Geospatial assessment of the effects of increasing surface temperature on soil erosion in Ibadan, Nigeria

Olusola O. Adetoro* and Shogo E. Garuba

Space Applications and Environmental Science Laboratory,
Institute of Ecology and Environmental Studies,
Obafemi Awolowo University,
Ile-Ife, Nigeria
Email: omoige@gmail.com
Email: elizabethgaruba@gmail.com
*Corresponding author

Abstract: The evident impact of climate change has been observed to be strongest and most comprehensive for the natural systems. The experienced modifications have been reflected mostly by ecosystems and by considerable alterations in soil formation and degradation processes, in soil properties and soil functions inclusive. Advancement in remote sensing techniques has brought about the possibility of obtaining and distribution of spatial information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. This paper seeks to identify the various GIS and RS techniques that have been employed in the assessment of the erosion of soil resulting from increasing temperature in the tropics and its applicability to Ibadan, Nigeria.

Keywords: geographical information systems; GIS; remote sensing; climate change; soil erosion; surface temperature; Nigeria.


Biographical notes: Olusola O. Adetoro is a researcher in the field of space applications for environmental management at the Institute of Ecology and Environmental Studies, Obafemi Awolowo University. Her research interests are geospatial technology for disaster risk reduction in coastal and urban watershed, socio-ecological assessment using UAV and community participatory approach, and land form changes and urban development.

Shogo E. Garuba is a doctoral research student at the Institute of Ecology and Environmental Studies, Obafemi Awolowo University. Her research focus is on the use of remote sensing for air pollution assessment in urban areas and the effect on human health.
1 Introduction

One of the resultant effects of greenhouse gas concentration arising from changing climatic conditions is warmer temperatures among other effects. This resultant warmer temperature is referred to as global warming. There has been an ambiguous warming of the climate system since the 1950s and majority of the observed changes have been noticeably unprecedented over decades to millennia. The atmosphere and ocean have witnessed increasing warmth, the amounts of snow and ice have diminished, and sea level has risen. Over the last 30 years, the global temperature has actually been on the increase and each year warmer than the previous one (IPCC, 2014).

The evident impact of climate change has been observed to be strongest and most comprehensive for the natural systems. Several areas are experiencing changing precipitation or melting snow and ice are altering hydrological systems, this has in turn affected the water resources in terms of quantity and quality (medium confidence). It has been observed that many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change. Nearing (2001) predicts that the increasing global warming is expected to have a serious effect on the hydrologic cycle including increased total rainfall and also increased frequent high intensity rainfall. Certain impacts on the human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (IPCC, 2014). Climate change has been identified as a force that will amplify existing risks and create new risks for natural and human systems. These risks however are unevenly distributed and have been found to be generally greater for disadvantaged people and communities in countries at all levels of development.

The increasing concentration of greenhouse gases in the atmosphere has brought about increasing warmer temperatures as well as increased rainfall amounts and also has brought about a serious rearrangement of atmospheric precipitation and in some areas increasing aridity. The experienced modifications have been reflected mostly by ecosystems (natural vegetation and land use pattern) and by considerable alterations in soil formation and degradation processes, in soil properties and soil functions inclusive. These resultant effects according to Nearing (2001) will go a long way to bring about significant changes to the soil through the process of erosion. These effects are visibly evident in the rate of erosion occurrence.

Erosion of soil basically refers to the process by which soil looses its properties through water or wind. This process has however become more visible as a result of the degrading environment arising from natural and mostly human processes. According to Gunawan et al. (2013), soil erosion refers to a natural process whereby soil materials are removed and transported via the action of erosive agents such as water, wind, gravity, and human disturbance. There has been an expected increase in the rate of soil erosion, arising from the changing erosive power of the rainfall which in itself, stems from the changing climatic conditions. The impact of warmer temperatures on the soil includes heating up unnecessarily of the soil surface which leads to excessive dryness of the soil.
and consequently brings about the loss of some of its properties which makes the soil vulnerable to the washing away of its surface and properties. Also increasing temperatures brings about an increase in rainfall and this coupled with the already damaged and reduced soil nutrient brings about erosion of the soil. However, the process of erosion resulting from climate change has been identified as an important and complex process due to the different interaction taking place in the process.

