markets. this to the eminent problems associated in the value which are poor routing and scheduling practices, insecurity challenge of banditry on the highways. Moreover, the prevalent issues of inadequate infrastructure and poor road conditions exacerbate the challenges faced by cold chain logistics in Nigeria. Many rural areas are poorly connected, making it difficult for farmers to transport their perishable goods to urban markets in a timely manner. The lack of reliable transportation options not only increases the risk of spoilage but

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue VIII August 2024

also discourages farmers from investing in high-quality produce, as they are aware that their efforts may result in significant losses due to logistical inefficiencies.

Additionally, the absence of a well-coordinated cold chain system has led to a fragmented market where smallholder farmers struggle to access larger distribution networks. This disconnection limits their ability to scale operations and meet the growing consumer demand for fresh produce and pharmaceuticals. Consequently, many farmers resort to selling their products at lower prices to local markets, further diminishing their profit margins and perpetuating a cycle of poverty.

The need for a comprehensive cold chain strategy is imperative to enhance the resilience of the agricultural sector in Nigeria. By fostering partnerships between the government, private sector, and agricultural stakeholders, a more integrated approach can be developed to address the multifaceted challenges of cold chain logistics. This collaboration could involve investing in infrastructure improvements, such as building cold storage facilities and reefer depots, as well as implementing training programs for farmers to educate them on best practices for post-harvest handling and storage.

Furthermore, leveraging technology, such as mobile applications and blockchain, can improve transparency and traceability within the cold chain. These tools can facilitate better communication between farmers, distributors, and retailers, ensuring that all parties are informed about the status of products throughout the supply chain. By embracing innovation and technology, Nigeria can build a more robust cold chain logistics system that not only reduces waste but also enhances food security and supports economic growth.

Finally, the current state of cold chain logistics in Nigeria presents significant challenges that must be addressed to meet the increasing market demand for perishable goods. By adopting a strategic approach that incorporates geospatial technology, infrastructure development, and stakeholder collaboration, it is possible to transform the cold chain landscape. This transformation will not only reduce product losses but also empower farmers, improve consumer access to quality products, and ultimately contribute to the overall development of the agricultural sector in Nigeria.

Future Prospects and Recommendations

The prospects for geospatial applications in sustainable cold chain logistics infrastructure for urban development in Nigeria are promising and multifaceted. The integration of advanced AI with geospatial technologies will enable more accurate predictive modeling for demand forecasting and route optimization. The use of Internet of Things (IoT) devices will facilitate real-time monitoring of cold chain conditions, improving quality control and reducing waste. Blockchain technology could be integrated with geospatial systems to enhance traceability and transparency throughout the cold chain. Additionally, drone technology may play a significant role in last-mile delivery and infrastructure inspection, especially in hard-to-reach urban areas. The rollout of 5G networks will allow for faster data transmission and more responsive real-time adjustments to cold chain operations.

To realize these prospects, several key recommendations should be considered. It is crucial to develop a comprehensive national policy framework that incentivizes the adoption of geospatial technologies in cold chain logistics. Investing in training programs to build local expertise in geospatial technologies and cold chain management is essential for sustainable implementation. Encouraging collaborations between government agencies, private sector companies, and academic institutions can drive innovation and implementation. Prioritizing the integration of renewable energy sources in cold chain infrastructure will enhance sustainability and reduce operational costs. Establishing national standards for data collection, sharing, and integration will facilitate seamless cooperation among stakeholders.

Furthermore, incorporating cold chain logistics considerations into broader urban development plans will ensure long-term sustainability. Implementing a system of regular audits and technology upgrades will keep the geospatial cold chain logistics infrastructure up-to-date and efficient. Engaging in knowledge sharing and collaborative projects with neighbouring countries can create a more robust regional cold chain network. By focusing on these areas, Nigeria can create a more efficient, sustainable, and resilient cold chain logistics system that supports urban development while ensuring food security and economic growth. Implementing these

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recommendations, along with adopting emerging technologies, will position Nigeria as a leader in innovative urban logistics solutions in Africa.

CONCLUSION

The application of geospatial technologies in developing sustainable cold chain logistics infrastructure represents a significant advancement in Nigeria's urban development. By utilizing spatial analysis, remote sensing, and geographic information systems, this approach provides a data-driven framework for optimizing the placement, design, and operation of cold chain facilities in urban areas. The integration of geospatial tools enables more efficient route planning, reduces food spoilage, and enhances overall supply chain resilience. This not only contributes to food security and economic growth but also aligns with sustainable urban development goals by minimizing energy consumption and reducing the environmental footprint of logistics operations. As Nigeria continues to urbanize, the strategic implementation of geospatially-informed cold chain infrastructure will play a crucial role in creating more sustainable, resilient, and food-secure cities. This approach sets a precedent for innovative urban planning that can be adapted and scaled across other developing nations facing similar challenges in their cold chain logistics systems. Furthermore, the successful integration of geospatial technologies in cold chain logistics can facilitate enhanced collaboration between various stakeholders, including government agencies, private sector firms, and local communities. Effective stakeholder engagement is crucial for ensuring that infrastructure development aligns with the specific needs and conditions prevalent in diverse urban environments. By utilizing geospatial data, decision-makers can identify critical areas that require intervention and invest resources strategically, ensuring equitable access to cold chain facilities across all demographics.

Moreover, the implementation of smart technologies, such as the Internet of Things (IoT) and real-time monitoring systems, can further improve the efficiency of cold chain operations. By harnessing geospatial information in conjunction with these technologies, businesses can track temperature fluctuations, manage inventory levels, and optimize delivery schedules with unprecedented precision. This real-time data empowers logistics managers to make informed decisions that enhance operational efficiency and minimize product loss due to spoilage.

As urban populations in Nigeria continue to rise, the pressure on food supply systems grows. Geospatial technologies thus offer a proactive solution to emerging challenges associated with urbanization, such as increased demand for perishable goods and the need for sustainable practices. By developing robust cold chain logistics networks informed by spatial data, cities can better respond to the dynamism of consumer needs while mitigating food wastage and optimizing resource use.

In conclusion, the strategic adoption of geospatial technologies within the cold chain logistics sector not only addresses immediate operational challenges but also contributes to the long-term sustainability and resilience of urban food systems. As other developing nations observe Nigeria’s advancements in this arena, there lies an opportunity for knowledge sharing and collaborative innovation, paving the way for a global movement toward food security and sustainable urban living. Ultimately, this forward-thinking approach underscores a vital transition toward smarter, data-driven urban logistics that can redefine the landscape of food distribution in cities worldwide.

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