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Table of Contents: Volume 6 Number 10 October 2015

ARTICLES

Research Articles

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Full Length Research Paper

Effects of integrating different soil and water conservation measures into hillside area closure on selected soil properties in Hawassa Zuria District, Ethiopia

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Land degradation is a serious global problem. Pursuant to the alarming environmental degradation, the government and non-governmental organizations have implemented various land rehabilitation programs. Among this the predominant one is area closures, through tree-planting and physical conservation measures such as terracing. This study was designed to investigate the impact of integrating soil and water conservation (SWC) measures into the area closure on the selected soil properties based on comparative analysis between closed area with SWC, closed area without SWC and open grazing land. A total of 30 composite soil samples from 0 to 15 cm depth were collected with 10 replications from each land uses. Soil parameters such as bulk density (BD), soil moisture content (MC), soil organic matter (SOM), total nitrogen (TN), pH, electrical conductivity (EC) and texture were analyzed. Data was analyzed statistically by using SPSS software packages. Mean comparison were made by using Tukey HSD test at P = 0.05. Results showed that higher mean MC, SOM and TN were recorded under closed area with SWC than closed area without SWC and open grazing while mean EC and pH were comparatively lower under closed area with SWC. Texture, BD and C/N ratio shows no significant variation with land uses. These results indicated that integrating SWC measures into area closure have a potential to improve soil properties. The findings generally suggest that integrating SWC measures into area closure was found to be the better option to improve physico-chemical conditions of degraded lands. Additional research was also recommended for practical generalization considering other variables like vegetation parameters that were not addressed in this study.

Key words: Area closure, soil and water conservation, grazing land, soil, degradation.

INTRODUCTION

Land degradation is a serious global problem, which causes the world's 8.7 billion ha of agricultural land, pasture, forest and woodland that accounts nearly 2 billion ha (22.5%) have been degraded since 1950

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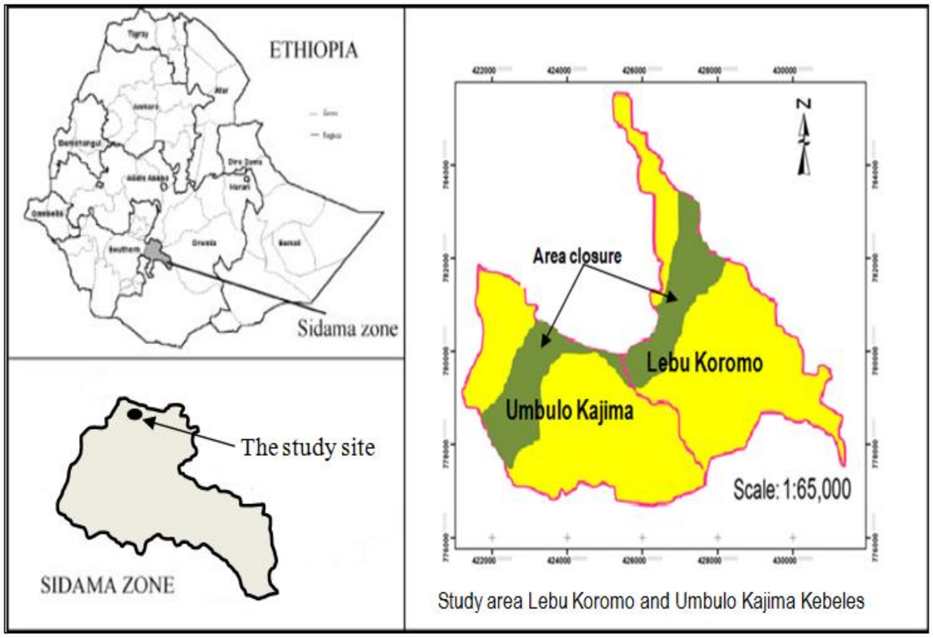

Figure 1. Map of the study area.

(Buckwell, 2009) and 5 to 10 million ha (0.36 to 0.71% of global arable land) are lost every year to severe degradation (WEF, 2010). Scherr and Yadav (1996) indicated that if such a severe trend of land degradation continues, 1.4 to 2.8% of the total agricultural, pasture and forest land will be lost by 2020.

Ethiopia has to struggle with numerous socio-economic and environmental challenges to achieve sustainable development. Land degradation is a typical phenomenon in many parts of the country. The expansion of agriculture, especially towards the steeper slopes due to ever-growing population, has accelerated soil erosion and land degradation (Daniel, 2002; Descheemaeker et al., 2006; Menale et al., 2008). In order to address the problems due soil degradation, biomass scarcity and loss of biodiversity, the reforestation/afforestation of degraded lands is often seen as the most effective rehabilitation technique in the tropics in general and Ethiopia in particular (Mulugeta and Demel, 2004). Among the various techniques of rehabilitation used, the predominant one probably is area closures, through tree-planting and physical conservation measures.

Ethiopian highlands in general and Hawassa Zuria in particular are susceptible to land degradation on account of climate, topography and population pressure. For centuries, people have exerted large-scale changes on the hill side landscapes, primarily through deforestation, uncontrolled grazing, and agriculture practice. These anthropogenic impacts have resulted in heavy degradation mainly on the hilly landscape of Hawassa Zuria. Large scale deforestation on hilly slopes generates soil erosion which results in loss of nutrient-rich top soil and thereby reducing the crop yield. At the same time rapid run-off would reduce recharge of ground water, while siltation affects water reservoirs and lakes as it is the upper catchment of Awassa lake. Cultivated lands are also affected by wide and deep gullies. Hilly areas are severely degraded, rocky outcrops are commonly observed. Consequently the local community faces food insecurity, shortage of water, forage and fuel wood (MoWR, 2009).

To solve these problems a project known as "Sustainable Management of Soil, Forest and Water Resources as a pilot model for the rural development in SNNPR, Ethiopia" was imitated by CDA in 2008. The project aims were oriented on the application of area closure to enhance soil protection against water erosion through biological and physical measures and support water management. Therefore, this study intended to investigate the effect of integrating physical and/or biological SWC measures into the hillside area closure to restore the degraded area in the Umbulo Kajimma and Labu Koromo kebeles, Hawassa Zuria District.

METHODOLOGY

Description of the study area

This study was carried out at Umbulo Kajimma and Labu Koromo kebeles in Hawassa Zuria District, in the southern Ethiopia. Umbulo Kajimma kebele and Labu Koromo Kebeles are located in (7° 1' 45'' N, 38° 16'30'' E) and (7° 6' 30'' N, 38° 22'45'' E) (Figure 1). The total population in the area is rural dwellers with a population density of 465.5 people/Km^2 (MoWR, 2009). In terms of agro-climatic zone, Hawassa Zuria district falls within dry *woina-dega* (or mid altitude) category. There is no river that flows through the district. The only water resource available is Lake Hawassa, one of the biggest lakes within the rift valley. The mean altitude of the district is 1,700 m above sea level and the annual rainfall ranges between 900 to 1400 mm. The rainy season spreads from March through September. Mean annual temperature ranges from 23 to 27°C (EOSA, 2007). Well drained eutric and hablic cambisol are the dominant soil types and excessively drained, deep to very deep, medium and course textured vitric Andosols are also developed on flat to gently undulating topography and rolling plain. The major landforms identified in the study area are level plains, rolling plains, hills, elongated escarpments and mountains with slopes ranging from level to very steep slopes (0 to 30%) (MoWR, 2009).

The natural vegetation in the area can be described and characterized in to two distinct categories. The one is dry afro montane vegetation occurring at higher altitudes of the hilly slopes. The second vegetation type is the lowland acacia woodlands occurring at the lower landscape of the hilly sides. Those woodlands in the highlands have a remnant tree also of high forest species which are sparsely available. However, because of high population pressure and extreme land shortage these forests are seriously threated by agricultural conversion and over grazing. The major woody species dominating the area are acacia species, *Albizia gummifera, Albizia schimperiana, Balanites aegyptiaca, Croton macrostachyus, Ficus sycomorus*, *Maytenus undata, Rhus natalensis* are common (Figure 1).

Sampling and data collection method

A reconnaissance survey was conducted to get the general overview of the area and to identify the study site containing both biophysically conserved and non-conserved adjacent areas having similar histories. According to the information provided by local elders, 50 years ago the whole hillside was fully covered with forest that has been degraded with time due to lack of ownership. Peoples of the Hawassa Zuria District and peoples from adjoining district have exploited the forest for construction, fuel wood and fencing. Expansion of cultivation land as the number of population increase was also led the residents to clear the forest and to put the area under severe degradation. The area closure was established 8 years ago on some part of the degraded hillside and some part of the hillside is still under severe degradation due to overgrazing.

For the purpose of this research some part of the area closure and the adjacent open grazing land which have the same slope, soil parent material and history but with different management intervention were selected. Then, the selected site was categorized in to three management units (closed area with SWC, closed area without SWC and open grazing land). The open area was included for the purpose of comparison as a control. Basically, the sites which were classified as closed area with SWC was (the site closed from interference of animals at which both biological (like enrichment planting) and structural (like bunds, trench, check dams, pits, ditches, gabions and ponds) SWC measures were commonly implemented), while closed area without SWC was (the site which was simply closed from the interference of human practice and livestock at which there is no management practices) and adjacent open grazing land.

Selected soil parameters sampling and measurement

To collect data from each land management units transects were established at a minimum distance of 70 m from each other. Along each transect, a 10 m * 10 m soil sampling plot were set with 50 m interval. Soil pits were dug at the middle point of each plot to collect undisturbed soil samples by core sampler for bulk density and moisture content determination. Before digging the pit surface soil 0 to 15 cm depth was collected by auger from each corner and the center of the plot. The collected samples from the three sites were mixed thoroughly and separately to form a composite soil 30 samples (3 land use × 10 replication). From each 1 kg of mixed samples was taken to Oromia National Soil Laboratory Ziway Soil Research Center for further analysis. Major live plants materials (roots and shoots) in each sample were separated by hand and then, soils samples were air dried, and pass through a 2 mm sieve for determination of selected soil properties. Particle size analyses were determined by using the Hydrometer method (Gee and Bauder, 1982), soil bulk densities were determined from the oven dry (at 105°C for 24 h) mass of soil in the core sampler and volume of the undisturbed soil cores using core sample method (Landon, 1991) and soil moisture content were determined gravimetrically by using core sample method. Organic carbon was determined by using Walkley-Black method and total nitrogen was determined by Kjeldhal Method (Bremmer and Mulvaney, 1982), pH was determined in water suspension with soil to water ratio 1:2.5 by pH meter and electrical conductivity was determined in water suspension with soil to water ratio 1:2.5 by Conductivity meter (Rhoades, 1996).

Data analysis method

Statistical analyses were performed to test the influence of soil and water conservation measures on soil properties using one-way ANOVA, and mean comparisons were made using the Tukey HSD test with $p < 0.05$. Pearson correlation was also used to correlate different soil parameters. The analysis was done by statistical software for social science (SPSS) version 17.

RESULTS AND DISCUSSION

Impacts of soil and water conservation measures on soil properties

Soil physical properties (texture, bulk density and moisture content)

Sand, silt and clay fractions and soil bulk density showed no significant difference with land uses while moisture content varied significantly ($p = 0.0004$) with land uses (Table 1). The soil under the three land use types was categorized as sandy clay loam textural class. Bulk density was not significantly affected with land uses. This may be due to the course textural nature of the soil of the study site or may be due to the age of the area closure. Wolde (2004) found that coarse-textured soil bulk densities were not affected by grazing intensity but, the slight difference found in this study can be explained by their difference in SOM content and compaction due to livestock trampling effect. Mulugeta and Karl (2010) and Yihenew et al. (2009) also reported that soil under non-conserved treatment was found to exhibit higher soil bulk density than treatments by SWC structures. The non-significant difference in texture may be due to the age of the area closure which was five years that can't make significant change on weathering.

The findings also indicated that mean soil moisture content under closed area with SWC (17.65±0.69) was

Table 1. Mean values (±SEM) of selected soil physical properties of 0 to 15 cm soil depth at different land uses.

Land use	Soil parameter				
	Sand (%)	Clay (%)	Silt (%)	BD (g/cm^3)	MC (%)
Open grazing	55.33(±2.290)[a]	34(±2.309)[a]	10.67(±0.989)[a]	1.053(±0.049)[a]	11.422(±0.897)[b]
Closed without SWC	54.33(±2.092)[a]	37(±1.528)[a]	8.67(±0.667)[a]	1.024(±0.031)[a]	13.562(±0.951)[b]
Closed with SWC	51.33(±1.978)[a]	38.67(±1.520)[a]	10(±0.730)[a]	0.927(±0.029)[a]	17.65(±0.692)[a]
P-Value	0.405	0.2193	0.2363	0.0729	0.0004**

** Significantly different at the 0.01 level; Bulk density (BD); soil moisture content (MC).

higher than under closed area without SWC (13.56±0.95) and open grazing land (11.42±0.9) which may be a result of water conservation structures which reduces runoff and evaporation and increases infiltration and soil moisture content (Stroosnijder and Hoogmoed, 2004). Other studies also showed that soil water content is a factor that can be affected by land use type because of changes produced in infiltration, surface runoff, and evaporation (Zhai et al., 1990; Demir et al., 2007). It may also be due to higher organic matter content in closed area with SWC which is positively and significantly correlated with soil moisture content. Overgrazing and trampling by cattle and other unsustainable land management practices have resulted in the expansion of degraded landscapes with a sealed surface soil that impedes water infiltration and reduces the moisture content as a result of exposure of the soil to the sun emanated from the reduced ground cover (Mando et al., 2001; Maitima et al., 2009). Morgan (2005) also showed that the loss of vegetation due to overgrazing increases the rate of run off and erosion and decreases the amount of water in the soil.

Soil chemical properties

The total nitrogen ($p = 0.0002$), soil organic matter ($p = 0.0139$) and total carbon ($p = 0.0139$) were varied significantly with land uses. The mean TN, SOM and TC were higher under closed area with and without SWC than in under adjacent open grazing land. The carbon to nitrogen ratio (C/N) did not show significant difference with land uses (Table 2). The electrical conductivity (EC) and pH shows significant difference ($p = 0.0285$) and ($p = 0.0332$), respectively, with land uses and the mean EC and pH under closed area with SWC were lower than in open grazing land while no significant difference ($p > 0.05$) was observed between closed area with and without SWC and also between closed area without SWC and open grazing land (Table 2). SOM, TN, TC and soil moisture content were positively correlated with each other. EC and pH also have significantly positive correlation ($p = 0.01$) with each other while negatively correlated with TC, SOM and TN (Table 3).

