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Geospatial Technique Approach to Land Degradation Assessment in Ghana: The Case of the Ejura Sekyedumase District

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Abstract: This study examined the use of Geographic Information Systems (GIS) as a tool in assessing land degradation caused by water erosion in the Ejura Sekyedumase District, a major food crop production district in Ghana. Data used were land use/cover, slopes/digital elevation models (DEMs) and soil maps. The land use/cover map was derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) 2015 satellite imagery. Digital image processing techniques involving image enhancement, manipulation and classification were conducted for land use/cover analysis and images were reclassified with an erosion vulnerability map. A slope map (in degrees) was derived from the DEM. The digital soil map, which was classified according to Food and Agriculture Organization (FAO) groups, was reclassified according to the erodibility classes. The multi-criteria decision module, with a standardized and weighted linear combination approach (WLC) in IDRISI Kilimanjaro was used for the analysis. First, a fuzzy map was created for each map layer, which were later combined to produce a land degradation risk map. The study confirmed that land degradation risks due to erosion exist in the area. Specifically, the southern and central parts of the district were observed as low risk areas (21%), whereas only nine per cent of the area was under high risk. These areas were observed in patches around the southeast, southwest and north-central areas. This study demonstrates that remote sensing (RS) is a major environmental data source which, when integrated with GIS, becomes an effective tool for assessing and mapping land degradation.

Key words: Land degradation, Remote Sensing, Geographic Information Systems.

The world's greatest environmental challenges, as noted by the United Nations Environmental Programme (UNEP), are land degradation and desertification (UNEP, 2015), which affect approximately 29% of the global area across all agro-ecologies and 3.2 billion people globally (Quang *et al.*, 2014). In addition, 78% of degraded land has been found to reside in non-dryland areas, such as forests and semi-deciduous ecotones (Pender, 2009). Land degradation and desertification situations are worsened by climate change and poor management of agriculture (IPCC, 2012; 2013). In the developing world, it has been reported that land degradation has affected 1,400 million hectares of rangeland and dry forest, 339 million hectares of tropical rainforest, 300 million hectares of rainfed cropland and 45 million hectares of irrigated rangeland (Nsiah-Gyabaah, 1994). Africa has been described as the most vulnerable continent regarding land degradation (Pender, 2009). Among the anthropogenic factors that have promoted land degradation is unsustainable agriculture, which is a major economic activity in the developing world (Nsiah-Gyabaah 1994; El Baroudy and Moghanm, 2014; UNEP, 2015). Declining agricultural productivity and an increasing number of countries devastated by drought in sub-Saharan Africa (SSA) over the past two decades have raised serious concerns among African policy makers about whether the land can support the expanding population and produce enough sustenance to combat poverty and food insecurity (Johnson and Lewis, 1995). It is estimated that by the year 2020, land degradation may pose a serious threat to food production and rural livelihoods, particularly in poor and densely populated areas of the developing world (Scherr and Yadav, 1996). In Kenya, for instance, land degradation has been identified as a major threat to functioning ecosystems in areas classified as having high and low agricultural potential (Waswa, 2012). Around the northern Nile Delta in Egypt, E1 Baroudy and Moghanm

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(2014) identified sodicity, salinity, compaction, waterlogging and water erosion as factors of land degradation, which they attributed to the rise in the Mediterranean Sea level.

Since agriculture is the main economic activity in Ghana, the effects of land degradation can be significant. The United Nations Convention to Combat Desertification defined land degradation as "any reduction or loss in the biological or economic productive capacity of the land resource base. It is generally caused by human activities, exacerbated by natural processes and often magnified by and closely intertwined with climate change and biodiversity loss" (UNCCD, 2014). According to the Food and Agriculture Organization, land degradation is a process that encompasses soil degradation and erosion, which is referred as desertification in drylands (FAO, 2011).

