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Effect of Boko Haram Insurgency on Irrigation Activities Using Field and Earth Observation Data in Part of Northeastern Nigeria

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Abstract

The Boko Haram Insurgency in Nigeria has affected the socio-economic activities in most parts of the northeastern part of the country, leading to a low supply of food from agricultural output and increased poverty. Therefore, the main objective of this paper is to analyse the effect of the Boko Haram insurgency on irrigation activities in Kukuwa village. Data was sourced for interviews of 240 respondents and Landsat8_OLI for 2014 and Sentinel 2 for 2015 to 2019. The images were converted to NDVI and used to determine the spectral signatures for each crop using Spectral Matching Techniques (SMTs). The result indicated the majority of the farmers irrigated their farms as > 2 ha (69%) before the crisis, 2 ha (87%) during the crises and > 2 ha (62%) after the crisis, and the majority hired farmers for labour. The intensity of the irrigation was reduced during the crises and it increased after the crises. The result of the SMTs in 2014 indicated a high spectral signature for irrigation activities, with 227.07ha (29.6%) for tomatoes. In 2015 and 2016, low spectral signatures for crops were observed for 541.69ha (69.80%) and 519.5ha (66.94%), respectively. While the spectral result in 2017, 2018, and 2019 indicates a good appreciation of irrigation activities, which shows an increase in most of the dominant crops cultivated in the area, such as tomato, onion, watermelon, and pepper. Among the breakthroughs of this paper is the analysing the reflected signatures from the classified image for different crops through irrigation activities during and after the insurgency in the area. The accuracy assessment indicated fairly good with Landsat but very good with the sentinel images. The study suggests further research into the effe

1. Introduction

The emergence of insurgency in Northern Nigeria began in 2009, when an Islamic sect known as Boko Haram became violent. Previously, the group created in 2002 had conducted its operations in a conflict-free way, with the goal of advocating the creation of an Islamic state under Sharia law (Babagana et al, 2018; VanCreveld, 1996). Amongst the Northeastern states, the hotspot states are Adamawa, Borno, Yobe and part of the sub-Saharan Africa (Christopher, 2016; James, 2018; Jacob, 2021; Stig, 2022). The Boko Haram insurgency erupted in 2015, with around 7,711 people killed and several towns and villages taken seized by the group (ACAPS, 2014; Jacob, 2020). Almost 1.9 million people have been displaced, and over 4.8 million are facing a food security catastrophe (ACAPS, 2015; Olayinka, 2018).

The concept of insurgency has been shown as a forcible effort by an individual or group of people to resist or oppose the execution of law or the operation of government, to revolt in defiance of the state's constituted authority, or to participate in insurrection (Powell and Abraham, 2006). According to the definition of insurgency, it is a disruption of a nation's constitutional criminal law and international agreement responsibilities in the following circumstances, for example, as they attack unprotected citizens and their properties, resulting in injuries, deaths, and forced or massive internal displacement of people from their habitual places of residence (Imasuen, 2015). Different authors defined it differently like, Kilcullen (2006), insurgency is a strategy for a state or group of individuals in authority to struggle for control of a contested political area, depending on the political, economic, ideological, or religious aims. This idea distinguishes between traditional and modern insurgencies, emphasizing that the latter aspire to replace the established system. While this has many implications particularly when looking at the nature of our country Nigeria. Omilusi (2016), lamented on implications of insurgency in Nigeria which includes national insecurity, economic ramifications, infrastructure failure, and humanitarian issues. The main issues with food security have been the high cost of food and its scarcity since the commencement of the insurgency. Market instability, farmers' inability to produce, and the high cost of transportation to disadvantaged areas are just a few of the factors driving up food prices. High transportation costs to affected areas, farmers' inability to expand, and unstable markets are only a few of the factors driving up food prices and limiting availability. Because of the insurgency's influence, there have been casualties and property losses as a consequence of frequent bombings and other actions that have interrupted most socioeconomic activities in the region and had a negative effect on agricultural production because farmers seldom travel to the farm (Henry, 2017). Even though, among the aforementioned problems, different factors such as desertification, degradation and climate change induce conflict in most of the tough dryland regions that resulted in an increase in human displacement (Nsemba).*et al.,* 2021).

The concept of "terrorism" has been safety perceives, from different local, country to worldwide. The time period of terrorism has been applied in the course of the French Revolution within the late 18th century and benefit wide interest across the world (Stevenson, 2010). Various state and international organisation just like the UN, EU, United Kingdom, among others, described terrorism using different approaches. Consequently, for the motive of this paper, we conceptualized terrorism as intentional violence to cause death or severe frame damage, the taking of hostages to intimidate a people, or initiating the government and its security system or international businesses (Halibozek, et al., 2008). While food security is the degree of an individual's capacity to get access to foods that are nutritious and sufficient in quantity, some definitions of food safety specify that meals should additionally meet an individual's food possibilities and nutritional desires for energetic and wholesome lifestyles. Food safety has been described in special, complementary ways. The World Bank described food safety as a situation in which anyone has access to enough food to stay healthy and effective (World Bank, 1986). FAO (1983) has proven that the idea of safe food consists of making sure that every person always has physical and financial access to the simple meals that they need. One of the simple sources of food is agriculture, and it has been indicated that the majority of the people dwelling within the northeastern part of Nigeria are farmers.

Farming was discovered to be the most important activity in the area, and most farmers were terrified of being trapped on their way to their farms. Fear of being caught caused many farmers to avoid visiting remote farms and to limit their travels to nearby ones. Even if farmers are still able to produce, they confront challenges transporting their crop to towns and cities where it is in demand because insurgents have damaged transportation infrastructure, and cars driving on isolated routes risk being targeted. The prohibition on motorbikes, which were a mode of mobility for these rural residents, has made it difficult for their farm goods to reach markets (Iliyasu et al., 2015). Other activities, such as small businesses, marketplaces, schools, and other sources of revenue, have been severely impacted (Kah, 2017). The aforementioned challenges resulted in poor agricultural output due to the good climate and soil, and FAO (2016) indicated that more than 80 percent of the rural population in the area is dependent on agriculture and livestock and reduced labour supply, limiting access to land and other inputs, and causing different social and economic support systems to fail.

Analyzing the impact of the Boko Haram insurgency on agricultural operations utilizing modern technology such as remote sensing might provide a new perspective on most of the evaluations that have previously been provided without taking into account much time and space. Furthermore, the combination of field and remotely sensed data for insurgency detection can be one of the novelty research that can bring together (both datasets) and can be applied for identifying cropping activities, especially today when it has been indicated that the rate of soil quality is low due to poor management, which can result in food insecurity. Remote sensing data can help with the validation and understanding of cropping information's geographical and temporal distribution at the smallholder level. This highlights the need of investigating the impact of insurgency on agricultural activity in the region, despite the fact that cropping information should be provided by the National Bureau of Statistics (NBS). However, the data utilized is too coarse due to the nature of data collection and the type of sampling employed during data collection from chosen communities, some of which are inaccessible due to fear of being abducted or killed by insurgents. Furthermore, there is a lack of precision in areal coverage, which means it cannot provide exact geographical information on what crops are grown where. Also, other

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reports indicated that there are incorrect disseminations of information to the public pertaining to the Boko Haram insurgency, which triggers a lot of problems that could be used in explaining the nature of the insurgency and, on the other hand, problems within the security systems (Fox, 2020, and Daniel, 2020).