The mean SOM and TC contents under closed area with SWC were higher than the contents under closed area without SWC but mean SOM and TC under closed area with and without SWC were higher than in adjacent grazing land which may be due to the higher accumulation of organic materials as a result of increased plant biomass. SWC practices can bring current land use systems to a higher above and below ground biomass (and hence SOC) level by enhancing better ground cover. Stroosnijder and Hoogmoed (2004) also reported that the rainwater conserved through SWC structures is used for higher biomass production which in turn increases the organic matter content in the soil through litter and root decomposition. Dereje et al. (2003) reported similar result that inputs from the vegetation can have a positive impact on the organic carbon concentrations into the soil system. A study conducted by Wolde et al. (2007) shows soil organic matter and soil nutrients under area closure are significantly different compared to the adjacent free grazing lands. Studies by Yihenew et al. (2009) and Kebede et al. (2011) on crop field also reported that the non-conserved fields had lower SOC as compared to the conserved fields with different conservation measures. Mulugeta et al. (2005a, b) supported this result by reporting the decrease in vegetation cover and disturbance of the natural ecosystem have caused wide spread soil degradation, with an attendant decline in concentrations of soil organic matter (SOM). Dereje et al. (2003) indicated that temporal change in vegetation diversity and richness from lower to higher degree can change SOM concentration through the enhanced sediment trapping efficiency. Similar results were reported by Descheemaeker et al. (2006) in Tigray. The studies by Wolde and Veldkamp (2005) in Tigray on a semiarid continental climate indicated significant improvement in SOM and in total N an area closed for 5 years.

Lal and Bruce (1999) also generally indicated technologies for restoration of degraded soils by establishing ecological-based vegetation cover, using appropriate soil and water conservation measures, adopting water harvesting measures, enhancing nutrient recycling mechanisms, and controlling stocking rate. Adoption of these management practices increases the SOC stock through creating conducive medium for increasing above ground biomass and enhancing its

Table 2. Mean values (±SEM) of selected soil chemical properties of 0 to 15 cm soil depth at different land uses.

Land use	Soil parameter					
	TC	SOM	TN	C/N	EC	pH
Open grazing	0.593(±0.207)[b]	1.022(±0.357)[b]	0.071(±0.003)[b]	8.123(±2.521)[a]	0.207(±0.037)[a]	7.86(±0.205)[a]
CA without SWC	1.251(±0.161)[a]	2.155(±0.277)[a]	0.150(±0.006)[a]	8.264(±0.923)[a]	0.176(±0.031)[ab]	7.48(±0.188)[ab]
CA with SWC	1.387(±0.158)[a]	2.391(±0.273)[a]	0.138(±0.017)[a]	10.387(±0.919)[a]	0.093(±0.008)[b]	7.11(±0.144)[b]
P-value	0.0139*	0.0139*	0.0002**	0.5622	0.0285*	0.0332*

**Significantly different at the 0.01 level; * significantly different at the 0.05 level. Electro conductivity (EC) in (mmhos/cm), Total nitrogen (TN) in (%), Total carbon (TC) in (%), Soil organic matter (%) and carbon to nitrogen ratio (C/N).

humification (Singh and Lal, 2005).

The overall total nitrogen (TN) was higher under closed area with SWC than in soil under closed area without SWC. Mean TN under closed area with and without SWC was higher compared to the content under adjacent grazing land. The lower TN under open grazing land was due to lower organic matter content. Total N showed a significant correlation with SOM (+0.75, $p \leq 0.01$) (Table 3). Study by Kumlachew and Tamrat (2002) also reported that the total nitrogen content of the soil in different communities vary with the amount of organic matter. Mulugeta and Karl (2010) also reported that the land with physical SWC measures have high total nitrogen as compared to the non-conserved land. Million (2003) found that the mean total N content of the terraced site were higher than the average total N contents in the corresponding non-terraced sites. As carbon to nitrogen ratio (C/N) is an index of nutrient mineralization and immobilization where by low C/N ratio indicates higher rate of mineralization (Brady and Weil, 2002), rate of soil organic matter mineralization is lower under closed area with SWC. In addition, the lower C inputs because of less biomass C return on free grazing lands caused the reduction of SOM and TN (Girma, 1998). The most evident impact of grazing is the removal of a major part of above ground biomass by livestock that decreases the input of aboveground litter to the soil. Any reduction in litter inputs may have important consequences for soil nutrient conservation and cycling (Shariff et al., 1994).

The soil pH and EC under closed area with SWC were significantly lower than the soil under open grazing land which may be the result of relatively higher organic matter content in the closed area with SWC that increase H^+ in the soil that resulted into increase in soil acidity and reduces pH values. FAO (2005) showed that important chemical properties of soil organic matter are due to the weak acidic nature of humus. The higher EC under open grazing land may be as a result of higher evaporation rate that increase soil salinity level. This finding was supported by Seifi et al. (2010) report in that an increasing concentration of electrolytes (salts) like calcium salt (calcium carbonate) in soil will dramatically increase soil EC. Corwin and Lesch (2005) also showed that in arid climates, plant residue and mulch help soils to remain wetter and thus allow seasonal precipitation to be more effective in leaching salts from the surface and at the same time they reported that poor water infiltration can lead to poor drainage, water logging, and increased EC.

Conclusion

The result of the study indicated that soil parameters MC, SOM, TN, EC and pH show significant difference ($p<0.05$) while texture, BD and C/N ratio showed no significant variations with land uses. The soil properties in the area closure with SWC improving in some measured parameters such as moisture content, total nitrogen, soil organic matter, pH, EC as compared to closed area without SWC and open grazing land. Therefore, even if simple area closure without SWC can be an effective method to rehabilitating degraded hillsides incorporating SWC measures is the preferable way to speed up rehabilitation period. Generally, ecological rehabilitation/restoration can be an urgent and essential measure to solve the wide spread land degradation problems in Ethiopia. The present study also clearly indicated that to improve ecological components like soil it is more essential to incorporate different SWC measures in to the

Table 3. Correlation between selected soil properties.

	TC	SOM	TN	C/N	EC	PH	Clay	BD	MC
TC	1								
SOM	1.0(**)	1							
TN	0.751(**)	0.751(**)	1						
C/N	0.677(**)	0.677(**)	0.058	1					
EC	-0.667(**)	-0.667(**)	-0.412	-0.525(*)	1				
PH	-0.666(**)	-0.666(**)	-0.574(*)	-0.361	0.829(**)	1			
Clay	0.422	0.422	0.197	0.444	-0.390	-0.445	1		
BD	-0.625(**)	-0.625(**)	-0.517(*)	-0.410	0.594(**)	0.601(**)	-0.068	1	
MC	0.563(*)	0.563(*)	0.578(*)	0.209	-0.519(*)	-0.525(*)	0.187	-0.786(**)	1

Number of observation N= 30, ** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

area closure to foster the rehabilitation of degraded lands.

RECOMMENDATIONS

The present study has made the following recommends which could be helpful for the success of area closures as a means of rehabilitating degraded areas:

(i) Protecting the open degraded areas from interference of local people and animal grazing is the good option to assist the improvement soil physical and chemical properties.
(ii) Since carbon losses are related with loss of vegetation cover and soil erosion, management interventions that slow or reverse these processes can simultaneously achieve carbon sequestration. Area closure, thus, can be the good option to increase the stock of carbon in the soil and have the potentials of involving in carbon trading as a new forest valuation for sustainable natural resource management.
(iii) As SWC practices including area closure could protect and improve land resource, decrease sediment in downstream areas including lake Hawassa and improve hydrological condition and water quality of rivers, reduce disastrous flood and water logging, which could protect safety of lives and property through improvement of ecological conditions governmental and NGOs (especially, Lake Hawassa stakeholders) should give due attention to rehabilitate the whole hillside areas of the catchment.
(iv) Additional research is needed to more understand the interactive relationships among landscape positions, soil nutrients, management interventions, land uses and its history since vegetation and soil attributes depend on those factors.

Conflict of Interest

The authors have not declared any conflict of interest.

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Effect of lime and goat manure on soil acidity and maize (*Zea mays*) growth parameters at Kavutiri, Embu County- Central Kenya

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A greenhouse pot experiment was conducted to determine the effect of agricultural lime and goat manureon soil acidity and maize growth parameters using soils from Kavutiri-Embu County. Nitrogen and phosphorus fertilizers at the rates of 50 and 70 kg ha^{-1}, respectively, and goat manure at three rates (0, 5 and 10 mg ha^{-1}) and agricultural lime ($CaCO_3$) at six rates (0, 2.5, 5, 7.5, 10, and 12.5 mg ha^{-1}) were used for the study. The pot experiment was arranged in a complete randomised design and replicated three times. Maize, variety H513as test crop, was grown for a period of 8 weeks. The results were measured on maize crop parameters (plant heights, root lengths and dry matter biomass) and soil parameters (soil pH and exchangeable acidity). All the biophysical data generated were subjected to analysis of variance (ANOVA) and the difference between the treatments means separated using the Fischer's least significant difference at 5% probability level. Linear correlation analyses were done using the Microsoft Excel 2010. Results generally showed that soil acidity decreased with increasing levels of manure and lime. The treatment with 12.5 Mg ha^{-1} of lime and 10 Mg ha^{-1} of manure had the best reducing effect on soil acidity and better maize yield performances reflected in the highest pH (6.3), highest root length (41.3 cm), plant height (150.3 cm) and dry biomass weight (755.4 kg ha^{-1}) obtained.

Key words: Acid soil, agricultural lime, manure, maize productivity andpot experiment.

INTRODUCTION

Soil acidity is a major yield limiting factor for crop production worldwide. Land area affected by acidity is estimated at 4 billion hectares, representing approximately 30% of the total ice-free land area of the world (Sumner and Noble, 2003). In the tropics, substantial weathering of soils over millennia has resulted in the leaching of crop nutrient bases (mainly K, Mg and Ca) followed by their replacement by H, Al, Mn cations which have contributed to acid related stresses on crop production (Okalebo et al., 2009). Acid infertility factors limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements (Akinrinade et al., 2006).

In Kenya, acid soils cover about 13% of total land area and are distributed widely in the croplands of central and western Kenya regions, covering over one million hectares under maize, legume, tea and coffee crops, grown by over 5 million smallholder farmers (Gudu et al., 2007). Crop production is low and declining on such acid

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soils and particularly where acid forming fertilizers, such as di-ammonium phosphate (DAP) and other ammonia fertilizers have been applied continuously to already acidified soils over years (Nekesa, 2007). As these soils suffer in multi-nutrient deficiencies, application of mineral fertilizers has become mandatory to increase crop yields. However, mineral fertilizers are commonly scarce, costly; having imbalanced nutrition and their use could exacerbate the problem of soil acidity (Oguike et al., 2006; Nottidge et al., 2006). The practice of liming acid soils is not common in Sub-Saharan Africa (SSA), probably because of limited knowledge online usage and its effectiveness, availability and high hauling costs of liming materials (Okalebo et al., 2009).

Continuous cropping using incorrect fertilizer types has intensified soil chemical degradation of arable lands resulting in reduced capacity of soils to produce crops sustainably (Nandwa, 2003; Ayuke et al., 2007; Mugendi et al., 2007). According to Kisinyo et al. (2005), continuous cropping has led to development of soil acidity which is a major constraint to maize production on tropical soils due to toxic levels of aluminium (Al) and the concomitant phosphorus (P) deficiency that hinder plant growth.

The Fertilizer Use Recommendation Project (FURP) carried out between 1986 and 1991 by Kenyan Government in the rain-fed areas of the country, established area-specific and crop-specific fertiliser recommendations for various agro-ecological zones (KARI, 1994, Mochoge, 1992). Mochoge (1992) established that 29% of the trial sites which included quite a number from central Kenya and specifically Kavutiri area could not give conclusive fertiliser recommendations due to high soil acidity that affected the performance of most crops. Maize crop for example could not grow more than 100cm high. Kanyanjua et al. (2002), carried a liming study on some of these acid soils (pH 4.6) from central Kenya and came up with fertilizer and lime recommendations for the soils. The rates, however, they recommended were rather high that most resource poor farmers in the region cannot afford to purchase. Due to high cost of fertilizers and other farm inputs, management of acid infertility soils still remains a major challenge to smallholder subsistence farmers in the area and Sub-Saharan Africa at large. Hence theneed of searching for alternative ways and means of addressing soil acidity challenges (Makokha et al., 2001; Kimani et al., 2007). The main objective of this work, therefore, was to determine the combined effect of lime and manure on soil acidity improvement and maize productivity.

MATERIALS AND METHODS

The research was carried out for a period of eight weeks in a greenhouse pot experiment using soils from Kavutiri. Kavutiri is located in agro-climatic zone I at an altitude of 1700m above sea level (Jaetzold et al., 2007) on the eastern slopes of Mount Kenya, representing the acid soils of central Kenya. It is found at latitude 0°25´S and longitude 37°30´E with annual mean temperature of 18°C and total annual rainfall ranging from 1200 to 1400 mm. These soils are classified as Ando-humic Nitisols (Jaetzold et al., 2007) and are sandy-clay in texture. Soil samples from the top 0 to 20 cm were collected from a farmer's field at Kavutiri for laboratory analysis and pot experiment. The sampled soils from different points were thoroughly mixed to get one representative composite sample. The composite sample was used for pot experiment and for physical chemical soil characterisation. However, for physical and chemical analyses, the soil samples were air dried, ground and sieved to pass through a 2 mm sieve.

The soil samples were analysed for soil texture, pH, organic carbon, total N, extractable P, exchangeable Ca, Mg, Na and K, and cation-exchange capacity. Soil texture was determined by the Bouyoucos hydrometer method as outlined by Okalebo et al. (2002), soil pH was measured electrometrically in a 1:2.5 soil-water suspension (McLean, 1982), organic carbon was determined by the modified Walkley-Black method (Nelson and Sommers,1982), total nitrogen by the Micro Kjeldahl method (Bremner and Malvaney, 1982) whereas soil exchangeable bases were extracted using Mehlich-3 (M-3) procedures (Mehlich, 1984; Bolland et al., 2003). The extractable P was determined by Bray 1 Method (Bray and Kurtz, 1945). Cation exchange capacity was determined by the ammonium-acetate saturation method (Thomas, 1982). The initial soil physico-chemical properties are summarised in Table 1.

Chemical analytical characteristics of goat manure and agricultural lime

The manure samples used were sourced from farmers around Kavutiri area. The samples were air dried until a constant weight was obtained. The dried manure samples were then ground and passed through 2 mm sieve. The samples were analysed for P, K, Na, Ca and Mg using the dry ashing method as explained by Kalra and Maynard (1991). The chemical analytical results for these samples are summarized in Table 2.

Analysis of lime nutrient content

The standard method of analyzing $CaCO_3$ equivalent as described by Ryan et al. (2001) was used for lime analysis. Table 3 shows the lime analytical results. The lime was found to be rich in calcium carbonate (35.2%) but slightly poor in Magnesium oxide (17.1%).

Design and set up of greenhouse pot experiments

The pot experiments were conducted at the Departmentof Plant and Microbial sciences greenhouse, Kenyatta University. Soil quantities of 4 kg were weighed from the composite soil samples collected from the field and put into each pot. The experiment had 18 treatments from the combination of three levels of manure (0, 5 and 10 Mg ha^{-1}) and six levels of lime (0, 2.5, 5, 7.5, 10, and 12.5 Mg ha^{-1}) which were thoroughly mixed with the soil (Table 4). The treatments were replicated three times and were arranged in three rows in a Complete Randomised Design (CRD). The spacing between the rows was 0.75 m while between pots in a row was 0.5m. This was to mimic the field spacing such that one hectare could hold 26600 pots with two maize plants. The locations of pots in the greenhouse were rotated regularly to minimize the effect of variations in ambient light and temperatures. Phosphorus (P_2O_5) using triple super phosphate (TSP) fertilizer at the rate of 50 kg $ha^{-1}$and nitrogen (N) using calcium ammonium nitrate (CAN) fertilizer at the rate of 70 kg ha^{-1} were applied. CAN was top-dressed at the 4^{th} week after planting. The test crop was maize (*Zea mays*, variety H513). Three seeds were sownper pot and thinned to two after emergence.