Advancement in remote sensing techniques has brought about the possibility of obtaining and distribution of spatial information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. The spectral bands used by these sensors cover the whole range between visible and microwaves. Rapid developments in computer technology and the geographical information systems (GIS) has helped provide a platform whereby spatial data obtained from remote sensing are processed to help provide useful information that can be used for the identification, monitoring and assessment of natural disasters including soil erosion. Gunawan et al. (2013) opine that RS and GIS framework has been able to provide stakeholders with an opportunity to prepare more accurate spatial maps in less time and at less cost. The availability of GIS tools and more powerful computing facilities makes it possible to overcome difficulties and limitations and to develop distributed continuous time models, based on available regional information (Ande et al., 2009). Therefore, RS and GIS provides room for a better monitoring of spatial issues as the remotely sensed data are now being analysed using GIS and more accurate presentation of information is being done.

This paper seeks to carry out a review of past works that have been carried out on the effects of increasing global temperature on soil erosion and the application of GIS and remote sensing techniques in monitoring these effects in the tropics using Ibadan Nigeria as the case study.

2 Statement of the problem

The evidences of land degradation resulting from climate change indulging practices will however continually be visible. One of these major effects is soil erosion. Erosion according to Ande et al. (2009) is a natural geomorphic process that takes place continuously over the Earth’s surface. However, this natural process has become accelerated through anthropogenic perturbations bringing about severe impacts on soil and environmental quality. Soil erosion, according to Segura et al. (2014), is a physical process whereby soil looses is particles through water or wind. This process is triggered by certain environmental factors including precipitation intensity, soil characteristics, topography of the terrain, and land cover type. There have been studies on the impact of global warming bringing about warmer temperatures and how this affects the environment. Although soil erosion has been identified as a natural geomorphic process, the increasing temperature has further exacerbated the problem through excessive rainfall aiding the excessive washing away of the soil properties. the seasonal distribution of rainfall in the humid and sub humid regions are characterised by a continuous long rainy season with no real dry season or by two rainy seasons that is separated by a short dry season characteristic of the dry season during the low sun period. However, the tropical areas have typically short rain characterised by intense storms having relatively high median drop size bringing about very high total energy load. This coupled with the
generally unstable structure of soils in the tropics causes ready slaking. This also brings about an abrupt and sharp desiccation which causes the development of a surface crust which eventually reduces infiltration rate (Lal, 1983).

According to Lal (1983), the rate of soil erosion is more severe as compared to that of the temperate region. This is due to the fact that, the ground flora is less developed as a result of the less radiation it receives, the humus layer is thinner and the organic matter undergoes more rapid biodecomposition as a result of prevailing high temperature and finally because the rains are more frequent and more intense. There is therefore a need to examine what research has been carried out in this aspect using remote sensing and GIS techniques as soil erosion remains a continually disturbing environmental issue due to the composition of the tropical environment.

2.1 Aim

The aim of this paper is to identify the various GIS and RS techniques that have been employed in the assessment of the erosion of soil resulting from increasing temperature in the tropics using Ibadan, Nigeria as a case study.

2.2 Study area

The study area is Ibadan city, in the South Western part of Nigeria. It lies between 7º23'47"N to 7º39'64"N and 3º55'0"E to 3º91'67"E. It is an area of 3,080 km² with a population of about 1,338,659 according the population census result of 2006.

Figure 1  Study area map (see online version for colours)
3 Methodology

In carrying out this review, a search was conducted for all available materials that carried out a research on how increasing global temperature has affected the rate of soil erosion using RS and GIS techniques.

All data used for this review are secondary data. These were sourced from the internet, published journals and other research documents.

Firstly, material that dealt with issues of soil erosion and global temperature were sought for.

Secondly, materials that bordered on the assessment of how global temperature has affected soil erosion were also sought for.

Also material that employed the use of GIS and RS techniques to carry out this assessment were sourced for.

A filtering of the acquired materials was conducted to be able to determine the materials that are useful for the purpose of this review.

4 Remote sensing and GIS application in soil erosion

The extensive application of RS and GIS is seen in so many of researches carried out on the assessment of soil erosion. This is partly due to the fact that soil erosion is an environmental issue that has become a source of concern particularly in the tropics. The following were identified as how RS and GIS techniques have been used to monitor soil erosion.

4.1 Source of data

Remote sensing has been identified as a very useful source of data for the monitoring of environmental changes occurring regularly. Data obtained from remote sensing has been used to obtain data used for the monitoring of changing climatic conditions (Chapman and Thornes, 2003) such as the location of sinks as well as CO$_2$ concentration in both land and the ocean (Science, 2007). Also, GIS according to Larsen (1999) has a very important role to play in environmental monitoring and modelling for combining distributed field-based measurements and remotely sensed data. Chapman and Thornes (2003) however opine that due to the fact that climatological and meteorological phenomena are naturally spatially variable, GIS therefore serves as a useful solution to the management of vast spatial climate datasets for a wide number of applications including soil erosion monitoring and management.