Several empirical studies have been conducted in Northeastern Nigeria, primarily on the effect of the insurgency on food insecurity (Babagana et al., 2018; Iliyasu et al., 2015; Awortu, 2015), which have been indicated to have hindered the flow of grains, which was 294,940 tons and lowered to 94,500 tons, which has been shown to have a significant effect on the value chain in agriculture in the region (Mohammed and Ahmed, 2015). Some research concentrate on socioeconomic and food security issues (Awodola and Oboshi, 2015; Oladayo, 2014; Ogochukwu, 2013; Odita and Akan, 2014; Adelaja and George, 2019; Adelaja *et al.,* 2019), and vulnerability to conflict (Martin Shields and Stojetz, 2019; George *et al*., 2020). Therefore, these studies have demonstrated practically how insurgency has altered the socioeconomic activity of the local residents.

In Nigeria, research of effect of insurgency on farming activities using GIS and remote sensing approach is scarce. Ibrahim et al., (2021) attempted to use Sentinel-2 to determine crop type for smallholder farmers in Nigeria. The outcome demonstrates an exceptional output on the problem of mixed cropping that occurred in the majority of smallholder farms. However, the study was unable to examine the impact on insurgency. While Deborah *et al.,* (2020) demonstrated the impact of insurgency on settlement and agricultural land using remotely sensed data (Landsat) which indicated a drastic change on a direct effect of both landuses. From the findings, the method of classification happened to be too general and coarse data meaning no specific crop classification on the changes.

Nevertheless, many more studies are being undertaken outside of Nigeria utilizing alternative methodologies, such as crop production on smallholder farmers (Sweeney et al., 2015; Defourny, 2019; Karlson et al., 2020; Gumma *et al.,* 2020; Nasirzadehdizaji, *et al.,* 2019; Chen et al., 2019) and the use of MODIS crop area estimation (Gumma *et al.,* 2011; Gumma *et al.,* 2014; Gumma *et al.,* 2015). Yulin et al. (2020) used SRTM and sentinel images to mask mountainous regions. While Song et al., (2021) combine Landsat, Sentinel, and MODIS sensors for crop mapping. Other research on mapping fallow fields and object-based temporal dynamics. (Belgiu and Csillik, 2018; Deji et al., 2022), yield estimations and large-scale farming (Kristof et al., 2018; Merryn et al., 2019), crop and tree categorization (Markus *et al.,* 2016), crop disease mapping (Yanru et al., 2020). On the other hand, other findings detected the activities of Islamic State in Syria and Iraq (ISIS) which has shown method of income generated from the agricultural sector. Hadi and Eckar (2016) used remote sensing using MODIS Terra Satellite and Landsat technology in the detection of crops grown in 2014 and 2015 by the ISIS for their income generation, which has not been put into consideration. Furthermore, Jaafar (2018) studied the effect of conflict on rural dwellers and crop production in Syria using GIS and remote sensing data. The study has shown a promising result that indicates it can be applied for forecasting and crop modeling.

Most of the aforementioned studies concentrated on crop area estimation and yield, without looking at how it affects insurgency. While other authors looked at the socio-economic impact of the insurgency. Therefore, the novelty of this study is the combined approach that has been applied using the remote sensing technology (Earth Observatory) and field data to capture individual farmlands (10-meter resolution) for different years in the determination of the effect of Boko Haram using the spectral signatures of different cropping systems in the irrigated area. Therefore, this study has been one of the most groundbreaking in the areas of effect of insurgency on agriculture studies.

Therefore, the main objectives of this study are to;

- Investigate the impact of the Boko Haram insurgency on changes in farmland size and labour intensity.
- Analyse the spatio-temporal distribution of irrigated crops using Sentinel Image

2. Materials and Method

2.1 Study Area

The study was conducted in Kukuwa Tasha, Gujba Local Government Area of Yobe State. The area lies Between Latitude 11°50'11"E and 11°52'39"E and Longitude 11°8'37"N to 11°9'36"N. This area has been one of the important agricultural areas in the state that is into irrigation activities. Different varieties of crops are cultivated, especially during irrigation due to the distribution of tributaries of streams and rivers within the topography of 450 to 480 meters above sea level, and the hottest months are March, April and May, with temperatures ranging from 39°C to 42°C and rainfall within 500mm-1000m. The climate within the Sahel in the north and the Sudan Savannah in the south has been severely under threat of desert encroachment, thereby creating arid and semi-arid conditions (Ali, Brian, Richard, and Peter, 2014). Crops produced in the area, particularly on the irrigated farms, are tomatoes, onions, peppers, watermelon, and other vegetable crops such as cucumbers, cabbage, and lettuce.

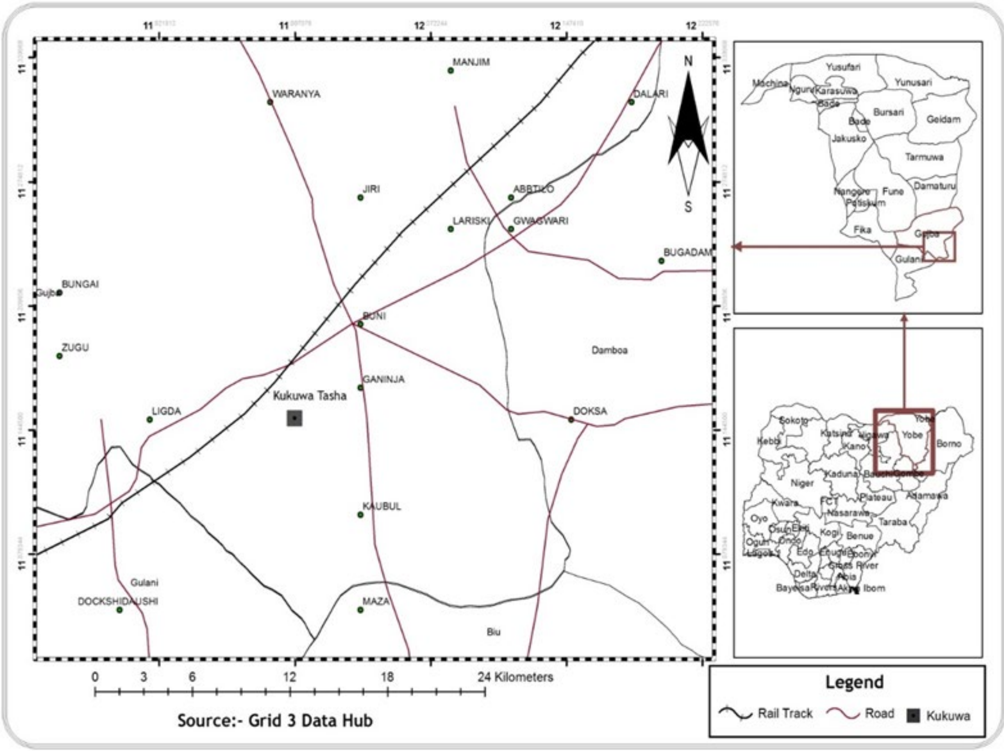

Fig. 1 *Study area*

2.2 Sources of Data

The reconnaissance survey was carried out so as to be able to provide insight on how to organize the actual field work, and in so doing, the nature of the farmlands and type of crops with the help of Google Earth images and a field checklist (as summarized in Figure 2). These include various research tools and instruments, such as Sentinel and Landsat images were used. A Global Positioning System (GPS) (Garmin) was used for the sampling data collection.