Table 1. Initial soil physico-chemical properties of Kavutiri soils used in the study (0 to 20 cm).

Parameter	Sample 1	Sample 2	Mean
$pH_{(water)}$ (1 :2)	4.12	4.30	4.21
Exchangeable acidity (me %)	2.8	2.6	2.7
Extractable P (Mg kg^{-1})	1.09	1.21	1.15
Exchangeable K (me %)	0.6	0.5	0.55
Exchangeable Na (me %)	0.4	0.4	0.4
Exchangeable Ca (me %)	3.6	3.0	3.3
Exchangeable Mg (me %)	1.2	0.9	1.05
Base saturation (%)	24	23	23.5
CEC (me %)	23.6	23.2	23.4
Total N (%)	0.13	0.14	0.135
Organic C (%)	1.4	1.6	1.5
Sand %	48	49	48.5
Silt %	8	7	7.5
Clay %	44	44	44
Texture class	Sandy Clay	Sandy Clay	Sandy Clay

Table 2. Chemical analysis of goat manure.

Fertility index	$pH_{(water)}$	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	DM (%)	OC (%)	Total N (%)	C:N (ratio)
	6.82	0.12	0.95	1.28	0.9	0.34	95.4	25.4	1.94	13.1

Table 3. Chemical analysis for agricultural lime used in the study.

Parameter	Total nutrient content (%)
Calcium carbonate ($CaCO_3$)	35.2
Magnesium oxide (MgO)	17.1

Maize plant data collection for analysis

Maize data collection was carried out at 4th and 8th week after planting (WAP). One of the two plants from each pot was randomly selected at the 4th week while the remaining plant at the 8th week after planting for analysis. The plant height was measured from the soil level to the tip of the youngest leaf. At the 8th week, the pots were split open and soil carefully separated from the fibrous roots to retrieve the roots. The average length of the roots from the main stock was then measured in centimetres using a ruler. Lastly, all the shoots and roots materials were chopped into small pieces, placed in sampling brown paper bags No. 10 and oven dried at 50°C for 48 h. Their dry weight were recorded in grams per pot and converted to kg/ha by multiplying by 53200 (total number of maize plants per ha).

RESULTS AND DISCUSSION

Effects of the amendments on soil acidity

Results of soil potential hydrogen (pH) and exchangeable acidity (Hp) are presented in Table 5. Treatment with 10Mgha^{-1} manure and 12.5Mgha^{-1}lime (M_3 $L_{6)}$ recorded the highest pH value of 6.3 which translates to a 49.6% increase from the initial level value of 4.21 (Table 1). There was a gradual pH decrease as lime and manure levels decreased to the lowest value (4.4) in treatment with no manure but with 2.5Mg ha^{-1} lime (M_1L_2). This value was still slightly higher than the control treatment (4.1) value which had declined by 3.1% from the initial value of pH 4.21. The pH from the various treatments decreased in the order of: M_3L_6 > M_1L_6 > M_2 L_6> M_3 L_5> M_2L_4> M_2L_5> M_3 L_4> M_1L_5> M_2L_3> M_3L_3> M_2L_2> M_3L_2> M_1L_4>$M_3L_{1,}$while exchangeable acidity (Hp) decreased with increase in lime and manure levels in the order of: M_1L_1> M_1L_2> M_1L_3> M_1L_4> M_1L_5> M_2L_1> M_1L_6> M_2L_2> M_2L_3> M_2L_4> M_2L_5> M_3 L_1> M_3L_2> M_2L_6> M_3L_3> M_3L_4 = M_3L_5 = M_3L_6 (Table 5). Treatments; M_3L_4, M_3L_5, and M_3L_6, had the lowest Hp value of 0.1 for each. A gradual increase in Hp was noticed as lime and manure decreased to the highest value of 2.8 in the control

Table 4. Treatment combinations and their actual rates as applied per pot in greenhouse experiment.

Treatment No.	Treatment code	Description	Actual amount applied/pot	
			Manure(g)	Lime(g)
1	$M_1 L_1$	Control (No Manure and Lime)	0	0
2	$M_1 L_2$	Manure (0 Mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	0	5.0
3	$M_1 L_3$	Manure (0 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	0	10.0
4	$M_1 L_4$	Manure (0 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	0	15.0
5	$M_1 L_5$	Manure (0 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	0	20.0
6	$M_1 L_6$	Manure (0 Mg ha^{-1})+ Lime (12.5 Mg ha^{-1})	0	25.0
7	$M_2 L_1$	Manure (5 Mg ha^{-1})+ Lime (0 Mg ha^{-1})	188	0
8	$M_2 L_2$	Manure (5 mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	188	5.0
9	$M_2 L_3$	Manure (5 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	188	10.0
10	$M_2 L_4$	Manure (5 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	188	15.0
11	$M_2 L_5$	Manure (5 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	188	20.0
12	$M_2 L_6$	Manure (5 Mg ha^{-1})+ Lime (12.5 Mg ha^{-1})	188	25.0
13	$M_3 L_1$	Manure (10 Mg ha^{-1})+ Lime (0 Mg ha^{-1})	376	0
14	$M_3 L_2$	Manure (10 Mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	376	5.0
15	$M_3 L_3$	Manure (10 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	376	10.0
16	$M_3 L_4$	Manure (10 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	376	15.0
17	$M_3 L_5$	Manure (10 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	376	20.0
18	$M_3 L_6$	Manure (10 Mg ha^{-1})+ Lime (12.5 Mg ha^{-})	376	25.0

Table 5. Mean Soil potential hydrogen (pH) and exchangeable acidity (Hp) at the end of 8 weeks after planting (WAP).

Treatment No.	Treatment Code	pH (H_2O) 8 WAP	% Change from the initial value(4.21)	Hp (me %) 8 WAP	% Change from the initial value (2.7)
1	$M_1 L_1$ ^{c}	4.1^f	- 3.1	2.8^a	7.7
2	$M_1 L_2$	4.4^f	3.6	1.4^b	-46.2
3	$M_1 L_3$	4.7^f	11.9	1.3^c	-50.0
4	$M_1 L_4$	5.1^e	21.6	1.1^d	-57.7
5	$M_1 L_5$	5.4^d	19.7	1.0^e	-61.5
6	$M_1 L_6$	6.0^b	15.9	0.8^f	-69.2
7	$M_2 L_1$	4.9^e	26.6	1.0^e	-61.5
8	$M_2 L_2$	5.3$^{d e}$	29.5	0.8^f	-69.2
9	$M_2 L_3$	5.4^d	36.3	0.7^g	-73.1
10	$M_2 L_4$	5.7^c	35.9	0.5^h	-80.8
11	$M_2 L_5$	5.7^c	42.0	0.4^i	-84.6
12	$M_2 L_6$	6.0^b	19.2	0.2^k	-92.3
13	$M_3 L_1$	5.0^e	23.8	0.4^i	-84.6
14	$M_3 L_2$	5.2$^{d e}$	28.7	0.3^j	-88.5
15	$M_3 L_3$	5.4^d	34.7	0.2^k	-92.3
16	$M_3 L_4$	5.7^c	34.7	0.1^l	-96.2
17	$M_3 L_5$	5.8$^{b c}$	38.0	0.1^l	-96.2
18	$M_3 L_6$	6.3^a	49.6	0.1^l	-96.2
S.E.D	-	0.118	-	0.042	-
$L.S.D_{5\%}$	-	0.238	-	0.084	-
P-Value	-	< 0.001	-	< 0.001	-

Means with different letter(s) along the same column are statistically different at P= 0.05.

treatment (M_1L_1) as shown in Table 5.

In all the treatments except control, pH progressively

Table 6. Mean plant height and dry matter (DM) weight at 4 and 8 weeks after planting (WAP).

Treatment No.	Treatment code	Plant height (cm)		DM weight			
		4 WAP	8 WAP	4 WAP		8 WAP	
		(cm)	(cm)	(g/plant)	(kg/ha)	(g/plant)	(kg /ha)
1	$M_1 L_1$ ©	34.0^{j}	89.7^{h}	1.2^{i}	63.8	6.7^{k}	356.4
2	$M_1 L_2$	39.0^{i}	115.0^{g}	1.8^{h}	95.8	7.4^{j}	393.7
3	$M_1 L_3$	42.0^{h}	116.3^{f}	2.3^{g}	122.4	7.9^{i}	420.3
4	$M_1 L_4$	44.0^{gh}	119.0^{f}	2.7^{f}	143.6	8.4^{h}	446.9
5	$M_1 L_5$	45.0^{gh}	124.3^{e}	2.9^{f}	154.3	9.0^{g}	478.8
6	$M_1 L_6$	47.3^{fg}	124.0^{e}	2.9^{f}	154.3	9.0^{g}	478.8
7	$M_2 L_1$	47.0^{fg}	126.3^{e}	2.8^{f}	149.0	8.9^{h}	473.5
8	$M_2 L_2$	49.0^{ef}	132.7^{d}	3.4^{e}	180.9	9.4^{g}	500.1
9	$M_2 L_3$	51.3^{de}	135.7^{cd}	3.3^{e}	175.6	9.9^{f}	526.7
10	$M_2 L_4$	53.3^{d}	139.0^{bc}	3.7^{d}	196.8	10.3^{f}	548.0
11	$M_2 L_5$	56.3^{cd}	140.7^{b}	3.9^{d}	207.5	11.3^{e}	601.2
12	$M_2 L_6$	54.7^{cd}	136.7^{c}	4.0^{d}	212.8	11.9^{d}	633.1
13	$M_3 L_1$	55.3^{c}	139.3^{bc}	3.9^{d}	207.5	11.9^{d}	633.1
14	$M_3 L_2$	58.3^{bc}	141.3^{b}	4.3^{c}	228.8	12.4^{c}	659.7
15	$M_3 L_3$	61.3^{a}	143.7^{b}	4.7^{b}	250.0	13.0^{b}	691.6
16	$M_3 L_4$	62.3^{ab}	146.3^{ab}	4.7^{b}	250.0	13.8^{a}	734.2
17	$M_3 L_5$	63.7^{a}	150.3^{a}	5.0^{a}	266.0	14.2^{a}	755.4
18	$M_3 L_6$	61.0^{ab}	148.7^{a}	5.1^{a}	271.3	14.1^{a}	750.1
S.E.D	-	1.746	1.771	0.104	-	0.243	-
$L.S.D_{5\%}$	-	3.542	3.591	0.219	-	0.493	-
P-Value	-	<0.05	<0.05	<0.05	-	<0.05	-

*Means with different letter(s) along the same column are statistically different at P=0.05.

increased while the Hp decreased with increase in manure and lime application.This could be attributed to the reduction of Al^{3+}ions concentration in soil solution and in exchangeable sites as a result of Ca in lime and manure effect on the reduction of Al ions in the soil solution. This increase of pH with manure application agrees with the findings of Egball (2002), Mucheru (2003) and Summer(1997) who reported that addition of organic manures to acid soils lead toan increase in soil pH, decrease of Al ions in soil solution and thereby improve soil conditions for plant growth.

The rise in pH and reduction of soil exchangeable acidity can also be associated with the presence of basic cations (Ca^{2+} and Mg^{2+}) (Fageria et al., 2007) and anions (CO_3^{-2}) in these liming materials that are able to react with H^+ ionsfrom exchange sites to form H_2O + CO_2. Cations occupy the space left behind by H^+ on the exchange sites leading to rise in pH. The change in soil pH with time concurs with the findings by Fageria (2001a) who reported that significant chemical changes could take place within 4–6 weeks after applying liming materials if a soil has sufficient moisture.

The rise of soil pH through addition of manure could have been caused by the consumption of H+ due to humic-type substances which have a large number of carboxyl, phenolic and enolic functional groups as proposed by Wong et al. (1998).These substances are formed during decomposition processes and are relatively stable against further decomposition.Their capacity to consume H^+ therefore, controls their buffer characteristics and their ability to neutralize soil acidity. This finding agrees also with the findings of Mokolobate and Haynes (2002) who reported rise of pH after use of lime and manure as amendments in acid soils.

Effect on plant height

Table 6 presents the results of plant height and dry matter. Analyses of variance indicated that there was significant difference (P <0.05) between treatments. It was observed that treatment with 10Mg ha^{-1}manure and 10Mg ha^{-1}lime (M_3L_5)recorded the highest plant heights both at 4thand 8th WAP of 63.7 and 150 cm, respectively whereas the control treatment recorded 34.0 and 89.7cm as measured in 4th and 8th WAP, respectively, which were significantly (P <0.05) the lowest heights of the experiment. The order in which plant heights decreased according to treatments was: M_3L_5>M_3L_6>M_3L_4>M_3L_3>M_3L_2>M_2L_5>M_3L_1>M_2L_4>M_2L_6>M_2

L_3>M_2L_2>M_2L_1>M_1L_5>M_1L_6>M_1L_4>M_1 L_3>M_1L_2>M_1L_1.

Effect on dry matter

The dry matter of the maize as shown in Table 6 indicates that the control treatment (M_1L_1) had the lowest dry matter weight of 1.2 and 6.7g per plant at 4th and 8th WAP, respectively which corresponds to 63.8 and 356.4 kg ha^{-1},respectively. There was generally significant (P<0.05) increase of dry matter with increase levels of manure and lime in the order of: M_1L_1<M_1L_2<M_1L_3<M_1L_4<M_2L_1<M_1L_5<M_1L_6<M_2L_2<M_2L_3<M_2L_4<M_2L_5<M_2L_6<M_3L_1<M_3L_2<M_3L_3<M_3L_4<M_3L_5 <M_3L_6.The highest dry matter weight in week 8 was 755.4 kg ha^{-1}obtained by treatment with 10.0Mg ha^{-1} manure and 10.0 Mg ha^{-1} lime while in week 4,the highest weight was 271.3Mg $ha^{-1}$and was obtained by treatment M3L6 (10.0Mg ha^{-1} manure and 12.5 Mg ha^{-1} lime).

Effect on root length

Mean root lengths as influenced by lime and manure application are presented in Table 7. It was observed that root length significantly (P<0.05) increased with increase in inputs from one level to the other. Treatment M_3L_6 had the longest roots averaging 41.3 cm, a significant difference of 555.5% longer that of control (6.3 cm). The order of root lengthsin terms of treatments from the longest to the shortest was as follows: M_3L_6 > M_3L_5 > M_3L_3 > M_3L_4 > M_3L_2 > M_3L_1 > M_2L_6 > M_2L_5 > M_2L_4> M_2L_3 > M_2L_2 > M_1L_6 > M_1L_5 > M_1L_4 > M_1L_3 > M_1L_2> M_1L_1.

