LAND DEGRADATION & DEVELOPMENT
Land Degrad. Develop. (2013)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ldr.2215

SOIL EROSION ASSESSMENT IN KONDOA ERODED AREA IN TANZANIA USING UNIVERSAL SOIL LOSS EQUATION, GEOGRAPHIC INFORMATION SYSTEMS AND SOCIOECONOMIC APPROACH

P. J. LIGONJA[1,2]* AND R. P. SHRESTHA[1]

[1]*Natural Resources Management Field of Study, School of Environment, Resources and Development, Asian Institute of Technology, PO Box 4, Klong Luang, Pathumthani 12120, Thailand*
[2]*Mafia District Council, PO Box 85, Tanzania*

Received: 9 November 2012; Revised: 23 February 2013; Accepted: 23 February 2013

ABSTRACT

Soil conservation measures including cutoff drains, tree planting, Crops diversifications and destocking were implemented in Kondoa eroded area (KEA) for decades. This study assessed soil erosion changes in KEA and examined drivers of changes using Universal Soil Loss Equation, Geographic Information Systems and socioeconomic survey. Soil erosion was predicted by using data on soil, digital elevation model, rainfall and land use/cover visually interpreted from multitemporal satellite imageries. The predicted average soil erosions were 14·7, 23 and 15.7 Mg $ha^{-1}y^{-1}$ during 1973, 1986 and 2008, respectively. The area under very high soil erosion severity that was 30% in 1973, 26% in 1986 and 25% in 2008, whereas the area with high erosion severity was 26% in 1973 changed into 49% in 1986 and 2008 indicating recent stabilization. The area with moderate erosion increased from 15%, 16% and 18% during the same period. Field survey confirms a decrease of soil erosion in KEA compared with the past showing better soil conservation. Age of farmers, long-term adoption of conservation practices and on-farm tree planting were found to be the major factors contributing toward reduced soil erosion. Major limitations in soil conservation were poor mainstreaming of conservation activities on local production systems and lack of institutions promoting conservation at the community level. The study concluded that long-term conservation investment for restoration, protection and socioeconomic support contributes significantly in land rehabilitation in KEA. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS: soil erosion; soil conservation; HADO; Kondoa eroded area (KEA); USLE; Geographic Information Systems; socioeconomic determinants of erosion

INTRODUCTION

Land degradation is threatening Earth's climate, forest, biodiversity, food and energy supply and in turn the existence and well-being of human kind (United Nations, 2009). The term 'Land Degradation' refers to the reduction of utility of land and the failure of soil to potentially provide biological and economic productivity due to processes of soil erosion, soil compaction and loss of soil nutrients resulting into decline of production of pasture, rangelands, cropland, forests, woodland, destructions of habitat and loss of biodiversity (Pagiola, 1999). Land degradation such as soil erosion is a major problem especially in semiarid areas, such as Kondoa eroded area (KEA) of Kondoa district in Tanzania (United Republic of Tanzania, 1995). By 18th century, when Rangi people settled in KEA, it was well-wooded, but clearance of vegetation and increase of soil erosion resulted from increasing population, overgrazing, burning vegetation to control tsetse flies and unselective clearing land for cultivation (Christiansson, 1996). Severe soil erosion in the area made the Government of Tanzania to implement Dodoma region soil conservation project (HADO) since 1973. Originally, HADO was run by central government only, with major focuses on physical measures of soil erosion controls and tree planting. These measures included constructions of cutoff drains and contour bunds, restoration of gullies by grass planting and stone check dams, establishment of tree nurseries and demonstration woodlots and prevention of activities, such as tree cutting, grazing and cultivation in certain areas (Nshubemuki and Mugasha, 1985).

