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Leveraging on GIS to Enhance Efficiency and Promote Good Governance in Subsidized Fertilizer Distribution: Case Study of Njoro Sub-County, Kenya

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Abstract

In line with its interventions to tackle food insecurity and achieve Sustainable Development Goal (SDG) 2, the Government of Kenya in 2022 allocated 3.55 billion Kenya Shillings as a subsidy to support farmers in purchasing fertilizers. Despite this initiative, however, corruption has led to the diversion of fertilizers to private shops, thus jeopardizing the intended distribution to needy farmers. This study aims to demonstrate the application of Geographic Information Systems (GIS) to enhance efficiency and promote good governance in the distribution of subsidized fertilizer. The GIS approach addressed multiple factors, namely, reducing farmers' travel distance to access fertilizers, ensuring proper accountability for distributed fertilizers, guiding farmers in their use of the appropriate type and quantity of fertilizer based on soil and crop types, and increasing overall food production. Data applicable to eligible farmers such as land parcel details, soil information and crop types were obtained from the Ministry of Agriculture and integrated into a geodatabase. Spatial and statistical analyses revealed that most farmers operate on a small-scale and are located more than 40 km from the main government fertilizer depot, making transportation costs prohibitive. The proposed solution is to establish sub-depots at the ward level within a three-kilometer radius for easier access. A user-friendly dashboard displaying farmers' locations and farm data was created to enhance transparency and accountability, while optimizing fertilizer distribution logistics. The study showed that GIS is a powerful tool for enhancing the efficiency and promoting good governance in the distribution of agricultural inputs, thus ultimately contributing to improved food security and sustainable development.

Keywords: *SDGs, Food Security, Geographic Information System, Fertilizer Distribution, Good Governance.*

1. Introduction

The Food and Agriculture Organization (FAO) of the United Nations defines food security as a situation where all people have constant physical, social, and economic access to sufficient, safe, and nutritious food, that would meet their dietary needs and food preferences for an active and healthy life (FAO, 2006, p.1). Food insecurity, therefore, denotes the lack of sufficient access to enough, safe, and nutritious food to lead a healthy life (FAO, 2021). Hunger, on the other hand, is a direct derivative and assumes chronic proportions when a person is unable to consume enough calories consistently to live a healthy life (FAO, 2019, p. 4). Under-nutrition is defined as a scenario when a person consumes insufficient amounts of energy-providing nutrients to satisfy the requisite needs for maintaining their health because of either hunger, food insecurity, or both (Maleta, 2006). The percentage of the undernourished population is an indicator of hunger and is used by FAO to measure the world's progress towards achieving Sustainable Development Goal (SDG) 2, which is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (United Nations, 2015). This requires that the four pillars of food security, namely, food availability, food access, food utilization, and food stability be effectively aligned (Gil et al., 2019), (Bach. & Aforesaid, 2014), (FAO, 2008).

Food security is a critical issue in Kenya, where a significant portion of the population faces challenges related to food availability, access, utilization, and stability. Agriculture is the backbone of Kenya's economy and a major source of food. However, food production is often constrained by factors such as climate variability, land degradation, and limited agricultural inputs. Kenya is highly susceptible to climate-related shocks such as droughts, floods, and erratic weather patterns. These events often disrupt agricultural production and food supply chains, leading to food shortages and price volatility. Similarly, smallholder farmers frequently face challenges accessing quality seeds, fertilizers, and modern farming equipment (FAO, 2020). Moreover, infrastructural development, particularly in rural areas, is inadequate. Poor road networks and limited market access make it difficult for rural communities to access agricultural inputs and to buy and sell food (FAO, 2018).

Kenya is in fact among the hunger hotspots identified on the world map by FAO and WFP (2022) that are considered to be of extreme concern in the context of food insecurity and of deserving of an early warning in this respect. The food insecurity situation was further worsened when Russia invaded Ukraine in 2022. The fact that prior to the conflict Ukraine had been one of the key global suppliers of fertilizer has seen fertilizer prices skyrocket, with this likely to severely limit usage and result in lower crop yields (Hassen and El Bilali, 2022); Breisinger et al., 2022). In September 2022, in an attempt to address this problem, the Government of Kenya (GoK) made available 3.55 billion Kenya Shillings to subsidize 71,000 Mt (1.42 million x 50 kg bags) of fertilizer for growing food crops during the short rainy season (Ministry of Agriculture & Land Development, 2022).

The GoK introduced its first agricultural subsidy in 2009 in direct response to the high fertilizer prices in 2008 and to spur on agricultural production (Makau et al., 2016). However, recent reviews by the International Food Policy Research Institute (IFPRI), for instance, have questioned the effectiveness of this intervention. Some of the challenges that the system faces include a lack of awareness about soil deficiencies, which result in the improper selection of fertilizers (Kenya Wallstreet, 2023). Fertilizer subsidies in Kenya have significantly increased the use of fertilizers among smallholder farmers, leading to higher crop yields and improved food security. The subsidy programs have helped to reduce input costs, making fertilizers more affordable and accessible to low-income farmers. Despite these benefits, the effectiveness of the subsidies is often undermined by issues such as inefficiencies in distribution, targeting problems, and the parallel sale of subsidized and commercial fertilizers (Jayne & Rashid 2013), (IFPRI, 2021).

