Climate Related Infrastructure System Failure and Its Implication on Agrarian Products and Processes

Goyol, S.S[1*], Wapwera, S.D[2], Jambol, R.A[3] and Baklit, G.[1]
[1]Department of Geography and Planning, University of Jos, Nigeria
[2]Department of Urban and Regional Planning, University of Jos, Nigeria
[3]PACTE Laboratoire, Institut d'Urbanisme et Geographie Alpine Universite Grenoble Alpes, Grenoble, France

Abstract

Agrarian Infrastructure systems in most developing countries fail due to their critical nature and exposure to climate risks. The aim of this paper is to examine climate related infrastructure system failure and its implication on agrarian products and processes. The study contributes to a better understanding of an approach to establishing risk and criticality of road infrastructure assets and determining geographical variation of the consequence of infrastructure failure/ disruption on agrarian systems. A mixed-method approach adopting a multiple case study of three agrarian communities (Shendam, Mangu and Riyom) to assess how climate risks and infrastructure criticality varies across communities in Plateau state of Nigeria. Data were collected through survey questionnaire with 229 infrastructure users on identified climate risk events, likelihood of infrastructure failure/ disruption and the consequences of failure/ disruption. Face-to-face interviews with 22 infrastructure managers also provided in-depth information on institutional capacity for road asset management. The data obtained through the questionnaire were subjected to Kruskal Wallis statistical test for significant differences to determine geographical variation in climate risk levels, infrastructure criticality, consequences of infrastructure failure/disruption. Content analysis was employed using NVivo software (version 11) to systematically quantify and analyse responses of transcribed qualitative data obtained from face-to-face interview. Findings indicate that, the long-established approach of generalising climate risks and impacts over regions underrates strategies for climate risk reduction and despite geographical variations the risk of agrarian losses is on the increase across the selected locations. Based on the results obtained recommendations were made towards adaptation and resilience strategies for effective risk reduction to help practitioners, policy makers and the academia.

Keywords: Agrarian losses; climate hazards; infrastructure disruption; risk; and road systems.

Introduction

Agrarian systems which are dependent on transport infrastructure systems for ensured food supply, sustainable livelihood systems, and the continuous growth of the economy are increasingly at risk of damage and/or disruption. The agrarian sector is a major contributor to economic growth globally by contributing significantly to nation's Gross Domestic Product (Awokuse and Xie, 2015). The sector plays strategic roles of providing food for the population (Adegoke et al., 2014), livelihood support for economically active populations (National Bureau for Statistics Nigeria, 2017) and raw materials for industries (Ozor et al., 2016). As growing populations necessitates the sector's reliance on infrastructure systems to expand production in order to meet the rising demand for food and raw materials, both direct and indirect effects of climate change are recorded either on infrastructure systems or on agrarian activities (Rosenzweig et al., 2014). Roads located at low elevations and constructed below grade are at risk of flooding. Heavy rainfall and resultant runoff does not only erode road surfaces but also wash off bridges and completely cut off communities. Climate change and the rising trend of climate hazard events does not only increase the probability of infrastructure damage or disruption but also places a higher risk of agrarian losses. This challenges the stability of agrarian systems and in turn, growth of agrarian economies. Although climate change possesses challenges, Schweikert et al. (2014) hold the opinion that it can provide opportunities for governments to expand considerations for infrastructure investment plans.

Risk is the probability of a known loss, which is a function of the consequences and likelihood of an event occurrence. In this paper, risk of agrarian losses refers to the likelihood of resource loss for an individual farmer or a community due to a climate failed infrastructure. The extent of agrarian loss can range from losses in a bad start of the growing season to post harvest losses (List and Coomes, 2017). As such, losses may extend beyond the boundaries of an agrarian area, increasing the cost of repair or reconstruction of damaged infrastructures as well as increased burden on government's resources for the recovery of affected communities (Negi and Anand, 2017, Yusuf and Kumar, 2018). Hence, risk is expressed as the probability of a climate event occurring against the possible impact. This is given by:

*Risk= Probability or likelihood of occurrence * Severity of impact*

A risk assessment process can be useful to determine infrastructure assets with significant potentials to influence management strategies through the prioritisation of the most critical assets. Criticality refers to the degree of importance of an infrastructure system. This is often based on the consequences of an infrastructure failure or disruption. Agrarian infrastructures, particularly road systems, are vital for agricultural production, freight and trade such that a disruption in the supply chain results to huge financial losses (Boehlert et al., 2015). Agrarian livelihoods are generally controlled by reliable road systems for access to resources and market forces (Neumann et al., 2015). Roads form an integral part of transportation infrastructures such that the higher the risk of failure, the more critical they are termed. Sustainable agricultural production is determined by resource availability and accessibility, of which road systems is a link and the potential impacts of climate change on transport infrastructures undermines efforts towards sustainability (World Bank, 2010, Krimly et al., 2016, Boehlert et al., 2015). As such, assessing the importance of individual road components including road pavements, bridges, culverts and drainages may suggests specific strategies to minimise potential failure, disruptions and losses.

