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The Vectorisation and quantification of some gully sites in Southeast Nigeria to determine their extent and Rates of Gully change.

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Abstract

In this work a study of gully erosion in southeast Nigeria is presented. The study of gully development on a regional scale is currently undermined by the inherent costs associated with consistent field monitoring and the lack of historic measurements to perform time series analysis. As a result, there are very few studies which implement long term analyses of gullies in the region as a collective. Consequently, the building of knowledge of the role of environmental changes on the development of gullies is inhibited. Remote sensing methodologies, via the Landsat archive, are used as a low-cost data source to allow analyses of gullies over the time period 1986 to 2015. 14 gully sites, identified via field work validation of remote sensing imagery, are monitored in terms of extent and rates of change. Digital Elevation Models (DEM) and remote sensing imagery are used to detect topographical and landscape characteristics and to calculate gully dimensions. The gully areas and % change graphs show how the gullies have been changing over the years. The older gullies Iyioku, Okigwe, Njaba and Igboukwu show that their development precedes 1986 but also, aside from Iyioku, that along the way gully % rate of change has been reducing. The more recently formed gullies, all the displayed gullies are showing positive relationships between time and gully size although the proportional change each year is changeable. For instance; Iyioku and Okigwe have similar characteristics in terms of gully area and at yearly gully change in metre squared per square metre. This can be found in 2015 gully areas and 2014/2015 yearly gully change in metre squared per square metre of 1701881m^2 and 0.05m^{2}yr-1 for each unit area and 666930m^2 and 0.04m^{2}yr-^{1} for each unit area respectively. In a similar fashion Urualla and Orlu gullies show similar characteristics, with (43569.9m^2, 0.07m^{2}yr-^{1}) and Orlu (47297m^2 -0.05m^{2}yr-^{1}) respectively showing almost similar characteristics and magnitudes in area sizes and yearly gully change.

Introduction

Gully erosion has been progressing in the continent of Africa rapidly for many generations, owing to the settled conditions attendant on European rule, it has become urgent importance and it is now recognized as a vital problem (Fleitmann et al. 2007). Until recently, the human inhabitants were not sufficiently numerous in

Africa to bring about gully development as can be observed today which has now increased by natural processes (Mulwafu 2011).

Sub-Saharan countries in Africa are plagued by serious environmental degradation resulting in desert encroachment, drought, and soil erosion due to either wind impact or very highly intensive rainfall, resulting in heavy runoff and soil loss. The Food and Agriculture Organisation (1993) have identified the crop land of south-east Nigeria as an area that is in increasing danger from soil degradation and in particular gully erosion. According to Udo (2010) and Igwe (2012), gully erosion has caused massive soil loss, greatly reducing agricultural production in the area, has destroyed lives and properties, and forced community displacement as unsafe or unsustainable ancestral homes must be abandoned.

In southeast Nigeria, anthropogenic activities such as mineral and resource exploration, and extraction have a detrimental effect on the environment and landscape. As recently as 150 years ago south-east Nigeria was covered by thick rainforest which included the indigenous tree species of Iroko, Bamboo, and Mahogany (Integrated Regional Information Network, 2011). The loss of vegetation cover is often a major consequence of resource extraction. Illegal activities conducted without regard to conservational laws are commonplace in the region, and the consequences are manifested in the landscape by soil erosion enacted by the processes of weathering and erosion.

Study Area

The study area is located in south-east Nigeria between 7^0 8’N 6^0 34’ E and 4^0 49’ N 8^0 15’ E covering a land area of approximately 57,758.034Km^2, as shown in **Figures 3, 4 and 5**. It is characterised by coexisting types of land use and land cover, which are mainly affected by gully erosion.

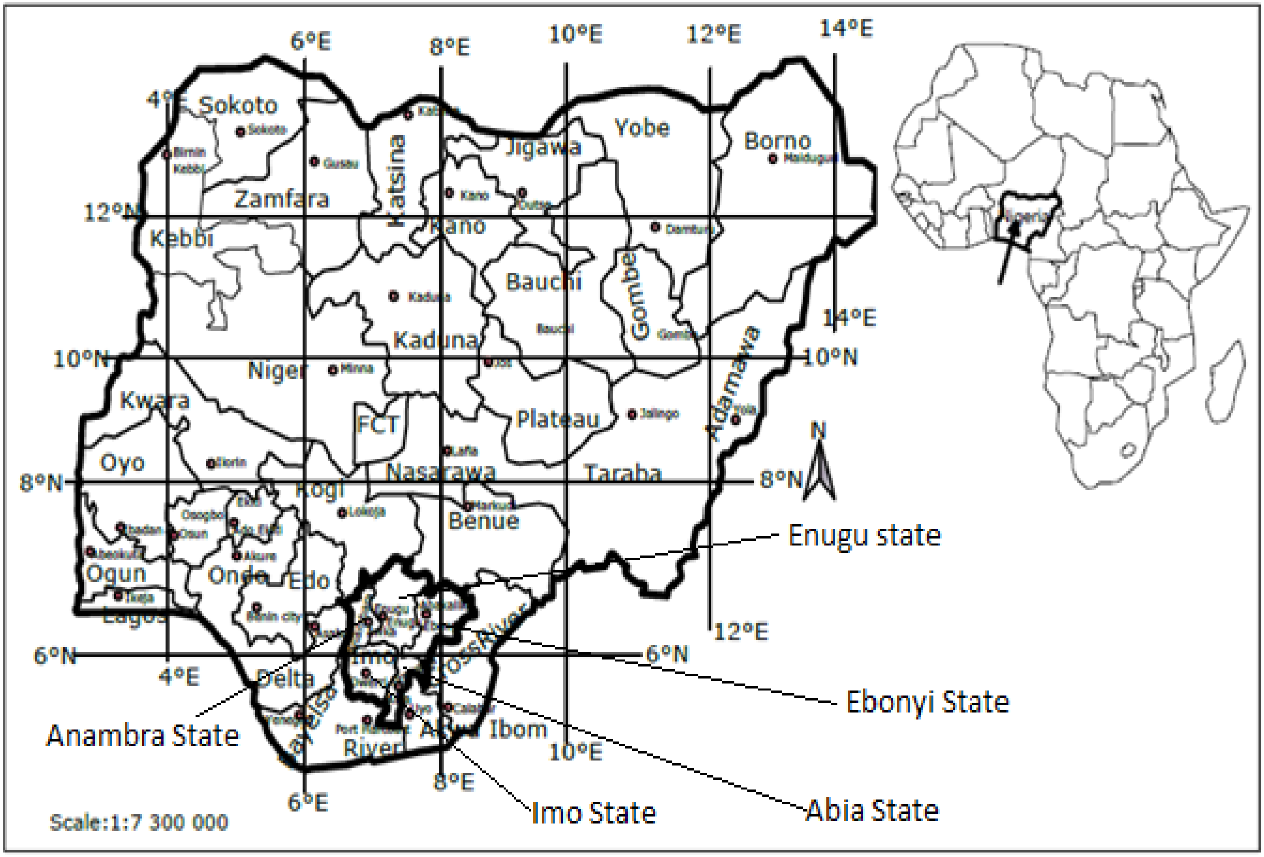

Figure 1:Nigeria highlighted within the continent of Africa. Study area outlined for context (Iloeje 2010)

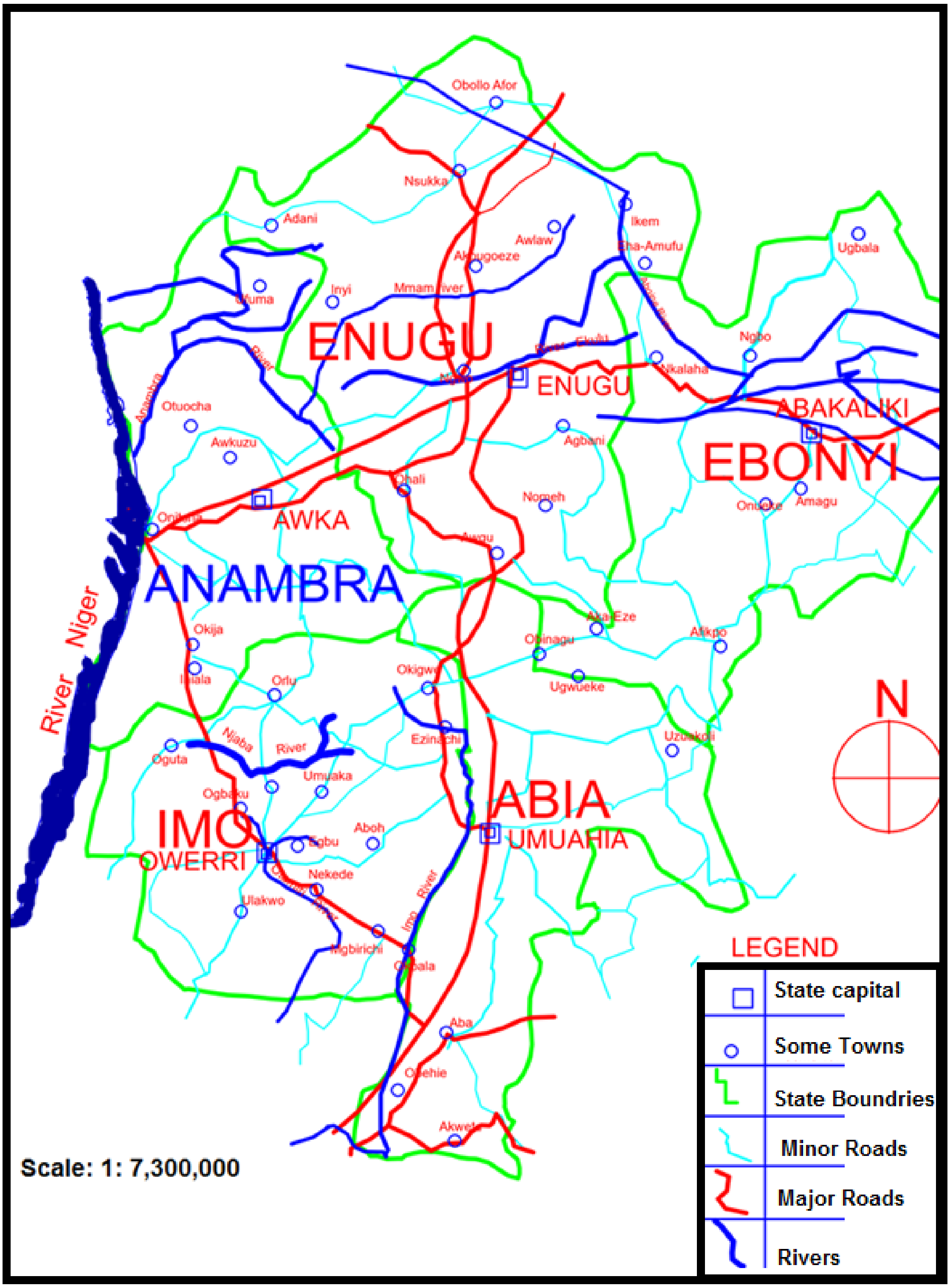

Figure 2: Map of south-east Nigeria showing rivers and major urbanisations (Iro, 2012)

