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Effects of Rural Roads on Agricultural Farmers and Related Transport Operators: Evidence from Kenya

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ABSTRACT: Rural transport infrastructure is widely recognized as an enabler of agricultural productivity and inclusive economic growth. This paper assesses the effects of rural roads on agriculture and related transport operators in Kenya. The study adopted a cross-sectional descriptive survey design and collected primary data from 37 farmers and 40 transport operators active in rural areas. The sample size was more inclusive and representative of major farms and transport operators, and therefore provided sufficient information that led to the study's conclusions. The sample was determined using standard sample-size procedures, including Cochran's formula, finite population correction, and proportionate allocation across the participants strata. The findings indicate that rural road conditions, especially during rainy seasons, affect transport efficiency, market access, crop losses, input access, and farm-gate profitability. Earth and marram roads were the dominant access routes, while transport charges increased substantially during wet seasons. Poor roads increased costs and reduced the reliability of agricultural logistics, constrained transport operations, and exposed perishable commodities to delays and spoilage. Conversely, improved rural accessibility was associated with better market participation, increased farmer incomes, and improved capacity of transport operators to serve the value chains in agriculture. The study concludes that targeted investment in all-weather rural roads is essential for strengthening agriculture and rural transport performance in Kenya.

Keywords: Rural transport; Agriculture; Farmers and transport operators; Market accessibility; Agriculture profitability

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1. Introduction

Since its establishment, the East African Community [EAC]'s priority policy objectives have focused on developing rural agriculture, which covers over 70% of the region's economy. Transport systems significantly influence agriculture and related operations, including marked accessibility. Rural roads provide farmers and small associated businesses with crucial access to input and output markets. Improved roads can increase agricultural productivity by reducing transportation costs and improving market access, thereby not only enabling faster returns on road investments but also accelerating farm businesses. Rural transport infrastructure is a foundational component of economic development in Low- and Middle-Income Countries (LMICs), particularly in agrarian economies where physical accessibility determines the efficiency of production and market systems [1–4].

According to the World Bank (WB), rural accessibility is the only metric used in the Sustainable Development Goals to track progress toward better transport services in low- and middle-income countries [3]. Moreover, the African Development Bank (ADB) states that there is a shortage of adequate roads to promote accessibility despite them being the main mode of transport on the continent, supporting 80% of goods and 90% of traffic. Currently, Africa has just 2 km per 100 km^2 of paved road, and only about 43% of the rural population in Africa has access to an all-weather road. Also, the fraction of paved roads in Africa is still about 53%, which limits people from accessing fundamental social services including healthcare, education, markets, and economic opportunities [5–8]. Across East Africa, rural road networks constitute between 70% and 80% of total road length. They are also the primary means of connectivity for dispersed rural populations, who rely heavily on agricultural production for subsistence and economic activities [9].

In developing regions, the lack of road infrastructure can hinder any successes that agricultural projects would yield in ideal circumstances. According to Refs. [1,10], improvements in rural transport systems significantly reduce transportation costs and improve market access and thereby promote farmers' production activities. These improvements facilitate improved productivity and increase income for farmers who can deliver their products to the market efficiently, on time, and with minimal damage to products such as vegetables [11,12].

The agriculture sector contributes about 30% of the Gross Domestic Product in EAC nations while directly or indirectly employing over 70% of the population [9]. While the sector depends heavily on rural roads, they are predominantly unpaved and often in poor condition across all classes, including feeder roads, district roads, county roads, and community access roads [2,13–16]. Moreover, this means that over 50% of the rural populations live in more than the United Nations Sustainable Development Goals (UNSDG)'s transport objective of 2 km from an all-weather road [17].

Additionally, inequalities in road quality between provinces and counties indicate pronounced disparities in the production from agriculture. For example, in Kenya, counties with less than 5% paved roads, such as Wajir, Lamu, and Samburu, tend to experience lower agricultural output than counties, such as Nyeri and Kiambu, where over 50% of roads are paved [18]. Therefore, addressing transportation quality gaps could be vital to ensuring that rural roads perform well in their main economic function of improving market access while promoting commercialization of the produce. Equally, it is worth noting that improving rural road access can increase farm gate prices by up to 20%, hence boosting the farmers' finances and overall well-being of their families and the larger community [18].

Overall, the importance of rural roads calls for targeted rehabilitation investments to boost production and reduce poverty. This paper assesses the effects of rural road conditions on agriculture and related transport operations in Kenya, which can potentially give the whole picture of the challenge in East Africa. We believe that it is vital to understand how good rural roads can boost agricultural activities, and that the gap between the quality of rural roads and agriculture should be filled up for the well-being of rural

populations. The study's findings will inform decision-makers and regional infrastructure development plans to ensure alignment with agriculture and transportation policies. By emphasizing rural mobility as a catalyst for agricultural growth, the study promotes interventions that prioritize rural areas disadvantaged by poor road access, contributing to sustainable economies and development for all layers of society.

1.1. Literature

Agriculture is a major driver of the economy, food security, and employment. Rural transport plays an essential role in supporting these sectors by aiding the movement of farmers' production, labor, farm inputs, and goods to different markets [18]. The literature indicates that efficient rural transport systems improve access to markets, reduce operational costs, and increase productivity among rural businesses and farmers [18–20]. According to Kaiser and Barstow [21], nearly 50% of African farmers live five hours or more away from markets. However, the same source indicated that rural transportation interventions yield positive impacts on market access, and the achievement of efficient access to markets is often visualized as an important method to improve the well-being of the world's rural poor. The challenge is that efficient transport systems are not easy to achieve in developing countries. The African Union Commission and the Organisation for Economic Co-operation and Development (AUC/OECD) [22] recommend that East African countries enhance transport infrastructure, specifically to support rural agriculture. Kenya and other countries in the region are predominantly served by earth and marram unpaved roads, which deteriorate rapidly during rainy seasons. Expectedly, this deterioration of rural roads is associated with increased transportation costs, delays in product delivery, post-harvest losses, limited market access, and under-optimization of agricultural products [4,23]. Several studies reported that poor mobility significantly affects productivity in agriculture operations, leading to increased costs, lower profitability, and limited market participation [16,19,23,24]. These studies also argued that transport operators face increased maintenance costs, are forced to undertake fewer daily trips, and incur overall seasonal increases in charges due to poor roads. Severe consequences are observed on perishable commodities, including fruits and vegetables, which are highly affected by transport delays and spoilage [16,18,21,25,26].

Rural roads in Kenya and other EAC countries are typically classified by function into district (collector) roads, feeder roads, and community/access roads. District roads are essential for local centers, while feeder roads are important for connecting villages and markets to collector roads. Similarly, community roads are essential for providing connection to social services, farms, healthcare, jobs, and education centers. Table 1 provides rural road networks, their conditions, and reliability to the population in EAC countries.

Table 1. Classification for Rural Road Networks in Kenya and other EAC countries [3,5].

	Rural Network %	Classification	Total Road Network (km)	Poor Condition (%)	Fair Condition (%)	Good Condition (%)	Population Reliance (%)
Tanzania	75	District, Feeder, Community access roads	144,430	61	2.3–2.5	30–35	70
Uganda	77	District, Community access roads	159,000	25–35	40–50	20–30	75
Rwanda	95	National Unpaved Road (Class 3), District Road 1 (Class 4), Feeder Roads (Class 5)	37,898	66–85	6.0–8.2	0.5–1	69
Kenya	50.8	Paved network, Gravel roads, Earth roads	121,486	4–18	8–22	60–80	70

Rural road networks in developing countries are predominantly constructed from gravel, lateritic soils, or engineered earth materials, making them highly susceptible to weather-induced deterioration, particularly through water and wind erosion [2,4]. As a result, a substantial proportion of these roads become impassable during rainy seasons, disrupting services and isolating communities [4], as well as extremely increasing transport costs [26,27]. Table 2 compares rural road networks, classification of unpaved roads, populations, GDP, RAI, and SDGs priorities in EAC countries.

