SOIL DEGRADATION IN DRYLANDS

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ABSTRACT

The paper attempts to highlight some of the issues of soil degradation. The paper has been divided into two. The first part analysed the issues of soil degradation were it shows that Soil degradation is widely recognized as a global problem associated with desertification in arid, semiarid and dry sub-humid zones, commonly called the 'drylands'. Yet, land degradation is a contested topic in its determinants, degree, distribution and effects. While the second part analyses the use of GIS and remote sensing in the analysis, determination and quantification of land degradation which shows that is more accurate and economical than the traditional method. The use of GIS and remote sensing in analyzing erosion and salinity has been determined. It also indicated that several models were applied for the analysis especially the use of RUSLE model when analyzing soil erosion. The study concluded that most of the World degraded areas; Africa has fallen within the most highly vulnerable zone.

Keywords: Soil degradation, erosion, salinity, GIS, Remote sensing

INTRODUCTION

Soil degradation occurred as a result of one or more process which lessens the current and or potential capability of soil to produce (quantitatively and or qualitatively) good or services. Soil, vegetation, climate and management are the main factors affecting environmental sensitivity to degradation, through their intrinsic characteristics or through their interaction with the landscape.

UNCCD (1996) defines land degradation as a "reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation."

In Gisladottir and Stocking (2005) Land degradation is widely recognized as a global problem associated with desertification in arid, semiarid and dry sub-humid zones, commonly called the 'drylands'. Yet, land degradation is a contested topic in its determinants, degree, distribution and effects. While long associated with drylands, which cover some 47 per cent of the globe's surface (UNEP, 1997), land degradation is considered by many observers to be highly variable, discontinuous, arising from different causes and affecting people differentially according to their economic, social and political circumstances (e.g. Mortimore, 1998). Uncertainty as to the extent and impact of land degradation is rife. Some sources routinely report that up to 70 percent of all drylands are 'desertified'; others suggest that the figure is no more than 17 per cent (Reynolds *et al*., 2003).

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Different levels of degradation risks may be observed in response to particular combinations of the aforementioned factors. For instance, a combination of inappropriate management practices and intrinsically weak soil conditions will result in environmental degradation of a severe level, while a combination of the same type of management with better soil conditions may lead to negligible degradation. Soil erosion results in loss of precious soil resources for cultivation and causes siltation of reservoirs and natural streams (Kothyari, 1996; Biswas *et al.,* 1999; Jain & Dolezal, 2000).

Land degradation is one of the most serious ecological problems in the world. It entails two interrelated, complex systems: the natural ecosystem and the human social system. Causes of land degradation are not only biophysical, but also socio-economic (marketing, income, human health, institutional support, poverty), undermining food production and political stability (UNCCD, 2004; and WMO, 2006). In a technology-governed and energy-intensive world, degradation of soil conditions has become a widespread problem with negative consequences for both agricultural, natural ecosystems and urban areas (Wander and Drinkwater, 2000; Biasioli *et al*., 2005).

Land degradation, a decline in the quality of the land caused by human activities, has become a major global issue (Eswaran *et al*., 2001). More than half of the dry areas worldwide are affected by land degradation (Dregne and Chou, 1994). Although water erosion is the dominant human-induced soil degradation process, an extent of 0.8 million km^2 suffers from secondary salinization caused by land mismanagement, with 58% of these in irrigated areas alone, and nearly 20% of all irrigated land is salt affected (Ghassemi *et al*., 1995).

According to WMO (2005) In an assessment of population levels in the world's drylands, the Office to Combat Desertification and Drought (UNSO) of the United Nations Development Programme (UNDP) showed that globally 54 million km^2 or 40 per cent of the land area is occupied by drylands. About 29.7 per cent of this area falls in the arid region, 44.3 per cent in the semi-arid region and 26 per cent in the dry sub-humid region. A large majority of the drylands are in Asia (34.4 per cent) and Africa (24.1 per cent), followed by the Americas (24 per cent), Australia (15 per cent) and Europe (2.5 per cent).