The study area lies within the humid tropical rainforest belt with an annual rainfall of approximately 1800-3000mm (Abayomi et al. 2001). Vegetation in the area is controlled by topography (which varies mainly from flat to swamp like regions), relief and lithology, with anthropogenic factors such as abandoned industrial sites also playing a defining role (Igwe, 2005). The vegetation ranges from rainforest to Guinea Savannah (Iloeje 2010). Dense vegetation with high trees is prominent around streams and shaley lowlands while guinea vegetation and isolated trees are prominent on sandy soils in highland areas (Obiadi et al. 2011). The tropical soil of the area supports extensive plantation forests, such as Oil palm, Rubber, Cocoa and Bananas (Aregheore 2009). Human activities such as bush burning, agriculture and construction works have greatly modified the natural vegetation in the area, potentially contributing to the creation and extent of gullies (Ujoh, et al.2011).

Statement of the problem

The devastation caused by gully erosion in southeast Nigeria is very poorly quantified, in spite of a series of studies carried out by researchers. What is required is a method allowing a regional to national analysis which can be obtained through the use of low-cost medium resolution remote sensing data as proposed in this study. Understanding the development and dynamics of major gully sites through the methods proposed in this study will also allow preventative measures to be enacted to reduce the need for future intervention. This gully preventive measures will be nipped in the board when gully development and change over time have been well understood. The problems associated with gully erosion are immense and include; loss of life and houses, infrastructural collapse and loss of agricultural land. The extent, role, and development of gullying in the studied region remains unmapped, unabated and unresolved.

This research work will provide facility to methodically trace and track gully development from early stage onset to mature stage through the use of remote sensing and GIS. The method presented here is to vectorise/quantify gullies to determine rates of change and identify what predominant environmental conditions are exacerbating gully formation in the area

Methodology

This study adopts remote sensing and GIS methodologies in processing the satellite data. This involves study area DEM analysis and gully area analysis. In the case of this study, the remote sensing data used in this research were acquired from Landsat images from December 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 2000, 2001, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013, 2014 and 2015. Attempts to compile a complete annual data set were impeded by unavailability of Landsat images in the study area from 1994 – 1999. During this time period the data was not available, not because of cloud cover, but because of data acquisition issues within this period. The study area is found in the tropical region where the presence of cloud cover is extremely common throughout the year (Iloeje, 2010).

The spatial resolution of Landsat Images from 1986 onwards is 30m x 30m, and is applicable for the study area, as the study area covers a very large area of about

57,758.034Km2. Previous research by Nduji (2008), observed that studying the development of large gully through time is well suited to the use of Landsat images. The data have been used in other related studies such as Okereke et al., (2012) and Manandhar, (2009).

A common error occurring in Landsat data acquired after 2003, SLC-OFF, was corrected using Focal Analysis in the software package Erdas Imagine. The error occurred as a result of a failure of the Scan Line Corrector (SLC) onboard the Landsat 7 Enhanced Thematic Mapper (ETM) sensor on 31 May 2003. Since that time all Landsat ETM images have had wedge-shaped gaps on both sides of each scene, resulting in approximately 22% data loss (Zhang, et al. 2007). The processing technique applied to correct for this error has the ability to fill gaps in each band with data from the closest pixel values not affected by SLC-OFF **Figure 3**. It does this by calculating their standard deviation and mean values, with a method known as Gap-filling Landsat 7 SLC-off (Chen et al. 2011). The error does not exist for Landsat 8 data. Each Landsat 7 band acquired in the month of December 2003 to 2013 that was used in this study were subjected to Gap-filling to fill the SLC-off data. The bands are Bands 1, 2, 3, 4, 5 and 6. The choice of these six bands area where they distinguish land cover and land use from one another, and measure ways they change over time (Bahadur 2009).

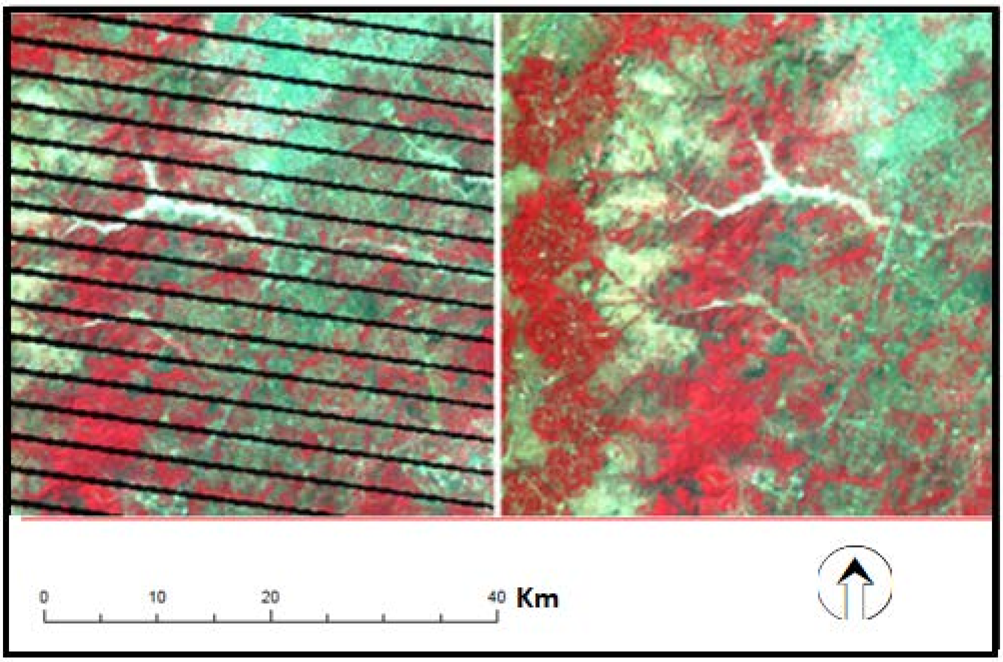

Figure 3: colour infrared Landsat 7 SLC-OFF data before and after correction (December 2013) with band combination of 4, 3, 2. (USGS 2013)

Google Earth images were used in order to aid analysis of gullies hidden from view in the Landsat images due to vegetation cover (Almeer 2012), weak spectral signatures, or because of the low spatial resolution of the Landsat image compared to the specific images sourced from Google Earth (Martinez-Casasnovas, 2003).

Google Earth images **Figure 4** were downloaded, and gully edges were digitized using the polygon tool from the Google Earth for digitization and quantification of the gully areas, starting from the first available year, 2006, to 2015 to act as a supporting dataset to the Landsat archive. Some of the gullies that are found in Landsat images are as well found in Google Earth images and they were digitized and measured to compare with Landsat measurement.

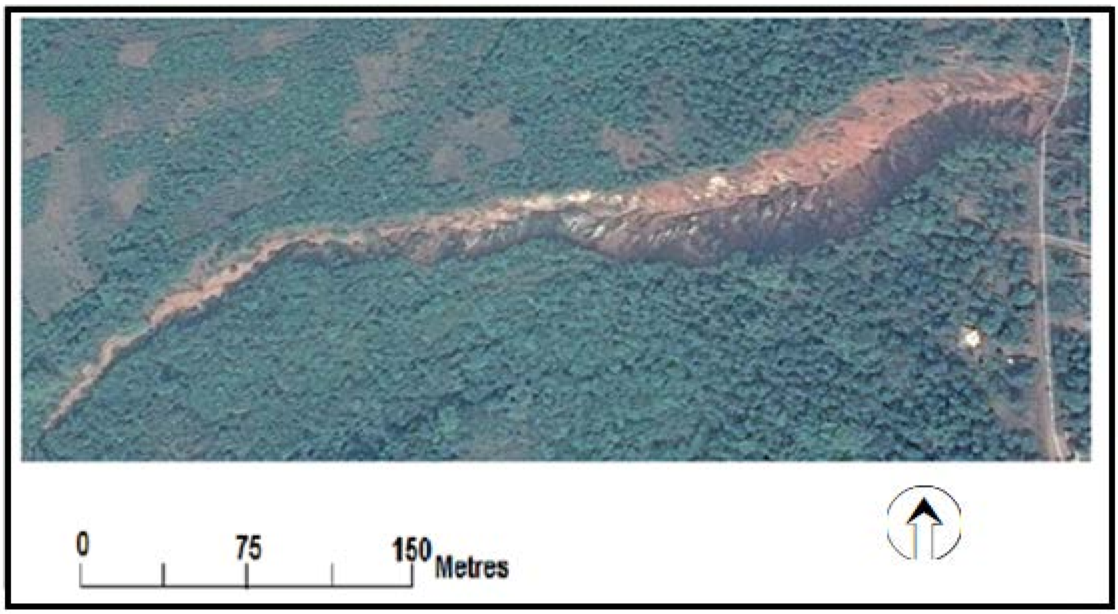

Figure 4: 2015 Google Image of Urualla gully site, SE Nigeria. (Google Earth image 2015)

Extracting Gully Test Sites for Analysis

Visual interpretation has long been a common method for detecting individual gullies from aerial photographs and satellite images. Some early examples are the interpretation of the one of the earliest photo images of Canadian Halifax Citadel of 1892 (Nicholson, 2003) where good examples being Nachtergaele and Poesen (1999) and Martinez-Casasnovas (2003). There have been many examples of Landsat, in particular, being used as the primary data source to extract information about Gully sites, some of them include (Shalab 2007; James et al. 2007; Zinck et al. 2001; Marakanye et al. 2012; Nduji, 2008; Okereke et al. 2012). In a similar manner, the Landsat archive will be used in this study to review and quantify the development of 4 of the 14 specific gully sites from 1986 to 2015. These are listed in **Table 1** with some visual example shown in **Figures 5**. The extracted information about the other 10 gully sites were done using downloaded Google images. The reliability of the Google images for this process was rechecked using extracted information from the 4 main gully sites, comparing with Landsat images. The 14 gully sites chosen for further analysis were the ones that can be observed visually both from the satellite and the Google Earth images used. Other gullies were covered by trees and buildings or deemed spectrally not good enough for analysis.