Table 2. Cross-Country Comparative Summary [6–8].

Country	RRN Length (km)	Unpaved (%)	Population (Million)	Agri-Share to GDP %	Rural Access Index (%)	SDG Priorities
Tanzania	~144,430	~97	61.7	30–35	61	SDG 1, 2, 8, 9, 13
Uganda	~123,000	Majority unpaved	45	24	25–40	SDG 1, 2, 5, 8, 9
Rwanda	~35,925	~95 includes feeder & unclassified roads	14	27	52	SDG 1, 2, 8, 9
Kenya	~28,150	50.8	58.2	21–23	~70	SDG 1, 2, 5, 8, 9, 10

Statistically, rail and road transport account for over 80% of freight and passenger traffic collectively. Kenya and other regional countries significant expanded their road networks over the last decade or so. In most cases, such road networks are concentrated on major roads and highways, downplaying the need to build rural access infrastructure. The bulk of smallholder agriculture occurs far from these roads, in areas that are not even served by unclassified roads [24]. Additionally, cost factors tend to limit the level of motorization in developing countries, including in East African nations. While these countries have tried to address rural mobility and accessibility issues, budgetary allocations seem to have been insufficient [2]. Without enhanced rural transport systems, the goal of improving production from agriculture and related activities is affected [28]. Most rural transport takes place on foot, amid an increase in bicycle and motorcycle use. Environmental considerations also influence transport-related activities and systems in remote areas [29]. For instance, extensive networks intensify various activities, leading to environmental degradation and negative social impacts. From this perspective, there is a need to consider diverse environmental issues in rural transport development, including flexibility and design, local climatic and topographic conditions, availability of raw materials, soil and vegetation cover, heavy equipment, and introduction of work crews [1]. In agriculture and SMEs, transport determines the availability of labor for production and for components of produce reaching markets.

Through the literature, it is evident that existing studies emphasized rural roads' importance mainly to connect remote locations. However, insufficient attention was given to the performance, accessibility, affordability, and reliability of rural transport services. Therefore, a major gap remains the limited empirical evidence integrating the effects of rural transport infrastructure and the performance of agriculture [30]. There is a lack of evidence on how rural transport constraints affect farmers and transport operators. This study uses data collected from concerned stakeholders to address these gaps and provide evidence on relationships between agriculture and rural transport services.

1.2. Scope of the Study

This paper assesses the impact of rural transport systems on agriculture in Kenya. The study explores how rural roads influence agriculture in all stages, from production activities to market accessibility, business performance, and operational costs. The research covers the quality of rural roads, seasonal accessibility, and the challenges experienced by farmers and transport operators, such as crop losses, increased costs, market accessibility and fluctuations, and the overall effects of transport in supporting rural agriculture-based economic development. To this end, the paper addresses the following objectives:

i. To assess the condition of transport infrastructure in Kenyan rural areas.
ii. To examine the effects of rural transport on agricultural productivity and market accessibility.
iii. To investigate how transport costs influence agricultural operations and profitability.
iv. To examine the impact of poor road conditions on crop losses and transport efficiency.
v. To evaluate challenges faced by farmers and transport operators due to poor transport systems.

1.3. Conceptual Framework

Conceptually, the study is anchored in rural accessibility and market access perspectives, which argue that transport infrastructure influences agriculture outcomes. Transport can have different effects on agriculture based on distance, travel time and cost, reliability, and access to input and output markets. Within this framework, the quality and accessibility of a rural road is treated as the main factor, while cost, seasonal road accessibility, market distance, and delivery delays serve as transmission channels through which transport affects production, crop losses, and farmers' income and overall performance.

The conceptual relationship adopted in the study can therefore be summarized as shown in Figure 1 in which rural transport infrastructure affects efficiency and market accessibility, which in turn influence agricultural commercialization, post-harvest management, input access, transport operations, and rural household income. The framework also recognizes seasonal variation, especially rainy-season road deterioration, as an important factor in the relationship between rural transport and economic outcomes.

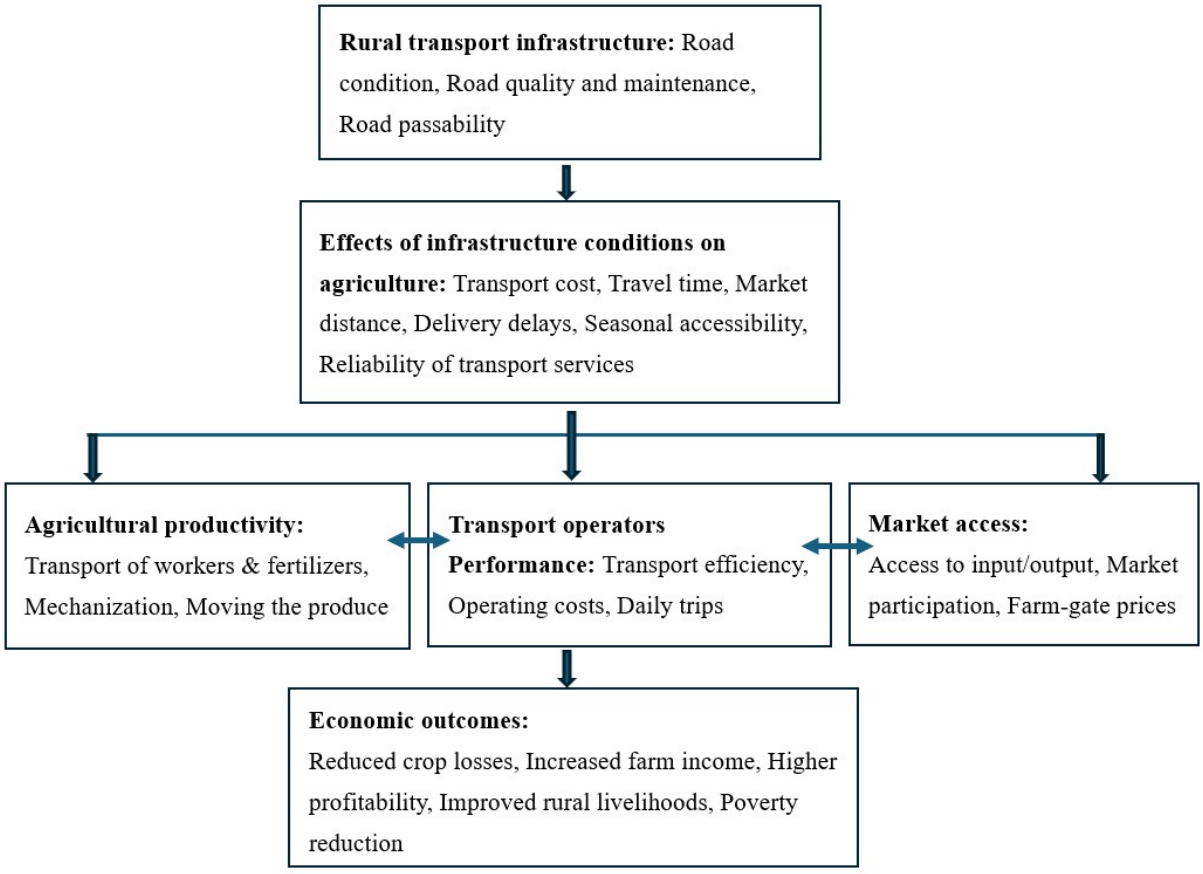


Figure 1. Conceptual framework.