A risk and criticality assessment of agrarian systems is essential for a better understanding of vulnerabilities and also to inform knowledge for decision making on appropriate prioritisation of infrastructure assets. It is against this backdrop that this paper seeks to examine climate related infrastructure system failure and its implication on agrarian products and processes by establishing the risk and criticality of road infrastructure assets and by determining the geographical variation of risk, criticality and consequence of infrastructure failure/ disruption on agrarian systems.

Literature Review

Road Infrastructure Criticality and Vulnerability

Transport infrastructures, particularly road systems are generally associated with global economic growth as it improves agricultural productivity, reduces poverty levels and advances the non-agricultural sector. Gollin et al. (2013) in a research on rural economy, observed that road development has strong links with farm output, production levels, poverty levels, and the development of non-farm sectors. Patel (2014), Storeygard (2016), and Fungo and Krygsman (2017) assert that roads in good conditions reduces travel time and cost, enhances business, commercial and economic activities along routes, as well as increase traffic flow and profitability. On the other hand, lack of good road infrastructure compounds the challenge of accessibility. Lack of access to input services can result in low use of inputs and modern agricultural technologies, sequel to low agricultural productivity. Poor road network particularly in agrarian area can be a barrier not only to the movement of produce to points of demand but also the integration of labour markets across space thereby hindering economic development (Gbadebo and Olalusi, 2015, Starkey and Hine, 2014). Shamdasani (2016) in assessing the relationship between road infrastructure and economic growth in India, specifically identified ways that improved rural road infrastructure enabled households to diversify cropping for higher returns, enhanced access to input and market services, and easy hire on labour. Through this process, producers were able to market farm produce to improve household income.

Likewise, several research conducted in Nigeria identified the importance of road transportation to agriculture from a number of perspectives: access to farm inputs and agricultural services (Afolabi et al., 2016), ease in movement and marketing of farm produce (Adeoti et al., 2014), reduced level of food wastage (Akinwale, 2010, Olubomehin, 2012), reduced prices of food and transport cost (Okoye et al., 2010), as well as the access to other non-farm services (Tunde and Adeniyi, 2012). On the whole, poor road conditions hikes production costs leading to low returns on investments, affects income levels accompanied by increase in poverty levels all of which challenges sustainable agricultural development.

In terms of road infrastructure development, Nigeria currently has the largest road network in West Africa and the second largest in Sub Saharan Africa yet falls short of the international benchmarks (World Economic Forum, 2013). The government provides over 80% of road infrastructure (Goyol and Pathirage, 2017) and each tier, federal, state, and local governments, assume responsibility for roads under its administration. More than 65% of Nigerian roads are classified as local government roads, 16% as state roads, and 17% as federal roads out of which 70% are in a deplorable state making them vulnerable to threats such as floods**.** Despite the fact that the local government owns a wider coverage of road infrastructures, Emmanuel and Olamigoke (2013) point to poor investment in road infrastructure as the major cause of poor road conditions in Nigeria. It is worth taking note that over 90% of passenger and freight movement, particularly agricultural freight, in Nigeria is by road, moving food crops from agrarian communities to markets, processing points and urban centers. A typical agrarian community is characterized by poor road infrastructure among others (Yunusa, 2008), which are more often unpaved feeder roads with laterite surfaces and poor drainages. Similarly, Porter (2014) observed that only about 30% of rural roads are all season roads thereby affecting agricultural production and rural livelihoods.