Furthermore, there are only 118 National Cereals Produce Board (NCPB) distribution points countrywide that are supposed to serve all 47 counties across the country. However, some counties are far too large for only one or two distribution points to suffice. This forces farmers to travel long distances to the NCPB depots, thus attracting high transport and ultimately higher production costs (Kenya Wallstreet, 2023). Moreover, the subsidies are sold in tandem with commercial fertilizers and cater for only 10% of the annual demand for fertilizers (International Agronomy Foundation, 2022), thus creating room for market diversion. The general suitability based on a model used in Malawi is to determine which farmers cannot afford the fertilizers at the market price − premised on the fact that the smaller the acreage of land under cultivation, the lower the farmer's purchasing power (Holden & Lunduka, 2010). This model has turned Malawi from a perpetual food beggar for nearly two decades to a self-sufficient nation (Chinsinga, 2012). In Kenya, the fertilizer subsidy has been known to attract rent extraction, which is the propensity of lawmakers to squeeze payments (i.e. "rents") in some form in exchange for favorable legislation, further accelerated by social and political connections (Shiundu, 2016). It has been argued that a third of the subsidized fertilizer ends up in the hands of non-targeted farmers (Kenya Wallstreet, 2023).

GIS is defined as an integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes (Longley et.al., 2015). GIS technology’s transformative power lies in its ability to handle spatial data with precision, integrate various data sources, and provide visual and analytical tools that support a wide range of applications. GIS technology has revolutionized agriculture by enabling precision farming, improving resource management and supporting sustainable practices. Its ability to integrate and analyse spatial data provides farmers with powerful tools to enhance productivity, reduce costs, and promote environmental sustainability. Against this background, the main objective of this study was to demonstrate the use of GIS technology in enhancing the efficiency and promoting good governance in the distribution of subsidized fertilizer distribution in Njoro Sub-County, Nakuru County, Kenya.

2. Methodology

2.1. Description of the Study Area

This study was conducted in the Njoro, Lare and Kihingo Wards, Njoro Sub-county, Nakuru County, as shown in Figure 1.