1.4. Theoretical Foundation

The conceptual framework is informed by rural accessibility theory and market access theory. Rural accessibility theory is a manifestation of the World Bank's rural access index (RAI), a global metric for

measuring the proportion of rural populations within a specified distance of an all-season road. The theory focuses on physical proximity and transport infrastructure, including the proportion of people living within 2 km of an all-season road [2]. On the other hand, the market access theory is an evolution of market potential theory, which has been integrated into economic geography equilibrium models. This theory examines economic trade frictions, transaction costs, and how smallholder farmers connect with buyers, inputs, and pricing structures. There is a widespread consensus that smallholder farmers require improved access to agricultural markets to raise their farm productivity and living standards. In the context of East Africa, rural road infrastructure determines the efficiency with which farmers access inputs, transport produce, and participate in markets. Poor road conditions increase travel time, costs, and delivery delays, while improved accessibility enhances commercialization, productivity, and income generation. Seasonal deterioration of roads during rainy periods moderates these relationships by reducing road passability and transport reliability.

2. Materials and Methods

This section describes the methodology used to investigate the effect of rural transport on agriculture using Kenya as the empirical case study area. The methodology was organized to separate research procedures from findings. Accordingly, demographic characteristics, road-condition distributions, transport-cost estimates, income patterns, and other observed outcomes are presented in the Results section.

2.1. Study Area

Kenya was selected as the case study area because of its strong dependence on agriculture, its active rural transport and transport value chains, and the continued importance of rural roads in linking production zones to markets. The empirical component was conducted among rural farmers and transport operators who mainly use earth, marram, gravel, and paved roads to move inputs, production, and related goods. Kenya was therefore treated as an illustrative case through which broader rural transport challenges affecting the country and other countries in the region could be examined.

2.2. Research Design

The study adopted a cross-sectional descriptive survey design. This design was appropriate because it enabled data collection from farmers and transport operators at one point in time, allowing the study to assess existing rural road conditions, seasonal accessibility, costs, market access, crop losses, and transport-related operations. The design also supported comparison between the two key respondent groups: farmers who need access to inputs and markets, and transport operators who experience rural route conditions, operating costs, delays, and service reliability.

2.3. Target Population

The target population comprised two categories of rural economic actors. The first category consisted of farmers engaged in agriculture and marketing within the selected rural study area. The second category consisted of transport operators involved in moving agricultural produce, farm inputs, and other goods linked to rural agricultural businesses. These two groups were selected because they interact directly with rural road infrastructure and are affected by changes in road quality, travel cost, market accessibility, and seasonal travel disruptions.

2.4. Sample Size Determination and Sampling Procedure

The study adopted an exploratory case-study approach aimed at generating empirical evidence on the effects of rural transport infrastructure on agriculture and related transport activities in Kenyan rural areas

as a basis for drawing broader lessons for the country and East Africa. The sample size was determined based on stakeholder representation, respondent accessibility, available resources, and the need to obtain sufficient observations for descriptive and inferential statistical analysis.

As mentioned before, the study focused on two key stakeholder categories: farmers and transport operators. Farmers because they are the primary users of rural roads for accessing their farms and the markets, and transport operators because they connect farmers with sources of inputs and markets. The final sample comprised 37 farmers and 40 transport operators, yielding a total sample of 77 respondents. In numbers, the sample seems small. However, the strengths of this sample were in their representativity of almost all the major farms and transport operators in the study area. Also, they were sufficiently educated and had the composure and knowledge to inform this research.

Moreover, although standard sample-size estimation procedures such as Cochran's formula and Yamane's formula [31] provide useful guidance for survey research, the present study prioritized the inclusion of respondents with direct experience of challenges within the selected case-study area. The achieved sample was considered adequate for an exploratory cross-sectional assessment of rural transport conditions, market accessibility, travel time and costs, crop losses, and service performance.

2.5. Data Sources and Collection Methods

The study used primary data collected directly from participants through structured questionnaires and interviews. The farmers' questionnaire captured demographic characteristics, farm characteristics, road types and conditions, distance to market, distance to road, crop losses, transport costs, access to agricultural inputs, and income changes. The transport-operator questionnaire captured vehicle type, fuel type, business form, transport charges, route challenges, travel time, maintenance costs, daily trips, daily earnings, and commodities transported.

2.6. Validity and Reliability

Content validity was established through consultation with experts in transportation and agriculture, who reviewed the questionnaire items to ensure they captured the variables needed to produce reliable, sound results. A pilot review of the instrument was also undertaken to assess clarity, relevance, and consistency of questionnaire items. Ambiguous questions were revised before the main data collection exercise to improve reliability and reduce measurement error.

2.7. Data Analysis

The collected data were cleaned, coded, and analyzed using statistical software, including SPSS. Descriptive statistics, including frequencies, percentages, means, medians, minimum values, maximum values, tables, and charts, were used to summarize respondent characteristics, road type and conditions, transport costs, market access, crop losses, and income trends. Inferential statistics were used to examine relationships between selected variables, including market distance, crop loss, road's quality, and seasonal differences in transport charges. Spearman correlation, Kruskal-Wallis tests, Wilcoxon signed-rank tests, and regression analysis were used where appropriate, with statistical significance assessed at the 5% level.

2.8. Ethical Considerations

The study adhered to ethical research principles in collecting and using primary data. Respondents were informed about the purpose of the study, participation was voluntary, and informed consent was obtained before data collection. Confidentiality and anonymity were maintained, and no personal identifiers were used in the analysis. Respondents were also free to withdraw at any stage of the research process without penalty.

2.9. Limitations of the Study

The study was limited by its cross-sectional design and relatively small sample size. The findings should therefore be interpreted as exploratory and case-specific rather than as statistically representative of all rural areas in Kenya and East Africa. The study also relied partly on respondent recall, which may have introduced recall bias in reported income, costs, and crop losses. Seasonal road surface quality could not be observed continuously throughout the year due to time and financial constraints. Despite these limitations, the study provides insights into how rural transport affects agriculture and transport stakeholders in the Kenyan case-study context. The conclusions from this study must be treated with sufficient care in consideration of the limitations, including the small sample size and the use of a cross-sectional survey for data collection.

3. Results

3.1. Respondent Demographic Characteristics

The demographic profile of farmer respondents is presented in Table 3 and is at the beginning of the results because these characteristics describe the study participants rather than the research procedure. The sample of transport operators was almost homogeneous made of males aged between 27 and 53 years old. Females were missing, which is common in African culture, where they tend to be excluded from certain types of jobs, including the transport sector.

Table 3. Demographic profile of the farmers sample.

	Farmers
Total number	37
Female (%)	51.4
Male (%)	48.6
Participants aged more than 60 years old (%)	27
Participants aged 50–59 years old (%)	19
Participants aged 40–49 years old (%)	24.3
Participants aged 30–39 years old (%)	21.6
Participants aged less than 30 years old (%)	8.1
Participants with tertiary education (%)	40.5
Participants with secondary education (%)	32.4
Participants with primary education (%)	24.3
Uneducated participants (%)	2.8
Married (%)	83.8
Widows (%)	8.1
Divorced (%)	2.7
Single (%)	5.4
Average household size (number)	6.27
Members involved in agriculture per household (number)	3.16

3.2. Farming Characteristics

One of the study's objectives was to determine farming characteristics in the Kenyan case study area and interpret their relevance to the commercialization of agricultural products in the context of rural transport systems. According to the findings, two-thirds of farmers (67.6%) practiced commercial farming, while 27.0% practiced mixed farming systems. The remaining small proportion reported combinations of subsistence, commercial, and mixed farming, implying that most farmers were market-oriented and therefore highly dependent on available roads to move produce efficiently to markets.

3.2.1. Water Access

The study also sought to explore access to water, and results show that most of the farmers relied on rain-fed agriculture (54.1%), while 40.5% combined irrigation and rain-fed systems. Only 5.4% depended exclusively on irrigation. Heavy reliance on rainfall implies that seasonal road accessibility during rainy periods is likely to influence farmers' activities, production, and market access.

