Measuring Farm Technical Efficiency using Stochastic Frontier Production Function Model Approach

Mercy Ebere Ndubueze-Ogaraku (mercy.onu@uniport.edu.ng)
Department of Agricultural Economics & Extension, University of Port Harcourt https://orcid.org/0000-0001-7613-0109

Anil Graves
Cranfield University

Research

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Names of authors:

Mercy Ebere Ndubueze-Ogaraku & Anil Graves

Affiliation(s) of the author(s): Cranfield Institute for Resilient Futures School of Water Energy and Environment Cranfield University, Bedford MK 43 0AL, UK

Corresponding author email: mercy.onu@uniport.edu.ng

ABSTRACT

Agricultural productivity in Africa is the lowest in the world with many households not able to feed themselves. In Africa women make up 70-80% of the labour forces in the agricultural sector and play a core role in agriculture but underperform in terms of productivity largely because they lack access to physical and human resources. Well-being, a health resource is an important asset in production because people can work when they are healthy. The study is aimed to analyze farm technical efficiency of women farmers in Niger Delta, Nigeria. 216 female farmers were randomly selected from 18 communities of the three states in Niger Delta Nigeria. Stochastic production frontier function model was the analytical tools used. The result showed that farm size and labour positively influenced technical efficiency and was significant at 1% with a mean value of 68.8%. Farm efficiency level in Delta and Akwa Ibom States are not significantly different. However, technical efficiency level in both Delta and Akwa Ibom States are significantly different from Rivers State. Inefficiency variables of age and number of years spent schooling were significant at 5% and 10 % level respectively. The study recommends that women should increase the use of farm plots and labour resource for higher productivity.

Keywords Farm technical efficiency stochastic frontier

Introduction

Agriculture is a major source of livelihood for several people in the developing world providing employment for 5.5 billion people (Mehta et al. 2010). Smallholder farmers provide about 80% of the food supply in Asian and sub-Saharan Africa. In Africa, women make up 70-80% of the labour force in the agricultural sector and produce about 80% of the staple crops mostly used for household consumption (Gordon and Gordon 2007). Women are key players in food production in most developing countries, accounting for 43% of the agricultural labour force with 50% in eastern and southeastern Asia and sub-Saharan Africa (FAO 2012).

It has been observed that despite contributions made by women in food production, their performance is still low in terms of productivity. This is largely because of poor access to resources such as finance, skills training, and information services (FAO 2012). Women tend to spend longer hours than men working in farms in developing countries but lack access to production resources which are responsible for their low farm productivity. Farm operations such as sowing, weeding, fertilizing and harvesting staple crops such as rice, wheat and maize are mostly carried out by women. Women's contribution to secondary crops, such as legumes and vegetables, is even greater. FAO further reports showed that women produce most of the food consumed locally in the rural area where majority of the world's hungry people live. Contribution made by women in terms of production could be much greater if their access to essential resources and services, such as land, credit and training is improved. Eliminating obstacles that hamper women in food production is the key to achieving better farm yields. Improving women farmers' access to productive resources could also help increase their farms yields by 20-30% (FAO 2011). This is because women are seen as the quiet drivers of change towards more sustainable production systems and a more varied and healthier diet (FAO 2011).

The underperforming agriculture sector in many developing countries is so for a number of reasons. One of which is due to lack of resources and opportunities needed by women to make the most productive use of their time (FAO 2011). It has been reported severally that Africa's agricultural productivity is the lowest in the world (Nilsson 2013). Many are not able to feed themselves, leaving the people vulnerable to shocks. In addition, domestic food production growth in Africa has remained low, about 2.7%, which is barely above the population growth rate (Nilsson 2013). Several studies on farm productivity in developing countries were centered on estimating technical efficiencies using direct farm resources like farmland, labour, seeds and other materials used in production. Worthy to note is, despite intervention programmes and actions by the governments aimed at improving farm-level production in developing countries, it is sad to note that overall technical efficiencies of farms are still far away from the best frontier level ie 100%.