Land degradation in Ghana takes a number of forms, such as depletion of soil nutrients (i.e., loss of soil fertility), salinization, agrochemical pollution, soil erosion, vegetative degradation due to overgrazing and the cutting of forests for lumber and farmlands. These forms of degradation are associated with number of factors, including depletion of soil nutrients through poor farming practices, land clearing (i.e., clear cutting and deforestation), livestock overgrazing and inappropriate irrigation, urban sprawl and commercial development (Benneh *et al.*, 1990; Amanor, 1994; Alo and Pontius, 2008; Asuming-Brempong, 2010; Gaur *et al.*, 2015).

The Ejura Sekyedumase District (7°22'30.00" N -1°22'1.20" W), located in the Ashanti region of Ghana, has been experiencing immense land degradation in the form of soil erosion by water during the raining seasons, which is perhaps due to the topography (undulating hills) of the area (Ejura Sekyedumase District Assembly, 2006; Kemausuor *et al*., 2011). Crops are being cultivated in an ecologically fragile environment (e.g., steep slopes). Most soils suitable for farming are infertile due to the disappearance of semi-deciduous forest cover.

Land degradation due to soil erosion in the area, coupled with climate change, has far reaching socio-economic consequences. Poor rural communities are suffering from food insecurities among other hardships (Kemausuor *et al*., 2011; UNCCD, 2014). The spatial assessment of this situation would be crucial in reducing the negative impact on the socio-economic lives of those inhabiting the area.

A land degradation assessment is a complex process driven by both anthropogenic and natural forces, and its quantification and detection of spatial patterns is a great challenge (Waswa, 2012). Such an assessment can be accomplished through expert knowledge, land user opinions, modelling, field observations, monitoring and measurements, productivity change estimates, remote sensing and geographic information systems. Some of the methodologies used when assessing land degradation are the continuous surveying and monitoring of land degradation processes in a pilot area and in different environments; mathematical simulation modelling utilizes data from pilot areas to extrapolate information into other areas, for predictive purposes and for the use of a statistical and ecological framework using vegetation index data (Higginbottom and Symeonakis, 2014). For this study, geospatial techniques (El Baroudy and Moghanm, 2014), which involve geographic information systems (GIS) and remote sensing that provides spatial extrapolation, is used to analyse and map degraded portions in the area. This is accomplished by identifying threatened areas in order to direct policy decisions that will help mitigate those areas (Owusu and Gasu, 2002). The use of satellite imagery is cost-effective and time-efficient when huge land areas are to be monitored. Remote sensing imagery is appropriate when analyzing land use/cover patterns and integrating remote sensing into GIS makes it possible to depict the results in a graphic or map format (Gao and Liu, 2008; El Baroudy and Moghanm, 2014; Elbeih, 2014).

The objective of this paper is to produce an agricultural land degradation risk map for the Ejura Sekyedumase district in Ghana. This will serve as important information for district planners, environmentalists and agricultural policy makers throughout their planning processes for the district.

Materials and Methods

Study area

The Ejura Sekyedumase District is located in the northern part of the Ashanti region in Ghana and has a land area of 1,782.2 km^2 (Fig. 1). The area lies in transitional zones, between the semi-deciduous forest and the Guinea-Savanna ecotone. It is therefore characterized by forests and a savanna climate. The area experiences bimodal rainfall, with an average annual rainfall between 1200 mm and 1500 mm (Cudjoe, 2003). The major rainy season each year usually occurs between April and June, with a minor season from September to November, while the dry season extends from December to April (Kemausuor *et al.*, 2011).

The rainfall pattern in the area is very erratic. Relative humidity during the rainy seasons are high (90%) in June and low (55%) in February. Generally, the mean monthly temperature ranges from 21°C to 30°C. The warmest months occur from January to April, whereas the coolest months occur from July to August. Soils in the district fall under the forest and savanna ochrosols group. They range among sandy, loam or clay. Most of the soils are deep, light in color, well aerated and drained, with a moderate supply of organic matter and plant nutrients. The climate over the years has promoted the production of cereals, cashew, teak, vegetables, tubers (e.g., yam, cassava and cocoyam), plantains, livestock and poultry.