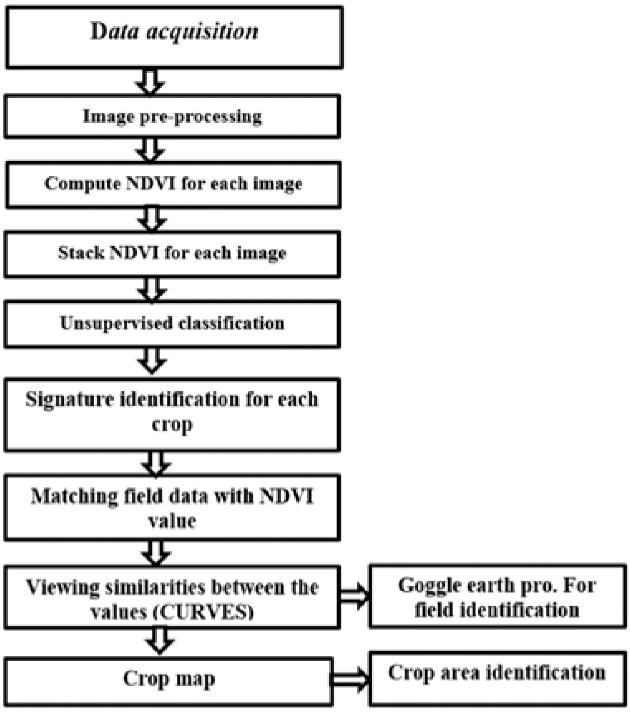

Fig. 2 *Summary of methodology*

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2.3 Interview and Field Observation

240 sampling points were used for data collection on cropping and out of 100 were selected for crop mapping validation (Figure 3). At the same time, farmers were interviewed on the sampled farms using a checklist for the face-to-face survey and field observation. The interview was conducted randomly within the irrigated areas of Kukuwa village.

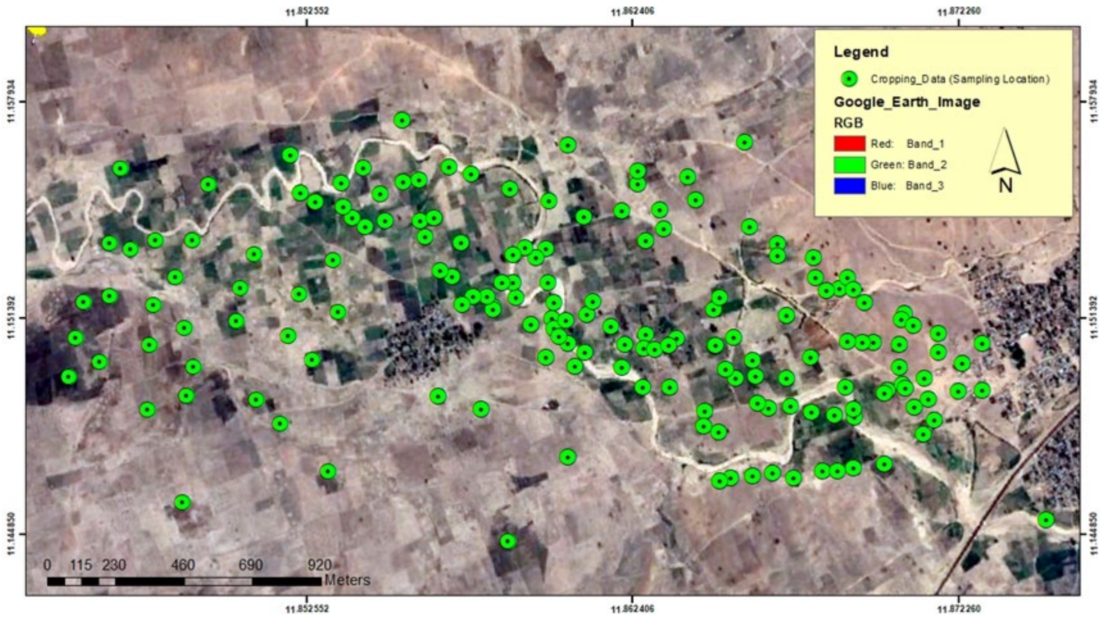

Fig. 3 *Sampling locations*

2.4 Satellite Data Pre-processing

Satellite data consists of multi-spectral images of the Earth's surface collected by satellites at different time periods and with different resolutions. Sentinel 2 (10 meter) and Landsat 8 (30 meters) were used for the purpose of this study and were downloaded from http://glovis.usgs.gov/. The Landsat was used for 2014 due to the fact that a sentinel was not available in that year (Table 1). The Sentinel-2A satellite was launched on June 23, 2015, as part of the European Copernicus program (ESA, 2016). It carries an innovative wide-swath, high-resolution, multispectral imager (MSI) with 13 spectral bands as shown in Table 2.

Table 1 *The description of Landsat8_OLI bands*

Band name	Bandwidth (µm)	Resolution (m)	Date
Band 2 Blue	0.45-0.52	30	2014
Band 3 Green	0.53-0.60	30	2014
Band 4 Red	0.63-0.68	30	2014
Band 5 NIR	0.85-0.89	30	2014
Band 6 SWIR1	1.56-1.66	30	2014
Band 7 SWIR2	2.10-2.30	30	2014
Band 8 Pan	0.50-0.68	15	2014

Table 2 *The description of sentinel 2 bands*

Sentinel 2 bands	Central wavelength (μm)	Resolution (m)	Date
Band 2 Blue	0.490	10	2015-2019
Band 3 Green	0.560	10	2015-2019
Band 4 Red	0.665	10	2015-2019
Band 8 NIR	0.842	10	2015-2019
Band 10 SWIR... Cirrus	1.375	60	2015-2019
Band 11 SWIR	1.610	20	2015-2019
Band 12 SWIR	2.190	20	2015-2019

2.5 Calculation of NDVI

Information pertaining to the cropping type for 2014 to 2019 was collected using a check list which included coordinates (latitudes/longitudes), crop type, and year on the sampled farms. From a Google Earthpro, a high resolution image was used for checking and rectification during the data collection. During the data extraction, attempts were made in order to compare the reflectance of the signatures using the Spectral Matching Techniques (SMTs) (as in Gumma *et al.,* 2016a and Gumma *et al.,* 2016b). The extracted cropping types were analyzed in Microsoft Excel by comparing different reflectance signatures to show the variations among the crops in the area, as an example shown in figure 4.