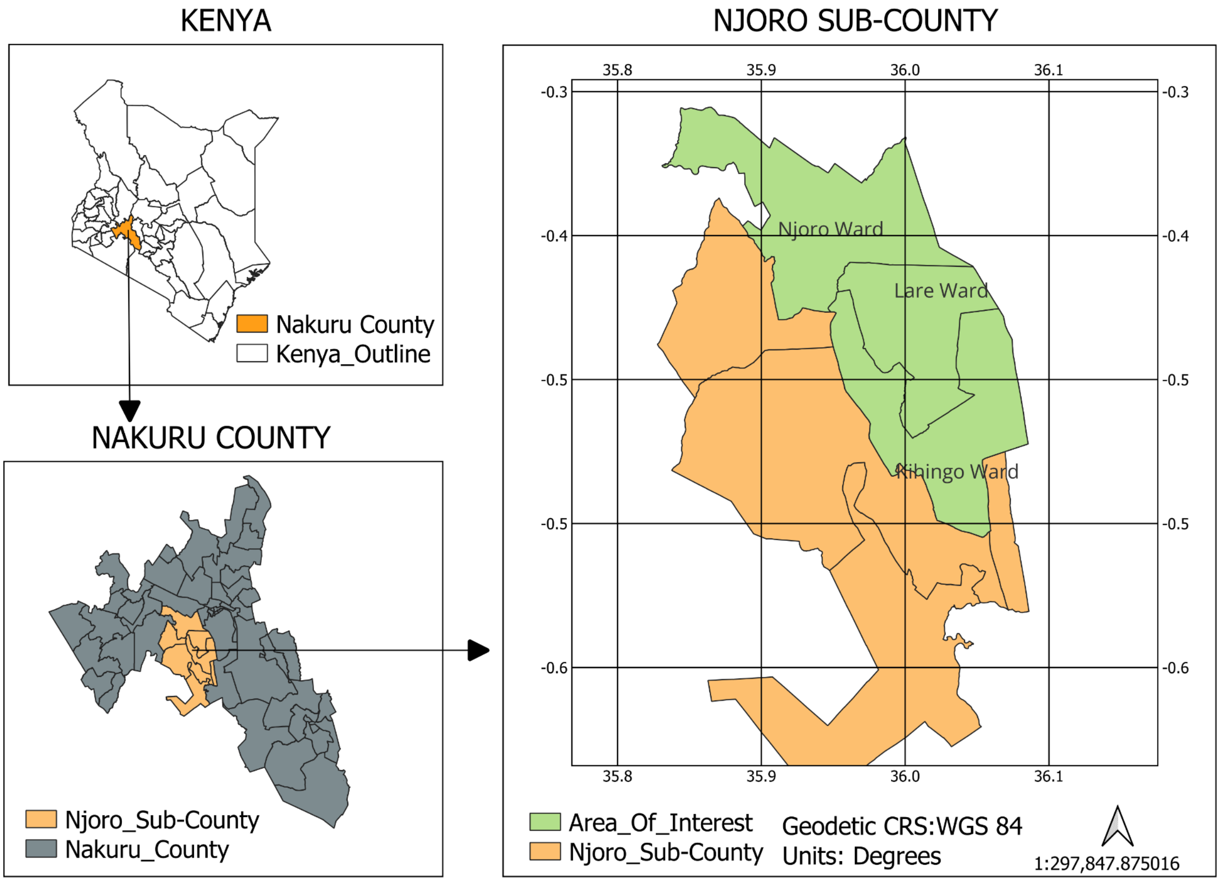

Figure 1: Map of the Study Area

This represents an important agricultural hub in Kenya's Rift Valley region. The ecological zones within Nakuru County are influenced by climate and physical morphological factors. The area encompasses forests such as Menengai Crater and Mau Escarpment. The soil types include *latosolic, planosolic*, and *alluvial* deposits. The climate zones range from low rainfall areas, such as Gilgil, to high rainfall zones on the Mau Escarpments.

2.2. Data Sources and Tools

Details of the data collected for this study and their sources, that included both primary and secondary sources, are elaborated in Table 1. Figure 2 shows an overview of the methodology adopted. The tools and software used include Quantum GIS, Google Earth Pro, PostgreSQL, Google Sheets and ArcGIS Online.

Table 1: Data and their Sources

Data	Format	Source
Farmers who have registered for subsidized fertilizer	Hard Copy	Extension officers and sub-county headquarters , Njoro
Registry Index Map	Hard Copy	Survey of Kenya
Soil Types	Shapefile	KALRO & ISRIC
Ground Control Network	Shapefile	Google Earth Pro
Administrative Boundaries	Shapefile	Africa Open Data
Road Network	Shapefile	Open Street Map