3.2.2. Mechanization

According to the findings, mechanization was relatively high among respondents, with 62.2% reporting the use of tractors or machinery. While 21.6% of respondents reported no mechanization, about 16.2% used animal traction, implying a growing modernization of practices in agriculture despite the impact of poor road networks in limiting the movement of machinery, fertilizers, and harvested produce.

3.2.3. Farm Sizes

The study also focused on exploring farm sizes to understand the volume and degree of impact of rural transport on farmers and small businesses. According to the outcomes, farmers owned an average of 4.31 acres/hectares of land, while 4.05 acres/hectares were actively cultivated. Farm sizes ranged from 0.5 to 15 acres/hectares, indicating substantial variation between smallholder and larger-scale producers, suggesting intensive use of available agricultural land.

3.2.4. Vehicle Types

According to the findings, motorcycles were the dominant mode of transport, accounting for 47.5% of operators, followed by large lorries (>5 tonnes) at 25.0% and pick-up vehicles at 12.5%, Tuktuk 7.5%, Long-Truck (2–5 ton) 5%, and Tractor-Trailer 2.5%. The outcomes highlighted the important role motorcycles play in overcoming poor rural accessibility, especially where roads are difficult for larger vehicles to navigate.

The study also found that most operators (65.0%) used petrol-powered vehicles, while 35.0% used diesel, consistent with the prevalence of motorcycles and smaller vehicles. Nearly all respondents (97.5%) operated as individual businesses, with only 2.5% working for registered companies, suggesting a highly informal transport sector that is potentially vulnerable to road deterioration and seasonal disruptions. Transport operators covered an average daily distance of approximately 99.8 km, reported average fuel costs of about Kenyan Shilling (KES) 2921 per day, monthly maintenance costs averaging KES 14,740, and mean daily earnings of approximately KES 14,694. However, some extreme values were observed, suggesting possible outliers or data-entry inconsistencies that require further verification during advanced analysis.

3.2.5. Rural Road Infrastructure and Seasonal Road Conditions

The study examined rural road infrastructure and seasonal road conditions to determine which roads farmers use to move inputs and farm produce. According to the findings, the dominant road types serving farmers were earth roads (37.8%) and marram roads (37.8%), collectively accounting for over three-quarters of routes in the study area. Only 18.9% of respondents reported access to paved roads, while gravel roads represented a very small proportion (5.4% combined gravel and gravel–marram roads). This distribution shows a heavy reliance on relatively poor, weather-sensitive road infrastructure. Earth and marram roads are particularly vulnerable to seasonal deterioration, which may hinder effective transportation of the produce and market accessibility.

Among transport operators, earth roads were the most used routes (55.0%), followed by paved roads (35.0%), while gravel roads accounted for 10.0%. This reinforces farmers' responses, confirming that transport systems are heavily dependent on unpaved road infrastructure.

Furthermore, road accessibility was highly favorable during the dry season. More than half of respondents (51.4%) described roads as being in fair condition, while 45.9% described them as good. Only 2.7% considered roads poor during dry periods. Using the Pavement Condition Index (PCI), a standardized 0 to 100 rating scale, fair (56–70) and poor (41–55) facilitated the determination of road quality. Fair roads are generally stable but show early signs of structural weakness and surface wear. Besides, poor roads are marked with uncomfortable riding quality and may show severe structural pavement defects. Besides, the study found that road quality deteriorated considerably during rainy periods. More than half of respondents (54.1%) rated roads as poor, while a fraction of 10.8% rated them as very poor. Only 18.9% thought that rural roads were sufficiently good during rainy seasons, while 16.2% of the respondents considered the roads to be fair. Transport operators generally viewed roads favorably during the dry season, with 55.0% rating roads as good and 40.0% as fair. However, it was a general view that road surface conditions worsened during wet seasons. During rainy periods, 32.5% of the respondents reported poor roads, 2.5% reported very poor roads, and only 22.5% reported that roads were good. These findings align closely with farmers' experiences and reinforce the seasonal deterioration of road quality.

Despite poor road quality during rainy seasons, most farmers (81.1%) reported that roads were not completely impassable, while 18.9% indicated that roads became impassable during rainy seasons. Transport operators were more likely than farmers to report road inaccessibility. About 40.0% of operators indicated that roads became impassable during rainy seasons, compared to 18.9% of farmers. This difference likely reflects the operational realities faced by transport providers, who frequently traverse long distances and encounter difficult road sections. The most frequently reported challenge among transport operators was mud (47.5%), followed by steep gradients (30.0%). Other challenges included potholes (7.5%), flooding (5.0%), and traffic congestion (5.0%). These findings indicate that weather- and terrain-related barriers are major constraints affecting the efficacy of transportation services that farmers need. The findings further reveal differences in how farmers and transport operators experience road accessibility during rainy seasons. Approximately 16.1% of farmers reported that roads become impassable during rain, compared to 33.3% of transport operators. This suggests that they are more likely to experience road inaccessibility than farmers, possibly because they travel longer distances and frequently use severely affected road sections. Farmers may rely on shorter local routes or alternative arrangements, whereas operators are directly exposed to poor road segments that disrupt logistics and the movement of agricultural produce.

3.2.6. Market Accessibility, Transport Costs, and Economic Effects of Road Transport

In this section, the study found that sampled farmers operate within moderate distances from markets and road infrastructure, although accessibility challenges remain significant for some respondents. Table 4 shows the market accessibility indication with respect to distances to the nearest road and market.

Table 4. Farmers' Market Accessibility.

Indicator	Mean	Median	Minimum	Maximum
Distance to nearest market (km)	5.60	5.00	2.00	21.00
Distance to nearest road (km)	3.02	3.00	0.20	7.00

Research indicated that transport costs represent a major determinant of farm profitability and market participation. Data showed that transport costs incurred by farmers were shown per trip with a mean of KES 239, a median of KES 200, a minimum of KES 50, and a maximum KES 1000. The frequency of market visits also offered insights into the degree of market engagement and commercialization among farmers. In general, about 25.8% of the respondents can visit the market 8 times per day. This was partly because they use their own vehicles and their farms are closer to the market, allowing them to make several trips between the farm and the market to transport fresh produce. However, the majority of the farmers

(71%) reported that they can visit the market once in 2 or 3 days, while 3.2% of the farmers only visit the market once 7 days.

The pattern indicates that many farming systems remain production-cycle dependent, potentially exposing farmers to post-harvest losses and price fluctuations due to infrequent market participation. Furthermore, the study explored the impact of road usage on agricultural productivity and market access. According to the findings, the ease with which the road is used can significantly influence not only production, but also transport efficiency and market participation for farmers. Poorer road conditions were associated with increased transport costs, limited market access, and crop losses amongst other negative outcomes. On the other hand, better roads were found to significantly improve farmers' income. This has been backed by Kaiser and Barstow [21], who reported farmers' income increase of up to 75% due to rural transport improvement by trail bridges.

All respondents reported that transport costs have increased over the last five years and acknowledged that poor road infrastructure negatively affects their ability to engage with markets. The study also estimated crop losses based on transport challenges. Disruptions and poor accessibility contribute to post-harvest losses, directly affecting farm profitability. Farmers estimated losing about 16.3% of produce due to road and transport-related challenges, with the median loss estimated at 15%. While some respondents experienced minimal losses, others reported losses as high as 50%. Also, transport operators reported huge cost variation between dry and wet seasons. Average transport charges increased from KES 4339 during the dry season to KES 5556 during the wet season, which is a substantial seasonal increase in expenses, as shown in Figure 2.