Geographical variation of risk and consequence of infrastructure failure

Nigeria, a developing country located in the tropical region falls within the Inter-Tropical Convergent zone (ITCZ), which has 2 seasons (dry and wet season). Due to its location and seasonal variation, the country experiences both droughts and floods prevalent in the northern and coastal south respectively, although seasonal floods are also experienced in the hinterland because of the two major rivers (Niger and Benue rivers) passing through the country. Desertification and deforestation are shifting the desert towards the central part of the country furthering the wide variation in temperature and rainfall distribution across the country. Plateau state, located towards the central part of Nigeria comprises of a highland (referred to a hydrological centre as most rivers in northern Nigerian get their source), and the surrounding lowland. A major tributary of the river Benue passes along the southern lowland, therefore the area experiences periodic floods. Just like other parts of Nigeria, experiences of recent years show notable changes in weather conditions resulting in new records of climate driven floods and its impacts on agrarian infrastructure systems. Although road systems play significant roles in developing sustainable agrarian livelihoods, the probability of a climate related impacts of climate events and the consequences thereof may vary geographically.

Nigeria has experienced disturbances of climate related events, such as increasing occurrence of heavy rain and consequent floods, a rise in average temperatures and changing rainfall patterns, leading to water shortages and the spread of plant epidemics. The impacts of climate change and related hazard events range from the damage and/ or disruption of agrarian infrastructure systems including transport systems and irrigation facilities, among others (Goyol and Pathirage, 2017). These already have significant implications for economic growth in developing countries such as Nigeria, where road infrastructure is the major form of agricultural freight and where future climate change is expected to hit hard (Künzel et al., 2017). Five (5) major climate related events are predominant in Nigeria: Floods, drought, epidemics (often triggered by temperature and rainfall variability), storms and extreme temperature. Floods and droughts have more devastating impacts in terms of the overall consequences on the economy and floods are particularly found to have significant effects on road infrastructure systems (Goyol and Pathirage, 2017).

Methodology

This paper utilises a comparative methodology to assess how climate risks and infrastructure criticality may vary across regions. The impacts of the five major climate related events identified (floods, droughts, rainfall variability, extreme temperature and storm) were assessed. The questionnaire surveyed respondents' opinion of the impacts of the identified risks on road infrastructure.

Area description and study design

Accordingly, this study adopts a multiple case study design where three (3) agrarian communities, Shendam, Riyom, and Mangu in Plateau State of Nigeria (Fig 1) are purposively selected to assess the risk of agrarian losses due to road infrastructure failure/ disruption. The selection criteria focused on issues of varied geo-political regions, high impact level areas, accessibility and levels of infrastructural development. Plateau state has three geo-political zones (north, central and southern zones) and these formed the natural stratum for the selection.