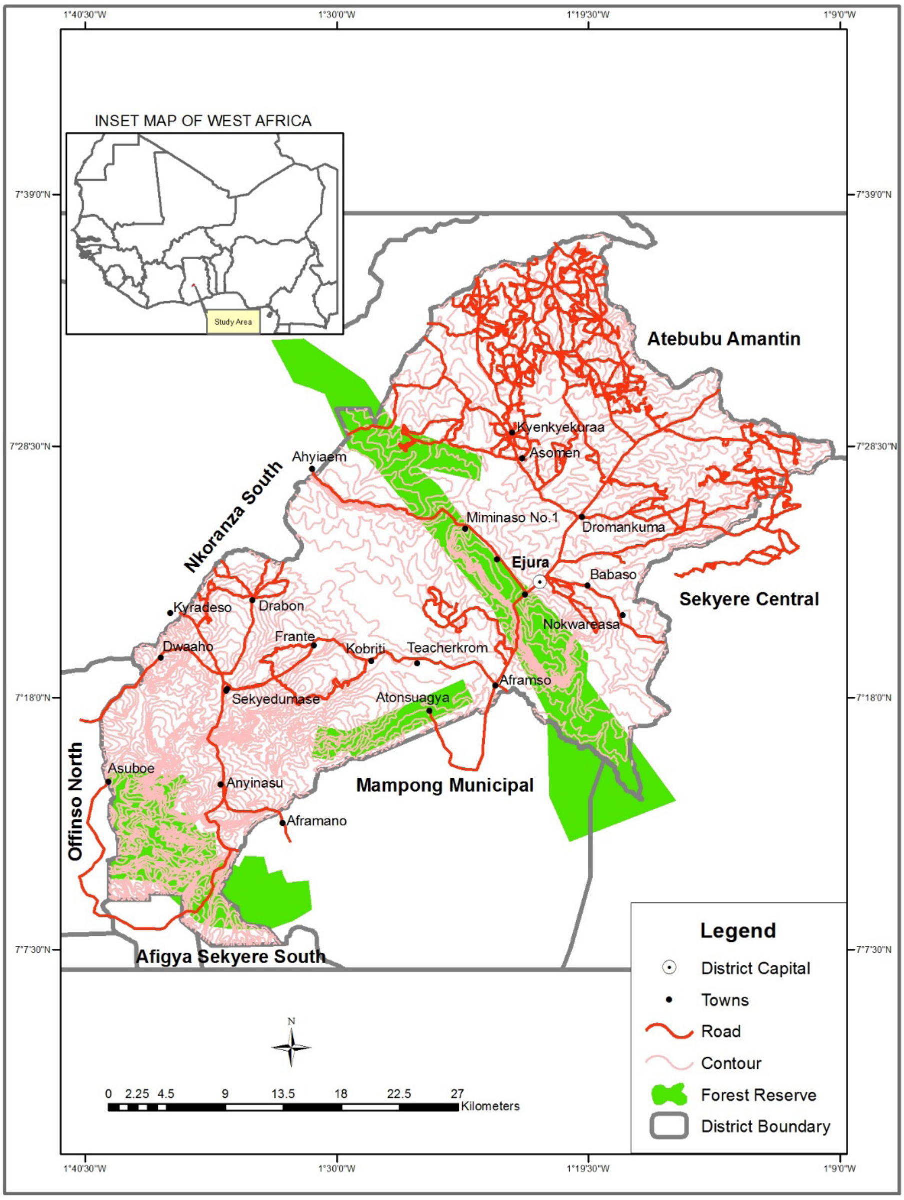

Fig. 1. The Ejura Sekyedumase District map.

Regardless of the contribution of food and livestock production in the district to the economic development of the district and the country, the district has been besieged with soil degradation over a sizeable area for a number of years, which has affected its agricultural production potential, specifically the food crops and consequently the livelihood of the people.