Relationship between maize growth parameters and soil acidity indices

The relationship between soil pH and maize growth parameters (dry matter and plant height) are shown in Figure 1a. A highly significant and positive correlation was observed between soil pH and the maize growth parameters. Dry matter showed a high correlation of r^2 =0.622 with pH changes in soil while that of plant height with pH was r^2 =0.7244.

In Figure1b, plant height had a negative linear correlation with soil Hp (r^2 = -0.9517) while that between dry matter and Hp was also high and negative with a coefficient of determination (r^2) of -0.7588.

In Figure 2, the relationship between soil acidity indices and root length is shown. Root length was found to have a positive linear correlation with soil pH (r^2 = 6598) (Figure 2a) and a negative non- linear relationship with Hp (r^2 = -0.969) (Figure 2b).The correlation study showed that soil acidity indices affect maize root differently. This trend agrees with Comin et al. (2006) who observed in their work effects of soil acidity on the adventitious root system in the field that soil acidity negatively affected the root branching and root length of maize crop.

The increase in plant height and dry matter weight with decrease in soil acidity can be attributed to improved efficient use of plant nutrients and their availability as a result of enhanced root system by liming (Fageria et al., 2004). Lime and P interactions are highly associated with soil acidity that limit root growth and proliferation, and nutrient uptake. This could have been the reason for poor performance in the control (M_1L_1) treatment in this study. Aluminium ions absorbed by roots can also precipitate root-absorbed P and hinder its subsequent translocation to plant tops (Mora et al., 2005)

The significant increases in maize growth with application of lime and farmyard manure observed in this study could be attributed to the readily available N and P nutrients supplied in the fertilizers applied and the favourable environment created by the manure and Ca from the lime. Tejada et al. (2006) reported that manure is a good amendment on soil that requires P and N to produce high yields.

The control treatment had the lowest maize biomass yield probably because of low available nitrogen due to low mineralization in this acid soil, and fixation of P thus making it unavailable for plant uptake. Poor performance could also be attributed to Al saturation. Yamoah et al. (1996) attributed 44% reduction in maize yield to acidity in soils.

Liming acid soils result in the release of P for plant uptake; an effect often referred to as ‘‘P spring effect”of lime (Bolan et al., 2003). Bolan et al. (2003) reported that in soils high in exchangeable acidity, liming could increase plant P uptake by decreasing Al, rather than by increasing P availability per se. This also improves root growth which alleviates Al toxicity by allowing a greater volume of soil to be explored. At the same time, liming creates a better environment for the release of P and decrease of soil acidity. Onwuka et al. (2009) reported that with the application of 2, 4, 6 and 8 mega grams per hectare of $CaCO_3$, the soil pH was increased from 5.02 to 8.04 while from western Kenya, it was reported that agricultural lime (Gudu et al., 2007) and Minjingu phosphate rock (Okalebo et al., 2009) significantly raised soil pH and maize yields. Dierolf et al. (1997) had earlier found out that application of lime to maize allowed the roots of maize to move up to 15 to 30 cm of depth in an acid soil. When the plant roots are increased, it will translate to the aerial biomass increase and that could be the reason why the treatment with 10Mg ha^{-1} manure and 12.5Mg ha^{-1} limein this study gave both the highest roots length and biomass yield.

The positive correlation of soil pH with the maize growth parameters implies that as the pH increased, the growth parameters also increased. Le Van et al. (1994) stated that as the exchangeable acidity is reduced, the plant roots performance is enhanced and nutrient uptake is improved, and thus becomes more effective in

Table 7. Mean plant root length at 8 weeks after planting (WAP).

Treatment No.	Treatment code	Root length (cm)	Treatment No.	Treatment code	Root length (cm)
1	$M_1 L_1$ ©	6.3^{j}	10	$M_2 L_4$	30.0^{d}
2	$M_1 L_2$	9.3^{i}	11	$M_2 L_5$	31.7^{d}
3	$M_1 L_3$	13.3^{h}	12	$M_2 L_6$	34.3^{c}
4	$M_1 L_4$	14.7^{h}	13	$M_3 L_1$	35.3^{c}
5	$M_1 L_5$	17.7^{g}	14	$M_3 L_2$	$37.0^{b\,c}$
6	$M_1 L_6$	19.0^{fg}	15	$M_3 L_3$	38.0^{b}
7	$M_2 L_1$	20.0^{f}	16	$M_3 L_4$	38.0^{b}
8	$M_2 L_2$	23.3^{e}	17	$M_3 L_5$	39.7^{a}
9	$M_2 L_3$	27.0^{e}	18	$M_3 L_6$	41.3^{a}
S.E.D	-	1.030	S.E.D	-	1.030
$L.S.D_{5\%}$	-	2.090	$L.S.D_{5\%}$	-	2.090
P-value	-	< 0.05	P-value	-	< 0.05

*Means with different letter(s) along the same column are statistically different at P=0.05.

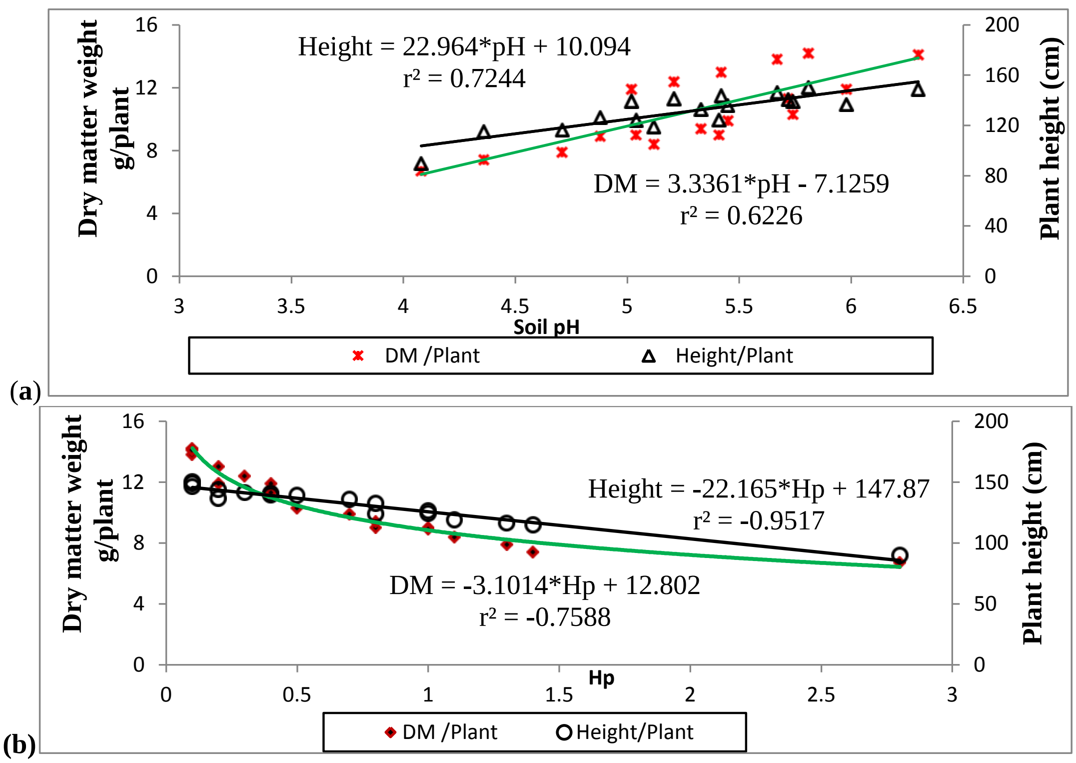
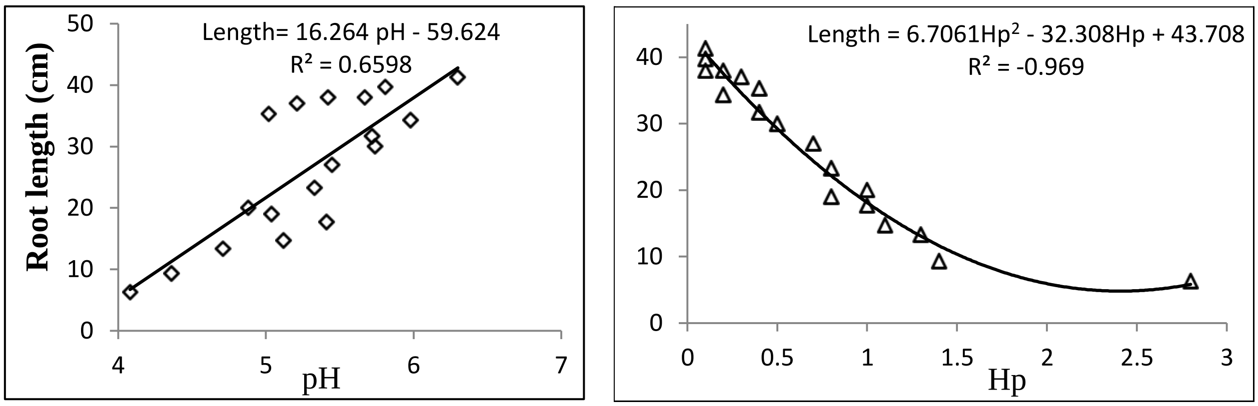


Figure 1. Relationship between maize growth parameters (dry matter weight and plant height) and soil Hp at 8 weeks after planting WAP. (a) pH and (b) Hp.

increasing plant yield parameters.

Conclusion

This greenhouse pot experiment study reveals that application of manure and lime to acid soils has a profound influence on soil pH, exchangeable acidity and consequently on maize biomass yield. In light of these findings, it is evident that combining 10 Mg ha^{-1} of manure and 12.5 Mg ha^{-1} of agricultural lime could be more effective in reducing soil acidity, hence enhancing



(a) (b)

Figure 2. Relationship between maize root length and soil acidity indices: (a) pH and (b) Hp at 8 weeks after planting WAP.

maize growth. Thus, the acid soils of Kavutiri- Central Kenya need manure in combination with lime to improve their soil chemical properties and consequently their productivity. This would be a promising alternative in developing more affordable acid soil management strategy.

Conflict of Interest

There is no any conflict of interest with the authors.

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Full Length Research Paper

Mapping gully erosion in Abia State, Nigeria using Geographic Information Systems (GIS) and remote sensing techniques

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Soil erosion is of major concern in Abia State, Nigeria. This study adopts a combination of Geographic Information Systems (GIS) and Remote Sensing as a tool to study and map soil erosion menace in Abia State. For this research, several datasets that represent climate, soil, geology, topographic and anthropogenic factors were used as the basic requirements for environmental modeling of soil loss using Universal Soil Loss Equation (USLE) for 1986 and 2003. The results show that 1082.58 tons/acres were lost in 1986 and 1120.59 tons/acres in 2003 in the study area. Also, a negative correlation was found to exist between soil loss and NDVI (Normalized difference vegetation index) value. Soil erosion vulnerability index map as well as risk prone areas maps was produced. This study shows the integration of GIS with remote sensing as an efficient and effective tool in the study and mapping of soil erosions.

Key words: Geographic Information Systems (GIS), Soil erosion, normalized difference vegetation index (NDVI), mapping, Abia State.

INTRODUCTION

Soil erosion is an ecological issue of great concern in the southeastern part of Nigeria in general and Abia State in particular. Erosion problems arise mainly from natural causes but their extent and severity are increasingly being attributed to man's ignorance and unintentional actions (Enabor and Sagua, 1988). According to Ofomata (2009), soil erosion, which is simply a systematic removal of soil, including plant nutrients, from the land surface by the various agents of denudation occurs in several parts of Nigeria under different geological, climatic and soil conditions.

Soil erosion is a dynamic geomorphic event operating on the landscape (Ojo and Johnson, 2010). In spite of technological advancement, erosion menace still remains a major problem in Nigeria (especially in South Eastern Nigeria). The yearly heavy rainfall has very adverse impacts altering existing landscape and forms. Such landforms create deep gullies that cut into the soil. The gullies spread and grow until the soil is removed from the sloping ground. Soil erosion when formed expand rapidly coupled with exceptional storm or torrential rain down the stream by head-ward erosion gulping up arable lands,

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economic trees, homes, lives, and sacking of families and valuable properties that are worth millions of naira (Umudu, 2008).

In this research, a combination of GIS and remote sensing techniques was adopted as an approach to study soil erosion in Abia State. The research seeks to establish correlation between Normalized Difference Vegetation Index (NDVI) and soil loss. The aim is to explore the possibility of using NDVI as a proxy for indirect measurement of soil erosion. This method involves a quantitative remote sensing study of soil erosion. By utilizing a Landsat ETM+ and Thematic Mapper (TM 5) imagery, this study was aimed at introducing much more simple and handy combinatorial method to retrieve some biophysical parameters so as to examine the soil erosion changes in Abia State. The remote sensing technique has often proved to be a veritable tool for modelling and estimating some biophysical parameters. For instance, recently remote sensing was successfully used to estimate evapotranspiration in the Tajan catchment area of Iran using MODIS images (Rahimi et al., 2015).

Specifically, the objectives of the present study are:

1. To estimate amount of soil loss to erosion in tons per acre per year.
2. To determine the land use types in Abia State from 1986 to 2003.
3. To determine the impact of vegetal cover in soil erosion process using NDVI.
4. To develop erosion vulnerability index for the State.
5. To develop a risk index and determine possible affected towns in the State for mitigation purposes.

The study area

The study area is Abia State, which is one of the 36 states in Nigeria. It lies between latitudes 4°45' and 6° 00'North and longitudes 7°00' and 8°09'East. The State is located east of Imo State and shares common boundaries with Anambra, Enugu and Ebonyi States to the North-West, North and North-East respectively. To the East and South-East, it is bounded by Cross River and Akwa Ibom States and by Rivers State to the South. It occupies a landmass of 5,833.77 square kilometers (Figure 1). Abia State comprises of seventeen (17) Local Government Areas (LGAs).

The rock system and geological history of this area are due to events that took place during the Mesozoic and Cenozoic eras respectively. Her geological structure is divided into three namely, upper coal measure, false-bedded sand stones, and lower coal measure. The upper coal measure formation is the largest geological formation in this region. It comprises mainly of coarse grains, alternating sediments of grey sands, dark shale which contains sands of impure coal in place of vertical horizon.

Abia State experiences a high annual rainfall (about 2000 mm mean/year) with corresponding high discharge of water as runoff that encourages soil erosion. It has a peak period between July and September. Rainfall events have been found to be highly correlated to erosion in all the representative land surface types (Jimoh, 2005).

MATERIALS AND METHODS

In this research GIS coupled with the remote sensing technique was adopted to achieve the stated aim and objectives. The primary data include SRTM DEM of Abia State. Also collected were certain relevant existing maps of the state relating to vegetation/land use, population data, geology, rainfall, administrative map, and soil map. The maps were printed and published by the State Ministry of Lands, Survey and Urban Planning, Umuahia, Abia State (2010). The population data was collected from the National Population Commission (NPC) office in Umuahia, Abia State (2011). The secondary data include information on rainfall distribution from January to December (1972-2010). The rainfall data was collected from the Meteorological Department, National Root Crop Research Institute (NRCRI), Umudike, Umuahia (2010).