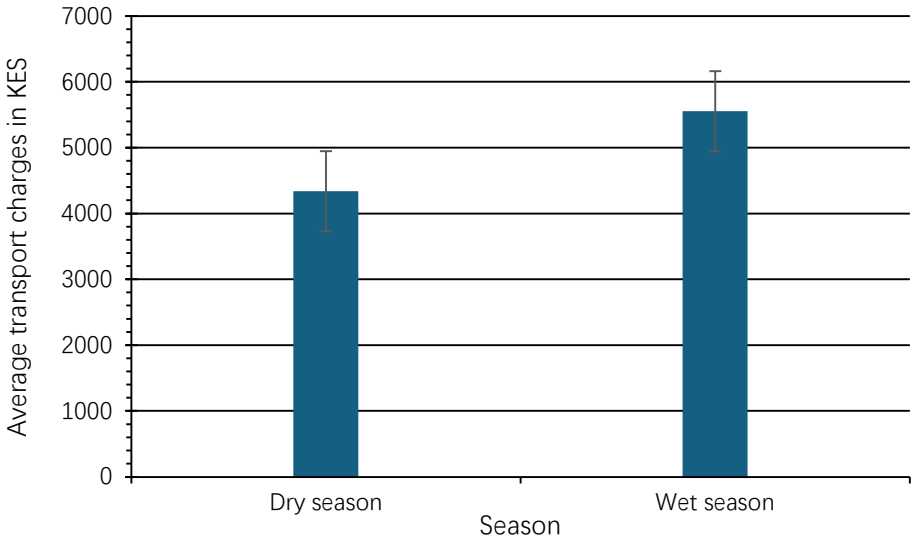


Figure 2. Average Transport Charges by Season.

Transport operators also provided valuable insights into the operational consequences of poor road infrastructure. The findings were that the majority of transport operators (91.7%) indicated that poor roads substantially increased vehicle maintenance costs. Similarly, 87.5% reported that delays reduce the number of daily trips completed, thereby lowering operational efficiency and profitability. Similarly, transport operators also reported wide variability in travel distances and daily earnings. The average daily distance was 99.8 km with a median of 22.5 km, while the mean daily earning was found to be KES 14,694 with a median of KES 2650. In terms of input assessment, all respondents (100%) indicated that road conditions affect access to agricultural inputs, which demonstrates the central role of rural transport infrastructure in agricultural production systems. Poor roads were perceived as a huge barrier to timely and affordable access

to seeds, fertilizers, agrochemicals, machinery, and labor services. The study revealed that major challenges affecting input accessibility were topped by delayed delivery, higher prices, and stock shortages.

Moreover, the study explored changes in farmers' income by comparing the current year against the situation as it was five years ago, as well as perceived change, with outcomes highlighted in Table 5.

Table 5. Mean Farm Income Comparison (N = 31).

	Value	% Increase or Decrease
Five years ago (KES)	245,506	-
Current year (KES)	496,464	102%
Number of farmers with income increases	27	87.1
Number of farmers with income decreases	3	9.7
Number of farmers with no change of income	1	3.2

Out of 31 farmers who reported on their income status, most of them (87.1%) reported that their farm income had increased over the last five years, while only a small proportion reported declining income (9.7%) or no change (3.2%). Moreover, respondents highlighted market prices and production levels as two dominant factors influencing changes in farm income. The study identified three main causes of crop losses, including travel delays (48.4%), spoilage (38.7%), and road inaccessibility (12.9%). These causes were associated with poor road infrastructure, particularly the surface, longer travel times, and seasonal travel disruptions, which can reduce product quality and delay access to markets. It was also found that pick-up, tuktuk, lorry-truck (>5 ton), and motorcycles are widely used by farmers, while tractor-trailer and lorry truck (<2–5 ton) were missing in the farmers' business, as shown in Figure 3. Similarly, the average travel time between markets and farms significantly varied with season, as illustrated in Figure 4.

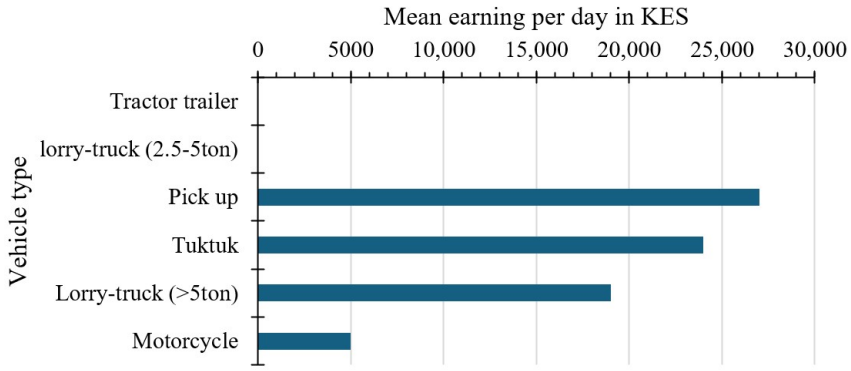


Figure 3. Type of Vehicle and Earnings.

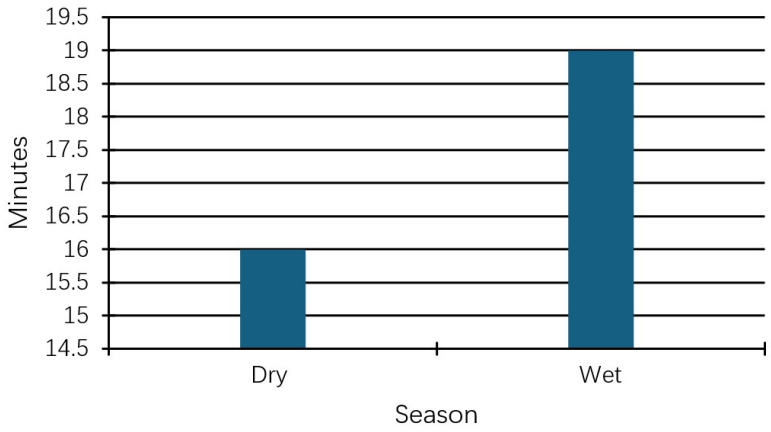


Figure 4. Average Travel Time: Dry *vs*. Wet Season.

According to the assessment of agricultural commodities, vegetables (n = 7), fruits (n = 5), and maize (n = 5) were the dominant categories of the produce handled by transport operators in the study area. Perishable commodities, including vegetables, fruits, tomatoes, and bananas, account for approximately 59% of all transported goods, indicating a strong dependence on time-sensitive produce. The transport operators' earnings by commodity type can be seen in Table 6.

Table 6. Transport operator daily earnings by commodity type.

Commodity Category	Mean Earnings (USD)	Number of Transport Operators
Cereals	348	1
Honey	232	1
Other	197	4
Vegetables	138	7
Maize	97	5
Tomatoes	12	2
Fruits	7	3
Banana	0.039	1

The study compared average transport costs incurred by farmers across different rainy season road conditions. Farmers operating on fair roads recorded the highest mean transport cost (KES 432) compared to those on good, poor, and very poor roads. However, as shown in Figure 5, the error bars overlap substantially, indicating high variability within groups. A Kruskal–Wallis H test was used to assess whether transport costs differed across the four rainy-season road-condition categories (good, fair, poor, and very poor) ($N = 31$). The analysis yielded an H statistic of 1.749 with 3 degrees of freedom, which was not statistically significant ($H(3) = 1.749, p = 0.626$). Using the consistent effect-size estimator $\varepsilon^2 = H/(N-1)$, the calculated epsilon-squared was 0.058. Although the descriptive results showed variation in average costs between road-condition groups, the inferential test does not provide sufficient evidence that transport costs differed systematically by reported road conditions.