Methods

To assess and map land degradation due to soil erosion in the area, indicators were required because land degradation is a process. Indicators have the potential to provide important and relevant information and, therefore, must be selected, used and interpreted with extreme caution because local conditions (i.e., underlying relationships that influence land degradation) vary widely. An indicator may actually indicate differences in the natural state rather than the inferred processes of degradation or improvement (Essa, 1970; FAO, 1979, 2011; El Baroudy and Moghanm, 2014). In light of this and based on the available literature, four indicators were selected and used:

i. Land use/cover map: It is assumed that agricultural fields are more vulnerable to land degradation compared to other land use/cover types (e.g., forest vegetation, reserved forests and watersheds).
ii. Soil map: Various soil types and their degrees of susceptibility are known. Sandy soils are highly susceptible to erosion and do not usually support plant growth, loamy soils are not highly susceptible to erosion (Jabbar *et al.,* 2005).
iii. Topography/elevation/DEM map: The slope of an area determines the ease at which erosion can occur. The higher the slope gradient, the higher is its vulnerability to both water and wind erosion and vice versa.
iv. Climatic data: The major element under climate is rainfall and its intensity.

The processes of gathering these data and how they were processed have been summarized in a conceptual model (Fig. 2).

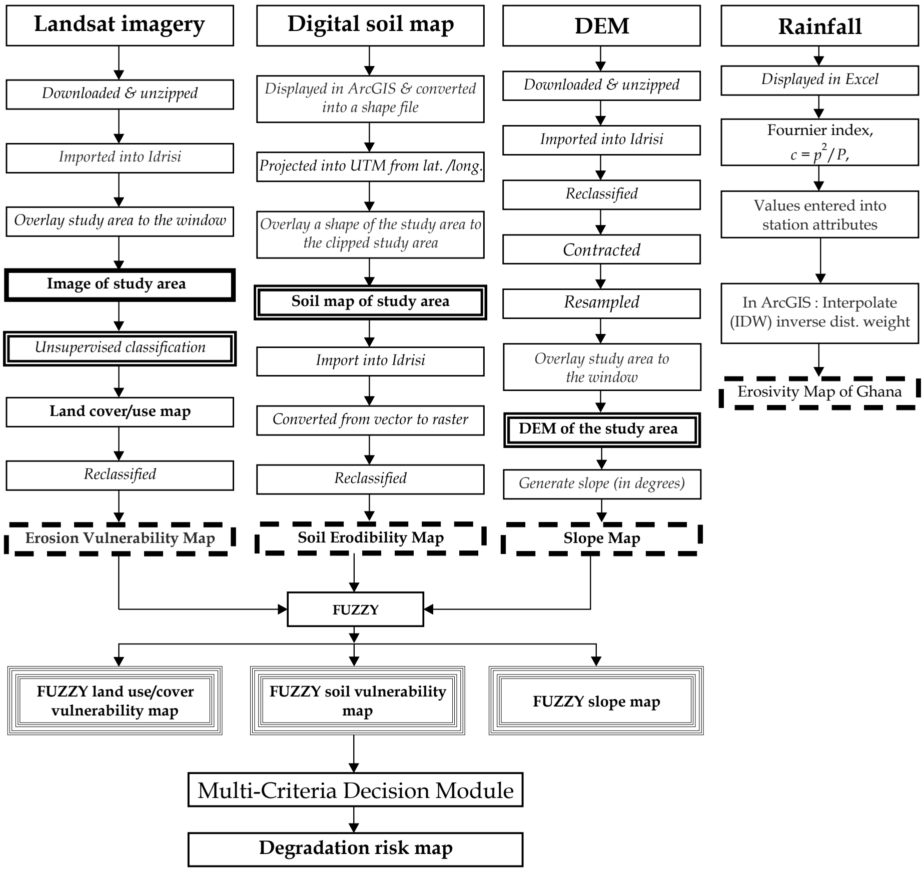

Fig. 2. Conceptual model for land degradation risk mapping.

First as depicted in the conceptual model, Landsat images were downloaded and imported into the IDRISI Kilimanjaro platform, where the study area overlaid and subset. Both unsupervised and supervised classifications were performed using a classification scheme to generate a land use/cover map. This map was reclassified to produce an erosion vulnerability map. Second, a digital raster soil map was displayed using ArcGIS 10.5 with a Universal Transverse Mercator (UTM) projection; the study area was overlaid and a subset was created. Furthermore, a digital elevation model (DEM) was downloaded and resampled; the study area subset and the slope map (in degrees) were generated. A fuzzy map was derived from erosion vulnerability, soil erodibility and slope maps. With the multi-criteria decision module, the fuzzy maps were modelled to generate a degradation risk map.