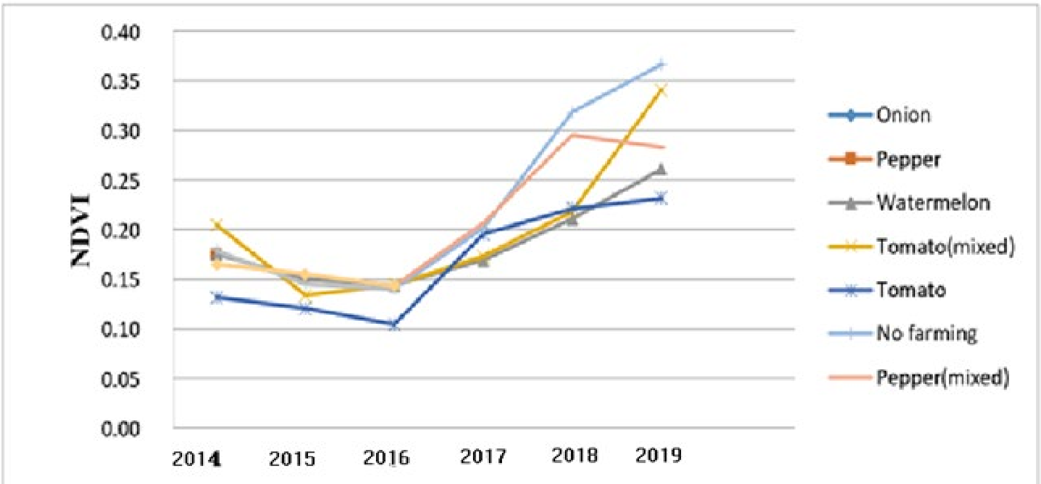

Fig.4 *Example of spectral matching technique (SMTs)*

The NDVI is based on the relative reflectance values in the red (Red) and near infrared (NIR) wavelengths: NDVI = (NIR-/Red) / (NIR+/Red). Vegetation indices are commonly used to reduce effects of atmospheric conditions or different soil backgrounds on spectral reflectance values.

For Landsat the formula for NDVI calculation is

$$NDVI= \frac{Band\ 4 - Band\ 5}{Band\ 4 + Band\ 5} \quad - \quad - \quad - \quad - \quad - \qquad (1)$$

For Landsat the formula for NDVI calculation is

$$NDVI=\frac{Band\ 4 - Band\ 5}{Band\ 4 + Band\ 5} \quad - \quad - \quad - \quad - \quad - \qquad (2)$$

For each Landsat8_OLI image, we calculated the NDVI, then clipped data to a common geographic range and assembled 2 phases of data into a time series stack. The NDVI temporal profiles of major cropping types were identified, which are majorly irrigated crops (tomato, onion, pepper, shrub land, uncultivated, irrigation/rainfed) and watermelons).

3. Accuracy Assessment

The accuracy assessment has been shown in table 3 using the overall accuracy and producers' accuracy obtained from equations iii and iv. Then these were used in the determination of the commission and omission of each crop type in the analysis so that the strength of the result could be shown to also give the quality of the individual classes.

The user's accuracy indicated the probability of a pixel interpreted on the image representing the actual category on the ground as calculated in equation iii.

$$\text{Users Accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{total number of classified pixel in that category (the row total)}} X\ 100 \qquad (3)$$

The producer's accuracy indicated the probability of a pixel that is correctly interpreted on the image as calculated in equation iv. (Anand, 2017).

$$Producer\ Accuracy = \frac{\text{Number of correctly classified pixel in each category}}{\text{total number of refrence pixel in that category (the column total)}} X\ 100 \qquad (4)$$

Table 3 *Interpretation for statistics accuracy*

Accuracy	Agreement
<20	Poor
21 - 40	Fair
41 - 60	Moderate
61 - 80	Good
81 - 100	Very Good

4. Result and Discussion

4.1 Changes in Farm Sizes and Farm Labour Intensity

4.2 Primary Occupations of the Respondents

The result has shown that about 61% of the respondents have farming as their primary occupation, while 20% are fishermen, 5% are civil servants, and 7% of the respondents are traders and other businesses, as shown in Figure 5. Which is in line with Ogunmefun and Achike (2015), who showed that the majority of the people living in the rural areas of the northwestern part of the country are farmers who are mostly engaged in farming activities in both the dry and rainy seasons. From the field information, it has been shown that people troop from various villages to participate in the harvesting, cutting, and drying of different perishable crops such as tomatoes, which usually fetch them money, and this contributes to the value chain. The processing of the irrigated crops has normally been done during the dry season. Young girls and boys participate in most of the processing activities as shown in Plate 1A, indicating women and children participating in tomatoes picking, while Plate 1B, showing the children employed for cutting and drying of tomatoes. Plate 1C, showing a young man employed for watering the tomatoes farm and Plate 1D, and showing children and women participating in selection, sorting and packaging of tomatoes. This finding is in line with the findings of Chukwuma and Stephen (2019) and James and Rosemary (2019) that the majority of the vulnerable people during the insurgency were women and children. They are mostly kidnapped and used as tools during the attack, particularly as informants or suicide bombers.

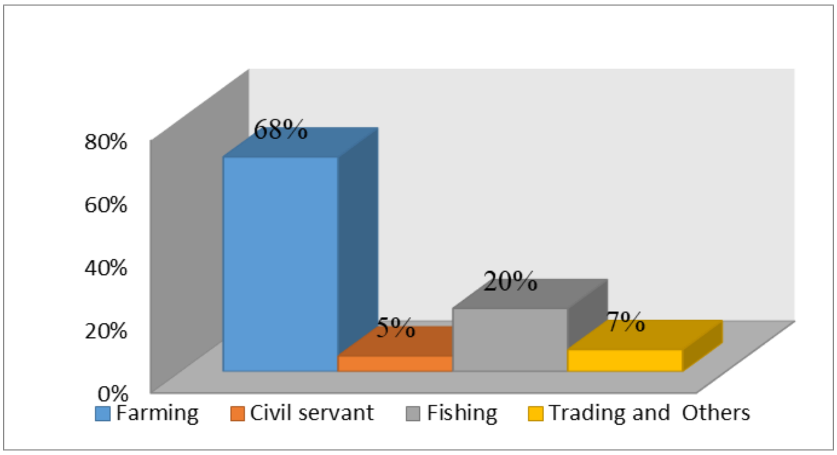

Fig.5 *Occupation of the respondents*

(a) (b)

(c) (d)

Plate 1 *Showing some activities in the farm (a) Harvesting; (b) Drying; (c) Watering; (d) Selection and packaging*

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4.2.1 Changes in Farmland for Irrigation Activities

Due to the insurgency in 2015, large areas of farmland were destroyed. Others, including markets and small shops, were burnt down. As such, people migrated to less affected areas while at the same time curfews were imposed for days, which contributed to the restrictions of farming, business activities, and the closing of markets. As a result, farm sizes decreased, as shown in Figure 6, particularly during irrigation (or dry season) periods when not everyone went to farm. However, it shows that before the crisis, farmers cultivated more land than during the crisis. Of course, they are not expected to go to the farms unless those farms are closer to their houses and the surrounding settlements. According to the National Bureau of Statistics (2009), marginal farms are less than a hectare, small farms are between 1-2ha, semi-medium farms are between 2-4ha, medium farms are between 4-10ha, and large farms are above 10ha. At this period, according to Alkali (2018), the insurgents are getting more sophisticated, thereby overpowering the security personnel in most of the strategic locations and reducing the socioeconomic activities, including farming activities.