The report of Ben-Belhassen and Womack (2002) study on farm technical efficiency in Missouri hog production adopted stochastic production frontier function in determining technical efficiency. The study showed a mean farm technical efficiency of 82%, implying that a large (18%) proportion of production was lost due to farm-specific inefficiencies. Furthermore, technology and managerial skills were the major determinants of technical efficiency (Aminu et al. 2013). It was also reported that a mean technical efficiency (TE) of dry season vegetable farmers in Ojo Local Government Area in Lagos State, Nigeria was 71.1% which showed a huge possibility for improvement for some farmers. This suggests that an average farmer would need to a 28.9% cost saving in the study area to achieve the best technical efficiency level. It was also found that coefficients of both illness episode and number of days absent from farm work showed positive and significant influence on technical efficiency of farms. The finding implied that farmers, who suffered prolonged numbers of illness episodes, had long days of absent from farm work, which increased farmers' inefficiency levels.

In same vein, Kussa (2012) study on health and farm productivity found that parametric estimation of inputs such as land, labour, soil fertility and fertilizer significantly increased crop production but illness showed negative correlation and elasticity of 0.53. This is an indication that illness is an important factor that affects farm level production. Still more, households exposed to illness achieved an average technical efficiency of 33.5% while households not exposed to illness achieved 48.9% suggesting that health affects agricultural production.

According to Simon and Shallone (2013) report on the impact of farmers' health and nutritional status on agricultural technical efficiency in Masvingo rural communities showed that land, labour, fertilizer and seed showed positive correlation to farm output. Adverse health, age, household sizes had positive effects on te inefficiency of the farmers. The report also viewed that health problem had direct and indirect cost on the productivity of farmers. The adverse health impacts on production outcomes are its effects on farm labour capacity. The assessment of impact of health on agricultural technical efficiency in Nigeria revealed that one per cent improvement in the health condition of farmers would increase efficiency by 21% (Egbetokun et al. 2012). Much of the farm technical efficiency studies were focused on farm resource and ill health variables. It is also surprising noting that not many studies have been carried out on farm technical efficiency of farms owned by women in the study area. It is on this background that this study adopted stochastic production frontier function model in estimating women farm technical efficiency level in Niger Delta Nigeria. Specifically technical efficiency ranges, averages were determined; also determinants of technical efficiency and inefficiencies of farms were estimated.

2 Research methods

2.1 Description of study area

This study is carried out in the Niger Delta, Nigeria. The region is situated in the southern part of Nigeria and bordered to the south by the Atlantic Ocean and to the East by Cameroon; it occupies a surface area of about 112,110 square kilometers (Adeyemi 2015). It represents about 12% of Nigeria's total surface area and it is estimated that by the beginning of 2006 its population will be over 28 million inhabitants. The region has huge oil reserves and ranks sixth exporter of crude oil and third as the world's largest producer of palm oil after Malaysia and Indonesia. The states in the Niger Delta are; Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo, Rivers States, with an area of 112,000 sq. km, a population of 27 million people, 185 LGA's, about 13,329 settlements (Adeyemi 2015). Further, the delta region leads in the production of timber, pineapple and fish, also; cocoa, cashew, cassava, rice, yam, plantain, banana and oranges are produced in large quantities in the area and vegetables such fluted pumpkin, cucumber, pepper and food spices are produced in the area. Also farming and fishing are the major occupation of the people (Omofonmwan and Odia 2009).