Data collection and database design/ management

To achieve the objectives within a GIS environment, there was a need to identify and create a database. Table 1 shows the data types, formats and sources. The implementation was accomplished using Microsoft Excel, IDRISI Kilimanjaro and ArcGIS 10.1.

As indicated above in Table 1, the first input for the model was remote sensing data, from which a land use/cover map was derived (Erencin, 2000). The high-resolution satellite imagery from the Landsat 7 (ETM+) scene was downloaded from GLCF, then unzipped and imported into the IDRISI Kilimanjaro software using the module "Import, Desktop Publishing Formats, GEOTIFF/TIFF". Prior to this, a vector boundary layer in the geographic coordinate system was displayed in ArcGIS 10.1 and projected into the UTM coordinate system to conform with the Landsat image; then, the vector boundary layer was imported into IDRISI and overlaid on one of the bands in a window outside of the study area.

Image processing

Initially, an unsupervised classification was performed using the CLUSTER module in IDRISI. The iterative process uses the full maximum likelihood procedure. This provides a very strong cluster assignment procedure. CLUSTER uses a histogram peak technique for the cluster analysis. This is equivalent to looking for peaks in a one-dimensional histogram, where a peak is defined as a value with a greater frequency than its neighbours on either side. Once the peaks have been identified, all possible values are assigned to the nearest peak and the divisions between the classes fall at the midpoints between the peaks (Eastman, 2001; 2003). Here, one seven-dimensional histogram was used to find the peaks. Thus, a peak is classified when the frequency is higher than that of all its cardinal neighbours. With CLUSTER, the user simply identifies which bands IDRISI should use to create the classifications and how many classes are need to categorize the land use/ cover features. Therefore, Landsat ETM bands 1-5 and 7 were used and eight land use/ cover categories were assigned. Based on an existing digital land use/cover map of the area prepared from 1991 Landsat imagery by the Centre for Environmental Remote Sensing and Geographic Information Services (CERSGIS) at the University of Ghana, personal knowledge of the area and scientific reasoning, five land use/cover types were identified. RECLASS was used to achieve these five classes. To generalize the cover types, the image was filtered using the mean (3 x 3 filter size with a 1/9 filter kernel). Each category (code) was then edited and assigned a land use/cover type. Using the symbol workshop, various colours were

Table 1. Data types, sources and formats

Data	Source	Format	File format	Scale
Satellite imagery Landsat 7 (path 194 & row 55) Acquired on 29/12/2015	https://glovis.usgs.gov/	Raster	GeoTIF	30 m resolution
Digital soil map	Soil Research Institute from the Centre for Scientific and Industrial Research (CSIR) in Ghana	Vector	Shape file	1:250,000
Digital elevation model (DEM)	Downloaded DEM from http://seamless.usgs.gov/Website/Seamless/	Raster	GeoTIFF	SRTM 3 arc-sec 37
Rainfall data	The Ghana Meteorological Agency in Accra.	Excel	Excel	National