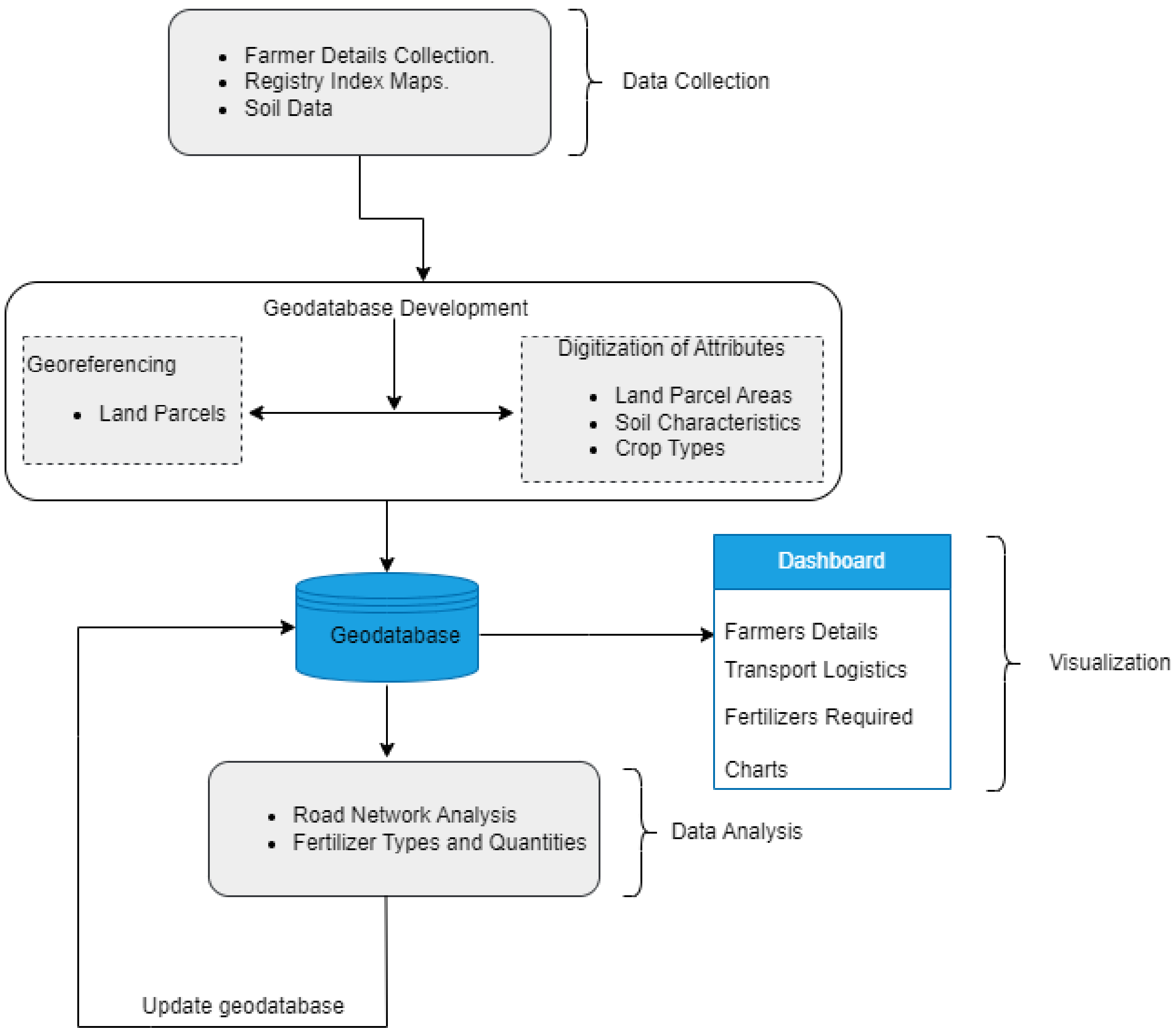

Figure 2: Methodology Flow Chart

2.3. Data Capture and Processing

The georeferencing process began with scanning old Registry Index Maps (RIM) into a digital raster format. Owing to faded ink on the RIMs, there was a need to collect ground control points from Google Earth Pro to use for georeferencing in respect of the features, such as road junctions and hospitals, employed for this. A total of 24 maps were georeferenced and saved in JPEG format. In QGIS, a spatial-lite layer served as a geodatabase for vector data storage. Guided by the collected farmer data, including title deeds and crop plans, the researchers were able to digitize the parcels belonging to farmers registered for the GoK subsidized fertilizer program were digitized. Parcel areas were calculated using QGIS's field calculator and compared against that indicated on the title deeds for quality check. Complementary data, such as sub-county and soil-type information, were added to each digitized parcel. The data were then exported for analysis in Google Sheets. Operations included converting individual farm areas to hectares and calculating total farm areas per ward and determining the dominant soil type per ward. The results were imported into QGIS and appended to the wards layer. Graduated visualization was conducted for farm sizes ranging from 27 to 112 hectares.

2.3.1. Fertilizer Distribution Analysis

The current details for Nakuru County's fertilizer distribution system were presented on a map. The depot's location was pinpointed in Google Earth Pro and imported into QGIS as a vector shapefile. A five-kilometer buffer zone around the depot was created to assess farmers' accessibility. Hypothetical depots were identified in each ward near major shopping centers and buffered at two-kilometer, three-kilometer and five-kilometer radii to evaluate farmer coverage. The shortest routes from the main depot to these hypothetical depots were determined using the ORS plugin in QGIS, with due consideration being given to factors such as distance and time. Farmers were assigned to their closest sub-depots, and average distances to each sub-depot calculated using vector analysis tools in QGIS. The results were exported to Google Sheets for further spatial analysis. These steps aimed to optimize fertilizer distribution by improving accessibility and reducing transportation costs.

2.3.2. Determination of Fertilizer Types and Quantities

Upon being presented with data such as *farm size, dominant soil characteristics* and *crop type,* an agricultural professional provided expert advice on the best types and optimal fertilizer quantities to be applied per acre. Using Google sheets, this study then proceeded to calculate the quantities of fertilizers that were required by each farmer. The quantity was estimated in kilograms and then in bags, which were rounded off to the nearest integer. Thereafter, the quantity in bags was summed for each ward and sub-depot.

2.3.3. Visualization

To support decision-making, an interactive dashboard was created using ArcGIS online to enable the integrated visualization of all the data on a single platform. To augment the integrated visualization, simple bar charts were used to represent qualitative data and to display the number of bags of fertilizer required for every sub-county and distribution zone. The other attributes associated with the data sets were made available to the user who could display this by simply clicking on the entity of interest.

3. Results and Discussion

3.1. Farm Locations, Sizes and their Implications

Currently, none of the farmers in the three wards has been able to access the fertilizers with any measure of convenience. This is evidenced in Figure 3, which shows a buffer around the NCPB Nakuru depot of a radius of five kilometers, which means that all farmers in this study area had to travel a distance greater than five kilometers to and fro to access the fertilizers. One way of reducing the distances that farmers needed to travel was by decentralizing the fertilizer distribution points to the ward level. It can be seen that within the radii of two, three and five kilometers around the hypothetical sub-depots (Egerton_Sacco, Gichobo Centre and Naishi_Centre) respectively, the number of farmers who were within this convenience zone and able to access the fertilizers using common means of transport comfortably increased significantly, as quantitatively displayed in Table 2.

Table 2: Number of farmers able to access the depots

Depot Name	Percentage of Farmers with Access		
	Two-kilometer Zone	Three-kilometer Zone	Five-kilometer Zone
NCPB_Nakuru	0	0	0
Egerton_Sacco	12.9	29.03	36.77
Gichobo_Center	14.19	18.07	40
Naishi_Center	5.81	19.35	40

According to the definition of small-scale farmers in the Nakuru County Development Plan (Nakuru County CIDP, 2018), it was also evident that the majority of farmers in the area of interest were small-scale farmers. The areas of farms by ward were determined as follows: Lare Ward - 111.78 Ha, Kihingo Ward - 69.66 Ha, Njoro Ward - 27.10 Ha. These values contributed to a better understanding of the requirement per ward and could be used in making vital decisions, such as the number of sub-depots that would be required per ward.