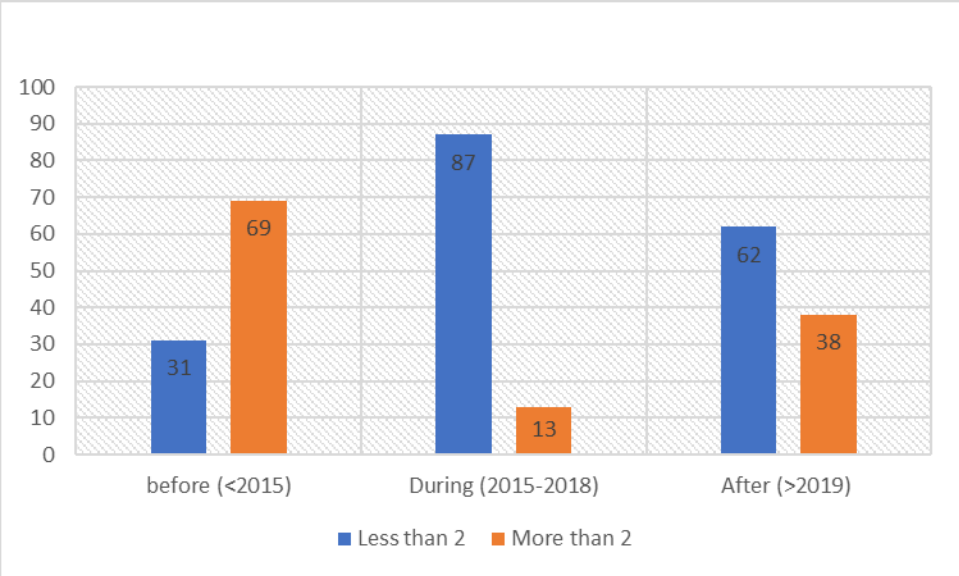


Fig. 6 *Changes in farm sizes as the result of the crises*

Using this as a yardstick, marginal lands were not cultivated by the dwellers. Specifically, based on the analysis, it indicated about 90% of the respondents had their farm sizes of > 2 ha (69%) before the crisis, 2 ha (87%) during the crisis and > 2 ha (62%) after the crisis. This means that the respondents were predominantly small and medium-scale farmers. Even though farm sizes differ by location, like in part of the country, Nwaiwu (2015) showed that the majority (74.9%) of the farmers have farm sizes of 1 ha. The implication of this finding shows a significant drop in food supply, which affected the other activities such as the people that participated in the harvesting, cutting, and drying. Other businesses that have been affected include packaging, marketing (both retail and wholesale), and transportation which generally affect the value chain. Business connections were seriously affected during the insurgency, such as the supply of chemical fertilizers, gasoline for generators, and seed. The agro-dealers, retailers, grain buyers, and transporters have been seriously affected. All business activities were reduced because it is difficult to supply, thereby increasing demand for food due to low supply. Mwangi *et al.* (2014) reaffirmed that during the insurgency there is low human mobility, which cuts off the food supply chain, and the herders fear attack for rearing their animals in the field during grazing, which reduces access to the market and makes the food commodity more expensive.

4.2.2 Sources of Labor on Irrigation Activities

Figure 7 indicates that the majority (67%) indicated they hired for labor before the crisis. On the other hand, during the crisis, the majority (71%) indicated they own the farm themselves, while the majority of farmers (59%) indicated they do their labour themselves after the crisis.