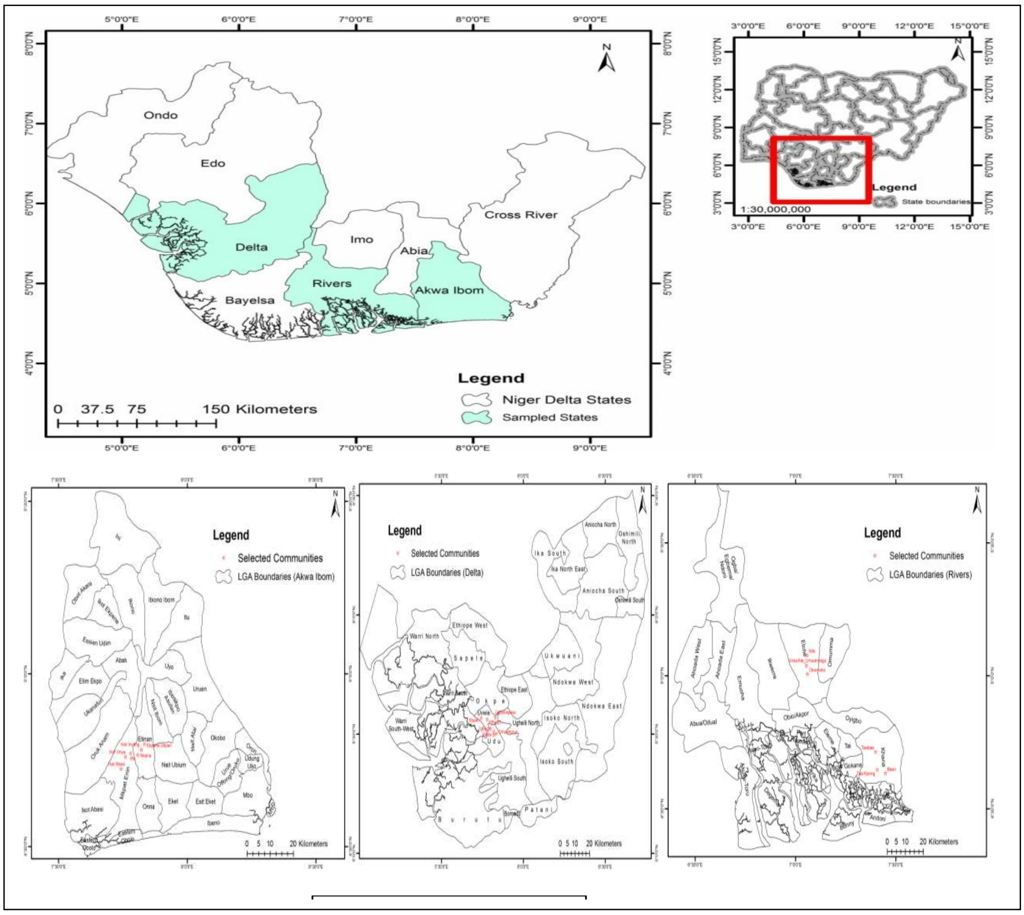

Fig1 Map of Niger Delta region showing study locations

2.2 Sampling technique and sample size

A multi-stage sampling procedure was adopted in the selection of three states in Niger Delta, Nigeria. Two Local Government Areas (LGAs) were chosen from Akwa Ibom, Delta and Rivers state each giving a total of six (6) LGAs. Three (3) communities were selected from each LGA constituting 18 communities and lastly 12 women farmers were randomly selected from each community making 216 farmers.

2.3 Methods of data collection

The study involved the use of both primary and secondary data. The primary data were generated using questionnaire and interview schedule while the secondary data was from the existing literature. The interview schedule consists of semi-structured questions was prepared in English and translated into local language in some cases. Questions were centered on socio-economic, demographic and institutional characteristics of households, quantity of inputs used in production alongside quantity of output generated during the period in view. The questionnaire was pre-tested using pilot survey to ascertain the reliability of the instrument.

2.4 Methods of data analysis

Descriptive statistics such as mean and percentages was used to achieved objective 1 while objective 2 was determined using the stochastic production frontier function software package. The Stochastic Frontier Production Function Model is an analytical technique used to determine technical efficiency and inefficiency of farmers' productivity at the same time. In this model, the dependent variable (y) is the farmers' farm yield or output measured in kg while independent variables are farm inputs such as farm size in hectares, seeds or cutting (planting materials) in kg, a quantity of farm labour in man-days. A unique feature of this model is the presence of two error terms (Ui-Vi). The Ui is the random error term which takes care of error in measurement while 'Vi' error captures the attributes of the farmers socioeconomic and access to health variables which affects or contributes to firm inefficiency level. The analytical tool is used to indicate farms operating at the best frontier region and the ones that are far away from the best frontier region of production.