Africa is particularly threatened because the land degradation processes affect about 46 per cent of the continent. The significance of this large area becomes evident when one considers that about 43 per cent of Africa is characterized as extreme desert (the desert margins represent the areas with very high vulnerability). There is only about 11 per cent of the land mass which is humid and which by definition is excluded from desertification processes. There is about 2.5 million km2 of land under low risk, 3.6 million km2 under moderate risk, 4.6 million km2 under high risk, and 2.9 million km2 under very high risk. The region with the highest propensity is located along the desert margins and occupies about 5 per cent of the landmass. It is estimated that about 22 million people (2.9 per cent of the total population) live in this area. The low, moderate and high vulnerability classes occupy 14, 16, and 11 per cent respectively and together impact about 485 million people (WMO, 2005).

Causes of Land Degradation

Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system. Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes, which are not fully understood. Interactions between the two systems determine the success or failure of resource management programmes (WMO, 2005).

The following are causes of degradation:

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I. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability).

II. High population density is not necessarily related to land degradation. Rather, it is what a population does to the land that determines the extent of degradation. People can be a major asset in reversing a trend towards degradation. Indeed, mitigation of land degradation can only succeed if land users have control and commitment to maintain the quality of the resources. However, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty and illiteracy can be important causes of land and environmental degradation.

III. Degradation is also a slow, imperceptible process, meaning that many people are not aware that their land is degrading.

IV. Loss of vegetation can propagate further land degradation via land surface-atmosphere feedback. This occurs when a decrease in vegetation reduces evaporation and increases the radiation reflected back to the atmosphere (albedo), consequently educing cloud formation.

Concept of Soil Degradation in Drylands

Soil degradation in drylands is one of the major environmental issues of the 21st century particularly due to its impact on world food security and environmental quality. Climate change, shifts in vegetation composition, accelerated soil erosion processes, and disturbances have rendered these landscapes susceptible to rapid degradation that has important feedbacks on regional climate and desertification (Ravi *et al*, 2010).

Soil erosion is often considered as a cause and an effect of desertification (Nicholson *et al,* 1998; Lal, 2001; MEA, 2005) and important feedbacks have been shown to exist among erosion, biodiversity loss and climate change (Figure. 1). An increase in rates of soil erosion because of climatic changes that increase aridity could result in enhanced loss of soil resources and a loss in biodiversity, which can further increase rates of soil erosion and result in loss of vital services from drylands, including the possible reduction in primary production and carbon sequestration (e.g., Chapin *et al*., 1997). Moreover, biodiversity loss (Figure 2) has been related to a decrease in ecosystem resilience the ability of the ecosystem to recover from disturbances (e.g., Elmqvist *et al*., 2003). Therefore, less diverse ecosystems are more prone to highly irreversible shifts to a desertified state induced by anthropogenic factors or climate fluctuations (Fig. 1). Soil erosion affects the productivity and spatial pattern of dryland vegetation and soil resources (Schlesinger *et al*., 1990; Puigdefabregas, 2005), and is recognized as a threat to sustainable agricultural production in arid and semi-arid landscapes (Lal, 2001).

In agricultural lands (including crop and rangelands), accelerated soil erosion is responsible for the loss of fertile topsoil, depletion of soil fertility and subsequent decrease in crop productivity (Lal, 2001, 2003; Li *et al*., 2008). The detachment, transport and deposition of fine soil, which holds most of the nutrients all affect the soil organic carbon pool and can, influence the global carbon budget (Lal, 2003; Li *et al*., 2008). Therefore, erosion results in loss of soil nutrients and the capacity of soil to hold water, and in an overall decrease in the ability of land to sustain vegetation. In addition, these erosion processes result in the movement of sediments and agricultural pollutants into water bodies, thereby affecting scarce freshwater resources in these dryland landscapes (Lal, 2001). Dust emissions resulting from wind erosion contribute to dust aerosols that are transported long distances and deposited

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over continents and oceans (Duce and Tindale, 1991; Swap *et al.*, 1996). Desert dust is a major contributor of tropospheric aerosols, which affect global climate, air quality and hydrological–biogeochemical cycles (Ramanathan *et al.*, 2001; Hui *et al.*, 2008). Consequently, the impacts of soil erosion processes can extend beyond the geographic boundaries of dryland regions (Ravi *et al*, 2010).