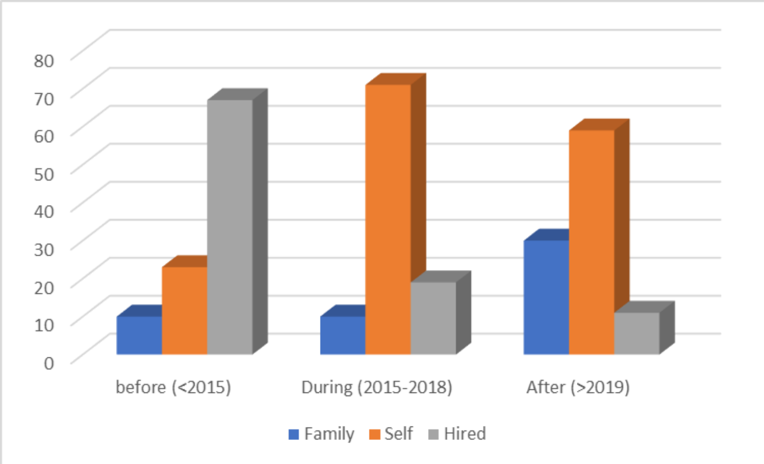


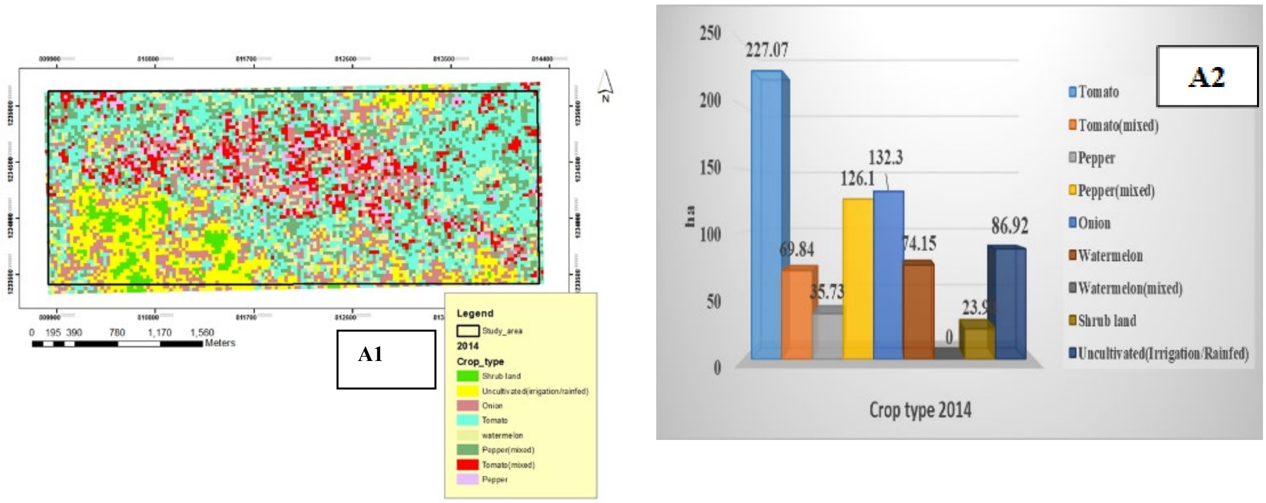
Fig. 7 *Sources of labor*

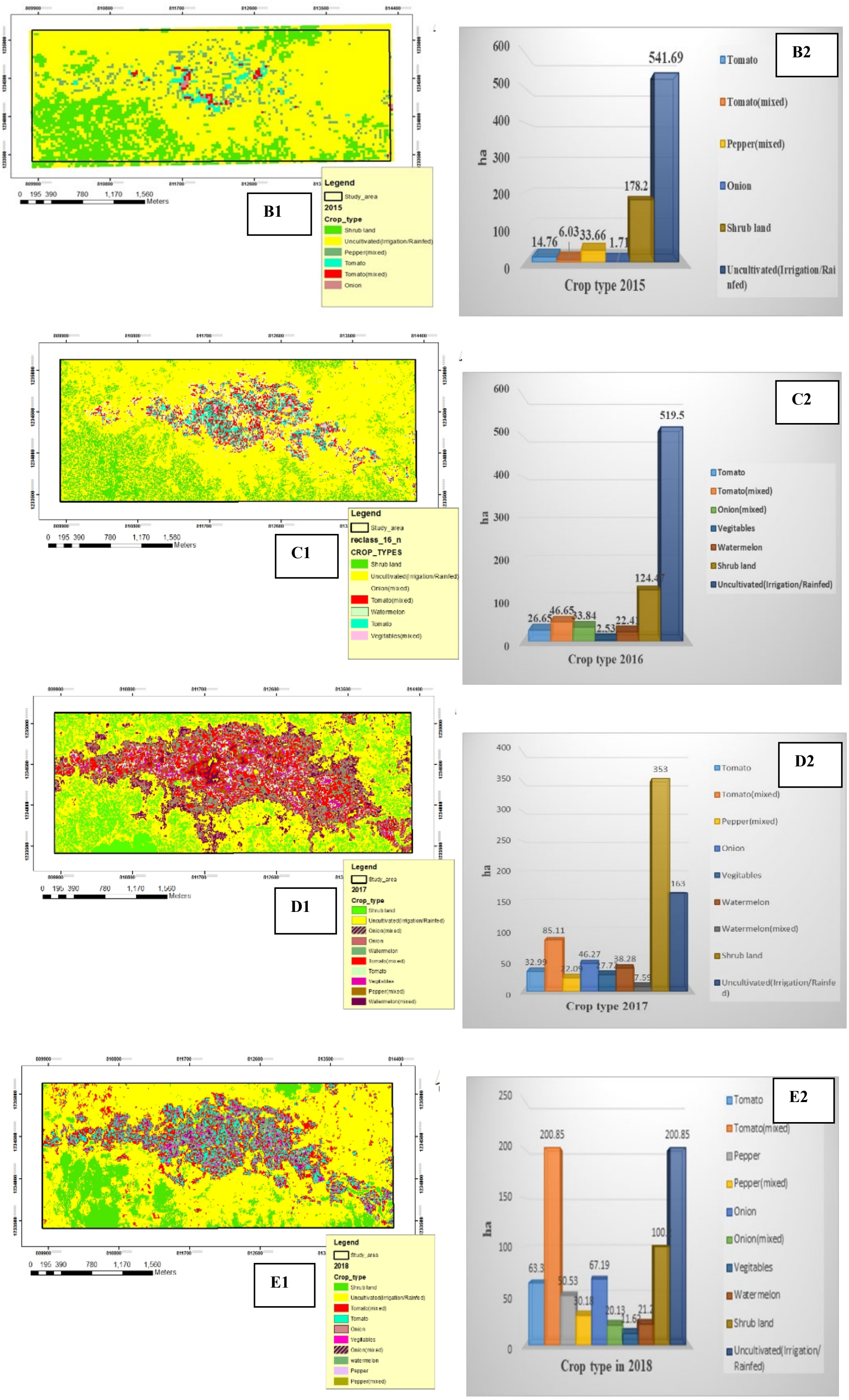
This implies a low farm input because there is less farming activity unless there is farmland that is closer to the house or within the surrounding settlements. If the farming input is low, the productivity will also be low, and the resultant will be fewer farming activities, which has directly affected cropping activities during the crisis. However, the reduction in human mobility has directly affected production during the insurgency. Sometimes people are afraid of moving around for fear of planted bombs on the road by the insurgent, so, therefore, this has affected the weeding, chemical spraying, fertilizer application, and harvesting (Ojo et al., 2018).

5. Crop Irrigation Spatial-Temporal Distribution Using Earth Observatory Data

5.1 Pre-crisis Irrigation Activities (2014-2019)

In 2014, the agricultural activities in the area were normal despite pockets of insurgency outside the study area. Therefore, almost all the area has been put to cultivation, particularly during irrigation (dry season). The dominant crop cultivated in that year was tomatoes, with 227.07ha (29.6%), as shown in Figure 8 A1 & A2. Tomatoes have dominated the northern central part. However, a lot of agricultural activities were dominant in the area as a result of people's being more inclined to tomatoes in large quantities due to commercial demand in most of the rural markets as earlier shown in Plate 1. The level of food production has increased extensively through the expansion of areas under cultivation (Madu, 2013). Large farm sizes are put to cultivation before the insurgency and the induction of more jobs and food into circulation.




B1
Legend
Study_area
2015
Crop_type
Shrub land
Uncultivated(Irrigation/Rainfed)
Pepper(mixed)
Tomato
Tomato(mixed)
Onion
Meters
B2
ha
14.76
6.03
33.66
1.71
178.2
541.69
Crop type 2015
Tomato
Tomato(mixed)
Pepper(mixed)
Onion
Shrub land
Uncultivated(Irrigation/Rainfed)
C1
Legend
Study_area
reclass_16_n
CROP_TYPES
Shrub land
Uncultivated(Irrigation/Rainfed)
Onion(mixed)
Tomato(mixed)
Watermelon
Tomato
Vegitables(mixed)
C2
ha
26.65
46.65
33.84
2.53
22.41
124.47
519.5
Crop type 2016
Tomato
Tomato(mixed)
Onion(mixed)
Vegitables
Watermelon
Shrub land
Uncultivated(Irrigation/Rainfed)
D1
Legend
Study_area
2017
Crop_type
Shrub land
Uncultivated(Irrigation/Rainfed)
Onion(mixed)
Onion
Watermelon
Tomato(mixed)
Tomato
Vegitables
Pepper(mixed)
Watermelon(mixed)
D2
ha
32.99
85.11
46.27
38.28
353
163
Crop type 2017
Tomato
Tomato(mixed)
Pepper(mixed)
Onion
Vegitables
Watermelon
Watermelon(mixed)
Shrub land
Uncultivated(Irrigation/Rainfed)
E1
Legend
Study_area
2018
Crop_type
Shrub land
Uncultivated(Irrigation/Rainfed)
Tomato(mixed)
Tomato
Onion
Vegitables
Onion(mixed)
watermelon
Pepper
Pepper(mixed)
E2
ha
63.3
200.85
50.53
67.19
100
200.85
Crop type in 2018
Tomato
Tomato(mixed)
Pepper
Pepper(mixed)
Onion
Onion(mixed)
Vegitables
Watermelon
Shrub land
Uncultivated(Irrigation/Rainfed)