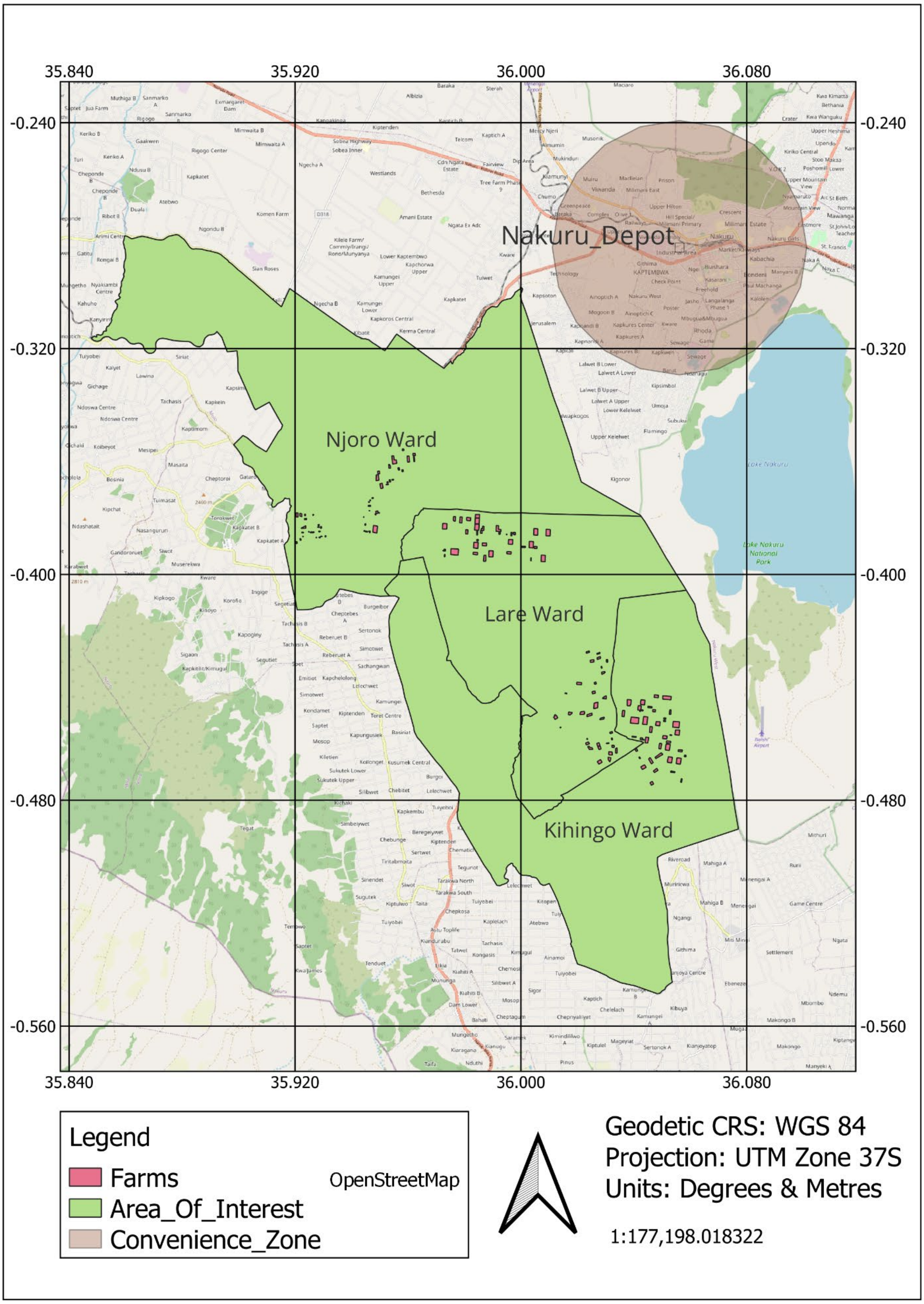

Figure 3: Farmer-Depot Travel Distance

3.2. Dominant Soil Types, Fertilizer Types and Quantities

The major soil characteristics of each of the farms were mapped, and an analysis of the dominant characteristic per ward was conducted and appended to the ward's shapefile. It was clear that both Lare and Kihingo wards have Anm as the dominant soil type, while the predominant soil type for Njoro Ward is Anh. As for the pH values, Njoro Ward has a value of 6.24, while the remaining wards have a pH of 5.7. Following consultations with an agricultural expert, the following facts were identified:

1) Farmers required two types of fertilizers: − one for use at the time of planting and the other during top dressing.
2) During both planting and top-dressing phases, the generally recommended quantity of fertilizer was 50 Kg per acre.
3) Among the subsidized fertilizers, such as DAP, CAN, UREA, NPK, and MOP, NPK proved to be optimal for the planting season. This is due to its balanced nutrient content, aligning well with most soil pH levels. Additionally, DAP proved to be a suitable alternative, particularly in cases where the soil phosphorus fixation capacity was known, thus benefiting the production of both vegetables and cereals.
4) For top dressing, the government was distributing only UREA − an alternative to CAN −, and the required quantities were calculated based on farm size.
5) For planting, the government subsidized only NPK fertilizer.
6) Based on the above information, the quantities of UREA and NPK that were required in every sub-depot and for each ward were calculated.

3.3. Geo-Visualization

3.3.1. Home Page

Once a user is logged into the dashboard, the following features are displayed: particulars of the user, title of the dashboard, functional buttons on the left and right, generated maps at the centre, and a legend for the map items. As illustrated in Figure 4, the layers available on the map are also displayed and can be turned on and off to enable the user to view only the required layers.