Stochastic frontier production function approach was developed by Aigner et al. (1977). They utilized the maximum likelihood analytical procedure. A study carried out by Mango, et al. (2015) argued that initial studies to measure technical efficiency for a cross-section of producers used deterministic frontier approach, which assumes that any deviations from the frontier are due to inefficiency. They explained that the outcome was the difference between potential and observed yield for a given level of technology and inputs. The result of such method implied that any farmer producing below the frontier was assumed to be inefficient. However, the deterministic frontier ignored factors beyond the control of the farmers which could influence efficiency. Hence, the deterministic approach was sensitive to the selection of variables and errors in data generation. It was reported by Chaudhuri (2016) that Aigner, Lovell and Schmidt and Meeusen and van Den Broeck independently developed the stochastic frontier approach to address some of the limitations of the deterministic frontier approach. Stochastic frontier model tends to separate technical inefficiency from noise by incorporating two error terms. In the new approach, the error term consists of two components, one is random and the other being a one-sided residual term representing inefficiency. The first error component also called a statistical noise accounts for random effects. The second component represents systematic effects that are not explained by the production function but are attributed to technical inefficiency ie reflecting measurement error or shocks beyond the control of the farmer.

2.5 Model Specification

Stochastic Production Function Frontier Model:

Stochastic production frontier function used in measuring the technical efficiency of farm productivity.

$$LnY = \beta_0 + \beta_1 In\, X_1 + \beta_2\, In\, X_2 + \beta_3\, In\, X_3 + e\left(U_{ij} - V_{ij}\right)\ eq\ 1$$

Where:

Yi is the production of crop yield of i[th] producer, Xi a vector of inputs used by the i[th] producer, a vector of unknown parameters.

$\beta_0 = Constant$

$\beta_1 - \beta_3 = Estimated\ parameters$

$Y = Yield\ /Kg$

$X_1 = Farm\ size\ in\ hectare$

$X_2 = Quantity\ of\ labour\ used\ in\ mandays$

$X_3 = stem\ cuttings\ in\ kg$

$U_{ij} - V_{ij} = A\ composed\ error\ term$

$V_{ij} = Radom\ error\ due\ to\ stochastic\ noise$

$U_{ij} = Randomness\ (\ technical\ inefficiency)$

The farm-specific technical efficiency (TE) is also defined in terms of observed output (Yi) to the corresponding frontier output (Yi) using the available technology to be estimated.

TEi = Yi /Yi* which is the same as Actual yield / Potential yield = eq 2

Technical Inefficiency Model

The *V*is are assumed to be independently and identically distributed normal random variables with mean zero and variance $\sigma^2 v$. The U_is are non-negative random variables associated with technical inefficiency of production, which are assumed to be independently distributed, such that U_i is obtained by truncation (at zero) of the normal distribution with mean, $Z_i\delta$ and variance,σ^2 . Where $Z_i$is a (1 ×m) vector of explanatory variables associated with technical inefficiency of production of firms over time and δis (m× 1) vector of unknown coefficients. The technical inefficiency effects, U_is are assumed to be a function of a set of explanatory variables, the Z_is and an unknown vector of coefficients δ.

$$Ui = \delta o + \delta \ln Z_1 i + \delta In Z^2 i + \delta In Z^3 i \qquad eq\ 3$$

Where

$Ui = \quad Technical\ inefficiency$

$Z_1 = \quad Age\ of\ farmer\ (\ years)$

$Z_2 = \quad Number\ of\ years\ spent\ schooling$

$Z_3 = \quad Traveltime\ to\ healthcare\ serive\ centre$

$\delta o = \quad Constant$

$\delta_1 - \delta_2$ = Coefficients of "Z" Variables

The stochastic frontier production function and the inefficiency model defined by equations (1) and (2) were simultaneously estimated using the FRONTIER (version 4.1c) software.

3 Results and Discussion

Table 1 Result of technical efficiency of farmers

Variables		Coefficient	Standard error	t-ratio
Technical Efficiency variables				
Constant/Intercept	beta 0	6.393	0.628	10.174***
Farm size in ha	beta 1	0.627	0.106	5.908***
Labour in man-days	beta 2	0.546	0.144	3.791***
Seeds/cuttings	beta 3	-7.124	1.440	-1.617 NS
Inefficiency variables				
Intercept	delta 0	-2.794	1.296	-9.442***
Age	delta 1	-8.324	3.639	-2.288 **
Years spent schooling	delta 2	0.224	0.123	1.820 *
Travel time to HCS	delta 3	-0.148	8.768	-1.686 NS
	sigma-squared	4.420	2.010	2.105 **
	Gamma	0.922	3.971	23.230 ***
Log Likelihood Function =	-236.751			
LR test of the one-sided error	18.251			
No of restriction =	5			