This method of digitization and quantification of Gully sites from the Satellite Images has been used by many Environmental scientists. Shalaby (2007), traced the gully patterns and monitored land cover changes in the North-western coastal zone of Egypt, using Landsat Images. Mararakanye, and Nethengwe (2012), equally utilized this approach in mapping areas devastated by gullies in South Africa. Nduji (2008), used this method in mapping and monitoring gully erosion sites in Nigeria. Also, this method can also be found in Hofle et al. (2013); and Taruvinga (2008) among others.

Table 1: The 14 Gully sites identified with their corresponding coordinates in Universal Transverse Mercator (UTM) in metres

	Gully Name	Easting	Northing		Gully Name	Easting	Northing
1	Njaba	279040.32	630127.83	8	Iyioku	330452.05	705080.71
2	Okigwe	290963.48	672395.90	9	Igboukwu	277896.15	676839.85
3	Orlu	283044.05	642487.15	10	Isinweke	317230.61	622463.35
4	Amucha	285607.00	633615.00	11	Nekede	277394.78	596903.36
5	Ngwo-1	323446.00	713518.00	12	Ngwo-2	323245.00	713784.00
6	Oguta	261516.24	632542.9	13	Urualla	285138.93	649246.3
7	Umuahia	328458.00	614902.00	14	Nawfia	685792.43	280062.58

Figure 51: Active gully-walls of Njaba Gully site

The chosen gullies are identified as Gully sites Iyioku, Okigwe, Njaba, Igboukwu, Orlu, Isinweke, Amucha, Nekede, Ngwo1, Ngwo2, Oguta, Umuahia, Urualla and Nawfia. Their coordinate details can be found in **Table 1**. Their identification as gully sites within the remote sensing imagery is possible partly due to distinct spectral properties but also as a result of unique shapes, subsoil exposure and typically reduced vegetation cover. Most importantly they are identifiable due to the clear spatial structure of rills and gullies.

Of the four large gullies initially analysed using Landsat data, the identified gullies of Iyioku and Okigwe were chosen due to their popularity as research areas (Nduji 2008) and for being subjected to government and Agency interventions (Okereke 2011). In comparison, Njaba and Igboukwu were chosen due to their relative youth which have calculated volumes size in 1986 of 38286m^2 and 27008 m^2 when compared with Iyioku and Okigwe with 1316860m^2 and 157543m^2 respectfully and the little or no government or agency intervention enacted. The further 10 gully sites were chosen due to their more recent development and their ability to be identified clearly from the Google earth image archive. The 14 main gully sites that were identified based on their coordinates and spectral values were digitised as shape files manually. An example can be seen in **Figure 6.** This process was carried out where possible for each gully, for each of the 30 years of Landsat images (except 1994-1999 values that were estimated with linear interpolation because of non-availability of Landsat data) and 10 years quality Google Earth images available for the study sites. Area estimates were then calculated in each case for the 14 gully sites to enable time series analysis and change detection. A total of 216 shapefiles were created using this process. To validate the use of the Google Earth image archive alongside the Landsat data, and as a form of quality assurance, the gullies were vectorised using both Landsat and Google Earth data for a sample of 3 of the 4 main gullies of Iyioku, Njaba and Igboukwu sites for the available years of 2006 - 2015. The Okigwe gully was not part of this process because Google Earth still has Landsat image covered on the area location of the gully. Pearson's correlation was conducted to determine if the gully area from Landsat correlates with gully area from Google Earth. Each gully was identically identified using the two different data sources at the 95% confidence level. For each gully examined a significant positive correlation ($p<0.05$) was shown with the lowest correlation being 0.723.

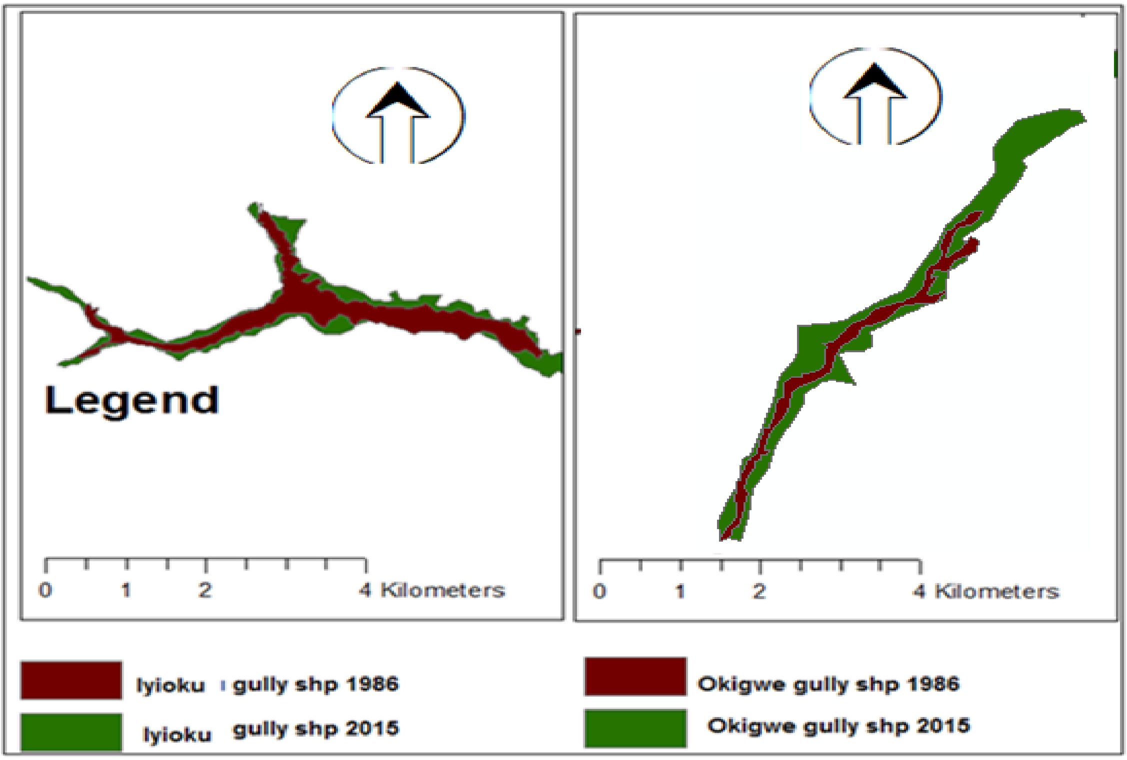

Figure 62: (a) Iyioku Gully shapefile 2015 overlaid by 1986 shapefile and (b) Okigwe Gully shapefile 2015 overlaid by 1986 shapefile

Presentation of the Results

This work tries to assess the 14 gully areas and their % change from 1986 – 2015 for older gullies and 2006 – 2015 for younger gullies respectively. The gully areas and % change graphs show how the gullies have been changing over the years. The older gullies Iyioku, Okigwe, Njaba and Igboukwu are shown in **Figures 7, 8, 9, and 10** respectively. They show that their development precedes 1986 but also, aside from Iyioku, that along the way gully % rate of change has been reducing. In gullies like Iyioku where in 2014 the % change is high, it could be attributed to meteorological changes. Linearly interpolated values are used throughout to account for the years 1994 – 1999, representing years of non-availability of Landsat imagery.

The more recently formed gullies of Orlu, Isinweke, Amucha, Nekede, Ngwo1, Urualla, Nawfia, Ngwo2, Oguta and Umuahia are shown in **Figures 11 - 20**. All of the displayed gullies are showing positive relationships between time and gully size although the proportional change each year is changeable. What is then apparent is that gullies are growing in general every year but the proportional change year on year is highly variable.

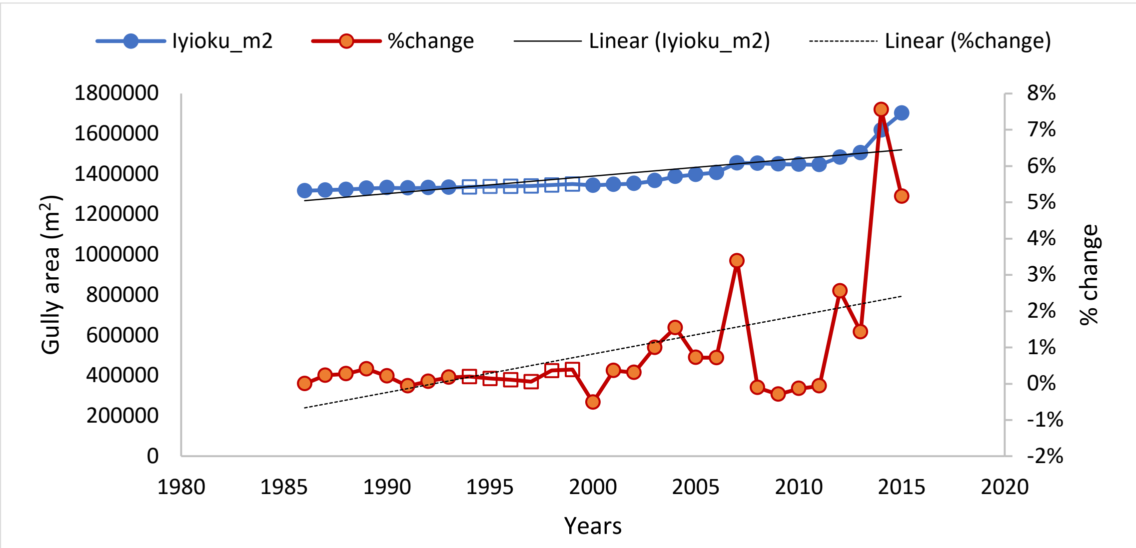

Figure 7: Iyioku Gully area and % change graph showing from 1986 – 2015 including interpolated values in white point. (Observed gully are in circle points while interpolated gully is in square points).