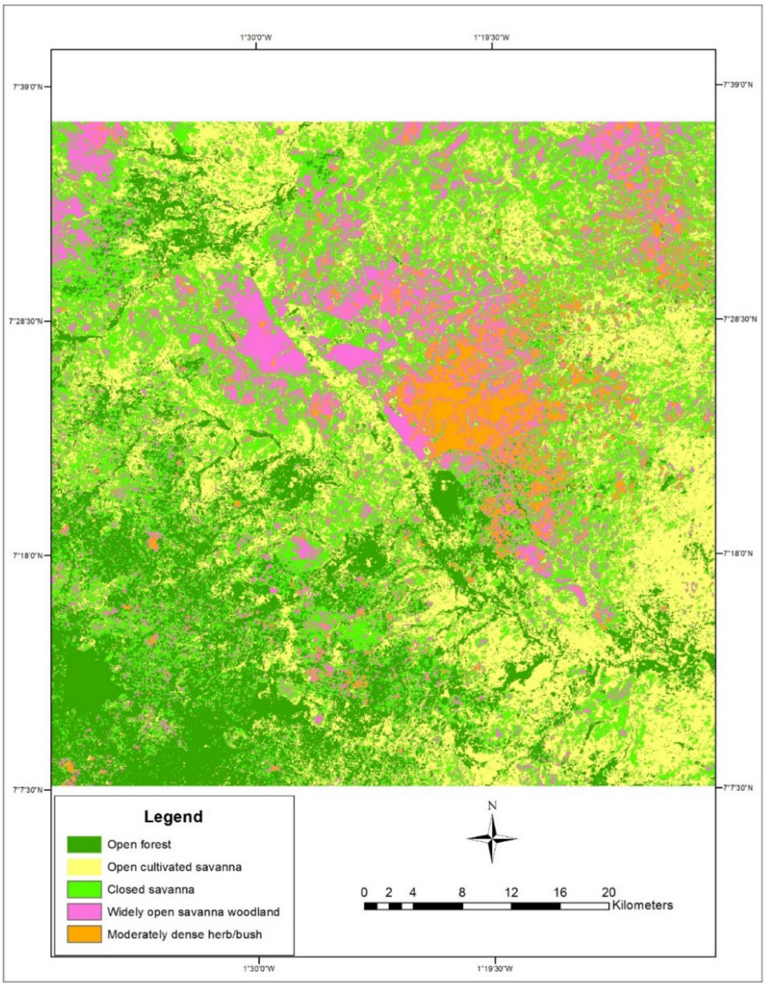

Fig. 3. Land use/cover map of the study area derived from Landsat imagery (GLCF, 2015).

assigned to each use/cover type, as shown in Fig. 3.

Soil erodibility

Based on the FAO classification, eight (8) soil groups were identified in the district. These soil groups are lixisols, which is the predominant soil group, followed by luvisols, which are concentrated in the east and are interspersed with fluvisols. Other soil groups are gleysols and plinthosols, which are found in the southeast and northwest, acrisols (in the southwest), leptosols patches (in the central and southwest), and planosols, which are the least influential and are located north of the area. Each of these soil groups has properties that affect soil degradation differently (OESPO, 1999). Soils vary in their resistance to erosion, which is partly based on their texture and the amount of organic matter (CEC, 1992; Bellinfante *et al.*, 2000). Resistance also depends on soil condition and depth. Soils that are high in silt, low in clay, or sandy are highly erodible (Sklar and Dietrich, 2001). The high erodibility of silty soils can be attributed to their weak structural stability (Hudson, 1995; Summer, 2000). Erosion is less in clayey soils due to better aggregation and in sandy soils, erosion is less due to its non-sealing surface. Based on these characteristics, the soil groups were assigned codes depending on the level of resilience to erosion, ranging from 1 to 5 (i.e., high to low resilience) (Table 2 and 3).

Table 2. Risk level and weights (soils)

Rate	Weight
Low	1
Limited	2
Moderate	3
High	4
Extreme/very high	5

Table 3. Soil groups and erodibility class

Soil group	Erodibility class
Acrisols	4
Fluvisols	1
Gleysols	1
Leptosols	5
Lixisols	1
Luvisols	3
Planosols	4
Plinthosols	4

Slope

Topographic factors, mainly slope gradient and length, are part of the land characteristics that determine the susceptibility of land to erosion, which results in fertility loss and therefore degradation. The area generally has a gentle topography ranging from 32 metres to 509 metres above sea level. Based on the DEM, a slope map was generated in degrees, with the IDRISI module SURFACE and reclassified into five gradient categories, as shown in Table 4

Rainfall erosivity

Erosivity, which is an indicator of the erosive power of rainfall, is a term used to describe the potential for soil to wash off a disturbed, devegetated earth into waterways during storms (Dogan, 1994; D'Odorico *et al.*, 2001). The potential for erosion is partly determined by the soil type and the geology of the site. Dense, clay-like soils erode less readily when it rains than sandy soils on the side of a hill. An important factor in erosivity is the force of precipitation that is expected when the earth is exposed (Zihni, 2000; Sklar and Dietrich, 2001).