Source Analysis of field survey data using stochastic frontier 4.1C software 2018

****,** & * is 1%, 5% and 10% respectively*

Data in Table 1 showed maximum likelihood estimates of parameters of technical efficiency of farm productivity in the Niger Delta Nigeria. The result showed that farm size and number of farm labour used showed positive sign at a 1 % level of significance each. The significant value of labour input and farm size farm resources alongside their positive effects affirm that these two inputs were the major factors driving the technical efficiency of farms in the region. The positive signs of the variables are in line with *a priori* expectations which implied that the resources contributed positively to the technical efficiency of farms in the region. Their respective elasticity of the farm output was 0.63% and 0.55%respectively. This means that one unit increase in the size of farm land and labour would induce a 63% and 55% increase in farm output and vice versa.

Estimated gamma parameter of the model was 0.92, implying that about 92% of the total variation in the farm output could be attributed to differences in technical efficiencies. Mean technical efficiency recorded in the region was 0.69 (i.e. 69%). This implies that farmers are still far away from their technological frontier by 31 per cent. Hence, there is a need for farmers in this region to strive harder to attain the best frontier in farm production. Inefficiency result is interpreted differently, a negative sign of parameters in the inefficiency model shows that the associated variable has a positive effect on technical efficiency and vice versa (Simon and Shallone 2013).

Inefficiency result showed that age of the farmers and the number of years spent schooling showed positive influence on technical inefficiency and were significant at 5% and 10 % level respectively. Age had a negative sign while the level of education was positive. The negative sign of age implies that as farmer increases in age, he would gain more experience in farming which could increase farm technical efficiency in other words farm inefficiency will be reduced. A positive sign of the level of education means that the variable would likely reduce technical efficiency and increase farm inefficiency level. This is likely to happen because, higher education level would mean better job options for farmers, which would result to paying less attention to farm business resulting to high technical inefficiency. Although travel time to healthcare service centre used as a proxy for healthcare access did show a significant effect. This contradicts the report of Black et al. (2019) which suggests that health and nutrition of women could have significant impact on agricultural productivity because they were restricted in their access to productive resources, opportunities and healthcare.

Table 2 Efficiency ranges of farm production in Niger Delta Nigeria

Ranges	Frequency	Per cent
11-20	2	0.9
21-30	2	0.9
31-40	5	2.3
41-50	8	3.7
51-60	25	11.6
61-70	59	27.3
71-80	72	33.3
81-90	43	19.9
Total	216	100.0
Mean	68.8	

Source Analysis of field survey data using stochastic frontier 4.1C software 2018

Table 2 showed deciles of technical efficiency in the area, it was observed that 33.3 % of the farmers recorded technical efficiencies range of 71% - 80% with a mean efficiency of 68.8% implying that 31.2% (100 - 68.8) percent of production is lost to technical inefficiency. This supports the findings of Azumah et al. (2019) which showed that the mean technical efficiency of irrigation farmers was 68%. Farmers who had TEs range of less than 50% was 7.8%. Those that recorded TEs range between 60-70%. Only 19.9% of the farmers had TE range of 80-90% and no farmer achieved 100% technical efficiency in farm production during the period. The result which showed that farmers were still operating below the frontiers of technical efficiency agrees with the findings of Asogwa at al. (2019). This implies that the farmers were not technically efficient in their farms.

Table 3 Travel time to healthcare service centre

Minutes	Frequency	Percent
1-10	52	24.1
11-20	47	21.8
21-30	56	25.9
31-40	16	7.4
41-50	26	12.0
51-60	18	8.3
61 & above	1	0.5
Total	216	100.0

Source Analysis of field survey data using stochastic frontier 4.1c software, 2018

Result in Table 3 showed that 25.9% of the women spent 21-30 minutes travelling to their healthcare service centre. Farmers who spent 1-10 minutes going to the nearest health provider was 24.1%, 21.8% spent on average 11-20 minutes, 12% of the respondents spent 14-50 minutes travelling to the health service provider while 8.3% of them spent about 51- 60 minutes to the health service provider. Majority of the respondents spent 1- 30 minutes visiting their healthcare providers.