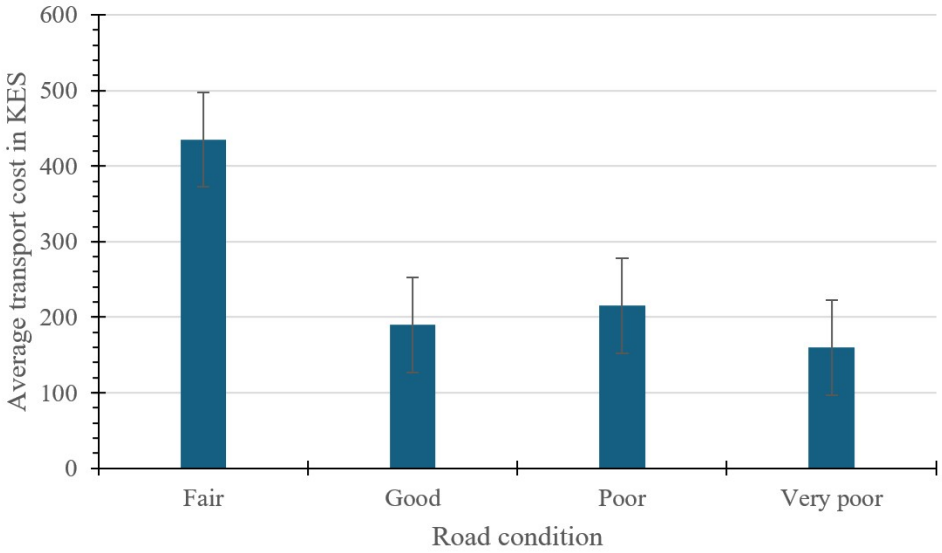


Figure 5. Fair, Good, Poor, and Very Poor Roads.

Moreover, a Kruskal–Wallis H test was conducted to examine whether reported crop-loss percentages differed across the four rainy-season road-condition categories. Similar to the examination of transport costs, the result was not statistically significant, H(3) = 6.027, p = 0.110, N = 31. The estimated epsilon-squared effect size was ε^2 = 0.201, suggesting a potentially meaningful magnitude of group differences in

this sample; however, the evidence was insufficient to reject the null hypothesis at the 5% significance level. Figure 6 compares average crop loss percentages across different road conditions during the rainy season. Farmers reporting good roads and very poor roads experienced relatively higher average crop losses, while fair roads showed lower losses. This suggests that although road quality may influence crop losses, other factors such as storage, timing of harvest, perishability of produce, weather conditions, and transport availability may also play an important role.

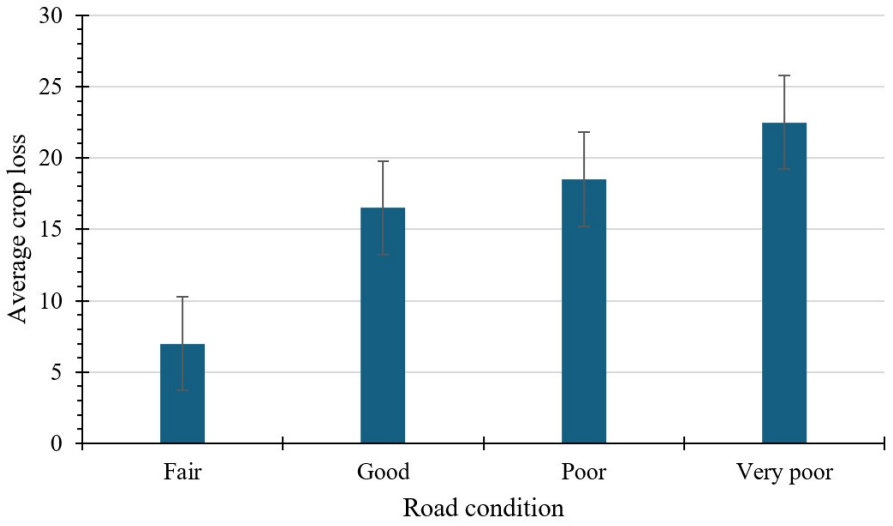


Figure 6. Average Crop Loss by Road Condition During Rainy Season.

As shown in Figure 7, transport costs tend to be higher for farmers located farther from markets. Most farmers live within 6 km of a market (22 of the 30) and generally pay lower costs, whereas 7 of the 8 farmers located beyond 6 km paid more than KES 100 per trip. The fitted trend line slopes upward, indicating that transport costs rise as distance increases, although the wide confidence band reflects considerable variation between farmers, including a few unusually high costs and one farmer located 21 km from the market. The Spearman correlation confirms a moderate, statistically significant positive relationship ($\rho = 0.538$, $p = 0.002$, $n = 30$), indicating that greater distance to market is associated with higher transport costs.

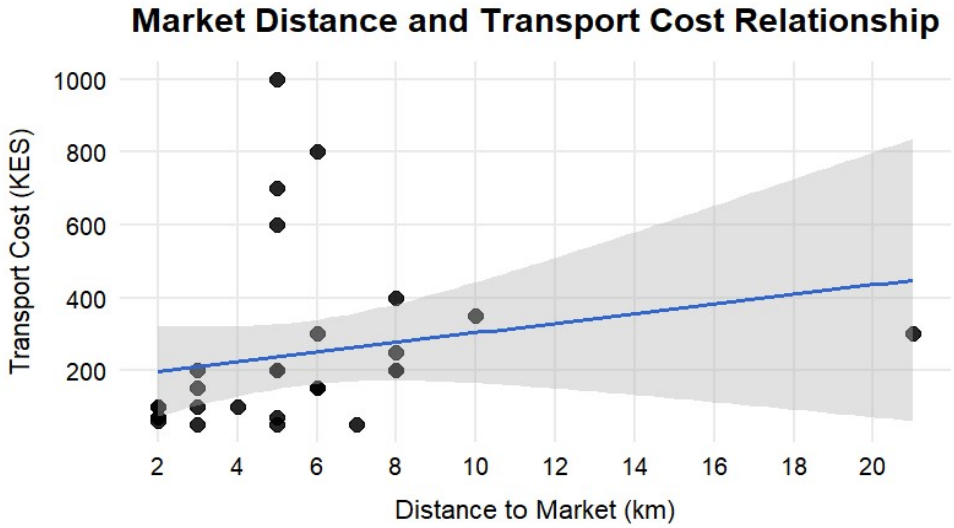


Figure 7. Market Distance and Transport Cost Relationship.

The scatter plot in Figure 8 does not show a consistent relationship between transport cost and crop loss. Reported losses vary widely across the 31 farmers, from under 1% to 50%, particularly among those paying low and medium transport costs. The trend line slopes downward, but this is influenced by a small number of farmers paying KES 400 or more, all of whom reported losses below 1%, and the wide confidence band shows considerable uncertainty. The Spearman correlation was negative but not statistically significant at the 5% level. This suggests that transport costs alone may not explain post-harvest losses, which are likely influenced by other factors such as delays, road conditions, and crop perishability.

Moreover, a paired Wilcoxon signed-rank test was used to compare transport charges reported by the same operators for the dry and wet seasons. The analysis included 15 complete pairs, with all 15 paired observations showing a nonzero difference. Mean transport charges were KES 4095.33 in the dry season and KES 5555.67 in the wet season, a descriptive increase of KES 1460.33. The difference was statistically significant ($V = 0$, $Z = -3.43$, exact two-sided $p = 0.000061$; effect size $r = 0.884$). This indicates that transport charges were substantially higher during the wet season among the operators included in the paired analysis. Although the findings are consistent with seasonal transport difficulties, the test does not by itself establish that poor road conditions caused the increase.