Available maps were scanned, converting paper map to digital/raster image. The scanned maps were georeferenced and digitized in ArcGIS 9.3 software environment. Feature extraction for Aster DEM and Elevation were also done using ArcGIS software. The bands 4, 5 and 7 of the acquired Landsat ETM, TM, and MSS imagery were enhanced using histogram equalization. The image was already rectified to a common UTM coordinate system (WGS84), and then radiometrically corrected. The rectified image was used in the creation of color composite map; a False Color Composite (FCC) was adopted for this research using bands 4, 5, and 7. In this research supervised classification was used. The homogeneous representative samples of the different surface cover types (information classes) of interest (known as training area) were identified on the imagery. The selection of appropriate training areas was based on the researchers' familiarity with the geographical area and their knowledge of the actual surface cover types present in the imagery. Maximum likelihood classification (MLC) method was used with remote sensing image data using Idrisi (R15).

The Universal Soil Loss Equation (USLE), which is a mathematical model used to describe soil erosion processes (Wischmeier et al,. 1960, 1978), was used to derive soil loss in Abia State. USLE was used in ArcGIS 9.3 (using Arc tool box) environment to calculate the soil erosion index for the study area (i.e. Abia State). A model was developed that executed the USLE formula using data from the study area (Figure 2). USLE is an empirical model and its formula is given as:

$$A = R\ L\ S\ K\ C\ P \qquad (1)$$

Where: A = average annual soil loss in tons per acre, R = rainfall and runoff erosivity factor, L = slope length factor, S = slope steepness factor, K = soil erodibility factor,C = cover and management factor, and P = supporting and conservation practices factor.

In general, the USLE model estimates soil erosion by rain drop impact and surface runoff.

Runoff erosivity (R) index

R is the rainfall and runoff erosivity index which is given as:

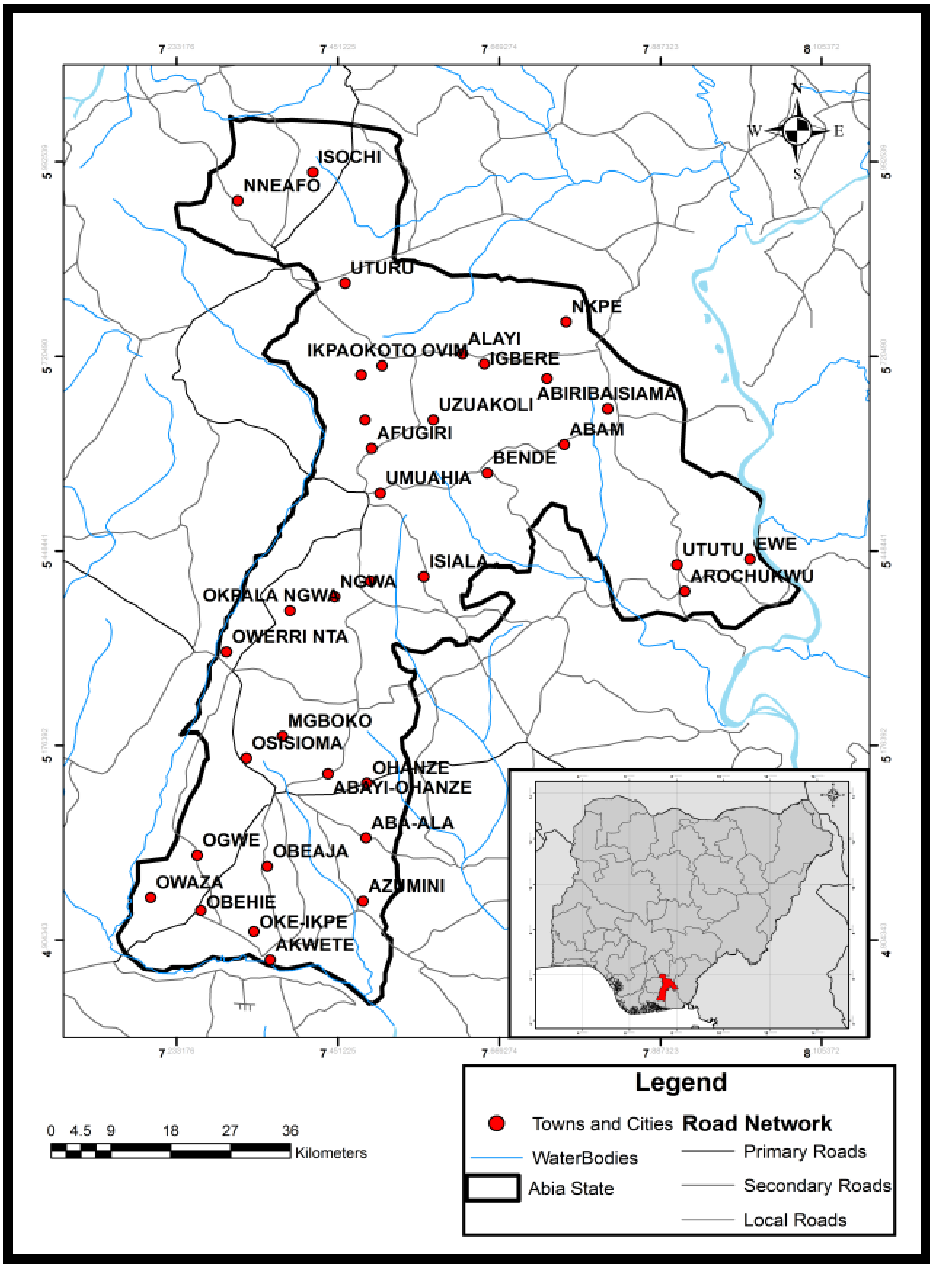

Figure 1. Map of Abia State, Nigeria.

R = EI30/100.

EI for a given rainstorm equals the product: total storm energy (E) multiplied by the maximum 30-min intensity (I30), E is the kinetic energy in the rainfall and I30 is in inches per hour. R depends on the amount of raindrop energy and rainfall intensity.

Slope length factor

L factor is the slope length factor. Slope length determines the concentration of water. Therefore, the greater the length of slope of a field the greater the concentration of water and run off. A DEM of the study area was used as the source data, and then flow direction and flow accumulation of the study area were computed using ArcGIS tools. The equation used for computing slope length is:

$$(DEM>Flow\ Direction>Flow\ Accumulation*Cell\ size / 22.13)^{0.4} \quad (2)$$

Slope steepness factor

S factor is the slope steepness factor. This is the steepness of the area of study. As a rule, the greater the slope steepness the more erosion that can be expected. DEM data for Abia State was used to compute the S factor in ArcGIS 9.3. The equation used to compute the slope steepness is:

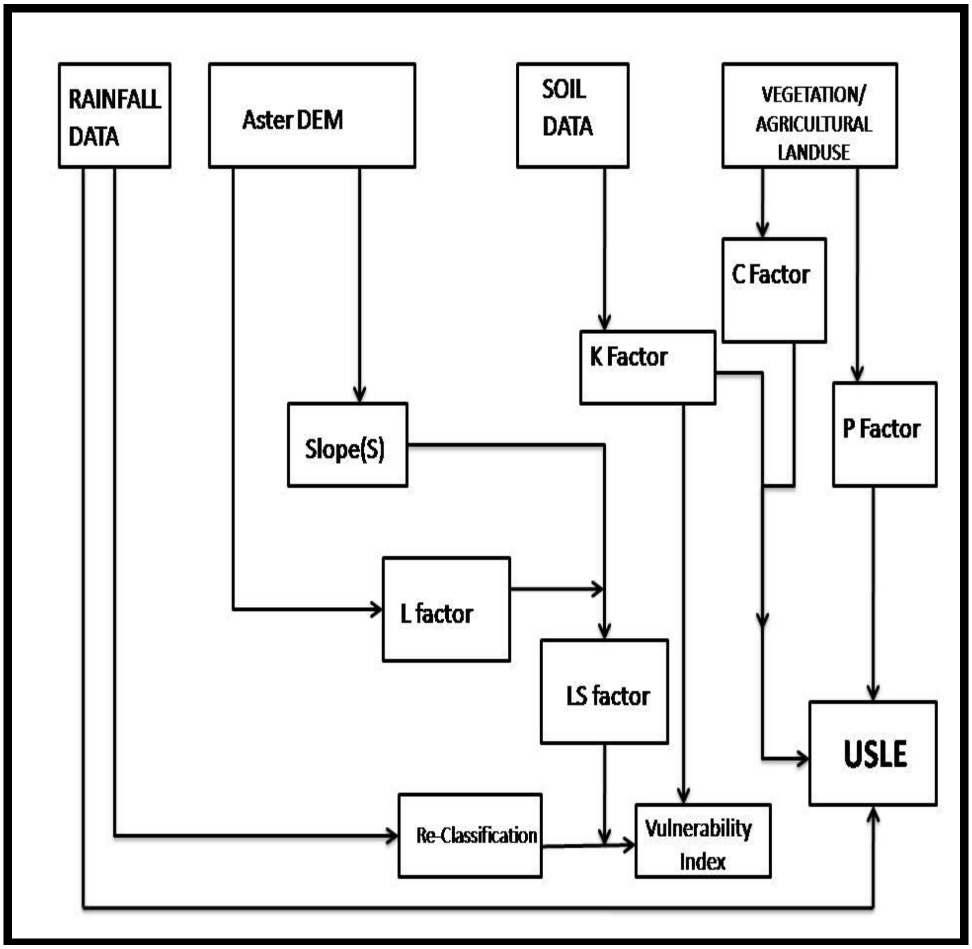

Figure 2. USLE Flow Chart adopted for this research.

(DEM > Slope > * 3.14 / 180 > sin slope / 0.0869)$^{1.3}$ (3)

Slope steepness factor (S) was then multiplied with the length factor (L) to derive the LS factor, which is the topographic factor of Abia State.

Soil erodibility factor

K factor is the soil erodibility factor. This is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. It depends on soil structure, texture and composition. In this project, K factor is based on values established in literature. A high K factor indicates a lower water infiltration rate thus more prone to erosion. K factor was derived from tables provided by Roose (1977).

Cover and management factor

Cover and management factor (C factor) indicates the influence of cropping systems and management variables on soil erosion. This factor depends on four sub factors: Prior land use, canopy cover, soil surface cover and surface roughness. The C factor for Abia State was obtained from two sources. C factors for Agriculture (land use), barren ground, primary and secondary forests, urban (Build-up area) and water were obtained from literature review (Roose, 1977). Based on the above, C factor was created for agricultural/vegetation land use, and land use/land cover type for 1986 and 2003.

Supporting and conservation practices factor

P factor is the supporting practices factor. These are the erosion control practices such as contouring, strip cropping, terracing etc. as well as land management practices that reduce soil erosion. The P-factor is the ratio of soil loss under the given condition to soil loss from up-and-down-slope farming as observed in the study area. Therefore it is a value between 0 and 1for each land use type in Abia State. A field trip to carry out ground truthing revealed that there were no measurable conservation measures in the study area.

Derivation of normalized difference vegetation index (NDVI)

The normalized difference vegetation index (NDVI) is a simple numerical indicator that can be used to analyze remote sensing measurements, to ascertain whether the target being observed contains live green vegetation or not (Jensen, 2007; Rouse et al., 1973). The NDVI is calculated as follows:

Table 1. Soil erosion classification index for Abia State.

Code	Index class	Class range
1	Severe	>200
2	High	200-100
3	moderate	100-50
4	Low	50-25
5	Very Low	<25

Table 2. Land use/land cover, soil loss and NDVI in Abia State in 1986.

Land use/land cover	Area (km^2)	Area (%)	Soil Loss (Ton/Acres)			NDVI	Scale NDVI
			MIN	MAX	MEAN		
Farmland	2402.054	43.69	0.00	1051.32	24.14	0.14	116.16
Built-Up Area	143.289	2.6	0.00	456.92	29.68	0.08	107.06
Bare Ground	514.405	9.35	0.00	1082.58	48.93	0.07	109.60
Secondary Forest	2297.833	41.8	0.00	503.01	9.22	0.18	119.13
Primary Forest	104.076	1.9	0.00	39.38	1.10	0.23	120.64
Water Bodies	5.318	0.096	0.00	4.57	1.35	-0.08	88.48
Wetlands	29.725	0.54	0.00	152.81	4.00	0.21	123.78

$$NDVI = \rho_{nir} - \rho_{red} / \rho_{nir} + \rho_{red} \quad (4)$$

Where: ρ_{nir}: Spectral reflectance measurements acquired in the near-infrared regions, and

ρ_{red}: Spectral reflectance measurements acquired in the red regions.

The NDVI value is transformed from -1 to 1 into an 8 bit (0-255) value image. The scale value was used in statistical analysis using correlation model.

Correlation model

The Pearson Product Moment Correlation model was used to determine relationship between soil erosion loss and NDVI value. The correlation model is expressed as follows.

Risk assessment

$$Risk = H * V \quad (5)$$

H = Hazard, and V = Vulnerability

The soil erosion risk was determined from Equation (5) and the values obtained were reclassified into five classes using ArcGIS software based on the criteria stated in Table 1.

RESULTS AND DISCUSSION

Analysis of land use/land covers change

For the purpose of land use/land cover (LU/LC) change analysis, features on the Landsat images were classified into 7 categories namely, built-up areas, farmland (agricultural), primary forested land, secondary forested land, bare ground, wetlands and water bodies. The images were taken in December and February when active agricultural activities in the study area are virtually non-existent. Tables 2 and 3 show the distribution of land use/land, soil loss, and NDVI for Abia State in 1986 and 2003 respectively. Change analysis was conducted on each of the LU/LC categories. The results obtained showed that farm land in the study area was about 2402.05 km^2 in 1986 but by 2003 this had reduced to 791.42 km^2. On the other hand, while built-up area was 143.289 km^2 in 1986 (covering 3%) it increased to 1791.314 km^2 in 2003 (covering 33%). The wetland witnessed a loss from 84.729 km^2 in 1986 to 29.725 km^2 in 2003. Bare ground areas experienced a 12% (674.235 km^2) increase in 2003 over the 1986 figure (514.405 km^2). Secondary forest in the study area was about 2297.83 km^2 in 1986 but it was reduced to 2045.45 km^2 in 2003. Primary forest increased marginally from 104.076 km^2 (2%) in 1986 to 105.358 km^2 in 2003. A decrease in the area of water bodies was experienced from 5.318 km^2 in 1986 to 4.16 km^2 in 2003.

Figure 3 shows the distribution of land use/land cover change in the study area from 1986 to 2003. Figures 4 and 5 show land use/land cover of Abia State for 1986 and 2003, respectively.

Soil loss estimation

In this study all factors of the USLE model (R, K, SL, C,

Table 3. Land use/land cover, soil loss and NDVI in Abia State in 2003.