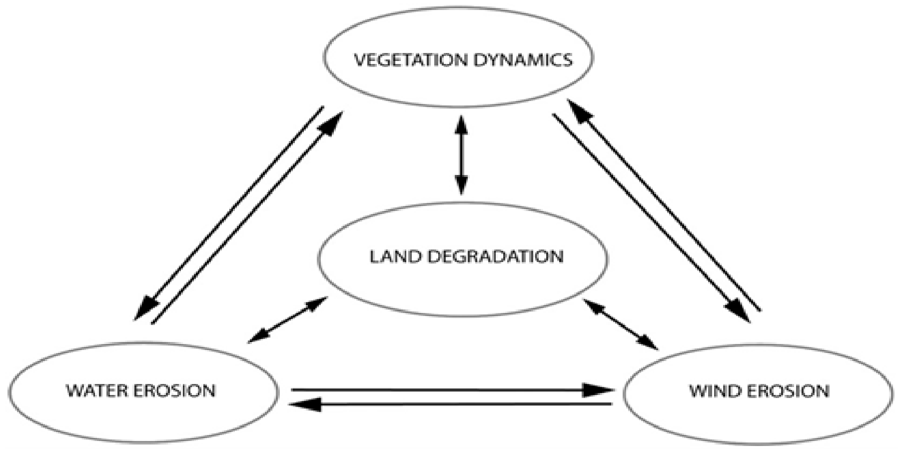

Figure 1. A Holistic Perspective of Land Degradation Dynamics by Considering the Interactions among Wind, Water and Vegetation Dynamic Processes (Modified from Sujith et al, 2010)

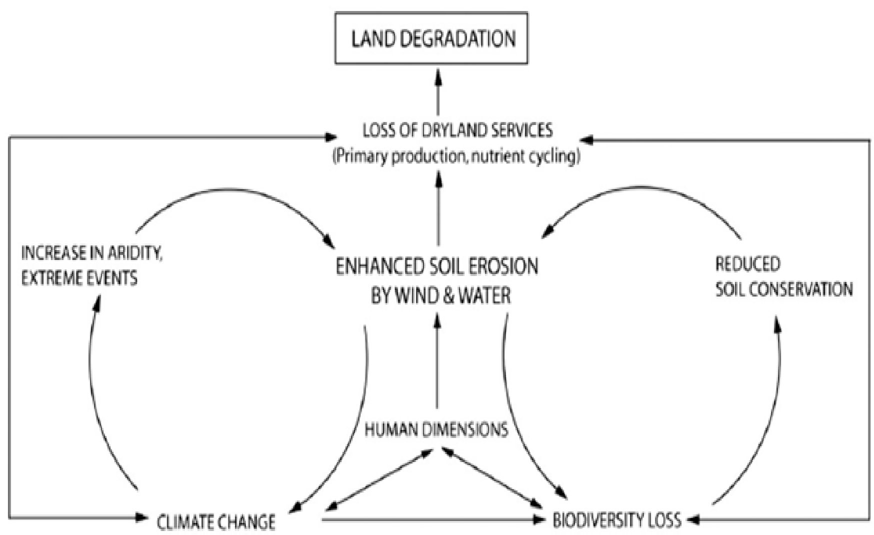

Figure 2. Conceptual diagram showing the interrelations among soil erosion, land degradation, climate change and biodiversity loss (*modified from MEA, 2005*).

The susceptibility of soils to erosion depends on several interrelated factors such as climate, moisture availability, soil properties, topography, land cover and management (Lal, 1994). Among biophysical controls, two factors are perhaps most important in dryland ecosystems: soil moisture and vegetation cover. First, soil moisture, even in air dry soils, can strongly affect soil susceptibility to erosion by wind through its effect on the bonding forces between soil particles (Ravi *et al.*, 2004). Soil moisture dynamics are in turn affected by soil physical and biological properties. Second, vegetation shelters the soil from erosive action of wind and water (Raupach, 1992). Cover by physical or biological soil surface crusts also affects erosion by wind and water (Belnap and Gillette, 1998; Singer and Shainberg, 2004). In

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addition, anthropogenic factors such as agriculture, grazing, soil management, fire, and urbanization further affect soil erosion (Doerr *et al*., 2000; Neff *et al*., 2005; Ravi *et al*., 2009b).