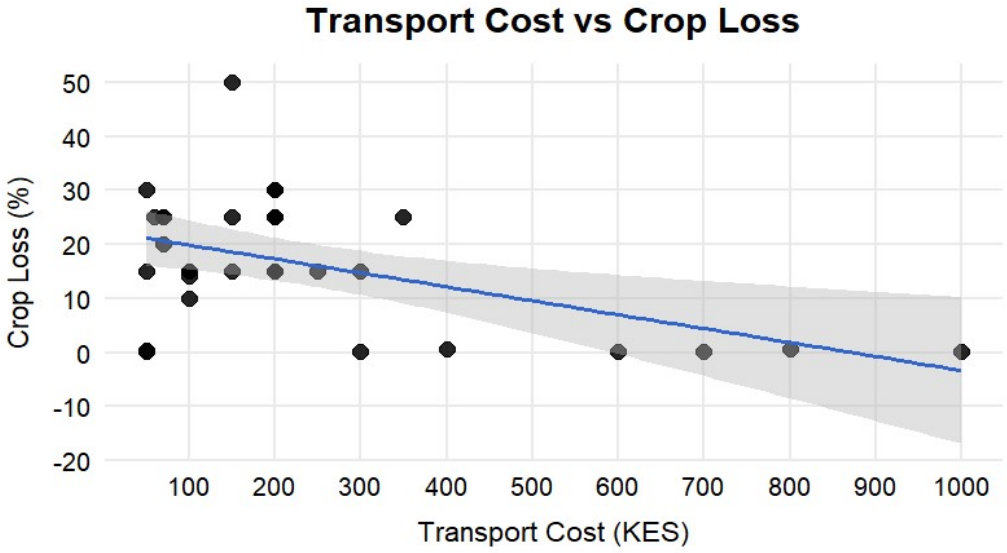


Figure 8. Transport Cost *vs*. Crop Loss.

A multiple linear regression model was fitted to examine the association of farm income in the current year with four road- and transport-related predictors: distance to the nearest market (km), distance from the farm to the nearest road (km), average transport cost per trip per kilogram, and estimated percentage crop loss. Figure 9 shows the relationship between observed and predicted farmers' income. The analysis used 30 complete cases. The overall model was not statistically significant, $F(4, 25) = 1.439$, $p = 0.251$, and explained 18.7% of the observed variation in annual farm income ($R^2 = 0.187$; adjusted $R^2 = 0.057$). None of the four predictors were statistically significant at the 95% level after adjustment for the other variables. The coefficient estimates and standard errors are presented in Table 7. Coefficients represent the expected change in estimated annual farm income associated with a one-unit increase in each predictor, holding the other predictors constant. These estimates should be interpreted as conditional associations, not causal effects. The relatively low adjusted R^2 and nonsignificant overall test indicate that the included road and transport variables did not adequately explain variation in farm income in this sample; suggesting that other variables such as production, market, household, and financial factors may have comparable importance.

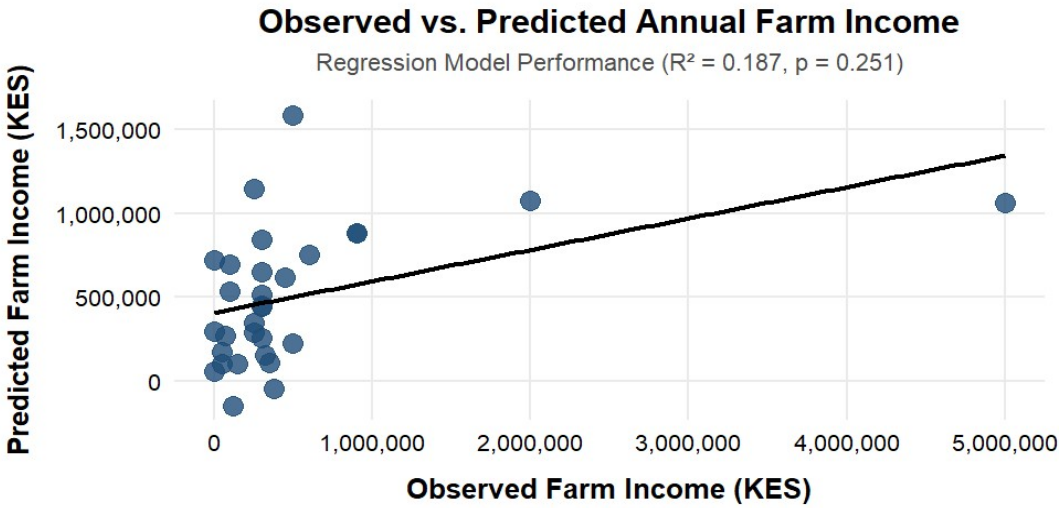


Figure 9. Observed and Predicted Farm Income.

Table 7. Farmers income model predictors.

Predictor	Coefficient (B)	Standard Error	*t*-Statistic	*p*-Value
Intercept	−456,155.10	497,687.58	−0.917	0.368
Distance to nearest market (km)	−8192.82	55,485.08	−0.148	0.884
Distance from farm to nearest road (km)	185,397.55	115,857.90	1.600	0.122
Average transport cost per trip	165.51	842.70	0.196	0.846
Estimated crop loss (%)	25,064.34	16,011.25	1.565	0.130

Note. B = unstandardized regression coefficient. N = 30; R^2 = 0.187; adjusted R^2 = 0.057; F(4, 25) = 1.439, p = 0.251.

3.2.7. Improvement Programs

A combined majority of respondents (64.9%) from farmers and transport operators reported ongoing road improvement projects, while 35.1% did not know about the existence of such activities. While many respondents suggest that authorities and stakeholders recognize infrastructure challenges and that interventions are underway, there is another significant fraction that thinks that these interventions may either be insufficient or not yet fully effective.

4. Discussion

The study investigated the effect of rural road conditions on agriculture and related transport operations. This was found to be a critical determinant of agricultural-based economic activities in Kenya, a country in which agriculture constitutes the primary livelihood in rural areas. The outcomes indicate that poor road conditions, particularly during rainy seasons, significantly affect almost all the steps involved in agriculture and associated operations due to transportation inefficiency. These findings are consistent with broader evidence previous researchers who suggested that road transport plays an essential role in rural economic development particularly when the economy hugely depends on agriculture [32,33].

4.1. Road Infrastructure and Agriculture

The association between road transport and agricultural productivity has been acknowledged by most of the farmers whose activities hugely depend on earth and marram roads, which are highly vulnerable to seasonal destruction [34]. Nonetheless, in the dry seasons, the quality of road infrastructure was judged to be fair to good, whereas in the rainy seasons, more than 50% of respondents described roads as poor or very poor. The seasonal decline in road quality has a substantial impact on agricultural productivity,

especially through disruptions in the movement of inputs and outputs [32,35]. Road conditions affect the delivery of seeds, fertilizers, agrochemicals, and machinery, and poor roads negatively affect their delivery. The findings support the existing body of knowledge on the importance of infrastructure in minimizing transaction costs and facilitating timely access to production resources [36,37]. Moreover, the predominance of commercial farming indicates a high reliance on reliable transportation systems. Commercial farmers tend to be more integrated into markets, and demand efficient transportation networks to maintain production schedules and profitability. Poor roads undermine this element of integration by increasing costs and adding uncertainty in agricultural operations [37–40].

4.2. Road Transport and Access to Markets

Another interesting thematic issue from the study is the relationship between road transport and market accessibility, which is one of the most important dimensions influenced by road transport in rural areas. On average, farmers were located relatively close to markets, but transport challenges remained substantial for them, which agrees with previous findings [39]. The positive association between market distance and transport costs indicates that farmers in distant locations from markets face greater financial burdens in seeking suitable buyers. The findings show that poor roads negatively affect market access, especially hindering commercialization of agriculture as a sector [36,39].

Across East Africa, market accessibility can increase smallholder farmers' participation in regional and national markets. Similarly, inadequate roads worsen the situation by isolating rural communities and reducing trading opportunities, thereby limiting farmers' ability to secure competitive prices for their products [29]. Limited market participation also increases vulnerability to post-harvest losses, price fluctuations, and reliance on local intermediaries. Improving road networks can increase market integration and strengthen rural-urban economic associations [41–43]. From this perspective, the findings reinforce the view that road infrastructure development is vital to improving agricultural competitiveness and regional trade opportunities [44].