Land use/land cover	Area (Km^2)	Area (%)	Soil loss (Ton/Acres)			NDVI	Scale NDVI
			MIN	MAX	MEAN		
Farmland	791.42	14.46	0.00	928.72	13.64	0.16	116.90
Built-Up Area	1791.314	32.58	0.00	584.86	33.46	0.08	101.09
Bare Ground	674.235	12.26	0.00	1120.59	36.46	0.10	104.95
Secondary Forest	2045.451	37.21	0.00	538.90	9.59	0.19	120.44
Primary Forest	105.358	1.91	0.00	626.60	11.92	0.21	118.61
Water Bodies	4.193	0.07	0.00	707.93	26.87	-0.11	106.44
Wetlands	84.729	1.54	0.00	73.75	1.62	0.23	123.81

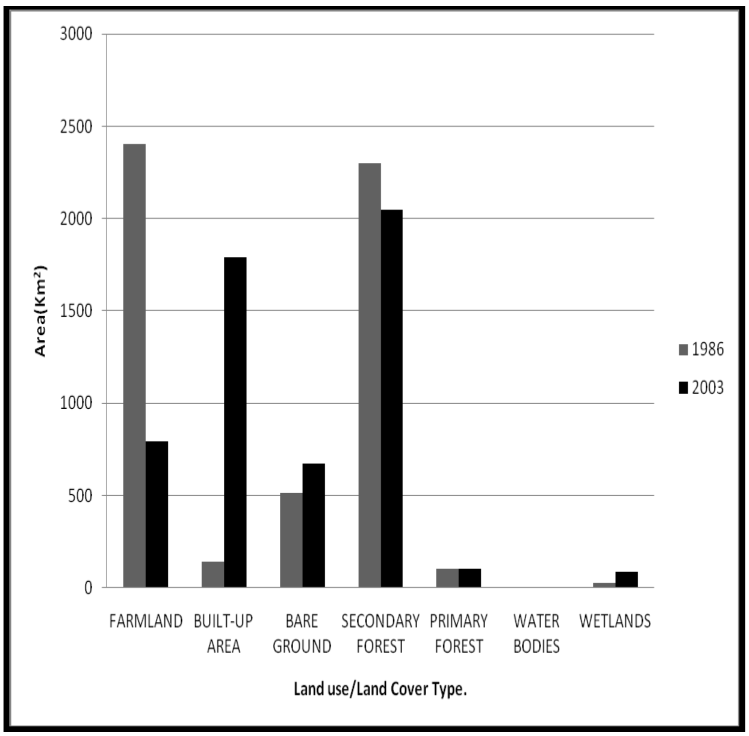

Figure 3. The land use/land cover change from 1986 to 2003.

and P) were integrated to estimate soil loss (ton/acres/year) for the study area due to erosion. Modeling erosion-induced soil loss using the land use/land cover type (as C factor) in the study area and the value ranges from 0 to 1,082.58 ton/acre in 1986 and 0 to 1,120.59ton/acre in 2003 (Figures 6 and 7). Soil loss for various land use/land cover was computed for the study area. For farmlands, in 1986 about 1051.32ton/acre (with a mean value of 24.14 ton/acre) was lost to soil erosion and 928.72 ton/acres (with a mean value of 13.639 ton/acre) in 2003. For built-up areas 584.863 ton/acres (with a mean value of 33.46 ton/acre) was lost in 2003 and 456.921 ton/acres (with a mean value 29.6803 ton/acre) in 1986. Bare ground being the most vulnerable to soil loss experienced 1082.58 ton/acres (with a mean value 48.9331ton/acres) in 1986, and in 2003, 1120.59 ton/acres (with a mean value 36.46 ton/acres) was lost to soil erosion in the State.

The value for secondary forest was found to be 503.009 ton/acres (with a mean value of 9.21ton/acres) in 1986 and 538.903 ton/acres (with a mean value of 9.58ton/acres) in 2003. Primary forest experienced an increase in soil loss from 39.38 ton/acres (in 1986) to 626.60 ton/acres (in 2003). For wetlands, 152.80 ton/acres (with a mean value of 3.99 ton/acres) in 1986 and 73.75 ton/acres (with a mean value of 4 ton/acres) in 2003 were lost to soil erosion in the area. Figure 8 shows soil erosion estimation map for each land use type in the study area.

Also, still using the land use/land cover type (as C

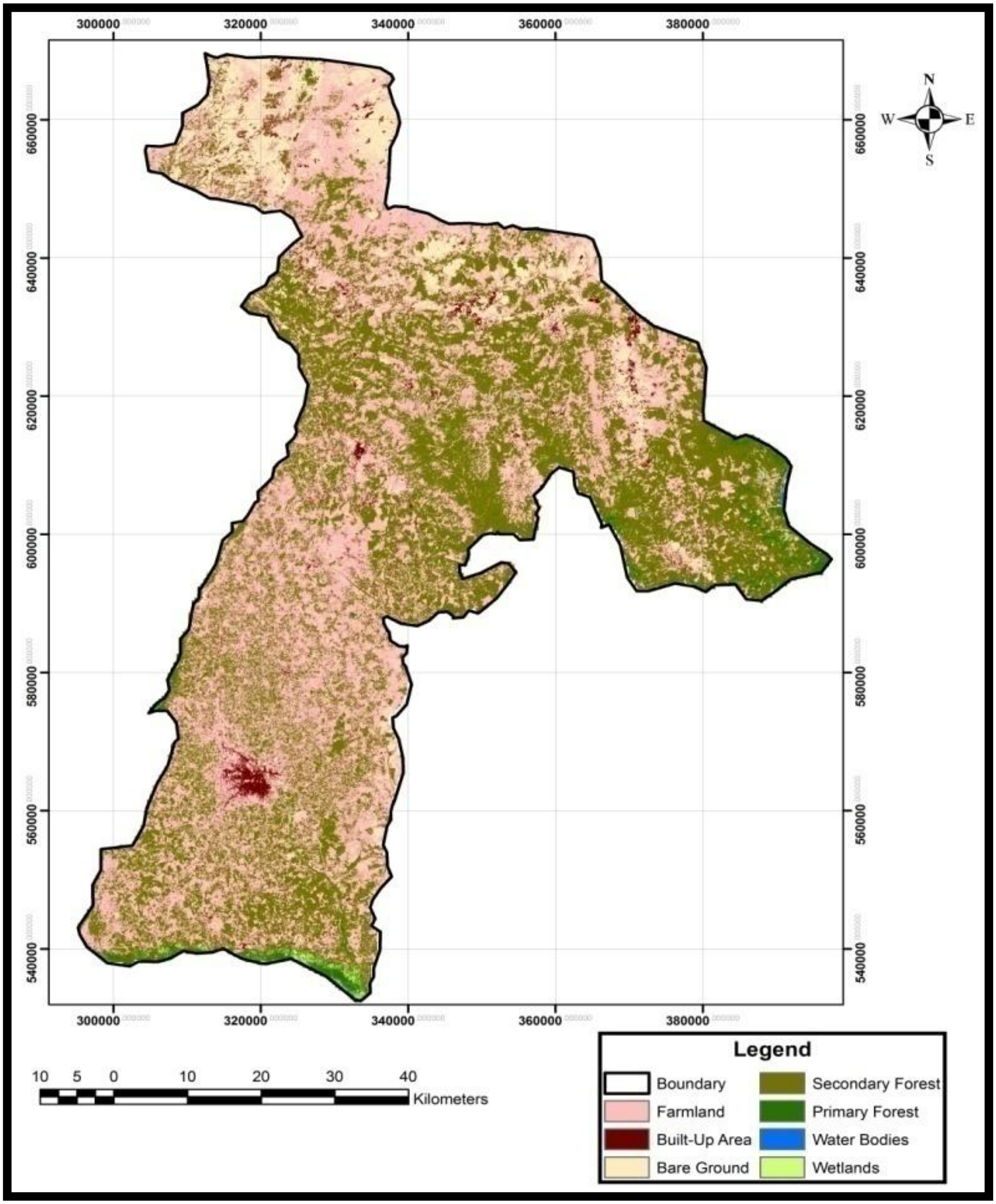

Figure 4. Land use/land cover map for Abia State for 1986.

factor) to model soil erosion, soil loss estimation was determined for each Local Government Area (LGA) in Abia State, for both 1986 and 2003 (Table 4). From the result of the analysis done, Umu-Nneochi has the highest value of 1082.58 tons/acres in 1986 and 1120.59 tons/acres in 2003. Isuikwuato ranks second with 568.45 tons/acres in 1986 and 594.65 tons/acres in 2003. In Ohafia, 544.89 ton/acres was lost in 1986 and 538.90 ton/acres was lost in 2003. Bende experienced an increase in soil loss from 525.73 ton/acres (in 1986) to

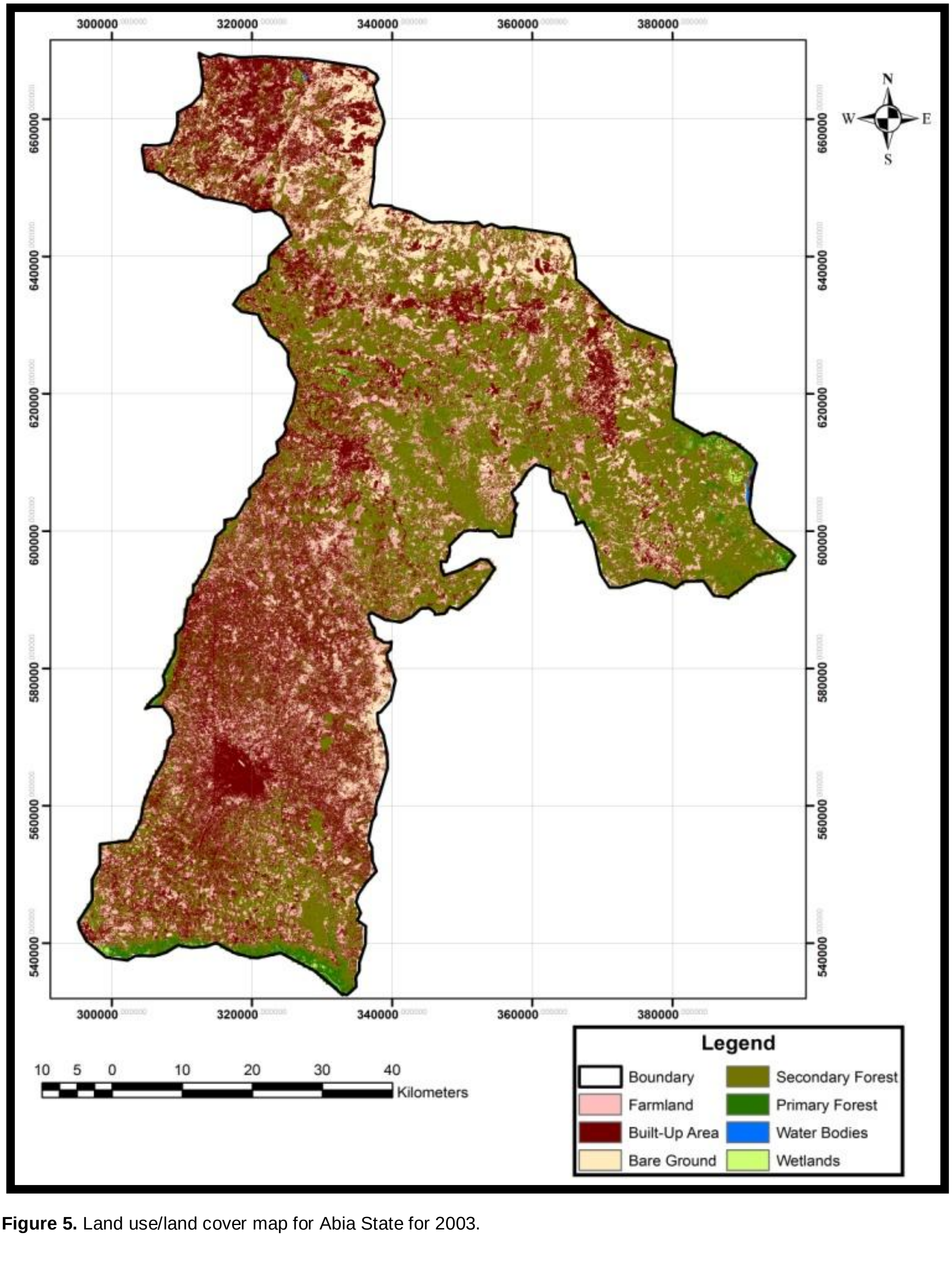

Figure 5. Land use/land cover map for Abia State for 2003.

547.54 ton/acres (in 2003). In Ikwuano, 154.98 ton/acres and 164.27 ton/acres was lost to soil erosion in 1986 and 2003 respectively. Soil loss values in the Abia State for each land use type are shown in Tables 2 and 3.

Mapping soil erosion vulnerability

The soil erosion vulnerability of Abia State was analyzed and mapped based on the criteria developed. As shown

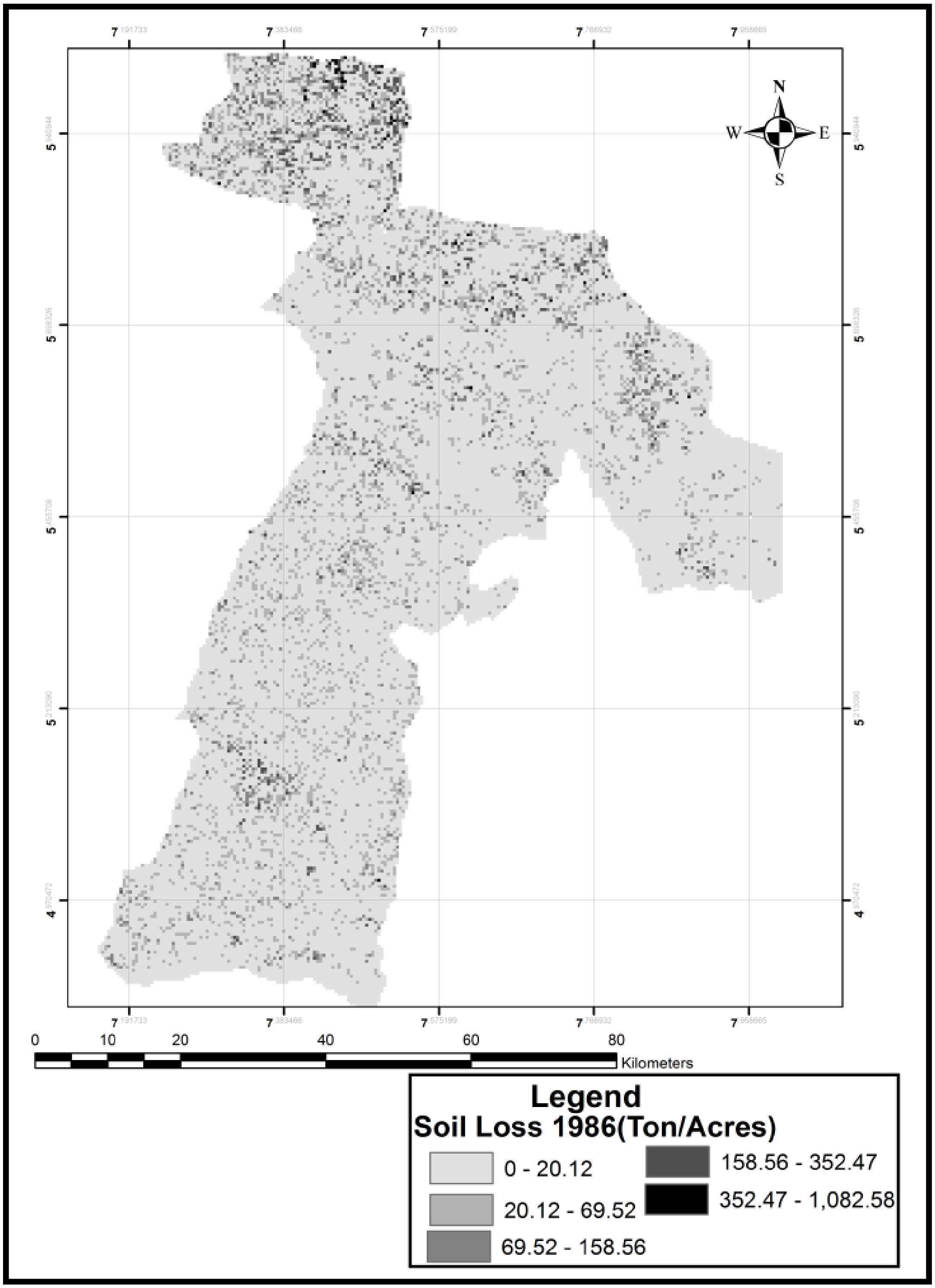

Figure 6. Soil erosion estimation for Abia State for1986.