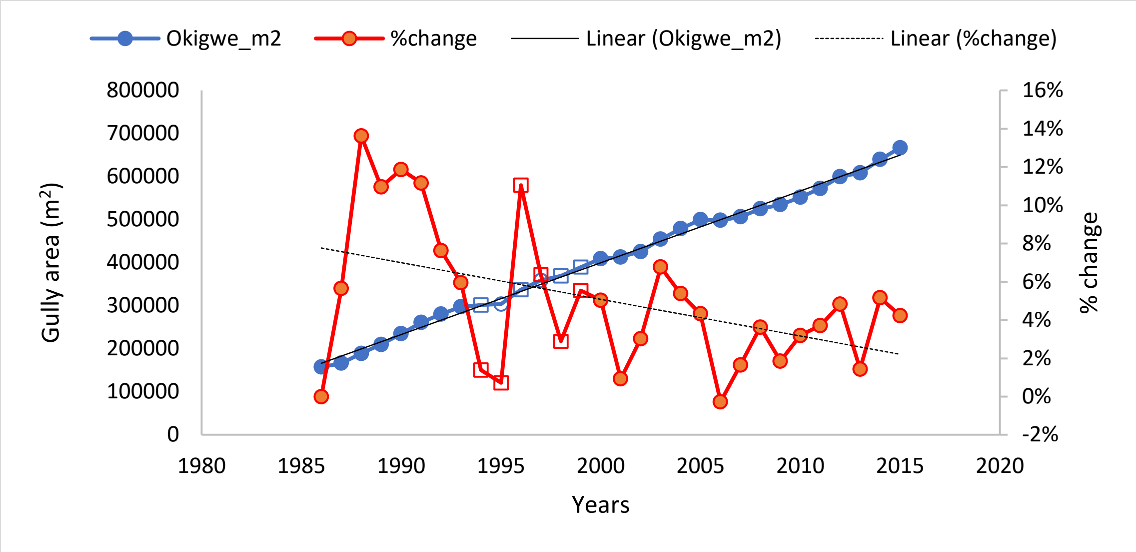

Figure 8: Okigwe Gully area and % change graph showing from 1986 – 2015 including interpolated values in square point. (Observed gully are in circle points while interpolated gully is in square points).

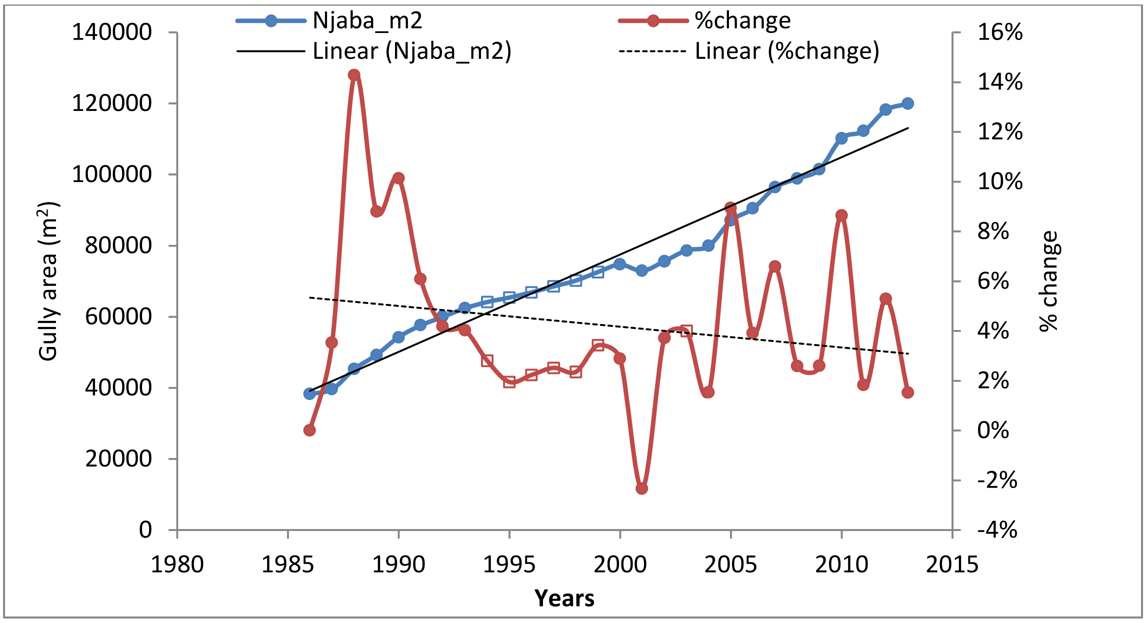

Figure 9: Njaba Gully area and % change graph showing from 1986 – 2015. Observed gully are in circle points while interpolated gully is in square points.

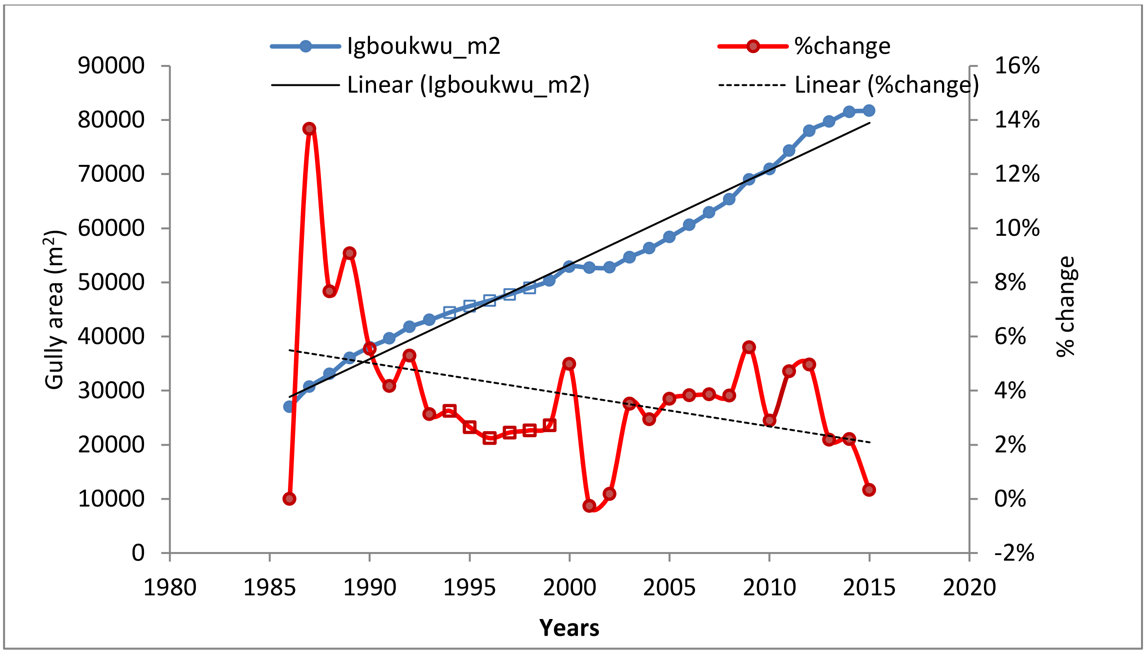

Figure10: Igboukwu Gully area and % change graph showing from 1986 – 2015. Observed gully are in circle points while interpolated gully is in square points.