Gunawan et al. (2013) carried out a research to assess the average annual rate of potential soil erosion in Manjunto watershed for each soil mapping unit using remote sensing data [normalised difference vegetation index (NDVI) and slope]. The NDVI value obtained from satellite imagery processing while slope value obtained from digital elevation model-shuttle radar topographic mission (DEM-SRTM) processing.

Ande et al. (2009) in a study carried out in the south-western part of Nigeria collected remotely sensed data (Landsat ETM) alongside meteorological data for the prediction of soil erosion in an agrarian environment with highly dissected hilly and rolling terrain in Ekiti, south western Nigeria. The RS data helped the researcher to be able to generate contour map and spot height point map and these information was then interpolated for
the generation of the digital elevation model of the study area. After which supervised classification and visual interpretation of the satellite image was carried out for the land use mapping.

Also, Qingfeng et al. (2008) carried out a research to test the sufficiency of using remotely sensed (Landsat TM) data alongside universal soil loss equation (USLE) in predicting the influence of soil erosion on the environment. Their results showed that the application of the remotely sensed data was very useful in calculation and prediction of soil loss in the Nihe Gou catchment in Chunhua County in Shaanxi.

Javed et al. (2012) carried out a study to identify and quantify climate change induced land degradation at watershed and village level in Jaggar Watershed of Eastern Rajasthan using remote sensing and GIS technique. The study utilised Standard Geocoded FCC LISS II data of 1989, and LISS III data of 1998 and 2009 on 1:50,000 scale for land use/land cover mapping. Maps were digitised, edited and analysed in GIS to ascertain land use/land cover changes. Comparative analysis of the land use/land cover statistics and village level household survey revealed that climate change has severely affected land use/land cover especially agriculture land.

Ustun (2008) also carried out a study in Turkey to model the rate of soil erosion using both remote sensing and GIS. The data used for the modelling was remotely sensed (Landsat-5 TM) and the GIS software ILWIS and ERDAS IMAGINE were both used to model the loss.

The Landsat-5 TM was used to derive the DEM of the study area and this DEM was then used to generate the slope map.

Several studies (Gelagay and Minale, 2016; Pradhan et al., 2012; Fu et al., 2005) have proved remotely sensed data to be a valuable and non-negligible tool in the monitoring and assessment of soil erosion as well as changes in the soil properties alongside other data sets such as meteorological data and climatic data. The information generated from remotely sensed data includes contour maps, TIN, DEM among others.

However, Zeng et al. (2013) have a different opinion as regards the use of remotely sensed data particularly in calculating vegetation index in soil erosion risk assessments. According to them, the vegetal cover is greatly influenced by atmospheric effects and the methods for correcting these effects are still imperfect and disputed. They therefore came up with a fast, indirect and operational method to conduct atmospheric correction of images for getting comparable vegetation index values in different times. This method attempts to find a variable free from atmospheric effects, e.g., the mean vegetation coverage value of the whole study area, as a basis to reduce atmospheric correction parameters by establishing mathematical models and conducting simulation calculations. Using these parameters, the images can be atmospherically corrected. And then, the vegetation index and corresponding vegetation coverage values for all pixels, the vegetation coverage maps and coverage grade maps for different years were calculated. This approach of theirs has opened an avenue to work with remotely sensed data and also reduce discrepancies that might arise from the atmospheric effects likely to affect the viability of these remotely sensed data sets.

4.2 Classification

Ustun (2008) carried out a digital classification of the Landsat-5 TM data covering the visible, infrared and microwave regions of the spectrum in order to detect the overall soil
erosion potential of the Ganos Mountain area in Thrace Peninsula, Turkey. The iterative self-organising data analysis (ISODATA) technique method of unsupervised classification was used in the study. Gunawan et al. (2013) also carried out the nearest neighbour classification method of classification to identify the land cover types in their study of the potential rate of soil erosion in Manjunto watershed, Bengkulu Province, Indonesia. Ande et al. (2009) in their study to predict soil erosion in Ekiti state western Nigeria also employed the supervised classification method on the Landsat TM data set acquired for the study. Zurayk et al. (2001) also carried out a classification of land cover types from the SPOT image of the study area (Lebanon) to be able to produce an erosion hazard risk assessment map. The classification was for the purpose of better understanding of the land cover of the study area. This classification was carried out in the ERDAS IMAGINE environment. The classification capability of GIS techniques has been demonstrated in several studies as seen in (Lee, 2003; Kouli et al., 2009; Jain and Kothiyari, 2000; de Jong et al., 1999) where it was explored in the soil erosion studies across various areas ranging across the globe.