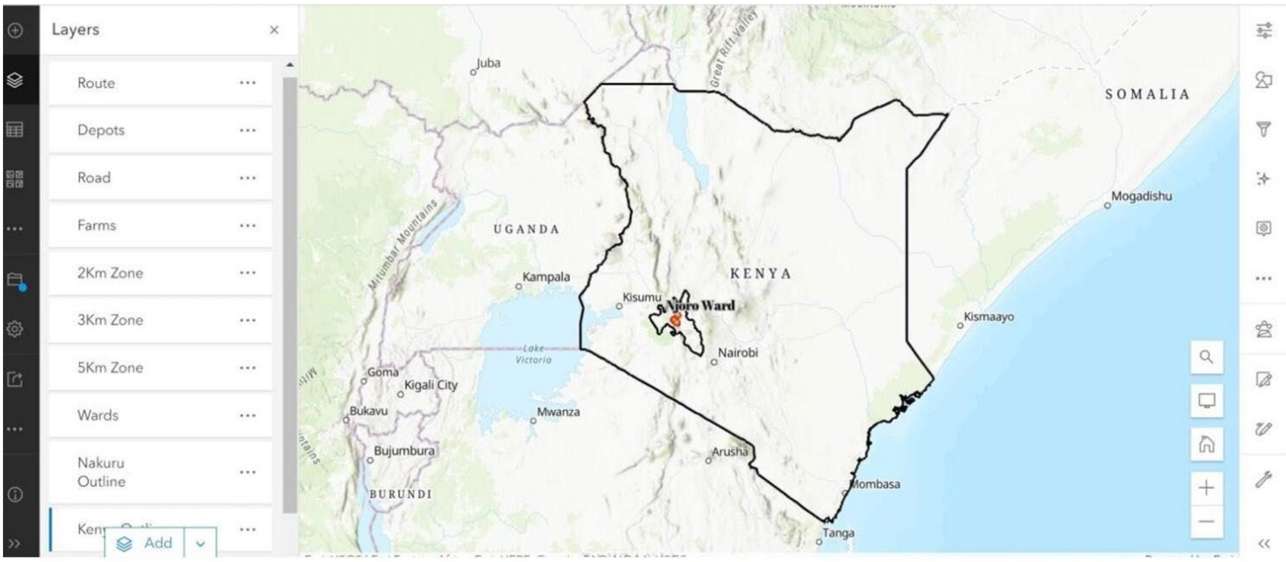

Figure 4: Different Map Layers

3.3.2. Farm Data

One can identify all the details that are attributed to a specific farm including those of the owner, the size of the farm, crop type(s), soil type(s) and the sub-depot that is nearest to the farm, the distance to it, and the quantity of fertilizer required for each farm. The size of the farms in each case was also symbolized according to the use of different color saturation levels. As shown in Figure 5, these could be interpreted using the legend on the right once the appropriate layer had been selected.

Figure 5: A display of the farm sizes

3.3.3. Sub-depots

The information on sub-depots can also be viewed with a pop-up showing all the data attributed to each sub-depot, including number of bags of each fertilizer to be delivered, number of farmers expected to receive their fertilizers from these points, and the average distance to be covered to access the depot. For example, as presented in Figure 6, the Gichobo Center sub-depot is at an average distance of 1.74 km from 34 farmers, who are expected to access their fertilizers from this sub-depot.

At the same time, one can determine from the depot layer charts the number of bags of fertilizer that would be required from each sub-depot.

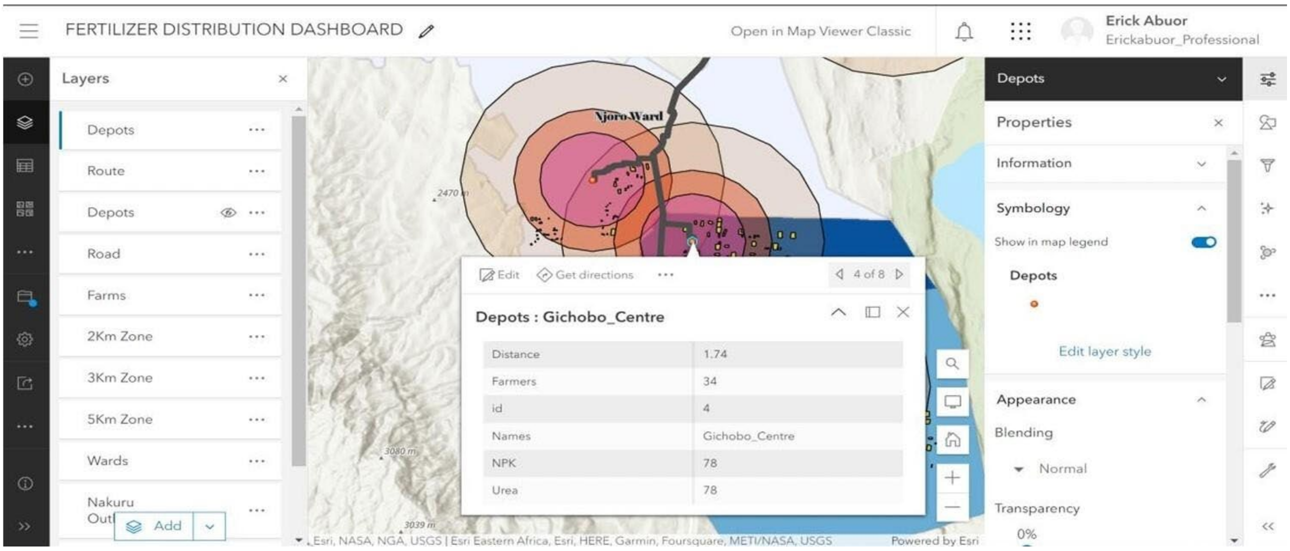

Figure 6: Sub-depot Details

3.3.4. Wards

The dashboard also enables one to view the ward details using pop ups, including total area of the farms in the ward, county and sub-county to which the farm belongs, soil pH, soil types and required fertilizer quantities. The wards have also been symbolized using different color saturation levels representing the different areas of farmers under the application. This information can be interpreted by using the legend on the right. There are also charts in this layer that represent the relevant data in the layer.