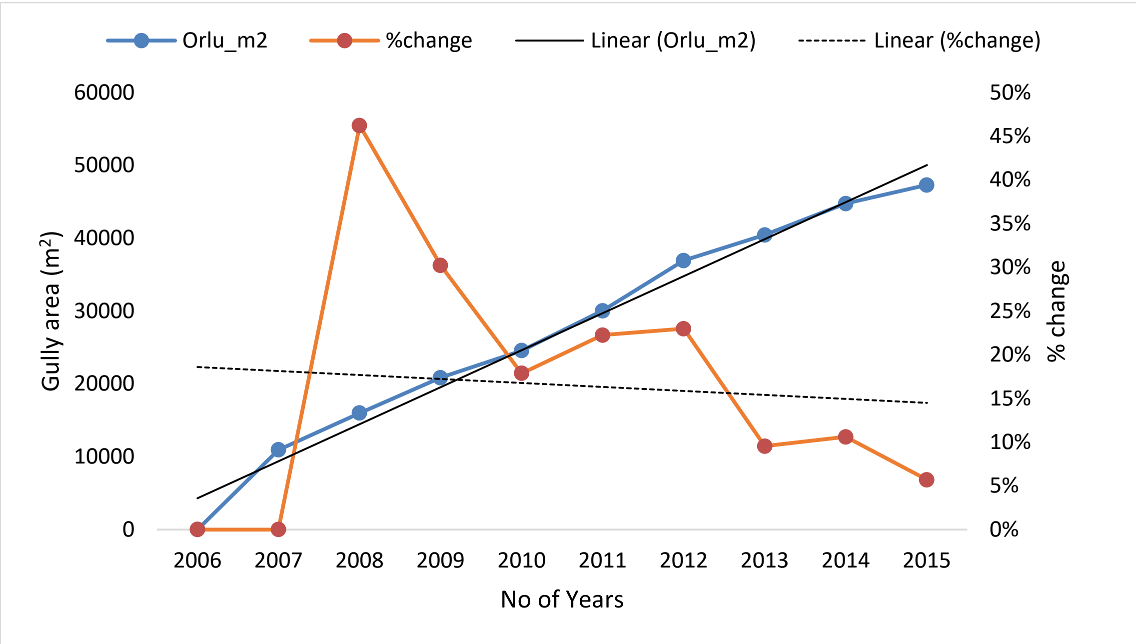

Figure 11: Orlu Gully area and % change graph showing from 2006 – 2015

Figure 12: Isinweke Gully area and % change graph showing from 2006 – 2015

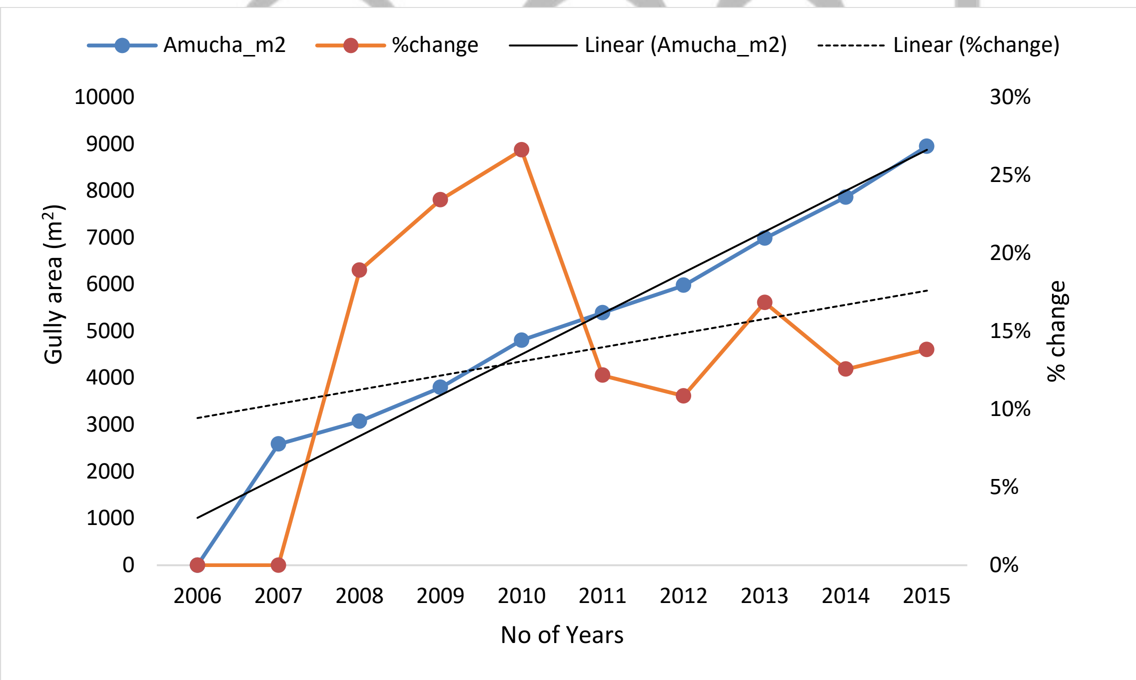

Figure 13: Amucha Gully area and % change graph showing from 2006 – 2015

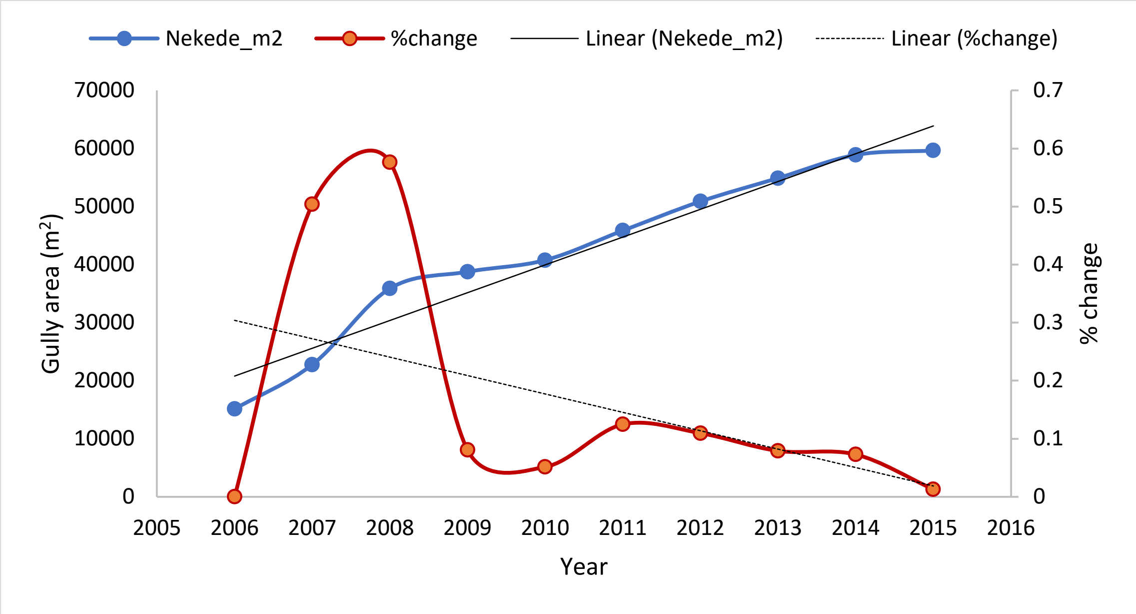

Figure 14: Nekede Gully area and % change graph showing from 2006 – 2015

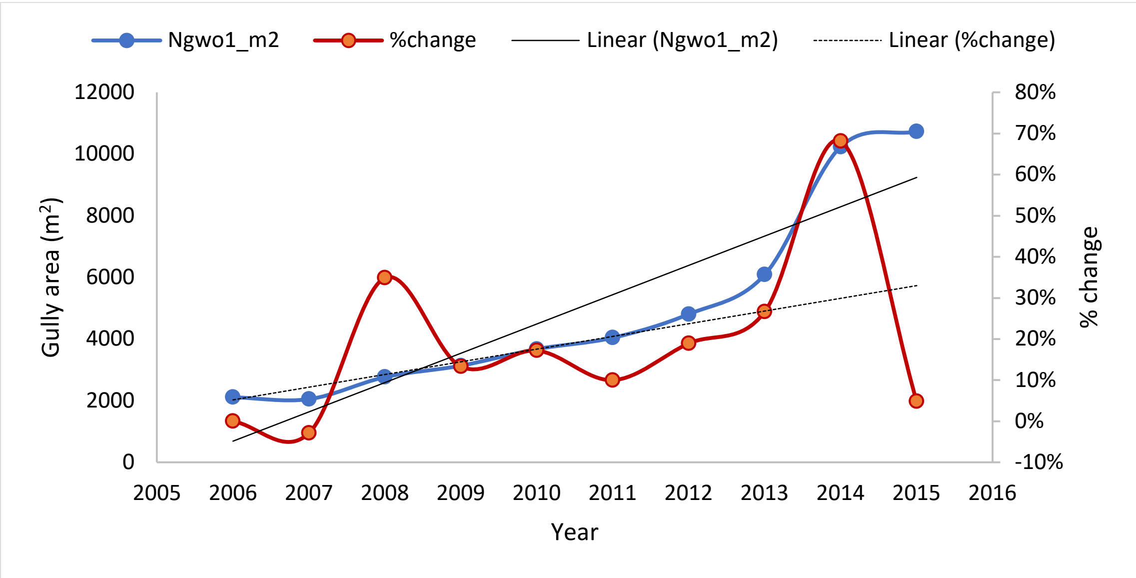

Figure 15: Ngwo1 Gully area and % change graph showing from 2006 – 2015

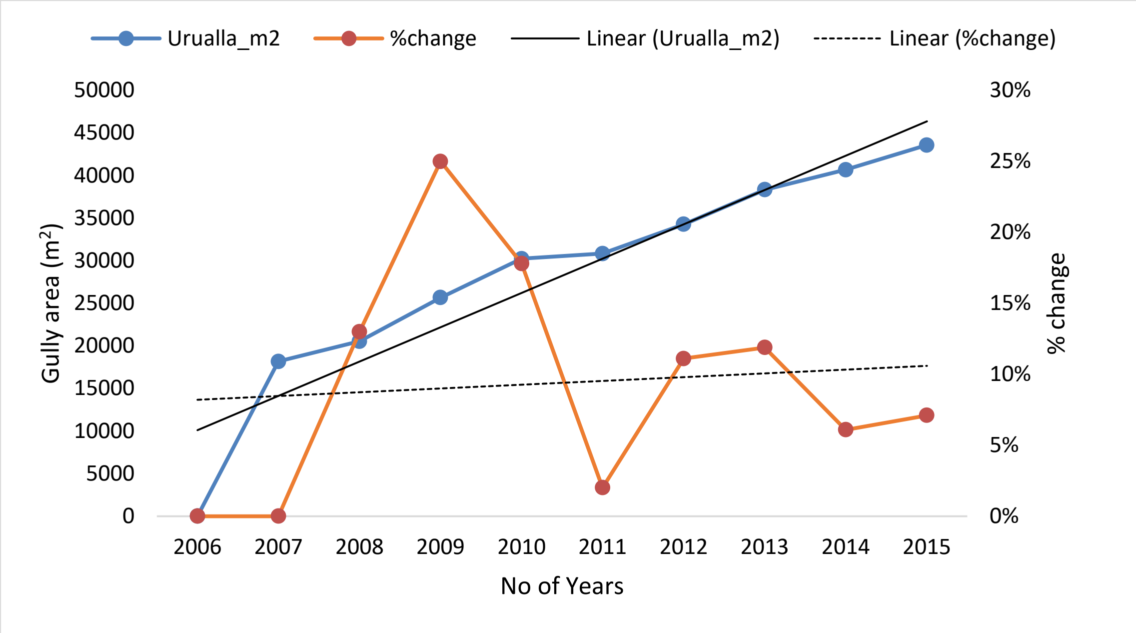

Figure 16: Urualla Gully area and % change graph showing from 2006 – 2015

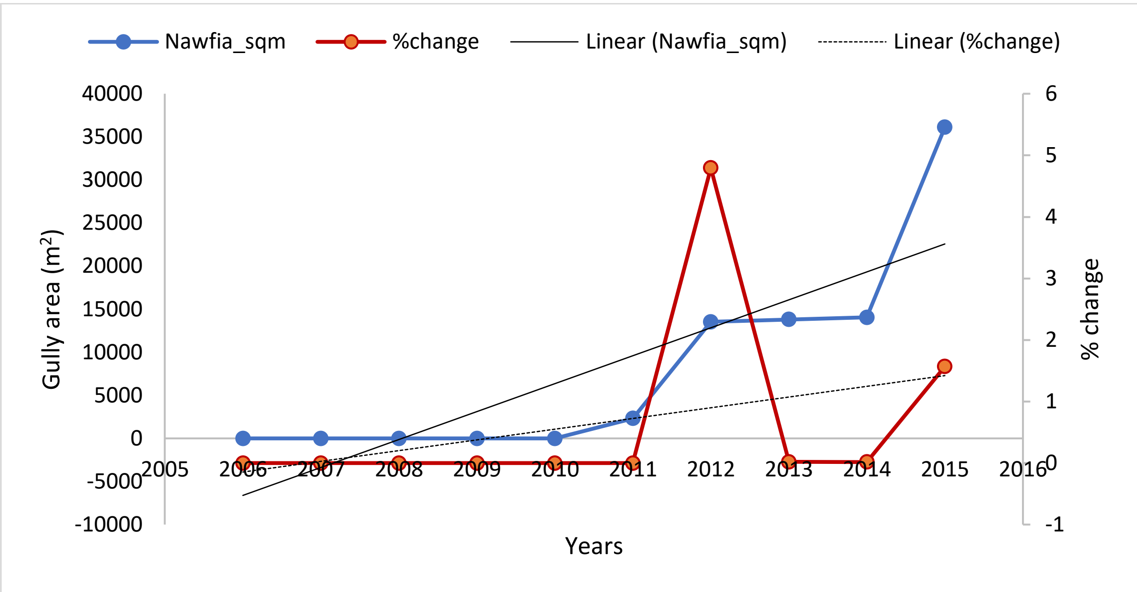

Figure 17 : Nawfia Gully area and % change graph showing from 2006 – 2015

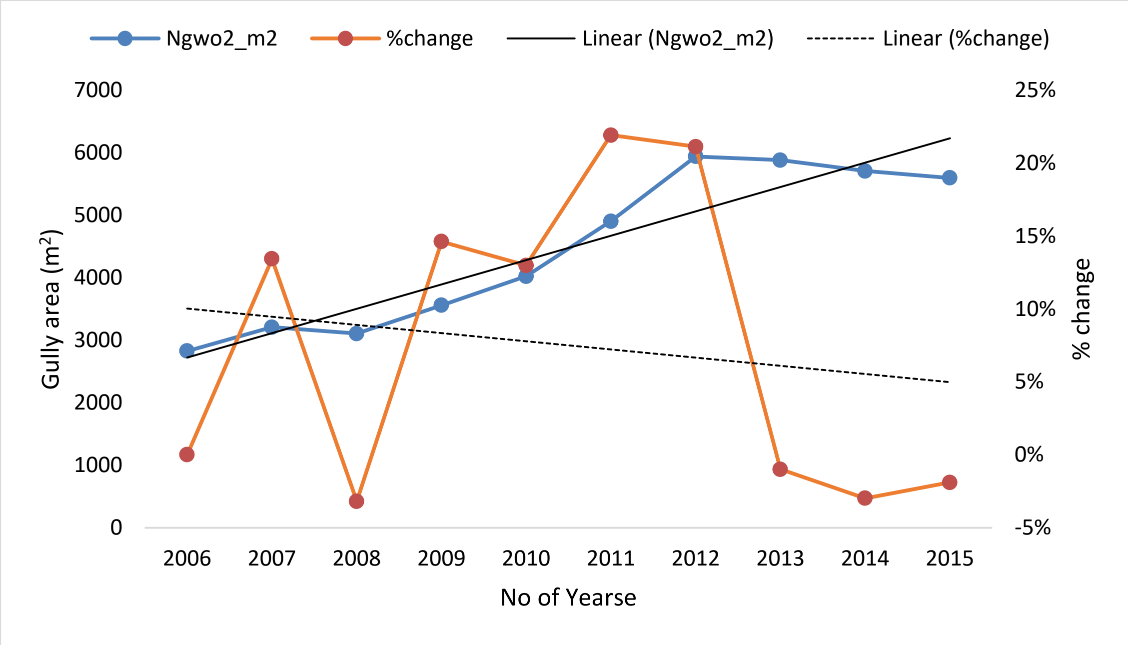

Figure 18: Ngwo2 Gully area and % change graph showing from 2006 – 2015

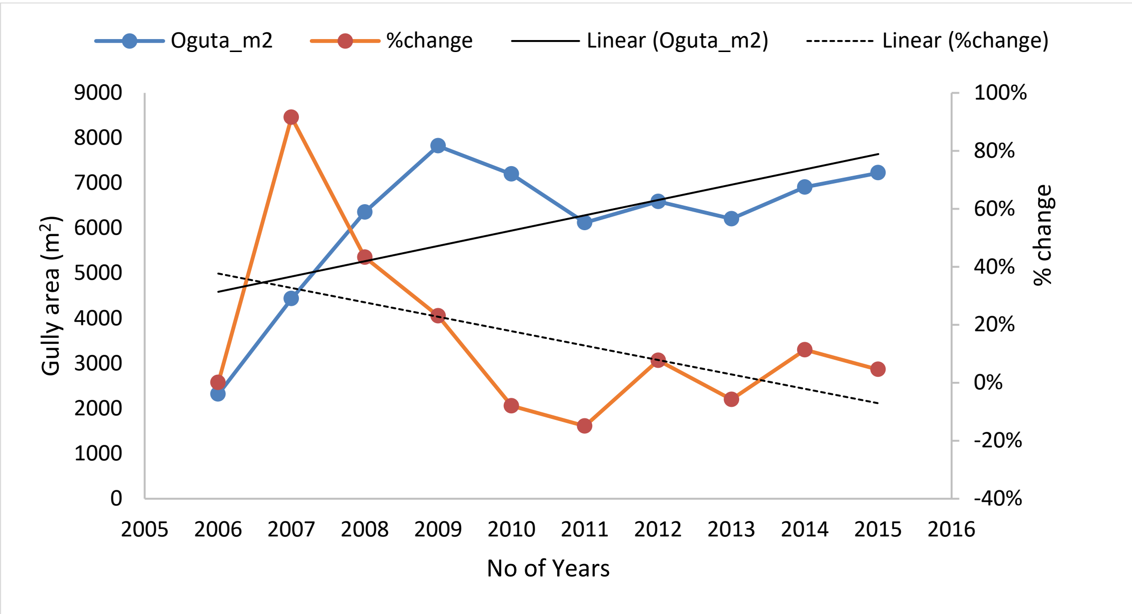

Figure 19: Oguta Gully area and % change graph showing from 2006 – 2015

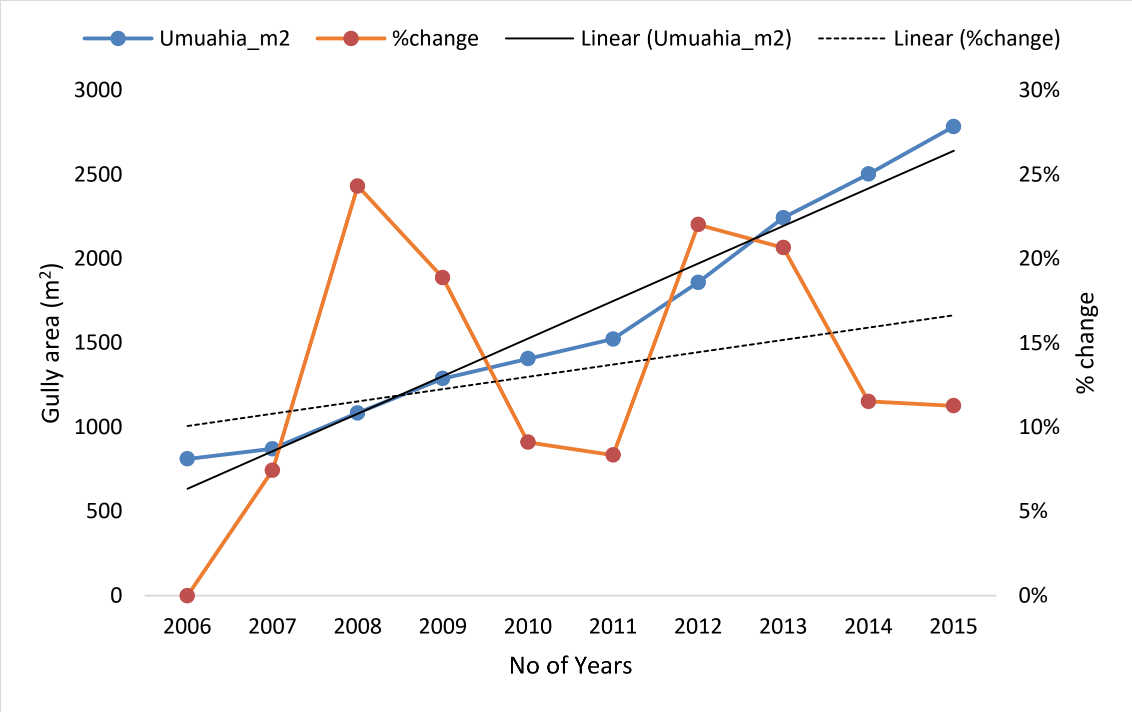

Figure 20: Umuahia Gully area and % change graph showing from 2006 – 2015

Discussion

Gully Extent and Rates of Change Over Identified Life Spans

The studied gullies have shown increases in area with time unless intervention has taken place. As examples the Iyioku and Njaba gullies have increased their area sizes from a level in 1986 of 1316860m^2, and 38286m^2 to 2015 1701881m^2, 114387m^2 respectively (**Table 2**). For Ngwo2 and Urualla from 2006 sizes of 2829m^2, and 0m^2 to 2015 levels of 5600m^2, and 43570m^2 respectively (**Table 2**). Anthony (2011) has reported, in work conducted on gully erosion of southeast Nigeria, that the Orlu gully increased from the year 2008 with area size of 18542m^2 to year 2009 with an area size of 21338m^2.