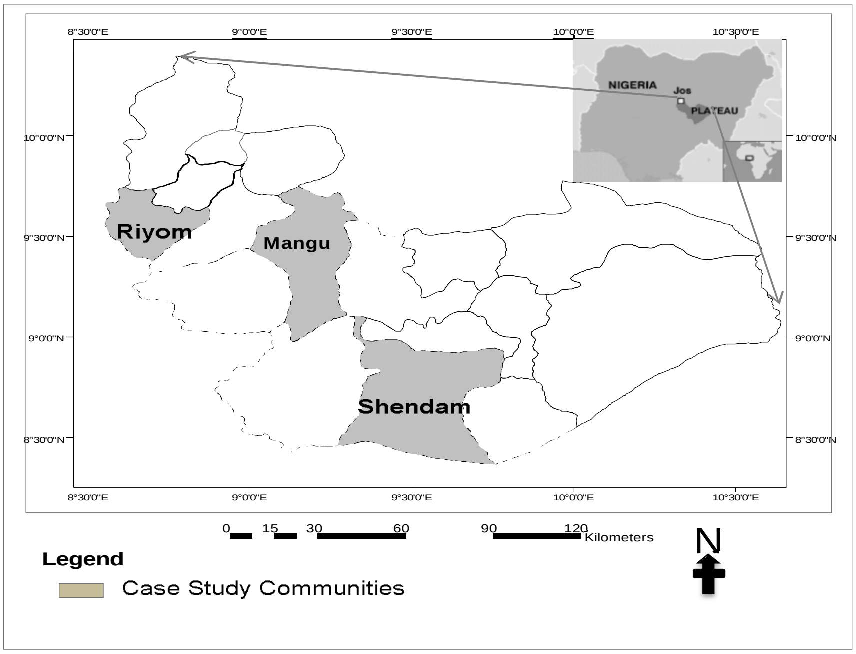


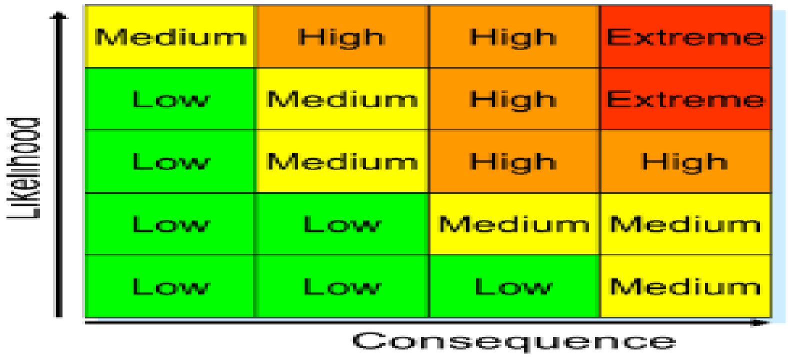
Figure 1: Case Study Communities

Data Collection Methods

The study adopted a mixed-method approach where both qualitative and quantitative data were elicited from a target population. This paper adopts a methodology to assess the criticality of agrarian infrastructure systems and the risk of agrarian losses, both infrastructure managers and infrastructure users were recruited in a survey. Data collected through a survey questionnaire with 229 infrastructure users elicited information on climate risk events, likelihood of infrastructure failure/ disruption and the consequences of failure/ disruption on agrarian livelihood activities. Alongside quantitative data, explorative interviews with 22 infrastructure managers provided in-depth information on extent of road damage/disruption, road asset management capacity and the institutional adaptation and resilience capacity. In considering that climate risk is a function of the likelihood against the consequences of a climate event, quantitative information on the likelihood and impact of perceived climate risks were collected on a scale of 5 ranging from 5 for extreme impact to 1 for No impact.

Data Analysis

Content analysis was employed using NVivo software (version 11) to systematically quantify and analyse responses of transcribed qualitative data based on coded themes while SPSS (version 24) utilized for both descriptive and inferential statistics to analyse the quantitative data obtained from the questionnaire survey. Assaf and Al-Hejji (2006) suggested the use of importance index to categorise the frequency and impacts of climate risk of the 5 point ordinal scale. Therefore, a weighting for the frequency scale was given to each response ranging from 1 for never to 5 for always. So also, weighting for the impact scale given to each response ranging from 1 for no impact to 5 for high impact. Therefore the climate risk matrix is used to present the climate risk scale (refer to Figure 2. Note: No impact is usually not represented as a threat on the impact scale).



Medium	High	High	Extreme
Low	Medium	High	Extreme
Low	Medium	High	High
Low	Low	Medium	Medium
Low	Low	Low	Medium

Figure 2: Climate Risk Matrix

Furthermore, the study utilises the Kruskal Wallis statistical test for significant differences to determine geographical variation in climate risk levels, infrastructure criticality, consequences of infrastructure failure/disruption.

Equation 1 was used for the statistical test for geographical variation in agrarian losses Kruskal Wallis (H) test for significant differences across locations.

$$\mathbf{H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_1} - 3(N+1)}$$

……………. Equation 1

Where R= sum of ranks in each group, N= total sample size, n_i = sample size of a particular group. The significance level is .05.

Findings and Discussion

Road Infrastructure failure/ Disruption its Criticality and Vulnerability

The results of the analysis reveal that the impacts of Irregular Rains and Floods on Road Infrastructure due to changing rainfall patterns and consequent floods have impacts on all categories of road infrastructure irrespective of their location and distribution. Heavier rain is becoming frequent and floods are sometimes experienced along water bodies in case studies 1 and 2 (Riyom and Mangu). Respondents, however, consider the impacts of these floods as minimal, as they are occasional and last only for a short period of time. Although floods are considered to cause less damage here, most respondents explained that due to the poor nature of roads, heavy rain washes off road surfaces, erodes portions of the roads, and causes water logging on laterite roads. This makes them unfit for driving on (common at the peak of the rain), weakens paved roads, expands cracks to potholes, erodes drain lines, overflows river banks, and submerges low bridges, and after the water level subsides, sand deposits are left on roads and drains become blocked.

Floods of various magnitudes have been recorded in the last decade; however, the year 2012 was particularly devastating, as during that year, the floods caused serious damage with greater impact at the lowland areas in case study 3: Shendam. Floods are becoming more frequent, experienced almost annually in the southern part of Plateau State. The impacts of floods in case study 3 include: damage to road surfaces, destruction of bridges, pillars, retaining walls, embankments, washout of culverts and drains, as well as rivers overflowing their banks and bridges becoming submerged. A summary of these impacts in case study communities is presented in Table 1.