Table 4 Farm technical efficiency Comparison

	Sum of Square	Df	Mean Square	F	Sig
Between Groups	6694.486	2	3347.243	68.367	0.000
Within groups	909817.089	18583	48.960		
Total	916511.576	18585			

Source Analysis of field survey data 2018

Result in Table 4 showed mean differences between groups and within groups as 3347.243 and 48.960 respectively in Rivers, Delta and the Akwa Ibom States. The test of significance showed a value of 0.000 at 1% level. This suggests a further enquiry to identify the farm groups that had a significant difference in their technical efficiency level.

Table 5 Multiple comparison of farmers technical efficiency

					95% Confidence Interval	
(I) State	(J) State	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Rivers	Delta	1.362*	0.161	0.000	0.967	1.756
	Akwa Ibom	1.134*	0.111	0.000	0.861	1.406
Delta	Rivers	-1.362*	0.161	0.000	-1.756	-0.966
	Akwa Ibom	-0.228	0.168	0.396	-.638	0.182
Akwa Ibom	Rivers	-1.133*	0.111	0.000	-1.406	-0.861
	Delta	0.228	0.168	0.396	-0.182	0.638

Source Analysis of field survey data 2018

* The mean difference is significant at the 0.05 level

Result in Table 5 showed multiple comparisons of farms technical efficiency of respondents which indicated a significant difference in farm technical efficiency in Rivers, Akwa Ibom and the Delta States at 0.00 level. Mean comparison between Delta State and Akwa Ibom States showed no significant difference in technical efficiency. Scheffe test of homogeneous subset further identified where differences exist.

Table 6 Homogeneous subsets of farmers' technical efficiency

Scheffe[ab]		Subset for alpha = 0.05	
State	N	1	2
Delta	2350	68.11	
Akwa Ibom	6760	68.33	
Rivers	9476		69.47
Sig.		0.31	1.00

a Uses harmonic mean sample size = 4418.323 (b) The group sizes are unequal. Therefore, harmonic mean of the group size is used.

Data in Table 6 classified mean differences to the homogeneous group. It is shown that farm technical efficiency level in Delta and the Akwa Ibom States are not significantly different but the technical efficiency level in Rivers State is significantly different from both Delta and Akwa Ibom States efficiency farmers. This means that farms in Rivers State were better managed than the ones in Akwa Ibom and the Delta States.

Conclusion

Farm productivity of women farmers in Niger Delta, Nigeria was analyzed using the stochastic production function model. The study showed that coefficients of farm size and labour inputs were significant at 1% level and had positive impact on farm technical efficiency. The result showed that 92.1 % of the farmers achieved technical efficiency level above 50%. However, no farmer was able to achieved TF range of 91 to 100%. Age and educational level of farmers were the significant technical inefficiency variables. Mean technical efficiency is higher in Rivers State than Akwa Ibom and Delta State. Majority of the respondents spent 1-30 minutes visiting their healthcare providers. The study recommends that farmers should increase the use of farm plot holding and labour resources. This will help to improve productivity and reduce farm inefficiency level in the Niger Delta Region, Nigeria.

Availability of data and materials: The author hereby declare that they can submit the data at any time based on publisher's request. The datasets used and/or analyzed during the current study will be available from the author on reasonable request.

Competing interests: There is no conflict of interest in the conduct and use of data generated from the project. The supervisor, Cranfield University UK and University of Port Harcourt, Nigeria is void of any such conflict. No previous submission of this article had been made to any scientific journal publisher and no "Conflict of Interest" among the authors and sponsors of the research.

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Authors' contributions: All authors read and approved the final manuscript.

Mercy Ebere Ndubueze-Ogaraku proposed the research, designed the data collection instruments, collected the data, analysed the data and wrote the first draft of the manuscript. Anil Graves provided guidance in the design of the research, methods of data collection and analysis, corrections, inputs and supervision to the entire research. All authors read and approved the final manuscript. We also confirm that the content of the manuscript has not been published or submitted for publication elsewhere except this journal.

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Authors' information (Optional): Mercy Ebere Ndubueze-Ogaraku (PhD) an Agricultural Economist is a senior lecturer in the Department of Agricultural Economics & Extension, University of Port Harcourt, Nigeria. She was a Post-Doctoral Fellow at Cranfield University, UK in 2017 to 2018. She is actively involved in teaching both undergraduate and graduate students for more than 12 years. My research interest is the application of economic theories and principles in proffering solutions to the problems of small holder farmers in developing countries.