Soil Degradation in Nigeria Drylands

The Drylands of Nigeria are found in the sudano-sahelian part of the country between latitude 11^0N to 13^0 45'N and longitude 3^0 45' E to 14^0 50' E (see Figure 3) they are characterized by:

I. Marginal climate and fringe ecosystem
II. Soil are moderately poor in fertility and soil degradation is widely spread (Essiet, 1990)
III. The rainfall regime is viable and has diminished by 25% since the relatively wet 1960s (Moretimore, 1989)
IV. Human population is increasing with the growth rate between 3.0 to 3.5% (World Fertility Survey, 1984)

The study of Harri (1999) shows that soils in the northern region of Nigeria are categorized as reddish brown or brown soils of the semi-arid and arid regions. They are also known as tropical ferruginous soils and are considered to be comparable to Ferric Luvisols. These are sandy soils that are made up of about 85% sand. Their pH values range between 6.0 and 7.0, and their bulk densities are about 1.4 g/cm^3 this makes it prone to erosion. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. For example, wind and water erosion is extensive in many parts of Africa. Excluding the current deserts, which occupy about 46 per cent of the landmass, about 25 per cent of the land is prone to water erosion and about 22 per cent, to wind erosion (WMO, 2005).

Soil degradation is caused by both human and natural factors, but in the Northern Nigeria human activities act as the major catalyst. This is because many of these actions (grazing, wood cutting, and agriculture) have deprived the soil of vegetative cover and have exposed them to the high erosive power of rainfall and wind (Abubakar, 2000). Many areas of the drylands are now under threats of severe land degradation as a result of unchecked human activities.

Moretimore (1989) examine on a broad scale the nature and extend of soil degradation in the region, even though Abubakar (2000) lamented that the study is limited in scope as it did not involve an empherical investigation to assess the extent of soil of degradation in each of the area that form the North-most State of Nigeria. The study of Abubakar (2000) in Katsina State shows that cropping causes a decline in fertility level because of nutrient mobilization by crops. The result indicated that the degradation of soil properties can be attributed to the effect of vegetation, clearance, tillage, grazing and cropping.

Man is the actor of environmental degradation, Olofin (2000) described some of the effects of Daming that contributed in the soil degradation during flooding (e.g, Hadejia-Nguru wet land, Konduga-Sambisa swamp and the lower Sokoto plains) took over thousands of hecters of agricultural land for many months every year and only a small fraction of the flood land was available for cultivation.

Furthermore, Olofin (1988) lamented that poor land management such as bush burning, removal of farm residue; over-cultivation, deforestation, and excessive use of chemical fertilizers combine uncomfortability with delicate climate conditions, illustrated by an increasing acidity and frequent specially expanding drought occurrence. Soil erosion by water

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and wind and the leaching of soil nutrient combined with the inappropriate application of fertilizers are gradually "Killing" the land in many areas.

While, Essiet (1990) explained that the soil of the dry lands are moderately to poor in fertility and soil degradation is widely spread. Essiet (2013) spelled out five (5) farming practices and sustainability indices for the drylands of Nigeria:

I. Organic fertilizers only: this practice is sustainable. It is however characterized by losses of nutrient and fine soil particles.

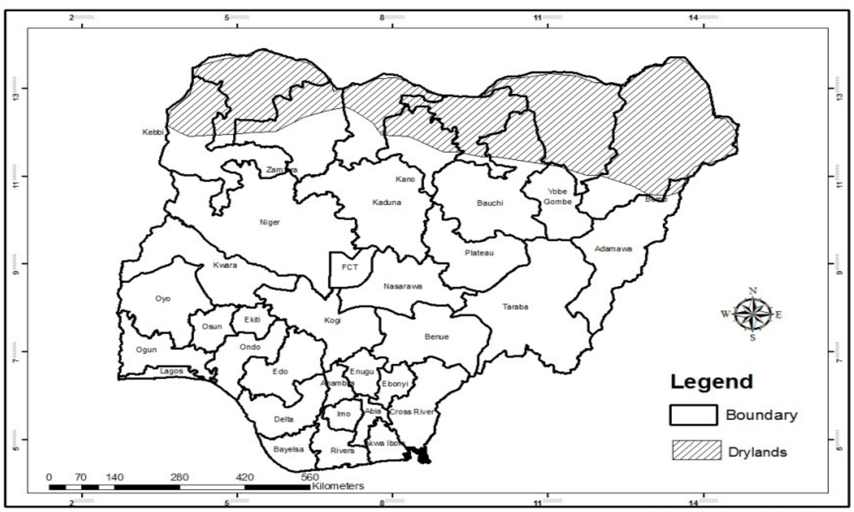
II. Inorganic fertilizers only: this practice is characterized by losses of clay and most nutrients and therefore not suitable

III. Organic plus inorganic fertilizers: hand cultivated; this farming method is most suitable in the area

IV. Organic plus inorganic fertilizers: Tractor plough; this practice is similar to the previous one except for the fact that tractors are involved in the land. The introduction of heavy equipment leads to breakup of soil aggregates, smearing and compaction all of which encourage soil erosion and general land degradation

V. Grain/legumes mixture: this is widely adopted farming practices in the drylands and is believe to enhance soil conservation. This has been explained in Essiet (1991; 1995). Essiet (1989) concluded under this practice no loss of clay content.