Looking at Gully area size and yearly gully change in metre squared per square metre for the 14 studied gullies to investigate the possibility of gullies having similar characteristics. For example, are yearly gully change in metre squared per square metre of gully size associated with the absolute size of the gully. For instance; Iyioku and Okigwe have similar characteristics in terms of gully area and at yearly gully change in metre squared per square metre. This can be found in 2015 gully areas and 2014/2015 yearly gully change in metre squared per square metre of 1701881m^2 and 0.05m^{2}yr^{-1} for each unit area and 666930m^2 and 0.04m^{2}yr^{-1} for each unit area respectively (**see Table 2**). In a similar fashion Urualla and Orlu gullies show similar characteristics, with (43569.9m^2, 0.07m^{2}yr^{-1}) and Orlu (47297m^2 - 0.05m^{2}yr^{-1}) respectively showing almost similar characteristics and magnitudes in area sizes and yearly gully change. The observation here tends to suggest that as gullies get old the more likely the yearly gully change in metre squared per square metre will reduce with younger gullies tending to have higher yearly gully change in metre squared per square metre as a percentage of size, but not in all gullies as can be seen in Oguta gully. The Oguta gully is younger than Iyioku but it continued to have some negative yearly gully change in metre squared per square metre. Also, Okigwe gully that is older, tends to have mostly positive yearly gully change in metre squared per square metre throughout the study period. This observation was as well recorded by Njoku, (2012) in the study of rate of gully change in Ohafia gully and Nkporo gully sites southeast Nigeria where Ohafia, which is older, had a reduced rate of change while Nkporo, which is younger, had a higher and faster rate of gully change irrespective of the gully area sizes.