Table 1: Impacts of Climate driven hazards on Roads in Case Study Communities

Case Study Communities	**Case Study 1 (Shendam)**	**Case Study 2 (Riyom)**	**Case Study 3 (Mangu)**
Physical Vulnerability			
Location	Lowland	Upland	Midland
Elevation (approx)	200m(amsl)	1200m (amsl)	1000m (amsl)
Hazard Event	Nature of damage/ failure		
1. Heavier Rains	- High deposits of sand on roads and in drain lines, thereby blocking the free flow of water. -Deterioration of road pavements, expansion of cracks to potholes, and erosion of drain lines	- Deterioration of road surfaces, particularly laterite surfaces. -Water logging causing roads to be unfit to drive on	- Erosion of road pavements. - Water logging causing laterite roads to be unfit to drive on (common at the peak of the rain
2. Floods	- Total washout of bridges and culverts. - Damage to bridge columns, retaining walls, embankments and culverts. - Erosion and / or total cut off of road portions	- Wash off of poor surfaces. -Washout of road surfaces and drainages	- Erosion of road pavements and drain lines. - Bridge submerge in overflowing waters leading to temporary disruption of transport services.

Source: Authors fieldwork, 2018

The collapse of bridges and the total washout of culverts are often the impacts of floods in Shendam. Though floods are occasionally experienced in Mangu and Riyom, heavy downpour with resultant runoff overflow rivers and submerging low bridges thereby temporarily crippling the movement of people, particularly farmers across villages. The intense amount of rain experienced around Riyom washes road surfaces making it difficult for the movement of goods and services. The road system (including carriage ways, bridges, culverts and drains) across the 3 case studies were found to be affected as various levels of damage, as identified by respondents. Most infrastructures were found to be vulnerable to adverse effects, due to their current condition. Participants indicated that more than 80% of the road infrastructure damage, disruption or failure was found to have contributed due to the condition of the infrastructure at the time of the event, thereby exacerbating the impacts.

A related study by Adefila and Bulus (2014) identified and classified infrastructure in Plateau State into advantaged, less advantaged and least advantaged categories. This study went further to assess the distribution and current conditions of infrastructure in selected case study communities. The findings based on key informant interviews are presented in Table 2.

Table 2: Road Infrastructure vulnerability in selected case study communities.

Road Infrastructure Exposure		
a) Availability	Number of Responses	Response Percentage (%)
• Not available	5	24%
• Available	16	76%
- Available but Insufficient	13	62%
- Available but in Poor Condition	6	29%
- Available and in Good Condition	1	5%
b) Condition		
• Laterite	3	14%
• Poorly constructed	7	33%
• Uncompleted	2	10%
• Abandoned	3	14%
• Ageing	2	10%
• No maintenance	4	19%

Source: Authors fieldwork, 2018

Findings on infrastructure availability reveal that 24% of participants indicated unavailability of roads in agrarian communities in the area while 76% indicated that roads were available however in various unfavourable conditions. Respondents who indicated that there are roads in agrarian areas, went further on one hand, to indicate that although there are roads, they are not adequate to promote a meaningful level of development and are in poor condition to support the smooth movement of goods and services representing 62% and 29% respectively. On the other hand, 5% indicated that roads were available and in good condition. In terms of infrastructure condition, respondents, in describing the nature of the roads, characterized them as laterite surfaces, poorly constructed, incomplete or abandoned, that they lacked maintenance and had aging infrastructures. Despite that 5% respondents indicated good condition of roads, they expressed concern that the poor maintenance culture may shorten the lifespan of such good roads. Furthermore, a respondent expressed that what they have as roads cannot be called such but considered as “death traps”. These conditions reveal the vulnerable nature of roads and the level of exposure of such areas to adverse conditions, such as heavy rain and floods. Key informants had a good understanding of the road conditions in the case study area, thus concluding that generally, the nature of the road system (poor surfaces, unpaved laterite roads), age of facility, design and construction methods, and poor management, were identified as the current condition of roads in agrarian communities.

Geographical variation of consequence of infrastructure Damage/ failure

In all 3 case study communities, most farmers are in the affirmative that the damage or failure of the road systems affects various stages of agricultural production ranging from farm operations to the marketing of agricultural products. Table 3 presents a summary of responses.