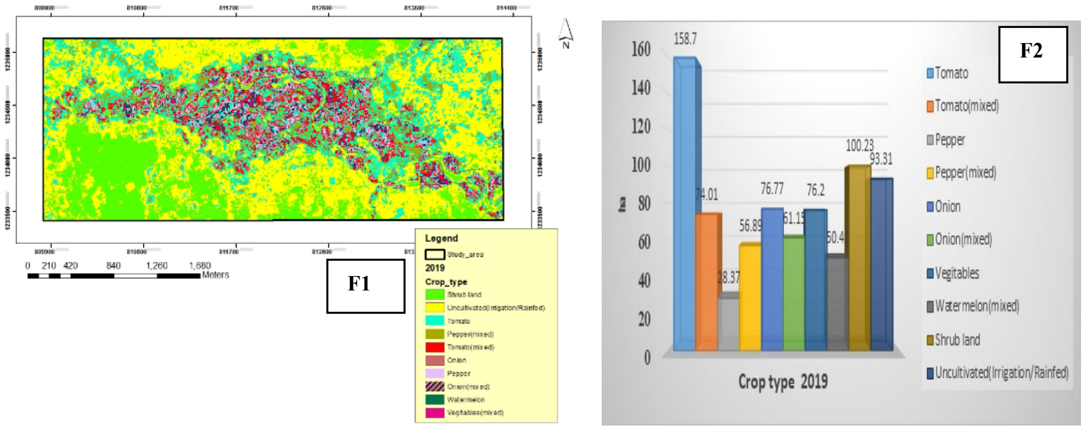


Fig. 8 *Spatio-temporal distribution of cropping irrigation between 2014 to 2019*

Due to the insurgency in 2015, large hectares of farmland were destroyed, markets were burnt down, and people migrated to less affected areas and with the imposition of curfew by the government, which resulted in the collapse of all activities, including farming, in areas close to homes. As a result, crop production was seriously affected, resulting in a shortage of stable food crops as well as an increase in the prices of these crops. Large hectares of land were left uncultivated, totaling 541.69ha (69.80%), as shown in Figure 8, B1 & B2. However, there are a few farmlands that were cultivated with 33.66ha for pepper mixed cropping, 14.76ha for tomato, and 6.03ha for tomato mixed, as shown in the center part of the area. The average farm size of the respondents after the insurgency was 1.48ha. This means farm sizes among the farmers in the area have been reduced by about 23.32% during the insurgency. This has been buttressed by many reports that show it stopped most of the agricultural and other business activities, thereby reducing the low supply of food with low-income generation as well as the increase in the price of food commodities and disrupting economic development (Orhero, 2015; Rasheed, 2013; Aluko *et al.,* 2016; Thomas and Richard, 2022).

These findings indicated a breakthrough from the previous result that utilized only empirical findings in analyzing the effect of the Boko Haram insurgency on agriculture or on socioeconomic and food security (Babagana *et al.,* 2018; Iliyasu *et al.,* 2015; Awortu, 2015; Awodola and Oboshi, 2015; Oladayo, 2014; Ogochukwu, 2013; Odita and Akan, 2014). The majority of their results required a geospatial entity to indicate the actual location of the effect, the results were obtained from the individual affected persons. This paper has utilized two approaches; the field data and the actual location of the affected farmlands using Earth Observation data (satellite images). The spatial cropping information that has been detected from the analysis of the temporal satellite images shows how the reflected signatures were used. In this case, the relevant information on farmlands that are under cultivation and those that are not has shown different reflections. So, therefore, the lower the reflected NDVI, the more farming activities, and the higher the reflected NDVI, the less farming activities. This approach has to be taken into consideration because it is the irrigation activities that are targeted. However, the studies of Deborah *et al.,* (2020) and Jaafar (2018), which applied remote sensing technology to the effect of insurgency on agricultural and other land uses, are too general and merge with other land uses and most of the cropping activities in the area. The study used a coarser resolution and did not capture individual signatures from the NDVI. During the classification, Land use and land cover were applied, so, therefore, there are elements of grouping different features together to form another. For instance, grass and trees could be considered as vegetation, while farmland could be grouped as one without looking at a single crop that is affected.

In 2016, there was relative calmness in some locations within the study area. The irrigation activities started to pick up as a result of some of the displaced people returning to their homes. In addition, crop cultivation has been found to have ameliorated Unfortunately, the effects of the insurgency are still felt throughout the region, as many markets were destroyed, and the majority of these markets are rural in nature, selling perishable commodities. Moreover, upon the return to their town after almost 2 years of exile, many of the farmers who managed to return were faced with the object of poverty, depression, and fear of what might happen next, and the destruction of Katarko bridge, which is the major road to the market for the transportation of the farm produce, which has reduced the effort of farming. The dominant crop cultivated is tomato mixed (Figure 8, C1 & C2), which occupies only 46.65ha (6.01%), followed by 33.84ha (4.36%) for onion mixed and 26.65ha, 22.41ha, and 2.53ha for onion, watermelon, and vegetables respectively. Leaving 519.5ha (66.94%) uncultivated land as shown in the majority of the north eastern part of the area, and 124.47ha (16.04%) shrub land as shown in the majority of the south western part of the area.

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In 2017, the relative peace continued to spill from 2016 to 2017. Figures 8, D1 and D2 show that the distribution of tomatoes and onions has increased compared to the previous year (2016). Tomato mixed (85.11ha), onion (46.27ha), watermelon (38.28ha), tomato (32.99ha) and other crops. In this case, more land is under cultivation during the irrigation period than before. Other business activities have continued to flourish, especially in the aspect of local trading and transportation. Besides, the rural markets have been found to have improved greatly with the reconstruction of the Katarko Bridge, which provided a means for transportation of the farm produce. Unfortunately, the impacts of the insurgency on irrigation farming are still felt across the area as many farmers have completely relocated to other places considered safer to farm, which has led to a significant decrease in the number of crops, especially onion, in the area.

In 2018, the agricultural activities in the area continued to increase, so almost all the irrigated areas were put to use. The dominant crops cultivated include tomato mixed (200.85ha), tomato (63.3ha), pepper (50.53ha) and onion (67.19ha), as shown in Figure 8, E1 & E2. However, the majority of the crops cultivated are dominated in the northern part of the area, and people in the area are more inclined to grow tomatoes in large quantities because of the demand due to the good market that flourishes for perishable goods in the area (see plate 1).

In 2019, the irrigation activities almost became normal (as in 2014). For that reason, almost all the farmers have come back to do their normal routine. From Figure 8 (F1 & F2), it is indicated the dominant crop cultivated is tomato with (158.7ha), tomato mixed (74.01), pepper (28.37ha), pepper mixed (56.85ha), onions (76.77ha) and onion mixed (61.15ha). Other emerging crops include vegetables and watermelon mixed with 50.14ha and 50.40ha respectively. The results showed a significant change and an increase in irrigated land, similar to what was observed in 2014. However, there are emerging crops that were mixed with other crops due to commercial demand and most of the crops cultivated dominated in the mid-central part. A lot of agricultural activities were dominant in the area as a result of people in the area being more inclined to tomatoes in large quantities because of the need due to the commercial activities in most of the rural markets in the area. As such, it booms. The other factor is the issue of soil nutrient improvement. Because, during the insurgency, the majority of the farms are put under cultivation for both the rainy and dry seasons. It has been reported that allowing the soil to fallow for some times may allow it to regain its nutrients (Ahmed, Adamu and Mohammed, 2015a and Ahmed, Jeb, Usman, Adamu and Mohammed 2015b). Yes, it is possible to agree with the improvement of soil nutrients. During the field investigation and interviews with the farmers, they explained the soil improvement and even the yield.