3.3.5. Fertilizer Distribution Logistics

The dashboard allows the user to visualize the shortest route from the main depot to the sub-depots. Through a popup, it is possible to determine the distance and the time covered to reach the relevant destination. For example, Figure 7 shows that the shortest route from Nakuru depot to the Gichobo Center sub-depot is 19.14 km and would require a driving time of 52 minutes.

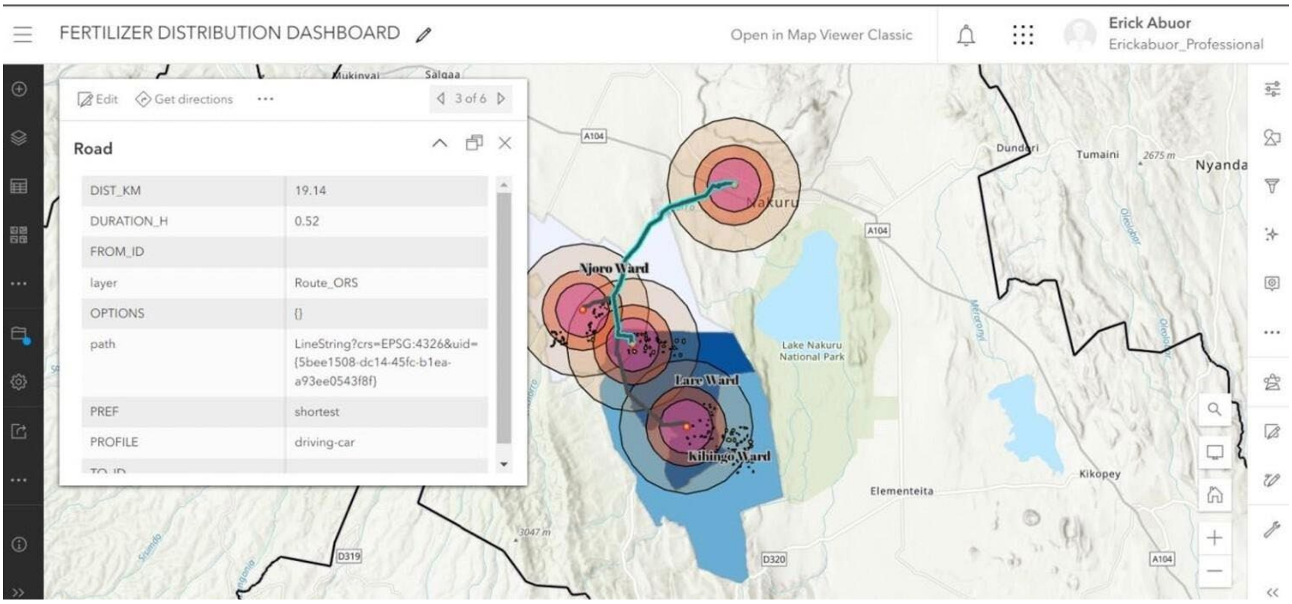

Figure 7: Automatically generated Shortest Route

4. Conclusions

The study reveals that small-scale farmers face challenges accessing fertilizer subsidies owing to the long distances they need to travel to collect the merchandise from central depots. This leads to ineffective subsidy utilization and is likely to ultimately hamper food security. Decentralizing depots to ward level would improve distribution efficiency by reducing travel distances to less than three kilometers. Besides enhancing transparency and accountability in the fertilizer subsidy workflows and overall program, the adoption of user-friendly geospatial dashboards would also streamline distribution efficiency. Integrating mobile communications to relay fertilizer collection notifications to farmers and the incorporation of the road condition could further enhance distribution efficiency. The study demonstrated that GIS technology offers a powerful tool for enhancing efficiency and promoting good governance in the distribution of subsidized fertilizer. By enabling spatial analysis, monitoring, data integration, transparency, and emergency response capabilities, GIS facilitates informed decision-making and the equitable distribution of agricultural inputs, ultimately contributing to improved food security and sustainable development.

5. References

Bach, C., & Aforesaid, B. (2014). *Assessing the Pillars of Sustainable Food Security*. European International Journal of Science and Technology, 3, 117–125.

Boulanger, P., Dudu, H., Ferrari, E., Mainar-Causapé, A. J., & Ramos, M. P. (2022). *Effectiveness of fertilizer policy reforms to enhance food security in Kenya: A macro–microsimulation analysis*. Applied Economics, 54(8), 841–861. Retrieved from: https://doi.org/10.1080/00036846.2020.1808180.