VI. Sorghum only: this practice is characterized by serious degradation resulting in losses of fine soil particles as well as nutrients. This is not sustainable and the cultivation of such crop is widely practice in the whole of the drylands of Nigeria.



Sourec: Adopted from Essiet (2013)

Figure 3. Drylands of Nigeria(*modified from Essiet, 2013*).

However, Dryland Rivers have extremely variable flows and river discharge, and the amounts of suspended sediments are highly sensitive to fluctuations in rainfall as well as any changes in the vegetation cover in the basins. The loss of vegetation in the headwaters of Dryland Rivers can increase sediment load and can lead to dramatic change in the character of the river to a less stable, more seasonal river characterized by a rapidly shifting series of channels. However, rainfall can lead to land degradation in other climates, including sub-humid (WMO, 2005).

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Furthermore, Buba (2000) analysed the rainfall in the drylands which shows that is highly variable in time and space and subjected to deflation or enhancement due to both natural and anthropogenic causes. Climate exerts a strong influence over dryland vegetation type, biomass and diversity. Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute the principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favours nomadic lifestyle. Vegetation cover becomes progressively thinner and less continuous with decreasing annual rainfall. Dryland plants and animals display a variety of physiological, anatomical and behavioural adaptations to moisture and temperature stresses brought about by large diurnal and seasonal variations in temperature, rainfall and soil moisture. The generally high temperatures and low precipitation in the drylands lead to poor organic matter production and rapid oxidation.

Another process that enhances soil degradation is the soil pollution, because it alters the soil properties. Yusuf (2013) described some of the soil pollutants which may leads to degradation, this includes; excessive use of fertilizer, pest and herbicides, industrial waste, mining and quarrying, urban and municipal, construction and oil spills. Which he concluded and recommended for reduce, reuse, and recycle of the pollutants. Yusuf (2012) lamented that any disruption or degradation of soil properties may render the soil unproductive.

Soil Degradation, GIS and Remote Sensing

Geoinformation technology (Remote Sensing „RS", Geographic Information Systems „GIS", and Global Positioning System „GPS") and their integration is the basal and essential technical core of the system of geospace information science that plays an important role for assessing and monitoring the environment and its components. Monitoring desertification and land changes over time is required in order to determine land condition trends: whether conditions are becoming worse, better, or staying the same (Fadhil, 2009). Ideally, indicators of change should be quantitative, sensitive to small changes, few in number, and simple to measure. Finding indicators that are unambiguously related to certain land degradation process or to desertification in general is important.

Several studies shows that Soil degradation could be studied and analysed using GIS and Remote sensing, like the study of Raina, *et al.* (1993); Baugh *et. al.* (2006) is an indication that shows how the technology can be utilized for land assessment. Remotely sensed data has a great potential for monitoring dynamic processed, including Stalinization. The ability to predict soil salinity accurately from remote sensing data is important because it saves labour, time and effort when compared to field collection of soil salinity data (Robbins and Wiegand, 1990)

Soil salinity problems generally occur in arid and semiarid regions and reduce crop production at different levels. Salinity is also a major limiting factor for crop yield in poorly drained soils (Mikati, 1997; Gafni and Zohar, 2001; Rogers, 2002; Patel *et al.*, 2002). In some areas of the world where salinity is a major problem, it is rather difficult to monitor the required ground information in the areas affected by salinity (Gates *et al.*, 2002).

In Cullu (2003) satellite imagery for monitoring salinity has proved feasible in large areas where salinity is already a serious problem (Su *et al.*, 1989; Metternicht, 2001). Despite some criticisms, remote sensing techniques have been shown to be a rapid and useful tool in monitoring and predicting salt-related crop productivity problems (Rahman *et al.*, 1994; Alsaifi and Quari, 1996; White, 1997).