6. The Result of The Accuracy Assessment

The result of the accuracy assessment in Table 4 indicated that in 2014, there were high omissions of pepper, pepper (mixed), tomato (mixed), onion, and shrub land, and this was before the insurgency in the area. This is an indication of the mixing of spatial pixels within the cropping area (Feilhauer *et al.,* 2014). This is not surprising because of the nature of the image used, which is Landsat (30-meter resolution) during the analysis. While in 2015 to 2019, sentinel products were used. The result indicated a magnificent output, however not properly represented due to some spectral problems and the arrangement of crops which are mainly cultivated on a small plot of land. The user accuracy as shown in table 4, for the year 2015, for shrub land, tomato and tomato (mixed) is as a result of the domination within a small area while there is less activity in the farm due to the insurgency problem. As such, little farming is seen and people go for the simpler work that cannot take longer time in the farm, such as farming tomatoes, and the majority are those that reside closer to the farm.

Table 4 *Overall accuracy assessment*

	2014				
	Crop_type	**Commission**	**Omission**	**Producer Accuracy**	**User Accuracy**
1	Shrubland	20.3	12.22	87.78	79.7
2	Onion	34.8	10.21	89.79	65.2
3	Tomato	22.7	14.33	85.67	77.3
4	Tomato (mixed)	31.4	8.2	91.8	68.6
5	Watermelon	12.9	40.1	59.9	87.1
6	Papper	42.1	12	88	57.9
7	Papper (mixed)	40	41	59	60
8	Uncultivated land	31	21	79	69

	2015				
	Crop_type	**Commission**	**Omission**	**Producer Accuracy**	**User Accuracy**
1	Shrubland	5	10.67	89.33	95
2	Onion	23	12	88	77
3	Tomato	5	12.96	87.04	95
4	Tomato (mixed)	11.09	25.6	74.4	88.91
5	Uncultivated land	25	21	79	75

	2016				
	Crop_type	Commission	Omission	Producer Accuracy	User Accuracy
1	Shrubland	14.98	22.09	77.91	85.02
2	Tomato	31	32.12	67.88	69
3	Tomato (mixed)	22.8	13	87	77.2
4	Watermelon	18.67	17.22	82.78	81.33
5	Vegetables	45	40.1	59.9	55
6	Uncultivated land	9.09	21	79	90.91

	2017				
	Crop_type	Commission	Omission	Producer Accuracy	User Accuracy
1	Shrubland	11	16.01	83.99	89
2	Onion	3.98	22.23	77.77	96.02
3	Onion (mixed)	34	21.76	78.24	66
4	Tomato	15.43	8.67	91.33	84.57
5	Tomato (mixed)	24.22	11.76	88.24	75.78
6	Watermelon	24.41	10.12	89.88	75.59
7	Papper (mixed)	14.21	15.56	84.44	85.79
8	Vegetables	13.7	7.56	92.44	86.3
9	Uncultivated land	31	12.21	87.79	69

	2018				
	Crop_type	Commission	Omission	Producer Accuracy	User Accuracy
1	Shrubland	4.87	12.22	87.78	95.13
2	Onion	20.11	10.21	89.79	79.89
3	Onion (mixed)	11.23	0.92	99.08	88.77
4	Tomato	10.01	14.33	85.67	89.99
5	Tomato (mixed)	5.54	7.97	92.03	94.46
6	Watermelon	3.89	40.1	59.9	96.11
7	Papper	0.77	22.01	77.99	99.23
8	Papper (mixed)	40.21	12.34	87.66	59.79
9	Vegetables	10.31	5.21	94.79	89.69
10	Uncultivated land	31	6.78	93.22	69

	2019				
	Crop_type	Commission	Omission	Producer Accuracy	User Accuracy
1	Shrubland	4.87	12.22	87.78	95.13
2	Onion	21	10.21	89.79	79
3	Onion (mixed)	11.23	0.92	99.08	88.77
4	Tomato	10.02	14.33	85.67	89.98
5	Tomato (mixed)	5.54	7.97	92.03	94.46
6	Watermelon (mixe	3.89	40.1	59.9	96.11
7	Papper	0.77	22.01	77.99	99.23
8	Papper (mixed)	40.21	12.34	87.66	59.79
9	Vegetables	10.31	5.21	94.79	89.69
10	Uncultivated land	31	6.78	93.22	69

Therefore, grass continues to grow as a result. There is a little mix-up due to some grasses that are growing within onions and uncultivated land, indicating a little commission of 23 and 25%, respectively. During this period (2015), a lot of farms were left uncultivated. As such, the few farming activities were merging with the grasses and resulted in spectral mixing in the interpretation (Liu *et al.,* 2015). In 2016, there was little improvement, especially in the class for uncultivated land during irrigation. Vegetables were introduced, including the poplar spinach that is cultivated along the streams of the villages in the area, and the classification of vegetables was relatively simple due to the limited number of samples for analysis. This limited sampling can help in reducing the accuracy level of the crop, which can lead to pixels being mixed in (Ibrahim *et al.,* 2021). The changes in the cropping systems within a year are mostly determined by economic demand and market factors (Zhong, 2012). This contributed to the domination of cultivating mostly tomatoes by the farmers. The results of 2017, 2018, and 2019 have shown a good representation of the cropping distribution, with fewer aches in 2017 for onions, and in 2018 and 2019 for uncultivated land. However, in these years, the number of crops increased as a result of more land being put into irrigation (with little normalcy in the area) in the area. Some farmers tend to go back to their normal activities, so, therefore, the uncultivated and shrub land begin to reduce in size. This resulted in a higher level of both users' and producers' accuracy. The results of the spectral classes are all within the acceptable limits and a good result when using table 4 for interpreting the classification, even though the use of Landsat with 30-meter resolution is not fully satisfactory because of the mixing of similar signatures for a small area, a problem of heterogeneous and highly (Immitzer, *et al.,* 2016). Similar findings using Sentinel images have indicated a magnificent result, especially for crop mapping (Hejmanowska *et al.,* 2021; Van Tricht *et al.,* 2018).

7. Conclusion

This paper has demonstrated the effect of the Boko Haram insurgency on irrigated fields using the combination of both field and Earth observation data in mapping the spatio-temporal distribution of crops during irrigation. It also shows the relevance of the use of remote sensing applications in some challenging environments that can be utilized for data acquisition. One of the breakthroughs of this study is the determination of the reflected signatures from the classified image for different crops through irrigation activities during and after the insurgency in the area.

The impact of Boko Haram's insurgency on farmland size and labor intensity indicated a severe effect on irrigated activities in the area. The majority of the farmers leave their homes during the insurgency for fear of any attack, which indicates fewer farming activities. Before the crisis, farmers irrigated more than 2ha before the intensity of the crisis and more than 2ha after the intensity of the crisis. There is an increase in job insecurity, and the cutoff of the value-added chain has resulted in low food supplies and poverty. Remote sensing analysis, especially Spectral Matching Techniques (SMTs), has been shown to differentiate or discriminate between different irrigated crops. There has been a significant change in the irrigated land due to insurgency. With the relative calmness occasioned by high irrigation activities in 2017, 2018, and 2019.

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