4.3 Mapping

The use of remotely sensed data in the monitoring of soil erosion cannot be over emphasised as shown in several studies that were reviewed for this paper. However, information derived from these data sets are presented within the GIS environment using the various GIS software platforms available for better presentation.

Yuksel et al. (2008) carried out an assessment of soil erosion risk in Turkey and derived a soil erosion risk map using remote sensing and GIS. The research used ASTER imagery to generate a land use/cover classification in ERDAS Imagine. The digital maps of the other factors (topography, soil types, and climate) were generated in ArcGIS 9.2, and were then integrated as CORINE input files to produce erosion risk maps. Zurayk et al. (2001) also employed the use of remote sensing and GIS to produce a generalised erosion hazard assessment map for Lebanon.

Gunawan et al. (2013) used RS and GIS techniques to produce a soil erosion map for Manjunto watershed, Bengkulu Province, Indonesia. The rate of erosion map was also derived from the remotely sensed data that some modelling was performed on in the GIS software environment.

Remotely sensed data provides information that is used in the GIS software environment to produce explicitly informative maps that will help decision makers as well as other people concerned to be able to have a clear understanding of the current and future situation of the state of the environment resulting from soil erosion as demonstrated by (Diodato and Ceccarelli, 2004; Badmos et al., 2005; da Silva et al., 2012; Panos et al., 2014; Desmet and Govers, 1996; Bahadur, 2009).

4.4 Modelling

The modelling of soil movements and their consequences play a significant role for environmental planning. Assessment of soil erosion risk is important to formulate effective soil conservation plans for sustainable development. The availability of GIS tools and more powerful computing facilities make it possible to overcome difficulties and limitations and to develop distributed continuous time models, based on available
information. Satellite data can be used for studying erosion features, such as gullies, rainfall interception by vegetation and vegetation cover factor. Digital elevation model (DEM) one of the vital inputs required for soil erosion modelling can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data. Geographic information system (GIS) has emerged as a powerful tool for handling spatial and non-spatial georeferenced data for preparation and visualisation of input and output, and for interaction with models. There is considerable potential for the use of GIS technology as an aid to the soil erosion inventory with reference to soil erosion modelling and erosion risk assessment.

In the soil erosion predictability and modelling using GIS USLE has been applied by most of the researchers. The USLE was established by Wischmeier and Smith since 1978, it is applied in many areas in the world. It is described by the following factor:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P. \]  

- \( A \) represents the potential long-term average annual soil loss in tons per acre per year
- \( R \) is the rainfall and runoff factor by geographic location
- \( K \) is the soil erodibility factor
- \( LS \) is the slope length-gradient factor; \( L \) is the length of the slope steepness, its unit is m; and \( S \) is slope angle, \( LS \) unit is radian
- \( C \) is the crop/vegetation and management factor
- \( P \) is the support practice factor.

The coefficients of the module and their maps can be achieved by using GIS tools and input data from the database which contains data including topological data, hydrological system, rainfall, soil map, auxiliary data (land-use/cover, administrative and catchments boundary) Figure 2 shows the main steps from input data (include average rainfall, DEM, soil type) to calculate \( R \), \( LS \), \( K \) coefficients, to create the outputs that are soil erosion potential and soil erosion zoning as identified by Ha (2011).

**Figure 2** Process of carrying out USLE in GIS (see online version for colours)

Source: Adapted from Ha (2011)
Ha (2011) applied this USLE to model the soil erosion as well as propose land cover solutions in order to reduce soil loss in Tay Nguyen area. From the study, a soil loss potential map was derived and it was concluded that GIS was very helpful in the achievement of the aim. Wijesekera and Samarakoon (2001) also employed the use of USLE to assess soil erosion by water in the Kegalle district of Sri Lanka. From his study, he concluded that modelling of soil erosion using GIS techniques has helped to provide a meaningful use of pixel-based remotely sensed land cover information which is very useful in decision making process. USLE have also been applied by other researchers including (Desmet and Govers, 1996; Renard and Freimund, 1994; Mati et al., 2000; Jabbar, 2003; Pandey et al., 2007; Bathrellos et al., 2010; Fistikoglu and Harmancioglu, 2002; Dabral et al., 2008; Erdogan et al., 2007).