Some factors can reduce or accelerate the yearly gully change irrespective of the gully age and gully size. For example, Columbus (2012) observed that Ngwo people have been controlling Ngwo2 gully. This study observed that this could be responsible for a reduction in the yearly gully change with negative proportional values reported of -0.01 in 2013 and -0.02 in 2015. This intervention is likely a reason why some gullies with large area sizes will cluster or have similar characteristics in terms of proportional yearly gully change with smaller gullies. For example Orlu gully with a vastly larger area size of 47297.2m^2 in 2015 and proportional yearly gully change of 0.05 and Oguta with area size of 7228.41m^2 and yearly proportional gully change of 0.05 possess the same rate of change and development characteristics The existence of a level of gully control measures at Orlu gully, as reported by Njaba council (2009), is an example where the theory of reduced rates for large gullies falls down. This is because the intervention is likely reducing the development to a lower level shared by the smaller gully. Examples like this are useful in determining the impact of intervention but are less useful in terms of establishing the drivers behind the erosion and gully development adding an unpredictable level of variability. A full understanding of this behaviour could only be achieved by monitoring entirely naturally developing gullies but allowing those that are affected indirectly by anthropogenic activity.

Long Term Gully Analysis, Extent and Rates of Change

Long term gullies are here defined as those gullies that have been developing prior to 1986 and have had some recognition by government, or environmental agencies in addition to some measure of study being carried out by researchers. The **Table 2** below reveals that the gullies have been in existence since before 1986 and as such the Landsat remote sensing record is unable to fully account for gully development for the full life cycles.

Table 2: Area covered in m2 by Iyioku, Okigwe, Njaba and Igboukwu Gullies from 1986-2015 (Years in red = linearly interpolated)

Years	Iyioku (m^2)	Okigwe_(m^2)	Njaba_(m^2)	Igboukwu_(m^2)
1986	1316860	157543	38286	27008
1987	1319890	166453	39635	30697
1988	1323453	189123	45289	33049
1989	1328842	209856	49279	36049
1990	1331644	234762	54279	38049
1991	1330812	260967	57582	39634
1992	1331674	280849	59990	41729
1993	1334004	297563	62406	43034
1994	1336634	301693	64160	44434
1995	1338543	303870	65413	45614
1996	1340042	337453	66875	46639
1997	1340784	358977	68562	47784
1998	1345643	369345	70179	48995
1999	1350931	389837	72586	50330
2000	1343984	409467	74679	52834
2001	1348847	413247	72934	52694
2002	1353001	425732	75649	52794
2003	1366532	454538	78679	54654
2004	1387634	478983	79883	56261
2005	1397650	499694	87025	58337
2006	1407632	498348	90424	60565
2007	1455212	506583	96375	62904
2008	1453652	524965	98866	65304
2009	1449421	534679	101426	68956
2010	1447452	551745	110196	70956
2011	1446541	572211	112200	74300
2012	1483450	599845	118134	77980
2013	1504673	608456	119924	79683
2014	1618323	639858	112056	81437
2015	1701881	666930	114387	81703

Iyioku and Okigwe Mature Gullies 1986-2015

From **Table 2** the two gully sites of Iyioku and Okigwe are shown to have developed prior to 1986 which marks the earliest extent of this study. The work of Nduji (2008) supports this. By the year 1990, some communities around and along Iyioku gully site, started independently to divert the run-off to catch-pits while giving farmers orders not to farm around the gully site. The evidence can be observed in 1991 when occupying an area of 1330812m^2, the gully receded along a negative trend of area changes of -832m^{2}yr^{-1} which presented as a temporary respite from erosion. The Iyioku gully which had an area of 1316860m^2 in 1986 exhibited a proportionately large estimated area change of 3030m^{2}yr^{-1} in 1986 – 1987 and developed to a size of 1701881m^2 by 2015. By 2015 the year on year area rate of change was a much higher than absolute area changes of 83558m^{2}yr^{-1}. A proportionate change was also exhibited between 2013/2014 but from observing the long-term trend of **Figure 7** the positive correlation between time and gully area is still evident although fluctuations in the proportionate area change continue. The containment from the communities, their positive mitigating actions, is believed to have resulted in the general fluctuations in the area rate of change which is as a result of unharmonized method of mitigation of the gully by those communities (Nduji 2008). The Iyioku gully is known to traverse 10 communities, with no harmonized agreement existing regarding the containment strategy (Nwaigwe et al. 2009). Some communities actively seek to control, while some do not. Generally, the response is guided by the immediate threat to livelihoods. This is potentially why there is inconsistency in its rate of area change over the study period regardless of mitigation strategies implemented.

The Okigwe gully site **Figure 8** began to threaten infrastructure including buildings, roads, electricity poles and water pipes by 1988 (Igbokwe, 1995). At this stage the gully covered 189123m^2, the threat to public infrastructure attracted state ministry of Environment and other agencies to intervene by 2000 and 2005 with cut and fill methods incorporated during the dry season to avoid run off. In addition, aggressive tree planting in and around the gully site took place during rainy season. This method was in agreement with the Food and Agricultural Organisation recommendation that gullies with very little water flow can be stabilized by filling and shaping, that is, if the surface water is diverted, and livestock and fire are kept out (FAO 2015). The year 2001 experienced a proportional area of change drop from 19630 m^{2}yr^{-1} to 3780m^{2}yr^{-1} and 2006 with area change of 20711m^{2}yr^{-1} to -1346m^{2}yr^{-1}. This gully has remained incessant in area size. The gully, which had an area of 157543m^2 in 1986 and experienced area change of 8910m^{2}yr^{-1} in 1986 – 1987, was calculated to have an area of 425732m^2 in 2002 and to have reduced to an area of change of 12485m^{2}yr^{-1} by 2002. By 2015, it had developed to an area of 666930m^2 but the area change increased to 27072m^{2}yr^{-1} between the years 2014 and 2015. The control measures could be the reason the gully started to reduce in size briefly in 2005/2006 with much less reduced area change evident more generally in 2001. What is not clear is why the area change fluctuated significantly. In 2014, an area of 639858m^2 is calculated and an area rate of change of 31402m^2 between 2013 and 2014, between 2014- 2015 the gully recorded a slowdown in absolute areal growth, seen in **Table 2**. This slowdown could be attributed to the measures which by now had started to stabilize and contain the gully development resulting in proportionate changes of <<4%. According to Okereke, (2013), the intervention of the Federal Ministry of Environment and Abia State Ministry of Environment is largely responsible for this successful control. The mitigation methods used were interventions like tree planting in and around the site, relocating people living around the gully site, and prohibiting people from cutting trees, hunting, and farming within 200 metres proximity. David, (2010) in his work "Poverty Leads to Environmental Degradation" reported that some of the government interventions could not work properly because the communities defy government orders to farm, fetch firewood and hunt around the gully sites but the observed slowdown in erosion brings a level of validity and success to some of the mitigation strategies.

Njaba and Igboukwu Young Gullies 1986 – 2015

In contrast to the older Iyioku and Okigwe gully sites, the Njaba (**Figure 9**) and Igboukwu (**Figure 10**) gullies are younger. The area size of Njaba in 1986 at the start of the study period was 38286m^2 with an area change of 1348m^2yr^{-1} estimated in 1986 – 1987 representing <4% proportional change. The gully continues to grow in size today, aided in its expansion by illegal sand mining along the site as observed from eyewitness evidence during fieldwork. Ukachi (2014), reported that illegal sand mining has been continuing since 1988 in the area and that the Njaba local government has been intervening to stop sand extraction in vulnerable areas since 2000. This study would suggest from the rapid increase in the area rate of change that this extraction activity precedes 1988. The area rate of erosion is exacerbated by sand miners defying public orders and, in some cases, security agents who have been employed to guard sites (Okorie, 2010) thus putting immediate economic gain above long term sustainability. The inconsistency in the control of the sand miners is a likely reason why by the year 2000, an area size of 74679m^2 is calculated for the Njaba gully but an area rate of change of -2226m^2yr-^{1} is exhibited between 2000-2001 resulting in an area size of 72934m^2 in 2001. Evidence that mitigation strategies have been effective and that not only controls but also refilling has taken place. In 2013-2014 a further significant reduction in gully area is seen of 112056 m^2 with an area rate of change of -7868 m^2yr^{-1} but by 2015, the area size of 114387m^2 has reported a positive area change once again of 2331 m^2yr^{-1} **Table 1 and Figure 9.** As stated earlier, the negative and positive area changes of this gully reflect the inability of Njaba Local Government and the communities to consistently prevent sand mining and other interference with the gully (Ukachi 2014).

The Igboukwu gully, seen in **Table 1 and Figure 10,** is located at the northern part of the Njaba gully. In 1986 the area size was 27008m^2 with the highest area rate of change of 3689 m^2yr^{-1} occurring between 1986-1987 and likely continuing a rapid increase in size evident prior to this year. By 1988 the area size was calculated to have grown to 33048m^2 with a further area rate of change of 2353 m^2yr^{-1} between 1988 and 1989 to produce an area size of 36049m^2 and subsequent area rate of change of 3000 m^2yr^{-1} from 1989-1990. The area change was found to have dropped to as low as $266m^2yr^{-1}$ between 2014-2015 but with an area in 2015 calculated of $81703m^2$. The reduced rate of change is a result of the implementation of runoff control in the area, constructed along the main runoff line (Patrick 2013). According to Patrick, gully bunds, catch-pits and runoff ponds were constructed along the major channels to reduce the influence of runoff to further control the expansion of the gully site. This mitigation strategy was in agreement with the recommendations of gully prevention and control laid out by Igbozurike (1989).