Table 3: Consequences of Infrastructure Damage/ Failure on Farm Activities

Consequences	Number of Respondents	Percentage (%)
High Cost of Inputs	229	100
Low yield	229	100
Poor Access to Farm & Communities	227	99
Food waste	227	99
Low Returns on Investment	225	98
High Cost of Transportation	223	97
Poor Access to Market & Market Services	219	96
Input waste	216	94
Spread of Plant Epidemics	213	93
Inability to meet Demand	197	86
Shifts in Farm Operations	194	85

Source: Authors fieldwork, 2018

All respondents (100%) indicated that infrastructure damage/failure has an influence on the cost of inputs and crop yield. 99% expressed that it affected accessibility to farms and communities as well as leading to high levels of food waste. 98% indicated it contributed to low returns on investments and 97% said it led to an increase in transportation cost. 96%, 94% and 93% accounted for the effect on access to market and market services, waste of inputs and the spread of plant epidemics respectively. 86% expressed that infrastructure damage/failure affected their ability to meet market demand and 85% indicated that it led to a shift in their cropping calendar and farm operations. In terms of accessibility, infrastructure damage/failure hinders access to farms and communities which made it difficult for farmers to move inputs to farms. Extension workers were also not able to access interior areas to offer advisory services to farmers. Accessing local markets was also a challenge and farmers found difficulty in selling farm products. Farmers who were not able to afford inputs such as fertilizers, herbicides and insecticides due to increased costs, suffered delays in applying them on the farm at the appropriate time affecting the overall yields of crops and contributed to the spread of plant diseases. Due to the time bound nature of crop production, farmers noted that even when they were able to access and apply inputs at a later date they still were not able to get good yields. As such delayed application of inputs was considered a waste of inputs.

In analysing the effects of infrastructure damage/failure on agricultural production, 3 classes of impacts (high, moderate and low) were used to rank the level of the impacts and this is presented in Figure 3.

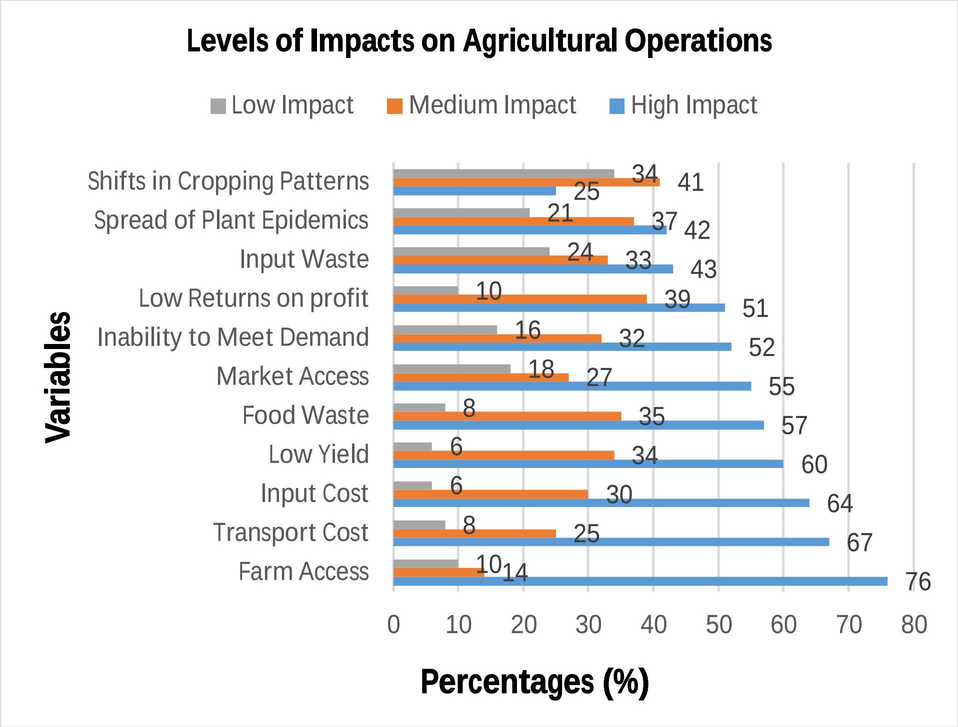


Figure 3: Level of Production Interruptions due of Infrastructure Damage/ Failure