4.3. Transportation Costs and Agricultural Profitability

The study also highlighted the relationship between transportation costs and profits drawn from agriculture. Poor roads directly increase transportation costs significantly. Farmers highlighted rising transportation costs, while transport operators reported significantly higher charges during the rainy season. Statistical assessments showed higher transport charges in rainy seasons than in dry seasons, reaching 200% in extreme cases, underscoring the sensitivity of transportation costs to road conditions. These findings are consistent with transport economics theories, which suggest that poor roads increase operating costs through components such as higher fuel consumption, more travel times, greater maintenance costs, and reduced daily trip completion rates [12,43]. These additional expenses are typically passed on to farmers through higher transport costs. However, it is reminded that this study did not find a direct statistically significant relationship between road condition and either transport costs or crop losses, potentially due to the relevance of other parameters in the context of Kenya.

In East Africa, agricultural profit margins are generally narrow, mainly because the sector is not modernized enough and lacks technological input, making increased transport costs a significant threat to profitability [44,45]. Indeed, such expenses limit the farmers' ability to invest in improved technologies and expand production due to limited access to distant but better markets. Increased logistics costs also reduce competitiveness and operational efficiency [46,47], and poorer roads amplify challenges, including those related to transportation and post-harvest production losses [47–49]. Of all the challenges, delayed transportation is a leading cause of crop losses, ahead of spoilage and road inaccessibility [48], highlighting

the need for integrated intervention schemes that combine infrastructure development with investments in storage, logistics services, and cold-chain facilities.

4.4. Transportation and Agricultural Value Chains

Based on the findings of this study, road transport infrastructure has significant effects on agricultural value chains, serving as critical intermediaries linking producers to markets, consumers, and suppliers [50–52]. Poor roads increase maintenance costs, reduce operational efficiency, and limit service coverage. Over 90% of transport operators highlighted that better roads would enable them to serve more farmers and do this in a much better way, indicating a strong relationship between road quality and access to the job market, enhanced employment, and creation of new small businesses along the roads [49,50,53]. From this perspective, the study supports regional development policies perceiving infrastructure investment as a catalyst for strengthening value chains, competitiveness, and economic diversification between primary production and profitability [52,54,55].

Categorically, this study's findings suggest that during favorable weather conditions, road infrastructure may not significantly constrain transportation and market access. However, the sharp decline in road quality between dry and rainy seasons highlights the vulnerability of rural transport infrastructure to weather conditions. Such deterioration may repeatedly contribute to delayed transportation, increased transport costs, crop spoilage, and reduced market access [2,56]. Although total inaccessibility affected a minority of respondents, even temporary impassability can significantly disrupt the supply chains, increase transport risks, and reduce farmers' access to markets and farm inputs [11,53,57–59].

Another finding from this research has been that results indicate notable variation in transport operator earnings across different agricultural commodities. Higher mean earnings are observed in cereals and honey, although these categories are based on a single observation each, limiting their statistical reliability. Vegetables and maize, which have relatively larger sample sizes, show more stable and representative earnings, suggesting they form the core of transport activities in the study area. Lower earnings recorded for fruits and tomatoes may reflect shorter transport distances, higher perishability, and lower transport charges. Overall, the findings suggest that commodity type influences transport profitability, but interpretations should prioritize categories with larger sample sizes for a more robust conclusion.

4.5. Policy Implications

It was found that diverse policy implications arise from the effects of road quality on agriculture and transport operations across Kenya. First, there is a strong need to invest in all-weather rural roads to reduce seasonal transport disruptions and improve year-round market accessibility. In addition, there is also a requirement for the country to optimize road maintenance programs to mitigate the effects of weather on the deterioration of rural road networks. Moreover, it seems imperative to integrate transport and agricultural policies to better coordinate rural road infrastructure development and maintenance with commercialization of the farmers' production. Government entities are urged to support the good condition of rural transport infrastructure through financing and maintenance programs. Ultimately, the regional transport corridor development should continue to implement initiatives that facilitate cross-border agriculture-related trade within East Africa. Policies supporting the viability of these findings have been previously reported in the literature [18,24,38].

5. Conclusions

Through its objectives, this study assessed the performance of agriculture and related transport operations in rural areas of Kenya with respect to rural road conditions. It therefore examined the effects of rural road conditions on agricultural productivity and market accessibility, transport costs of the produce,

and overall transport efficiency. Also, it evaluated challenges faced by farmers and transport operators due to inadequate rural transport systems.

The analysis of the findings, coupled with the awareness that agriculture is the most important sector for the development of rural areas in Kenya, can lead to the following conclusions:

- Poor rural road quality, particularly during rainy seasons, affects agricultural productivity, transport efficiency, market access, and post-harvest management. Rural roads were judged favorable during the dry season with 51.4% of farmers describing them as "fair condition" while 45.9% described them as "good condition". However, this changed during rainy seasons, when 81.1% of farmers reported that roads were not completely impassable, while 18.9% indicated that roads became impassable. Transport operators were more likely than farmers to report road inaccessibility, and about 40.0% indicated that roads became impassable during rainy seasons.
- Enhancing rural roads can contribute to improving market access and input delivery while reducing transport costs and boosting incomes from agriculture and associated transport activities. Farmers estimated losing about 16.3% of produce due to poorer roads, while 91.7% of transport operators indicated that poor roads substantially increased vehicle maintenance costs. Similarly, 87.5% of transport operators reported that delays reduce the number of daily trips completed, thereby lowering operational efficiency and profitability for both farmers and transport operators.
- Strengthening rural transport systems can be a powerful opportunity to catalyze transformation of agriculture, through enhanced commercialization and inclusive economic growth in Kenya.
- By addressing the physical and systemic constraints identified in this study, policymakers can create an enabling environment that supports food security and sustainable livelihoods. The study therefore underscores the central role of rural roads in agriculture as both a facilitator of economic activity and a cornerstone of long-term development in Kenya.

Overall, the study provides a clearer assessment of the effects of rural road infrastructure on agriculture and transport operations in Kenya. However, future research should be undertaken to assess levels of agricultural policy harmonization in the countries of the region. Furthermore, since all countries of the region do not have the same levels of reliance on agriculture, mainly due to land availability and national priorities, integrated research on alternative rural development priority factors should be conducted in Kenya and other countries of the region. The two recommendations are critical not only for the region to benefit from this study, but also because Kenyan rural areas and neighboring countries rural areas are mostly identical and there is informal movement of agricultural produce across borders.

Statement of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the authors used Cloud AI to assist with organization, consistency checking, and structure the manuscript. The authors reviewed and edited the content, verified the scientific claims and references, and take full responsibility for the final published article.

Author Contributions

Conceptualization, E.N., O.E.O. and E.A.N.; Methodology, E.N., M.N., J.M., L.M. and C.B.; Software, O.E.O. and E.A.N; Validation, J.M., L.M. and M.N.; Formal Analysis, O.E.O. and E.A.N.; Investigation, O.E.O. and E.A.N.; Resources, O.E.O.; Data Curation, E.A.N.; Writing—Original Draft Preparation, O.E.O., E.A.N., M.N. and L.M.; Writing—Review & Editing, E.N.; Visualization, C.B.; Supervision, E.N.

Ethics Statement

This study adhered to ethical standards for collecting and using primary data. Participation in the survey was voluntary, and respondents, including farmers, transport operators, and participating experts, provided informed consent prior to data collection. No personal identifiers were collected, and all responses were

anonymized to ensure confidentiality and privacy. The study did not involve any vulnerable populations or sensitive personal data requiring formal ethical board approval. The research was conducted in accordance with applicable ethical guidelines for social science research.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the authors upon reasonable request. Due to confidentiality considerations and the nature of primary data collection from individuals, raw survey responses are not publicly accessible but may be shared in anonymized form for academic and research purposes.

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Declaration of Competing Interest

The author declares that there is no conflict of interest regarding the publication of this paper. There are no financial, institutional, or personal relationships that could have influenced the research, analysis, or interpretation of findings presented in this study.

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