Different approaches exist when estimating the erosive effects of rainfall on soil (e.g., the sum of splash erosion and wash). Simple approaches were attempted to divide rainfall into a category with erosive effects and a category without erosive effects using a total amount or intensity threshold (Bollinne, 1977; Richter and Negendank, 1977; Seuffert *et al.*, 1988; Seuffert, 1992; Hudson, 1995; Ollesch and Seuffert, 1998; Marco da Silva, 2004). In another study, Oduro-Afriyie (1996) used the Fournier index to develop a map of rainfall erosivity for Ghana. This same method was used to develop rainfall erosivity in this study. Thus, the Fournier index, c, is defined as p^2/P: where, p is the rainfall amount during the wettest month and P is the annual rainfall amount.

Table 4. Gradient percentages generated from the DEM

Weight	Slope group (%)	Description	Area (km^2)	Area (%)
1	0-3	Very flat and gentle	1946.22	43.25
2	3-12	Medium	2452.42	54.50
3	12-20	Steep	84.95	1.89
4	20-35	Very steep	15.81	0.35
5	> 35	Extreme	0.55	0.01
Total			4499.95	100.00

Based on monthly rainfall over 30 years, erosivity values were calculated on a national scale and added to the station datasets. To generate a continuous surface, interpolation using the inverse distance weighting function (IDW) was used in ArcGIS, with 10 location points and an output cell size of 1315.32. This surface was then reclassified into five (5) categories, with the study area coinciding with the very low risk (1) category in terms of weight, as shown in Table 5.

Table 5. Rainfall erosivity classes

Weight	Class	Value range
1	Very low risk	47.4-56.2
2	Low risk	56.2-65.1
3	Medium risk	65.1-73.9
4	High risk	73.9-82.8
5	Very high risk	82.8-91.6

GIS analysis

Except the erosivity map, remaining three maps (land use/cover vulnerability, soil erosivity and slope percentage) were generated using the multi-criteria decision module. This is a non-Boolean standardized weighted linear combination (WLC) approach, in raster format, which generates a degradation risk map (Eastman, 2003). To use this module, a continuous scale is a prerequisite; therefore, the factors for each map were standardized using the FUZZY module to produce a fuzzy map on a scale of 0-255 bytes. For each map, the ratios were applied according to the weights indicated in Table 6 and 7, which had monotonical increases in function shape and a sigmoidal function type.

Table 6. Fuzzy categories for land use/cover

Category	Weight	Suitability rate
Open forest	1	0-51
Closed savanna	2	102
Wide-open savanna woodland	3	153
Moderately dense herb/bush with scattered trees	4	204
Open cultivated savanna	5	255

Table 7. Fuzzy categories for soil groups

Rate	Weight	Suitability rate
Low	1	0-51
Limited	2	102
Moderate	3	153
High	4	204
Extreme/very high	5	255

In the case of slope, control points of 3 and 20 were respectively set with monotonic increases in shape and sigmoidal function types to produce a fuzzy map that was equally weighted (0.333) using the multi-criteria decision module.

Results and Discussion

From the land use/cover map (Fig. 3), areas described as open cultivated savannas (shown in yellow) are the dominant land use type, which comprised 46% of the total land use/cover area. This is followed by a closed savanna (in light green), which has higher concentrations in the southern portion of the area (21%). The next land use/cover type is coloured pink and described as a wide-open savanna (including bare areas), which covers 17% of the total area and is concentrated in both central and northeast portions of the region. Open forests are pronounced in the southwestern corner (12%), with a cover type defined by moderately dense herbs/bushes with scattered trees and the least influential (3%) category is shown in brown, according to the legend.