Accessibility was identified as a major problem due to infrastructure damage. Apart from farmers' inability to transport inputs to farms, the loss of transport services for agricultural freight movement is observed to have a high impact as this led to large amounts of food waste due to farmers' inability to transport food crops from interior villages to market. Most road infrastructure damage and failure were found to occur at the peak of the rainy season when farmers have suitable opportunities to make profit on investments. Inability to market farm products at favourable prices affected income levels as farmers recorded low returns on investment. The economic effects of infrastructure damage/ failure were also identified. Farmers noted a general increase in the prices of goods. Farm inputs and agricultural services available were at a higher cost. Costs of both food crops and non-food items were higher. Commercial activities at local markets were said to decline as a result of low patronage, which in turn affected revenue generated from traders and motorists on market days. Also, farming seasons preceding major road infrastructure disruption were affected because farmers lacked the financial capacity for intense cultivation due to losses recorded in the previous season. Farmers with huge losses suffered temporary loss of production and eventually loss of livelihood. This had increased effects on poverty levels, physical and psychological health issues such as stress, anxiety and depression, in some cases leading to loss of life. A list of the effect of infrastructure disruption/ failure on agricultural production, economy and livelihoods is given in Table 4.

The study went further to use the Kruskal Wallis H test to assess if these consequences varied across case study communities and the following hypothesis was tested. Results of the H Test for each variable tested are presented in Table 5

H_O: The consequences of Infrastructure damage/ failure on farm operations are the same across case study communities.

Table 4 Consequences of Infrastructure Disruption

Agricultural operations	Economic Activities	Human Impacts
• Low yield • Waste of food crops • High cost of transportation • High cost of inputs such as fertilizer, and pesticides • Loss of production due to infrastructure damage	• Market instability and Price increase of goods • Low patronage of small-scale industries such as rice mills • Low returns on investments • Disruption of commercial activities due to supply chain disruption • Constraints on rural economy	• Loss of livelihoods • Increased poverty levels • Food Insecurity • Disruption of social activities • Human displacement • Physical and psychological health issues such as stress, anxiety and depression • Loss of human lives

Source: Authors fieldwork, 2018

Table 5: Kruskal Wallis H test for Significant Differences of Infrastructure Damage/Failure on Agricultural Operations between Case study communities.

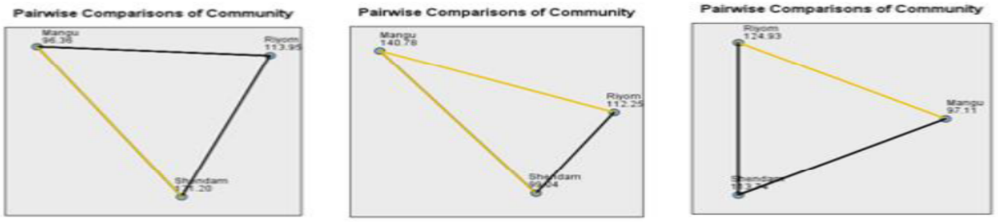
Effects of Infrastructure Damage/ Failure	H test (2)	Asymp. Sig	Decision
Cost of Transportation	18.168	.000*	Reject
Access to Farm & Community	15.106	.001*	Reject
Damage to Crops & Farmlands	8.259	.016*	Reject
Cost of Inputs	4.587	.101	Accept
Inability to meet Demand	4.045	.132	Accept
Low Returns on Investment	1.052	.591	Accept
Low yield	.793	.673	Accept
Spread of Plant Epidemics	.616	.735	Accept
Access to Market & Market Services	.603	.740	Accept
Shifts in Farm Operations	.555	.758	Accept
Waste of Inputs	.300	.861	Accept

The significance level is .05, $H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_1} - 3(N+1)$

Where R= sum of ranks in each group, N= total sample size, n_i = sample size of a particular group

From the results of the H test indicate that there were no significant difference in the effects of infrastructure damage/failure on most factors of agricultural operations across case study communities. The effects on cost of inputs, inability to meet demand, low returns on investment, low yield, spread of plant epidemics, access to market and market services, shifts in farm operations, and waste of inputs did not significantly vary across the three selected study communities. While the effect on transportation cost, access to farms and communities, and damage to crops and farmlands were found to significantly vary across the communities. Although the H test results show a significant variation between categories, it does not provide specific information about which community differs from the other. In order to determine where the difference lies across the 3 case communities, a post hoc pairwise comparison test was performed for each group with a corrected p-value. The results are presented in Figure 4 and Table 6.