Other models used in GIS for the prediction of soil erosion includes revised universal soil loss equation (RUSLE), coordination of information on the environment (CORINE), water erosion prediction project (WEPP) and Morgan-Morgan-Finney (MMF), CREAMS, ANSWERS and LISEM.

The CORINE method of soil erosion prediction was developed based on the USLE. In CORINE model, actual soil erosion risk is determined by combining two parameters including potential soil erosion risk data and vegetation cover data. The potential soil erosion risk is calculated as a function of soil erodibility, erosivity, and topography. The vegetation cover data is a very important parameter in erosion models since the intensity of vegetation cover significantly affects the rates of erosion. Using high-resolution satellite imagery, image classification techniques have been used to generate accurate and reliable land use/cover data (Yuksel et al., 2008).

Ustun (2008) however in the study of size of the amount of soil loss because of the erosion in the surrounding area of the Ganos Mountain over Thrace Peninsula region in Turkey employed the MMF model. They opted for Morgan method as it has a more powerful physical fundamental than the USLE method and is easier and more flexible method than the CREAMS method. Also, the CREAMS method is applicable only to field size areas while USLE has been found to be not suitable for large areas (Wijesekera and Samarakoon, 2001). Ande et al. (2009) also used MMF to predict soil erosion in an agrarian Ekiti environment with highly dissected hilly and rolling terrain in Southwestern Nigeria. The MMF model was developed to predict annual soil loss which endeavours to retain the simplicity of USLE and encompasses some of the recent advances in understanding of erosion process into a water phase and sediment phase. Although there exists several models that can be used to predict the rate of soil erosion, each of these models has their own strengths and weaknesses. However, in the application of GIS to soil erosion resulting from increasing surface temperature, the mostly adopted model is the USLE due to its observed simplicity and sensitivity to elevation change.

5 Remote sensing and GIS application in monitoring global

5.1 Temperature

According to Hecker and Gieske (2004), satellite data has been identified to prove useful in the study of global temperatures. These include the determination of surface emissivity...
and temperature, rock emissivity mapping and thermal hotspot detection such as forest fires or underground coal fires and volcanic activity.

Bradley et al. (2002) employed satellite land cover classification to carry out a modelling of the spatial and temporal road thermal climatology in rural and urban areas of west midlands UK, and the field analysis of urban canyon characteristics, physical variables of Albedo, emissivity and surface roughness were carried out within a GIS environment. This data set enabled them to be able to have an idea of the road surface temperature which was then used to predict and forecast the road surface temperature which is most particularly very useful during winter periods as per ice formation monitoring. Sun et al. (2007) also employed MODIS and advanced microwave scanning radiometer – Earth observing system (AMSR-E) to model an estimate of the evapotranspiration from land surface temperature (LST) and moisture over of the Southern Great Plains. The observed modelled spatial patterns of evapotranspiration and of key model parameters indicated that radiation and moisture availability are the controlling factors on evapotranspiration in the study area.

Anderson and Kustas (2008) used remotely sensed data to LST. The obtained information was then used to carry out a diagnosis of the biospheric stress resulting from soil moisture deficiencies. From the study, it was observed that remotely sensed data in the thermal infrared bands provides an effective substitution for precipitation data, providing much needed water information particularly in regions that are characterised by deficiency of data. (Qinghua et al., 2006; Raup et al., 2007; Weng, 2010; Bishop et al., 2008) also in their various studies of the increasing global temperature utilised remote sensing methods to examine the various ways in which the temperature of the Earth has been increasing in the times past. These studies ranged from glacier studies to temperature increase assessment.

In the study of increasing global temperatures, remotely sensed data in the thermal infrared bands have proved to be very effective as seen in the works reviewed in this paper. Thus, RS and GIS technologies provide a very useful technique that allows the better monitoring, analysis and reporting of temperatures around the world.

6 Discussion

The vast application of remote sensing and GIS in environmental and spatial studies has been seen in the study of soil erosion and increasing global temperature. This alongside constant development and improvement has brought about an ease with which these studies are now being carried out. However, there has been identified a need to incorporate these application alongside one another. In other words, in the future studies of how global warming affects the soil erosion in Ibadan, there is a need to make use of both temperature data as well as other data such as DEM, slope map and other data necessary for soil erosion studies derived from remotely sensed data. This is so as to have a better understanding of how much of the increasing temperature affects the rate of soil erosion in Ibadan as GIS tool has the ability to perform an interpolation and integration of all of these data sets.
References


Geospatial assessment of the effects of increasing surface temperature