Medium Term Gully Analysis, Extent and Rates of Change

These are gullies that are younger when compared with the 4 gullies discussed above. Some of the gullies defined as medium term have formed post 1986 and could not be detected with Landsat due to its low resolution of 30m compared with Google Earth images covered in most of the study area. 2 – 3m resolution satellites are available over some selected gully sites. The inability of Landsat satellite images to detect these gullies can also be linked to ground feature cover like forest and structures (buildings).

The Newly Developed10 Gullies 2006-2015

The 10 gullies are detected by Google Earth images from the year 2006 when high resolution Google Earth images were introduced in some areas in the study area. As can be seen in the **Table 3** below, some gullies like Isinweke, Oguta and Ngwo2 could have developed earlier than 2006 but because of non-availability of high-resolution Google Earth imagery, the research could not detect it from the available open source images prior to this date.

Table 3: Area covered in m^2 by the 10 Gullies from 2006-2015

No of Years	Orlu_ m^2	Isinweke m^2	Amucha_ m^2	Nekede_ m^2	Ngwo2_ m^2	Oguta _m^2	Umuahia_ m^2	Urualla_ m^2	Ngwo1_ m^2	Nawfia_ m^2
2006	0	3837	0	15131	2829	2315	812	0	2112	0
2007	10945	4446	2588	22756	3209	4435	872	18170	2051	0
2008	16004	4971	3077	35876	3107	6356	1084	20532	2766.32	0
2009	20843	5190	3798	38765	3561	7823	1289	25665	3135.2	0
2010	24567	6209	4809	40765	4024	7198	1407	30235	3674.32	0
2011	30034	6843	5395	45850	4906	6121	1524	30842	4042	2334
2012	36934	7867	5980	50876	5943	6592	1860	34268	4807.34	13529
2013	40456	8210	6988	54896	5884	6209	2244	38342	6087	13812
2014	44749	9014	7866	58893	5708	6912	2503	40678	10234	14062
2015	47297	10186	8954	59652	5600	7228	2785	43570	10734	36120

Several of the featured gullies are growing with little or no mitigation/controls in place. A prime example is found in Orlu gully **Figure 11** showing an area size in 2006 of 0m^2. As with the majority of studied gullies, the most recent data marks the largest area size, recorded in 2015, when it recorded an area size of 47297m^2 with area rate of change of 2548m^{2}yr^{-1} between 2014 and 2015. The gully development has been shown to be positive and gradual in terms of absolute area increases but as a proportion the area rate of change has been gradually declining with the lowest proportional increase shown in 2014/2015. Although this gully was not being actively controlled by the community over the study period, the negative trend is likely a consequence of the natural revegetation taking place in some parts of the gully as a response to diverted runoff deposits. The sediments deposited along the gully area help control the runoff and encourage revegetation on some affected areas.

The Isinweke gully that has area size of 3837m^2 in 2006 and recorded the highest area rate of change of 1024m^{2}yr^{-1} in the year 2011/2012 is shown in **Figure 12**. This gully has been growing in size but with a fluctuating proportional area rate of change over the years. The lowest area rate of area change was recorded of 343m^{2}yr^{-1} in 2012/2013. The accepted reason, taken from Eke (2014), is that control measures were adopted by a family whose house was threatened by the gully. These control measures involved diversion of runoff and tree and grass planting. As of 2015 the gully has continued to develop to an area size of 1172m^2 which could be that the gully overwhelmed the control measures although the linear development in terms of size increases largely remains consistent throughout the study period.

The Amucha gully shown in **Figure 13** is only detectable post 2006. The highest area rate of change is seen between 2014/2015 at 1088m^{2}yr^{-1} but doesn't represent the largest propotional change which is associated with 2009/10. Prior to 2015, the area change has been gradual with a generally linear relationship exhibited between time and area. At this gully site a notable event occurred with the closure of the track road in 2007 that crossed the gully to farmland used by the Amucha and Umuezike community. The road could have been an instigator of the gully erosion with the effects only visible post road closure. The increase in proportional erosion rises to a maximum of approximately 27% in 2009/10 before substantially reducing in the following years. Later, the farmers reopened the road in 2012/2013 (Njaba council, 2014) leading to a more variable area rate of change. For example, in 2010/2011 and 2011/2012 the gully was recording area changes of 586m^{2}yr^{-1} and 585m^{2}yr^{-1} respectively and rose to 1007m^{2}yr^{-1} area change by 2012/2013 marking a 17% proportional increase. In a similar way to Orlu gully the large proportional increases were seen in the early years of development before reducing to a variable but much lower area rate of change. Interestingly it is the absolute area change that remains the more consistent over the study period.

Nekede gully **Figure 14** follows almost the same trend as the Amucha gully. Okoro et al. (2011) report that the MCC sand Mine Company is largely responsible for the gully development and contribute to the gully increase in size, from the year 2008 with area size of 35876m^2 and area change between 2008/2009 of 2889m^{2}yr^{-1}. The gully has increased in area size consistently over the study period even following intervention from Imo state government to stop the illegal sand mine in 2008. This measure did not cause drastic reduction as the gully continued to grow in area that by 2013/2014 it had increased to area change of 3997^{2}yr^{-1}, adding toan area of 58893m^2 in 2014, but shows a slow growth in 2015 with area size of 59652m^2, with area rate of change for 2014/15 of 759m^{2}yr^{-1} less than what is obtained through out the study period.

The Ngwo1 **Figure 15** was estimated to have an area size of 2112m^2 and area change of -61m^{2}yr^{-1} by 2006/2007 but the gully continued to grow in area size. The highest area change was reported in 2012/2013 of 1280m^{2}y^{r-1} with area size of 6087m^2 but in between 2007 and 2015 the gully has continued to increase in size with the similar trend in high proportional area rate of change at the early stage of development and generally linear increase in absolute size with time. There is no reported intervention at this site within the timeframe of the study.

Urualla gully **Figure 16** again exhibits similar trends. The highest area changes of 5133m^{2}yr^{-1} is recorded in 2008/2009. According to Levi et al. (2013) the communities had been trying to contain the gully since 2011, but to no avail. The main runoff was later diverted to a more stable area through a channel in 2013 although, a neighboring community then channeled runoff to the area once again in the same year 2013. The gully, in a similar way to the majority of other gullies has experience a linear increase in size while exhibiting the variable proportional increases between 2006 to 2015 with the peak proportional change exhibited in 2013.

The Ngwo2 **Figure 18**, and Oguta **Figure 19** have a different trend to the majority of other gullies studied. As well as these the Nawfia gully is characterized by different behaviour in regard to area rate of change and size. The Nawfia gully **Figure 17** did not develop until 2011, the community reported that its development followed a road construction in 2010 close to the gully site (Okonkwo 2014). From 2011 to 2012 it exhibited an area rate of change of 11195m^{2}yr^{-1} to an area size of 13529m^2 in 2012. Active efforts were made by the community to contain its development but all to no avail (Okonkwo 2014). Following these mitigation events an increase in size was still recorded in 2015 due to the Nawfia road reconstruction in 2014, which required a rerooting of runoff back to the original site.

The Ngwo2 gully according to Ngwo people developed prior to 2006. The Ngwo community and the other adjourning communities close to the gully have been containing it through cut and fill of some arears close to roads and houses (Columbus, 2012). This agrees with the Food and Agricultural Organisation's recommendation to handle gullies as also adopted at the Okigwe gully site. That was the reason why the gully has been reporting slow and negative area change since 2012. Between2006 and 2007 the gully area size was 2829m^2 rising to 3209m^2 due to an area change of 380m^{2}yr^{-1}. The gully reduced in area between 2007 and 2008 with -103m^{2}yr^{-1}. The largest area changes of 1037m^{2}yr^{-1} was exhibited between

2011 and 2012 with the gully measuring 5943m^2. The mitigation methods were employed from 2012. At which point proportional changes were vastly reduced with sub 1% increases and even decreases in size were recorded. The relationship between the area and time deviates from the more consistent linear trend seen at other sites.

Oguta gully, according to Oguta Local Council (Eke 2014) developed when oil companies were moving their machines for crude oil exploration and exploitation. Before 2006 the gully was being contained by the community, local council and individuals. In 2006-2007, the area size was 2315m^2 and 4435m^2 and the gully has an area change of 2120m^{2}yr^{-1}. The gully increased in size until 2009 from which point changes were negligible or negative, with the 2009 gully size not being exceeded for the remainder of the study period**.** The mitigation strategies used here were cut and fill with grass planting which was employed in 2009 with immediate benefit (Eke 2014). The strategy truly contained the gully from this point on with the 2009 levels not exceeded for the remainder of the study period except 2014 and 2015 where there is marginal increase in area change.

The Umuahia gully returns to the more typical trend of the linear increase in gully size with respect to the year. With a strong correlation shown between these variables. In 2006 and 2007 the gully has an area of 812m^2 and 872m^2 respectively with an area change of a minimal 60m^{2}yr^{-1}. Typical to the development of the younger gullies in this study, the early development is characterized by large per centage changes peaking at approximately 24% for this particular gully. Although the gully is growing proportionally very quickly the gully has been adequately contained by the road contractors working at Enugu – Port Harcourt road who have prevented the gully from rapidly developing from a small to large scale feature. The contractors used soil to fill some parts of the gully to aid their working conditions and has encouraged vegetation to grow in those areas not experiencing high runoff (Okeke et al 2012). The containment was not deliberate, and the benefits are not easily visible as a constant increase in gully size is still visible in, although the proportional increase in gully rate of change has fluctuated with the main reductions in rate visible between 2008 and 2011.

Conclusion

The research has determined the quantification of gully extent, rates of change and rate of yearly gully change in meter squared per square meter of gully sites over identified life spans in a very successful manner which will allow site specific rather than generic trends to be identified. This study has detected changes in gully dimensions in association with Digital Elevation Models (DEM) and Mapped dynamics of deforestation and forest degradation in southeast Nigeria forests using radar satellite data and has successfully identified links between gully erosion rate and vegetation removal on the local and regional scale.

Following the identified causes and rate of gully change in the study area which has shown the ability of using remote sensing and GIS to monitor gully development, mitigation measures can now be put in place to prevent further gully development and be able to control already developed ones on a local and regional level and through civilian or governmental pathways.

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