Breisinger, C., Diao, X., Dorosh, P., Mbuthia, J., Omune, L., Oseko, E., and Thurlow, J. *Kenya: Impacts of the Ukraine and global crises on poverty and food security*. In Global Crisis Country Brief 1; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2022; 1–12.

Chinsinga, B. (2012). *The Political Economy of Agricultural Policy Processes in Malawi: a Case Study of the Fertilizer Subsidy Programme*. Retrieved from: https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/2249.

FAO (2021). The State of Food Security and Nutrition in the World 2021. Retrieved from https://www.fao.org/3/cb4474en/cb4474en.pdf.

FAO (2020). *Kenya at a Glance*. Retrieved from https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

FAO (2019). *The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns* (p. 4). Retrieved from https://www.fao.org/3/ca5162en/ca5162en.pdf.

FAO (2018). *State of Food Security and Nutrition in the World 2018*. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/f5019ab4-0f6a-47e8-85b9-15473c012d6a/content.

FAO (2008). Food and Agriculture Organization of the United Nations. *An Introduction to the Basic Concepts of Food Security (* p. 1). Retrieved from: https://www.fao.org/3/al936e/al936e00.pdf.

FAO (2006). *The State of Food Security and Nutrition in the World 2016* (p. 1). Retrieved from http://www.fao.org/3/a0726e/a0726e00.pdf.

FAO & WFP (2022). Food and Agriculture Organization of the United Nations and World Food Programme. *Hunger Hotspots: FAO-WFP early warnings on acute food insecurity - October 2022*. FAO and WFP. Retrieved from https://www.fao.org/3/cc3127en/cc3127en.pdf.

Gil, J. D. B., Reidsma, P., Giller, K., Todman, L., Whitmore, A., & van Ittersum, M. (2019). *Sustainable Development Goal 2: Improved targets and indicators for agriculture and food security*. Ambio, 48(7), 685–698. Retrieved from: https://doi.org/10.1007/s13280-018-1101-4.

Grote, U. (2014). *Can we improve global food security? A socio-economic and political perspective*. Food Security, 6(2), 187–200. Retrieved from: https://doi.org/10.1007/s12571-013-0321-5.

Hassen, B.T., & El Bilali, H. (2022). *Impacts of the Russia-Ukraine War on Global Food Security: Towards More Sustainable and Resilient Food Systems?* Foods, 11(15), Article 15. Retrieved from: https://doi.org/10.3390/foods11152301.

Holden, S., & Lunduka, R. (2010). *Impacts of the fertilizer subsidy program in Malawi: Targeting, household perceptions, and preferences*.

Hunger. (2022). *Food and Agriculture Organization of the United Nations*. Retrieved from http://www.fao.org/hunger/en/. (Date accessed: 24 November 2022)

IFPRI. (2021). *Policy Options for Improved Distribution of Fertilizer Subsidies in Kenya*. Washington, D.C.: International Food Policy Research Institute. Retrieved from: https://www.ifpri.org/publication/policy-options-improved-distribution-fertilizer-subsidies-kenya.

International Agronomy Foundation (2022). Annual Report on the State of Agriculture and Fertilizer Subsidies. IAF. Retrieved from: https://www.iaf.org/reports/2022.

Jayne, T. S., & Rashid, S. (2013). *Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence*. Agricultural Economics, 44(6), 547-562. https://doi.org/10.1111/agec.12073.

Kenya Wallstreet (2023). *Kenya's Fertiliser Subsidy Program hit by Challenges*. Retrieved from: https://kenyanwallstreet.com/kenyas-fertiliser-subsidy-program-hit-by-challenges/.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Systems and Science* (4th ed.). Hoboken, NJ: Wiley.

Makau, J.M., Irungu, P., Nyikal, R.A., & Kirimi, L.W (2016). *An assessment of the effect of a national fertilizer subsidy program on farmer participation in private fertilizer markets in the North Rift region of Kenya*. African Journal of Agricultural and Resource Economics, volume 11, Number 4: 292-304.

Ministry of Agriculture and Livestock Development (2022). *Fertilizer Subsidy 2022*. Retrieved from: .https://kilimo.go.ke/fertilizer-subsidy-2022/

Nakuru County CIDP (2018). *Nakuru County Integrated Plan (2018 - 2022)*. Final Copy. Retrieved from: https://nakuru.go.ke/wp-content/uploads/2021/11/3.-NAKURU-CIDP-2018-2022-FINAL.-copy.pdf

Pinstrup-Andersen, P. (2009). *Food security: definition and measurement.* Food Security, 1(1), 5–7. Retrieved from: https://doi.org/10.1007/s12571-008-0002-y

Shiundu, A. (2017). *The government suspends 22 NCPB managers over the theft of subsidized fertilizer.* The Standard. Retrieved from https://www.standardmedia.co.ke/counties/article/2000202395/government-suspends-22-ncpb-managers-over-theft-of-subsidized-fertilizer. (Date accessed: 28 November 2022)

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. Retrieved from https://sustainabledevelopment.un.org/post2015/transformingourworld

World Economic Outlook (2023). *Inflation rate, average consumer prices*. Retrieved from: https://www.imf.org/external/datamapper/PCPIPCH@WEO.