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Figures

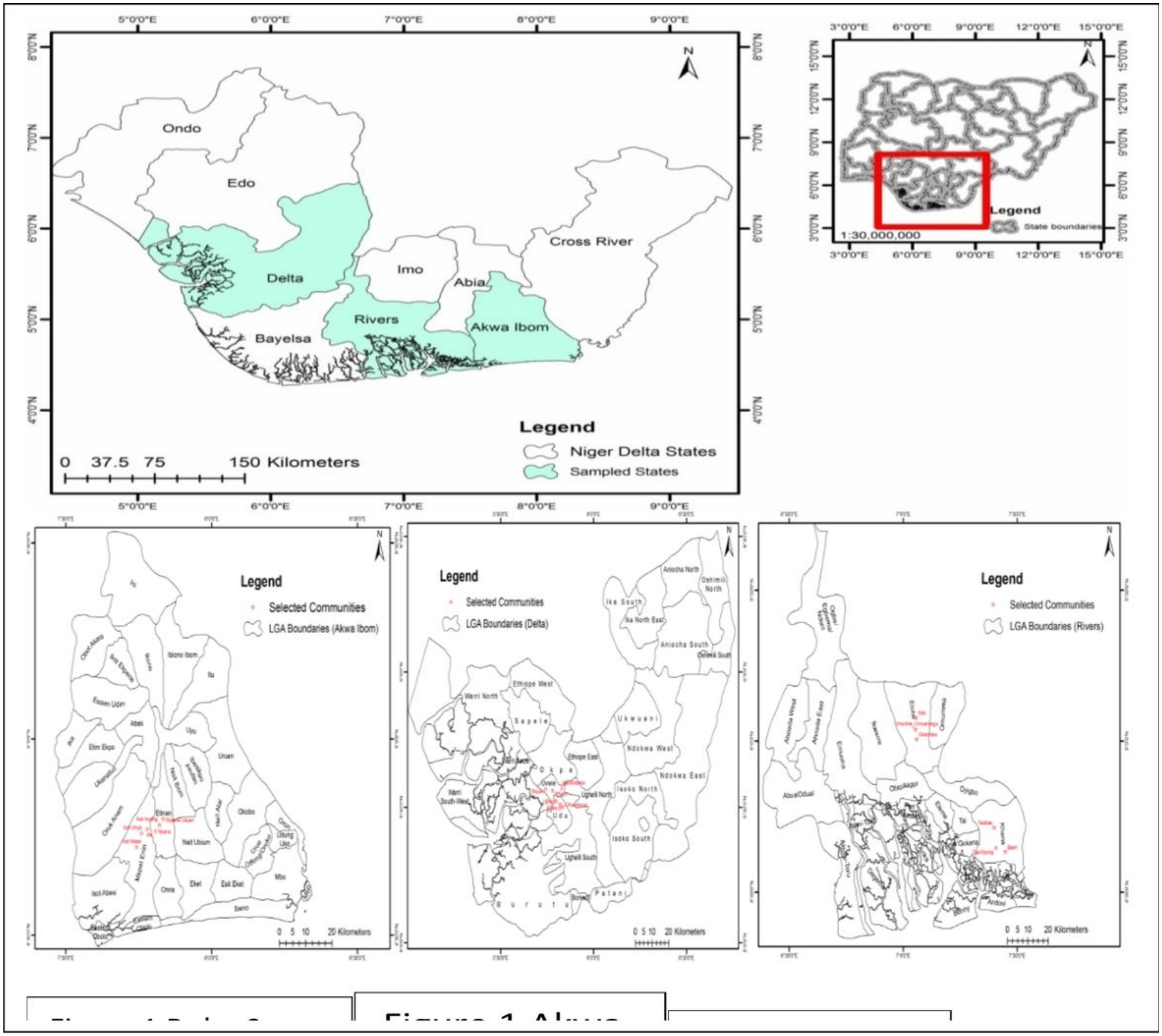

Figure 1

Map of Niger Delta region showing study locations Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.