a) Mann Whitney u Test for pairwise comparison



b) Box plots for Pairwise comparison

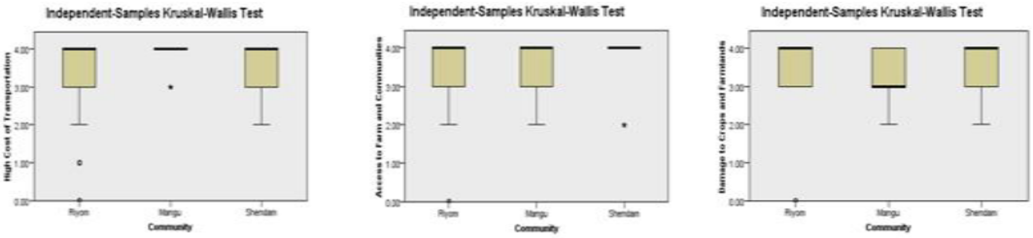


Figure 4: Pairwise Comparison of Effects by location

Table 6: Results of Post hoc Test

Variable	Location	Std Test Statistics	Adj. Sig.
Cost of transport	Mangu-Shendam	-3.875	.000*
Access to farms and communities	Shendam–Mangu	4.204	.000*
	Riyom-Mangu	-3.122	.005*
Damage to crops and farmlands	Mangu-Riyom	2.866	.012*

Adjusted significance value by Bonferroni correction for multiple test (.05/n) =.017

Following the H test results that the effect of infrastructure damage/ failure on transportation cost, access to farms and communities, and damage to farms and crops are significantly different across case study communities, a pairwise comparison with adjusted p value of .017 was carried out using a Mann Whitney U test and the results revealed that:

i) The effect of infrastructure damage/failure on transport cost was found to be significantly varied between Mangu and Shendam (p=0.00. This implies that there is a high variation in transport cost between Mangu and Shendam). The difference between the two communities is that Mangu records higher costs of transporting goods and services.

ii) The effect of infrastructure damage/failure on access to farms and communities was found to be significantly varied between Shendam: Mangu (p=0.00), and Riyom: Mangu (p=0.005). The difference between Shendam and Mangu is that Shendam experiences more floods with extensive damage to road facilities, and as such, causing difficulties in accessing farms and communities. Riyom is categorized under the least advantaged, in terms of road infrastructure, which has fewer road facilities than Mangu and therefore has more difficulties of accessibility.

iii) The effect of infrastructure damage/failure on loss of crops and farmlands was found to be significantly varied between locations Mangu and Riyom (p=0.12).

This analysis shows that three factors, namely effects of infrastructure damage/failure on transport cost, access to farms and communities and loss of crops and farmlands, record varied experiences across the three locations due to inherent characteristics in the communities.

Policy Implications of the Study

The findings of this study reveal that there are policy implications for agrarian road infrastructure development in order to ensure sustainable agricultural production and trade. These include:

- Considering the inclusion of climate change into the planning and design of road systems to guard against the collapse of the economy.
- Agrarian road development should be given priority in budgetary allocations in order to sustain the supply of inputs for improved productivity and supply chain agricultural products.
- Policies should be directed towards agrarian road investments to ease agricultural freight and policies to ensure that projects are fully implemented.
- Policies should consider agrarian road development as a means of reducing food waste.
- Provision of resilient road infrastructures to enhance communities' capacity for adaptation to current climate variability and future climate change.

Conclusion and Recommendations

Climate change impacts on transport infrastructure affecting agricultural production, both directly and indirectly, with consequences on livelihoods and economic development. Two major climate related hazards: heavy rain and floods, were identified to affect road transport infrastructure the most. The direct impacts include: damage to road surfaces and drain lines, destruction of bridges, pillars, retaining walls, and embankments, washout of culverts, as well as rivers overflowing their banks and bridges being submerged, water logging of laterite roads making them unfit to drive on (common at the peak of the rains), weakening of paved roads, expansion of cracks to potholes, sand deposits on roads and blockage of drains. The damage/ failure of infrastructure due to impacts from the climate related events lead to other secondary impacts, also referred to as cascading effects on agricultural production, as well as human and economic activities. The effects of infrastructure damage/ failure on agricultural operations affected transportation cost, access to farms and communities and damage to crops and farmlands, cost of inputs, ability to meet demand, returns on investment, yields, spread of plant epidemics, access to market and market services, continuous production, and led to waste of inputs. The study provided a list of effects on agricultural operations, as well as economic and human activities, however further analysis was only done on agricultural operations where the findings revealed variations across the three selected case study communities. There is, therefore, the need for further analysis of effects on economic and human activities.

Recommendations

This study has demonstrated that road infrastructure disruption/ failure as a result of climate change can lead to a sequence of negative events with significant effects on agricultural production and trade, as well as food security. Managing current and future climate change impacts on road transport infrastructure will safeguard efforts towards sustainable economic development and therefore a need for further research on the policy implications of such impacts is necessary.

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