Soil salinity is one of the major soil degradation problems that affect crop growth and productivity. Small scale soil maps and database are essential for adequate soil use and

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regional planning (Michelli *et al*, 2002). Most salt-affected soils can be identified by a white salt crust that will form on the soil surface; thus, these soils tend to have higher visible and NIR reflectance (Rao *et al*., 1995). This spectral response cannot always be used to identify saline soils, because soils with high sand contents will have visible and NIR spectral properties similar to salt crusted soils (Verma *et al*., 1994).

The adverse influences of widespread soil erosion on soil degradation and agricultural production, water quality, hydrological systems, and environments, have long been recognized as severe problems for human sustainability (Lal 1998). Most of the studies on Soil erosion using GIS and Remote sensing were analysed using the RUSLE model. The advancement of the technology to day helps in the development of new ideas and techniques in which criteria and attribute could be use in the identification and determination of areas affected with erosion. Different software packages were used in the analysis when it comes to Soil degradation analysis.

Many empirical models, based on geomorphologic parameters, were developed in the past to quantify the sediment yield for assessing soil erosion from the watershed (Misra et al. 1984; Jose and Das 1982). Many other methods are extensively used for prioritization of the watersheds (Bali and Karale 1977; Wischmeier and Smith 1978). In practice, the Universal Soil Loss Equation (USLE) and later the Revised Universal Soil Loss Equation (RUSLE) have been the most widely used models in predicting soil erosion loss. Traditionally, these models were used for local conservation planning at an individual property level. The factors used in these models were usually estimated or calculated from field measurements (Chen *et al,* 2010).

Adediji *et al*, (2010) used the Revised Universal Soil Loss Equation (RUSLE) parameters were assessed using Satellite Remote Sensing (RS) and GIS with a view to model soil erosion in Katsina area of Katsina State of Nigeria. Data on parameters such as slope factors, crop cover and management practice support (P) were obtained from obtained for Katsina area for Digital Elevation Model (DEM) and Landsat ETM +, 2002 of the area. The estimated potential mean annual soil loss of 17.35 ton/ac/yr based on the refined RUSLE was obtained for the study area. Also, the potential erosion rates from the erosion classes identified ranged from 0.0 to 4185.12 ton/ac/yr. About 65.47% of the study area was classified under the first class with erosion rate between 0.0 and 10 ton/ac/yr. The most severely eroded area with rates of erosion between 104.80 and 4,185.12 ton/ac/yr accounted for about 1.86% of the study area. On the whole, this study has demonstrated the significance of Satellite (RS) and GIS technologies in modeling erosion.

Also, Chen, *et al* (2010) applied the Revised Universal Soil Loss Equation (RUSLE), remote-sensing technique, and geographic information system (GIS) to map the soil erosion risk in Miyun Watershed, North China. By integrating the six factor maps in GIS through pixel-based computing, the spatial distribution of soil loss in the upper watershed of Miyun reservoir was obtained by the RUSLE model. The results showed that the annual average soil loss for the upper watershed of Miyun reservoir was 9.86 t ha-1 ya-1 in 2005, and the area of 47.5 km2 (0.3%) experiences extremely severe erosion risk, which needs suitable conservation measures to be adopted on a priority basis. The use of remote sensing and geographical information system (GIS) techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Millward and Mersey 1999; Wang et al. 2003; Boggs et al. 2001; Bartsch et al. 2002; Wilson and Lorang 2000). They showed that such methods provided significantly better results than using traditional methods.

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CONCLUSION

Population explosion and climate change has been the major factors for the soil degradation, the increase in aridity which enhances the soil erosion (water and wind) that leads to biodiversity loss and soil conservation. Most of the World degraded areas; Africa has fallen within the most highly vulnerable zone and sometimes the effect of aridity tends to relocate because of the movement of dunes which affect the agricultural activities. In agricultural lands accelerated soil erosion is responsible for the loss of fertile topsoil, depletion of soil fertility and subsequent decrease in crop productivity.

The application of Geographic Information System and Remote sensing in the study and of soil degradation has made it simpler and easier, and is more accurate, it also reduces time, capital and manpower especially when using algorithms and RUSLE model.The paper highlighted a different issue that has to do with the application of GIS in soil erosion and salinity. The paper recommend for more studies should be carrying out particularly using the application of Remote sensing and GISin the Nigeria's Drylands.

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