in Table 6, 7% (120,501 acres) of the State is vulnerable to severe soil erosion while 13% (195,493 acres) is covered by high soil erosion. The tendency of the State being affected by moderate form of soil erosion is just 20% (284,349.99 acres). In the State 27% (148,929.42 acres) is affected by low soil erosion while 33% of the remaining parts of the State experience very low level of soil erosion. Figure 9 shows the distribution of soil

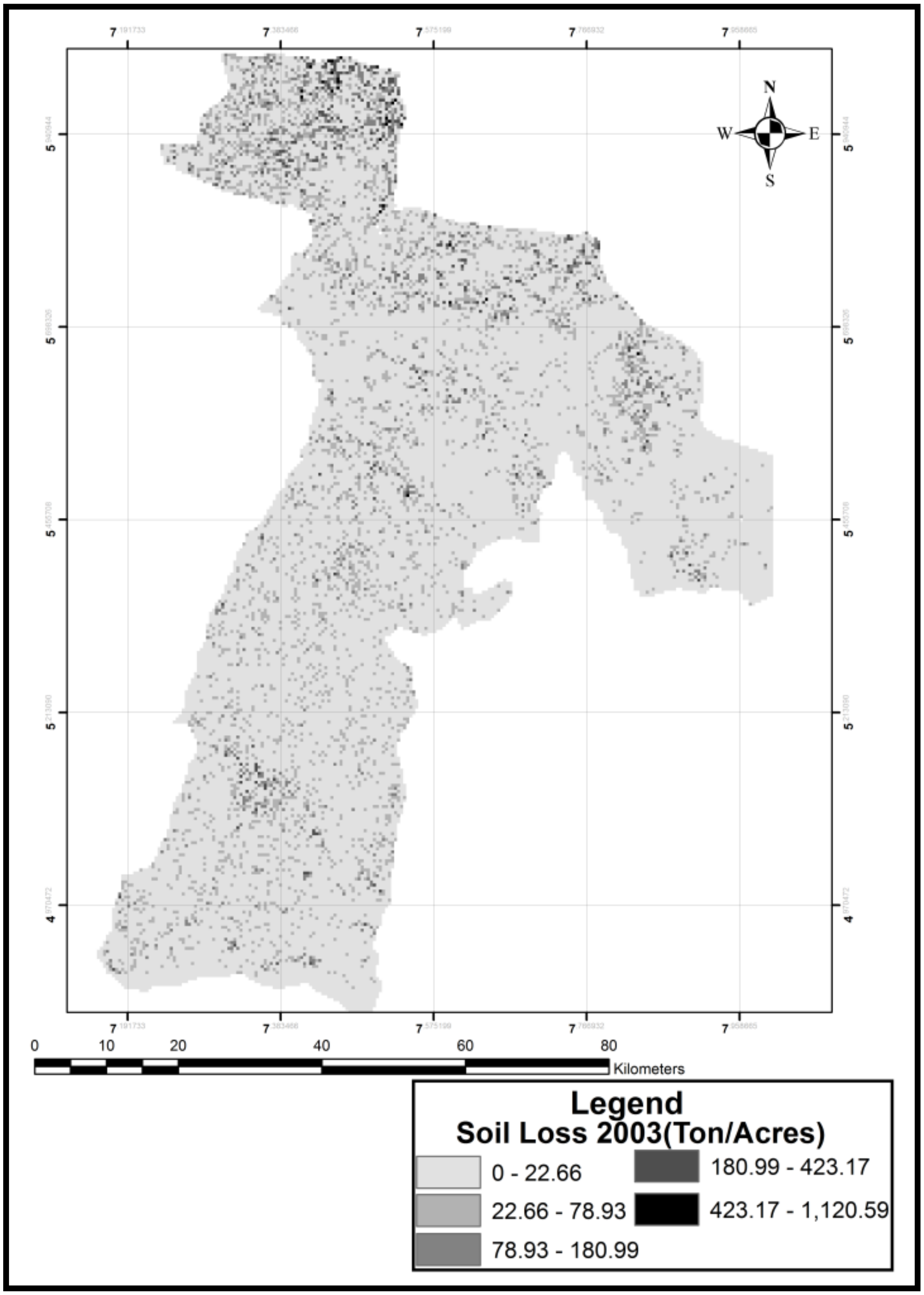

Figure 7. Soil erosion estimation for Abia State for 2003.

erosion vulnerability in the State.

Analysis of vegetation density (NDVI)

The normalized difference vegetation index (NDVI) was analyzed using Landsat-7 ETM+ and TM 5 imagery. NDVI values range from 1 to -1. The value 1(high) represents pixels covered by substantial proportion of healthy vegetation while -1(low) represents pixels covered by non-vegetated surface including water, manmade features, bare soil, and dead or stressed

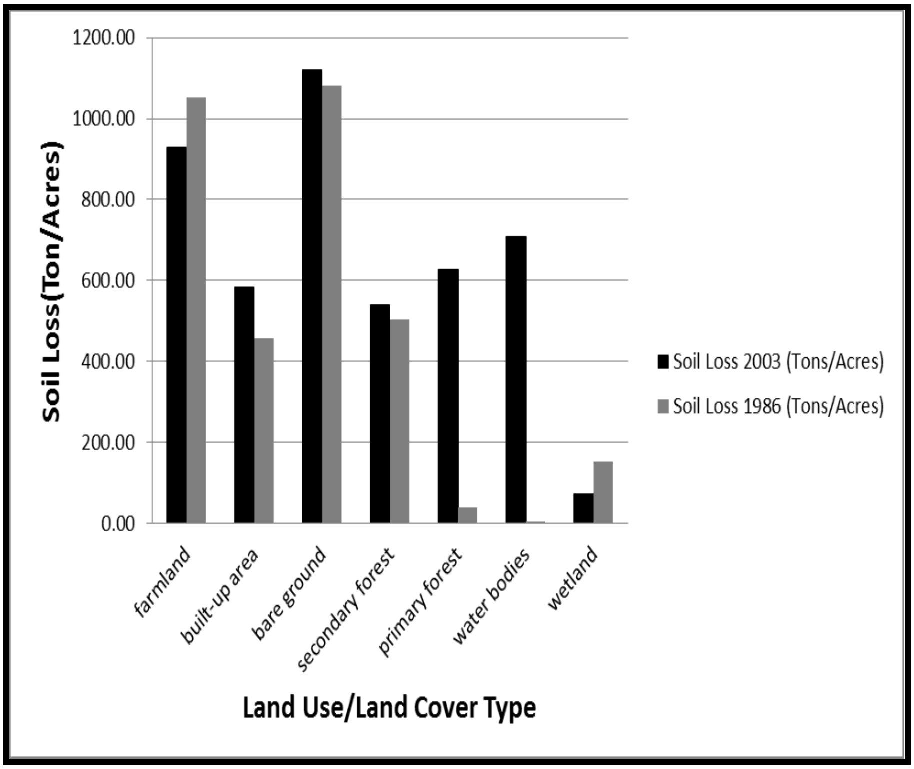

Figure 8. The distribution of soil loss in Abia State from 1986 to 2003.

Table 4. Soil loss (Tons/Acre) for each Local Government Area in Abia State.

Local government name	Soil Loss 1986 (Tons/Acre)	Soil Loss 2003 (Tons/ Acre)
Aba North	269.19	266.73
Aba South	219.09	224.01
Arochukwu	242.64	258.44
Bende	525.73	547.54
Ikwuano	154.98	164.27
Isiala Ngwa North	258.56	262.37
Isiala Ngwa South	140.6	154.39
Isukwuato	568.45	594.65
Oboma Ngwa	298.6	371.89
Ohafia	544.89	538.90
Osisioma Ngwa	232.6	236.86
Ugwunagbo	142.23	138.57
Ukwa East	208.31	222.41
Ukwa West	194.83	185.30
Umu-Nneochi	1082.58	1120.59
Umuahia North	412.95	720.89
Umuahia South	304.67	304.22

vegetation. NDVI value was scaled to 8 bit image to remove negative values for easy analysis in SPSS. The NDVI values are contained in Tables 3 and 4. As shown in the two tables, forested areas had the highest NDVI

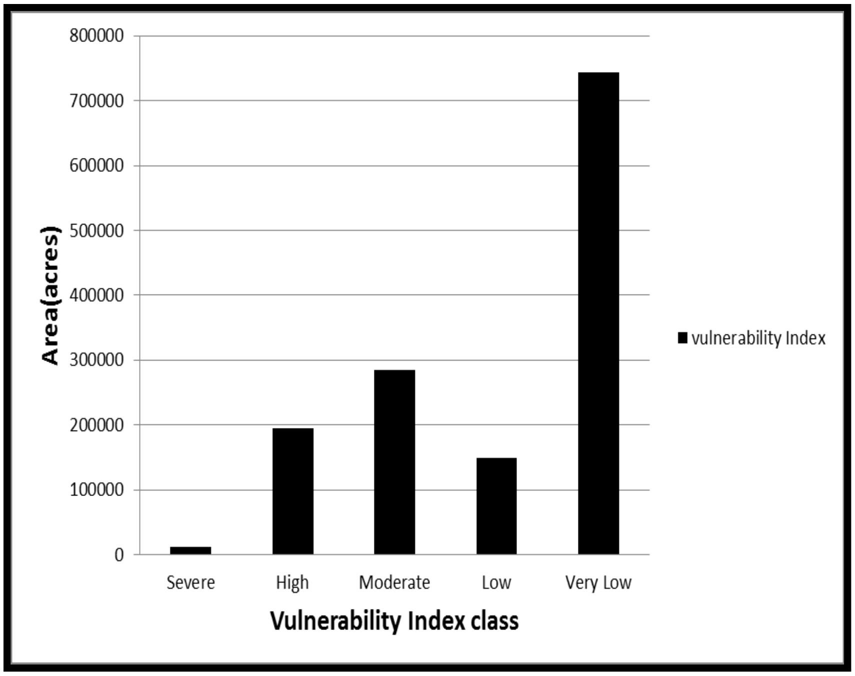

Figure 9. Areas covered by each vulnerability index class.

Table 5. Regression equations and co-efficient of correlation for Abia State in 1986 and 2003.

Year	Regression equation	R	R^2
1986	Y=28.262 - 0.101X	0.070	0.005
2003	Y=184.155 - 1.459X	0.976	0.953

value while built-up areas had the lowest. This was due to urban development whereby natural vegetation is removed and replaced by non-evaporating and non-transpiring surfaces such as metal, asphalt and concrete. Figures 10 and 11 show NDVI of the study area from 1986 to 2003.

Correlation analysis between NDVI and soil loss

The relationship between soil loss and NDVI was investigated for each land cover type through correlation analysis. It is apparent from the figures obtained that surface temperature values tend to negatively correlate with NDVI values for all land cover types. These correlations can be visualized by plotting the corresponding mean surface temperature values for all land cover types against the NDVI. The regression graphs of the study area from 1986 to 2003 are shown in Figures 12 and 13.

The negative correlation between soil loss estimation and NDVI clearly indicates that the higher the biomass a land cover has, the lower the soil loss. Thus, it is clear from this result that changes in land use/land cover affect soil loss. Regression equations and co-efficient of correlation values are tabulated in Table 5.

Modelling soil erosion risk and affected communities in Abia State

Risk in the context of this paper means the expected degree of soil loss due to potentially damaging erosion phenomenon within a given time. Soil erosion risk was determined by calculating its intensity across the study area. The results obtained were used to rate the various communities on the level of their proneness to soil erosion risk.

Soil erosion risk was determined by multiplying the hazard by vulnerability. The risk index and area coverage was determined for the State and is presented in Table 1. A spatial query analysis was conducted on the database to provide some useful information necessary to understand the phenomenon of soil erosion risk in the

Table 6. Soil loss (Ton/Ha) and risk rate of towns affected by soil erosion in Abia State.