The combination of the three maps previously discussed yielded a final map, which shows degradation risks on a scale of 0-255. Zero refers to low degradation risk and 255 refers to very high degradation risk. For policy purposes, the map was re-classed into three categories, which were interpreted as having low, moderate and high risks (Fig. 4). The analysis confirms that land degradation risk due to erosion exists in the area. Areas described by low risk are spatially located in the south and central parts of the district and

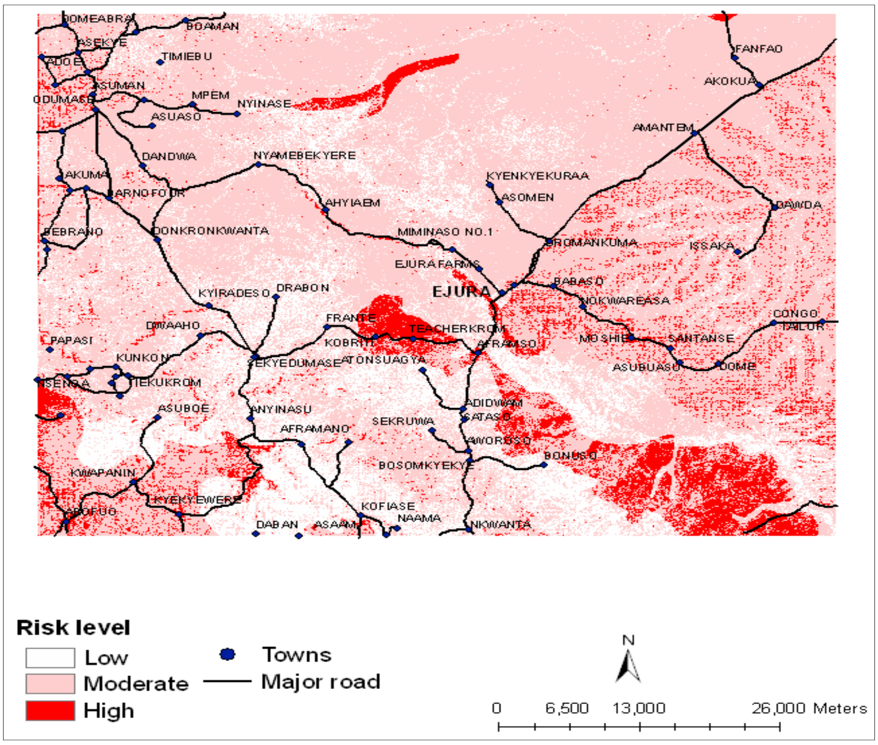

Fig. 4. Land degradation risk map.

cover an area of 906 km^2 (21%); moderate risk, which has the highest area coverage at 3202 km^2 (71%), covers the entire district. Areas identified by high risk (shaded red) cover an area of 394 km^2 (9%), which is the least area (Fig. 4). In total, moderate and high risks accounted for 80% of the area, which can be interpreted to mean that the district is at risk of land degradation due to water erosion.

The results demonstrate the capability of remote sensing and GIS techniques in analysing spatial data and presenting results in the form of a map. The methodology and results confirm similar works conducted in 1997 by Klintenberg and Seely (2004), where a land degradation risk map of Namibia was produced based on four indicators: population pressure, livestock density or pressure, rainfall and erosion hazards. Stemming from these results, there is a need for follow-up research, which should incorporate primary data (including socio-economic surveys). Such a step would help enrich the results. As such, rainfall erosivity usually varies depending on the time of year and the location, especially latitude and elevation. However, the inability to incorporate the rainfall erosivity map, as well negating the role of slope length, may be regarded as a limitation in the results.

Conclusion

To ensure food availability for the increasing population, environmental issues such as land degradation due to soil erosion should not be ignored. One major way to analyse such issue is to obtain adequate and reliable data. Remote sensing has proven to be a major source in obtaining environmental data. When the data are integrated into GIS, it becomes possible to analyse the data and present the results in the form of a map, which shows spatial variations as testified by this study. Therefore, it is necessary that researchers explore the capabilities of these new techniques, which can be integrated into our complex information systems to help in agricultural and environmental decision making.

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