Risk rate									
Severe		High		Moderate		Low		Very Low	
Town name	Soil loss	Town name	Soil loss	Town name	Soil loss	Town name	Soil loss	Town name	Soil loss
UmuOru	915.23	UraNtaUmuarandu	447.39	UmuUvo	269.33	Umuoru	89.21	Umuzomgbo	21.24
UmuNwaNwa	878.39	Amaokwe-Elu	527.7	UmuUhie	267.84	UmuomayiUku	135.75	Umuozuo	25.91
UmuKalika	858.16	UmuOmei	607.69	Umuosu	173.94	UmuOkohia	124.06	Umuosi	5.93
UmuIroma	1053.11	UmuOkoroUku	386.78	UmuosoOnyoke	231.82	UmuOcha	55.19	Umuokpe	8.73
Umuasua	839.61	UmuOko	334.58	Umuopia	272.36	Umunachi	90.66	Umuokorola	5.5
Owaza	1325.88	UmuOjimaOgbu	311.14	Umuokoro	231.84	UmuMba	138.65	UmuOhia	23.18
OnichaNgwa	925.86	Umuode	554.36	UmuOkahia	185.76	UmuEzeUku	106.59	UmuOcham	8.43
Okwu	864.89	UmuObiakwa	349.86	UmuohuAzueke	245.29	UmuDosi	90.66	Umumba	49.84
OhuhuNsulu	1152.95	UmuNkpe	469.29	Umuodo	234.11	UmuAla	135.75	UmuIkuUko	25.91
OhafiaIfigh	819.43	UmuNkiri	305.63	Umuocheala	156.27	UmuAjuju	135.75	Umuemenike	9.43
NdiUdumaUkwu	971.95	Umuihi	630.21	Umuobiala	151.09	Umuada	90.66	Umuellem	6.57
NdiOrieke	1455.25	Umuhu	542.45	UmuNta	218.41	Ubani	54.64	Umu Awa	0
MgbedeAla	751.25	Umuezu	379.09	Umunekwu	243.81	Ubaha	124.06	Umuakwu	6.57
Ekenobizi	1101.37	UmuevuOloko	491.33	Umulehi	275.39	Ovuoku	58.93	Umuabia	6.14
Asaga	821.5	Umueteghe	345.28	Umuko	190.19	Okpo	64.13	UmuAbayi	5.93
Amuzukwu	1154.74	UmuEnyere	425.16	UmuEzegu	272.36	Okoko	105.78	UkwaNkasi	7.37
Amiyi	797.79	Umuchiakuma	429.36	UmuEgwu	211.4	OkahiaUga	88.35	Ugbo	4.45
AmaUru	1200.78	Umuawa	336.5	Umudike	156.27	OgoOmerenama	113.61	OzuAkoli	9.64
AmaUke	1093.34	Umuarughu	349.11	Umuanyi	260.14	Oduenyi	60.14	Onuasu	0
Amanta	1556.38	Umuanya	352.91	Obor	251.29	Obiohia	51.57	Okwe	4.95
Akoli	1029.01	Umuamachi	309.45	Umuchima	216.91	Amuma	93.69	Okpuala	30.3
Abala	1371.49	Amaoku	478.8	Umu Aro	216.91	Obinto	79.66	Okopedi	16.99
Umuakwu	713.38	UmuAkpara	468.65	Oboro	209.46	Obieze	92.83	Okon	45.63
Umuopara	680.7	UmuAja	561.47	Obuohia	242.86	Obete	106.59	Okoloma	5.93
Uturu	1060.8	Umuahia	374.44	UmuAkwuAmeke	222.71	Egbelu	119.13	Ndiachinivu	6.32

study area. Spatial queries were used to determine risk prone areas (Towns) for different index classes in the study area. The communities were classified into severe, high, moderate, low and very low risk prone areas. The towns in Abia State affected by soil erosion and the level of risk are presented in Table 6. As Table 6 indicates, there are twelve (12) communities in the State with the highest values of soil loss (≥1000 tons/ha) and severe erosion risk. The communities are Amanta (1556.38 tons/ha), Ndiorieke (1455.25 tons/ha), Abala (1371.49 tons/ha), Owaza (1325.88 tons/ha), Amauru (1200.78 tons/ha), Amuzukwu (1154.74 tons/ha), Ohuhu-Nsulu (1152.95 tons/ha), Ekenobizi (1101.37 tons/ha), Amauke (1093.34), Uturu (1060.8 tons/ha), Umuiroma (1053.11 tons/ha), and Akoli (1029.01 tons/ha).

Overall, the results reveal that 40% of the State experiences severe form of soil erosion. About 32% experience high soil erosion; 17.51%

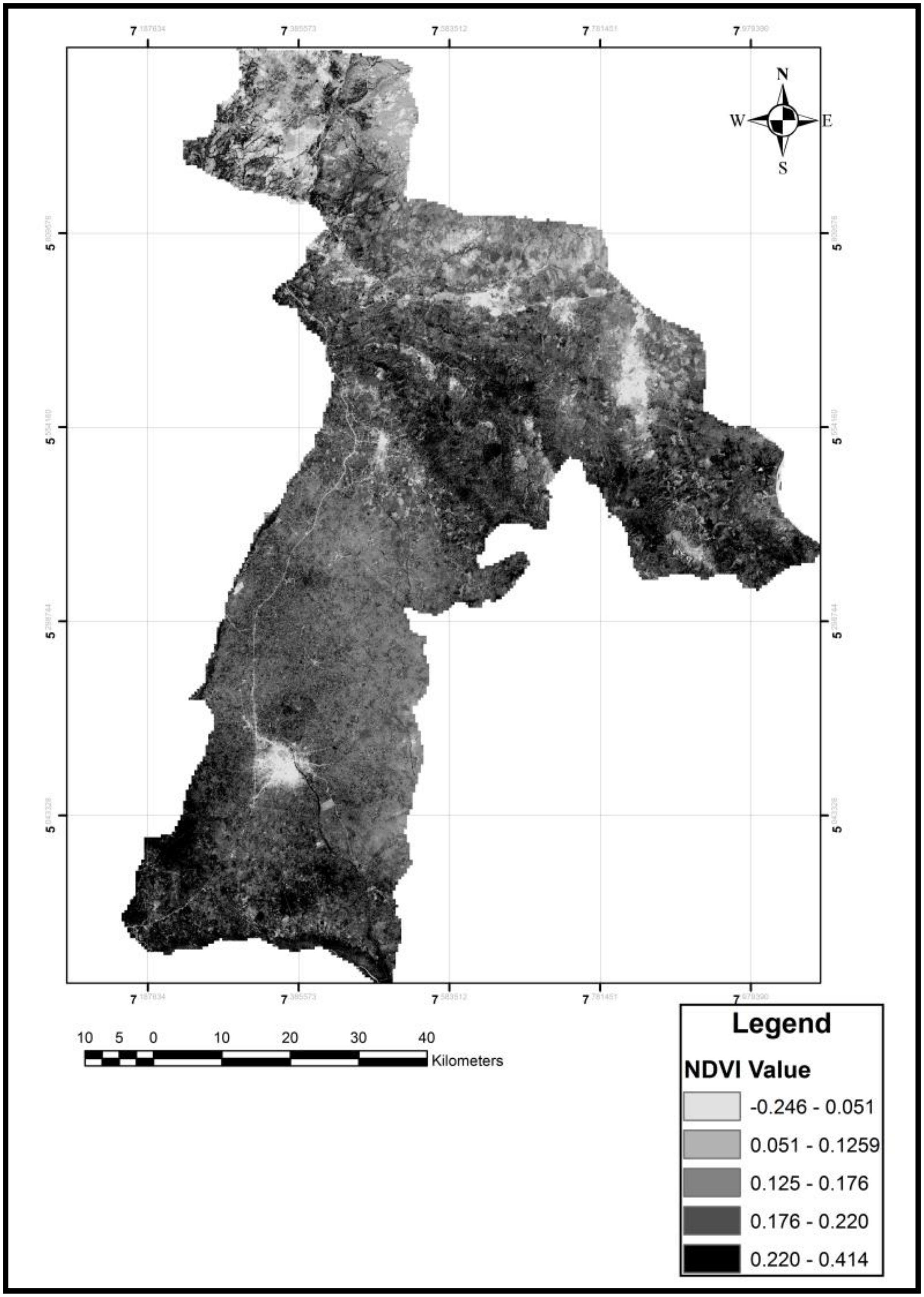

Figure 10. NDVI map of Abia State for 1986.

experience soil erosion moderately, while only 1% of the State is affected by very low erosion. From the results, it is obvious that several communities in Abia State stand the risk of significantly losing their lands, infrastructure,

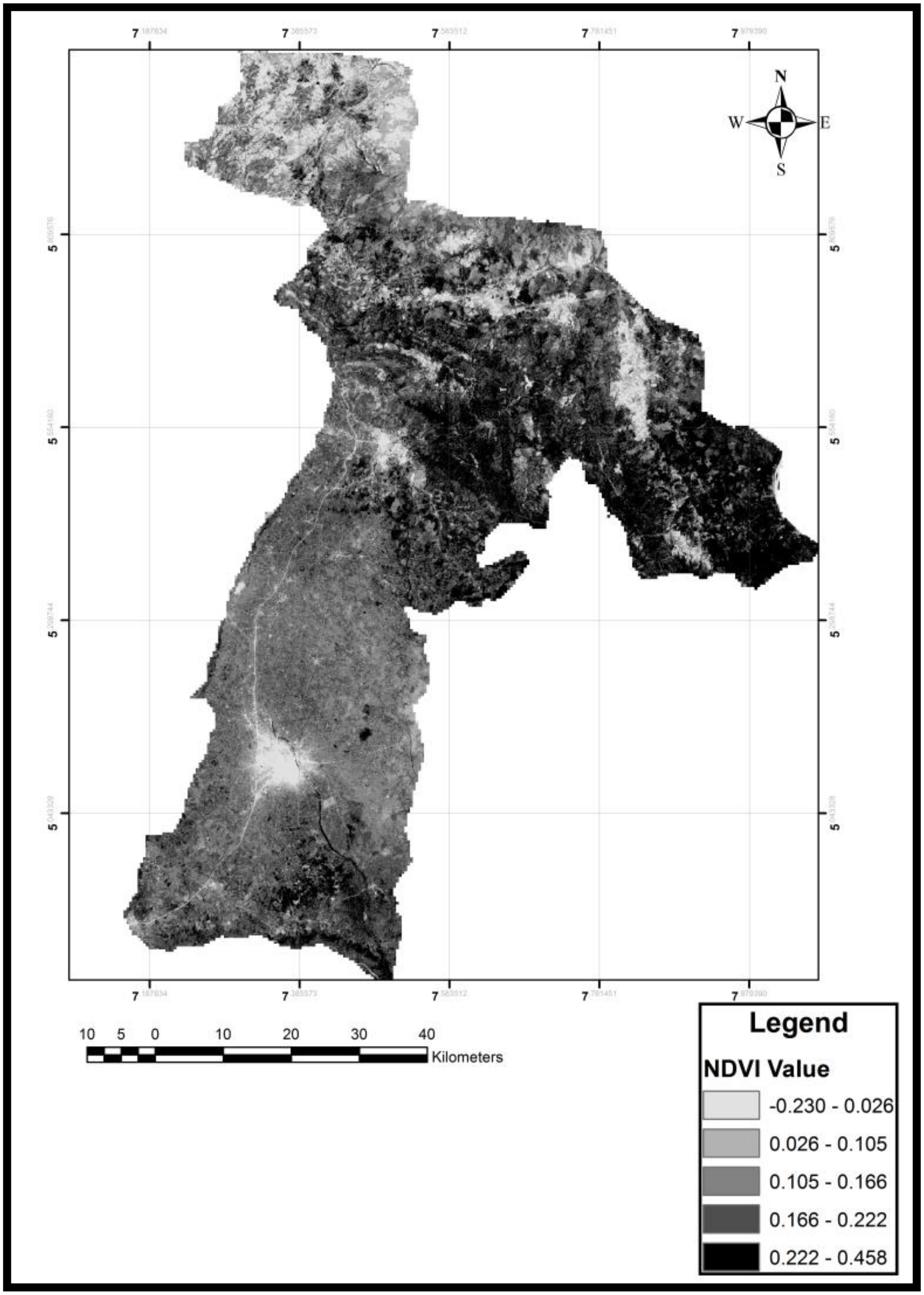

Figure 11. NDVI map of Abia State for 2003.

crops, rich natural resources and even lives to soil erosion, if appropriate and effective control measures are not put in place.

Conclusion

Primarily, this research presents a methodology for GIS-

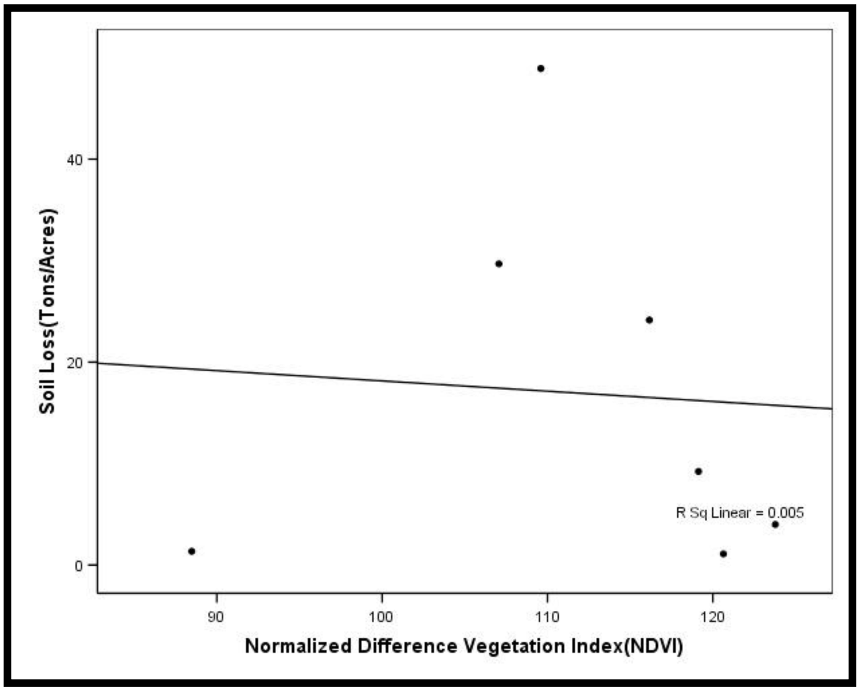

Figure 12. Correlation between NDVI and soil loss in Abia State for 1986.

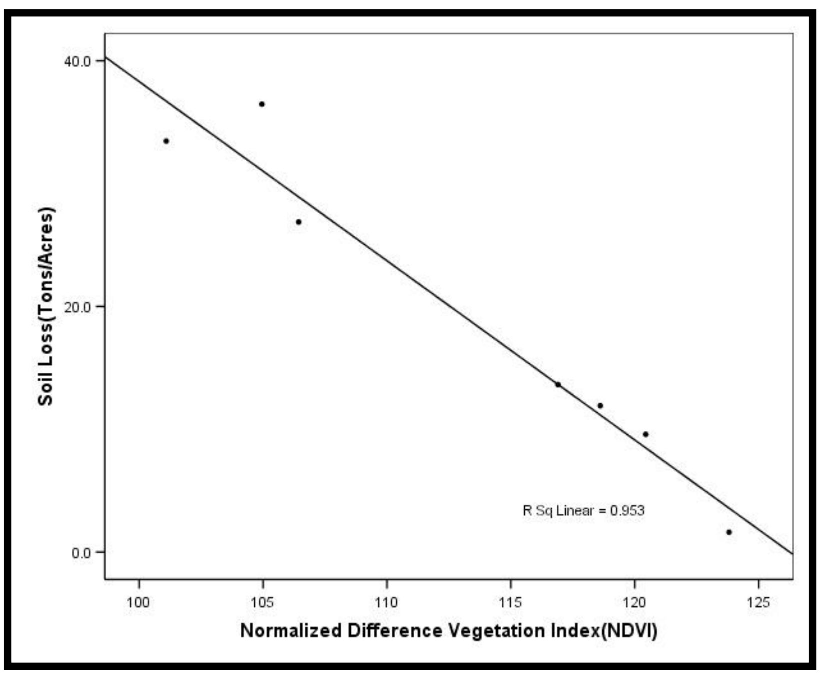

Figure 13. Correlation between NDVI and soil loss in Abia State for 2003.

based soil erosion risk assessment in Abia State, Nigeria, with relatively little basic information available. The study relied heavily on historical data, natural and human parameters, expert judgment, as well as the relationship between amount of soil loss and NDVI as an indicator to evaluate soil loss magnitude and risk intensity. The methodology adopted in this study can equally be replicated in areas or circumstances where there is little or no basic measurement or data for the direct study of soil erosion. The study of vulnerable areas and risk effects of soil erosion hazards is very helpful for determining the effect of certain mitigation measures, for which a cost-benefit analysis can be carried out. This type of information allows moving away from the “response-only” approach to disaster management, which has been endemic throughout the developing world, to one which incorporates prevention and reduction (Westen et al., 2010).

Conflict of Interest

The authors have not declared any conflict of interest.

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