In 1979–1989, livestock-keeping was completely banned in the area with expectation of a quick vegetation restoration (Nshubemuki and Mugasha, 1985). However, because of the importance of livestock in agro-pasture society, HADO second master plan of 1986–1996 had to reintroduce controlled livestock-keeping through stall-feeding of animals started in 1989. Since 1986, HADO also decentralized tree planting activities to schools and villages and provided socioeconomic supports for soil conservation through education and awareness, agriculture diversification, agroforestry and replacement of destructive economic activities, such as overgrazing by providing subsidized stall-feeding cows (United Republic of Tanzania, 1986). The operations of HADO activities have been dormant following donor withdrawal in 1996. However, local communities continue to practice conservation activities, such as by construction of contour bunds, contour ridge cultivation, mixed cropping, strip cropping, crop diversification, increase use of organic fertilizer, planting tree, protection of gullies and stall-

*Correspondence to: P. J. Ligonja, Doctoral Candidate, Natural Resources Management Field of Study, School of Environment, Resources and Development, Asian Institute of Technology,PO Box 4, Klong Luang, Pathumthani 12120, Thailand..
E-mail: st109005@ait.ac.th; paulligonja@gmail.com

feeding (Kangalawe *et al*., 2008). Policy change since mid-1990s which provided land tenure security, appropriate extension services in agriculture and livestock development, continued provision of subsidized improved cow to replace destructive large herds in the past and favourable market for crops, which provided incentives for soil conservation.

Despite large investment in rehabilitation, HADO project implementation was undertaken without prior studies (Eriksson and Christiansson, 1997). It is argued that increase efficiency in land management in both agriculture and natural landscape requires prior assessment of spatial distribution of soil erosion for selecting appropriate measures (Khity and Csaplovics, 2007). Throughout the project lifespan, little was known about the extent, status and trend of soil erosion in the area. There is no report on prediction of soil erosion by either modelling or field-based measurement in the area, which makes this study to be very important. Methods including plot studies, erosion-hazard surveys, time-lapsed photography and basin-suspended sediment yield have been widely applied to estimate soil losses in several African nations (Stocking, 1984). Plot level studies on soil erosion include those conducted in Tanzania by Staples in 1934, Zimbabwe by Hudson and others in the 1950s and by Dar Es salaam and Uppsala Universities Soil Erosion Research project (Chakela, 1992). Such study conducted in 1960–1965 in Shinyanga Tanzania reported a soil loss rate of 105 Mg $ha^{-1}y^{-1}$ (United Republic of Tanzania, 2002).

The plot level studies generate soil erosion information that is site-specific; its scope for understanding of soil erosion changes over a large area is limited (Chakela, 1992). Therefore, there is increasing scope of application of erosion models to predict soil erosion over large catchment areas. The available models for prediction of soil erosion are simple and empirical-based to complex and physical-based (Merritt *et al*., 2003). Simplified and rapid erosion assessment could be more valuable for decision-making on land management and planning, particularly where detailed erosion assessments are not yet feasible (Fan *et al*., 2004). This study used empirical-based model, Universal Soil Loss Equation (USLE), to predict changes in soil erosion in KEA. USLE has been widely applied all over the world at different scales mainly because of its simplicity and easy availability of data set (Hui *et al*., 2010). USLE estimates gross sheet and rill erosion but does not predict soil erosion along gullies (Wall *et al*., 2002). However, it is an appropriate model in KEA because gully erosions have been highly controlled in the area. In Africa, soil erosion prediction using USLE has been conducted in several parts of the continent. Igwe et al. (1999) suggested the use of USLE because its results matched well with actual patterns of soil erosion in Nigeria. Welle *et al*. (2007) recommended the use of USLE to estimate soil loss in the northern part of the Somali region of Ethiopia because the model does not underestimate soil loss as it is better to error on overestimation of soil loss rather than underestimation because the latter may lead to poor selection of control measures (Igwe *et al*., 1999).

Stocking (1984) argued that very high erosion >100 Mg $ha^{-1}y^{-1}$ is not uncommon for some parts of Africa with poor vegetation cover, although in most cases, moderate soil loss tends to dominate. Previous estimations showed worsening of soil erosion in Middleveld Swaziland (Morgan *et al*., 1997). In Kianjuki catchment in central Kenya, soil losses greater than soil loss tolerance were estimated (Angima *et al*., 2003); high soil loss was also reported in Nigeria (Igwe *et al*., 1999). Previous study showed annual average rate of soil erosion amounting to 75 Mg $ha^{-1}y^{-1}$ for the Magreb region in the northwestern part of Africa; 25 to 50 Mg $ha^{-1}y^{-1}$ and 10 to 25 Mg $ha^{-1}y^{-1}$ for southern and eastern Africa, respectively, and less than 10 Mg $ha^{-1}y^{-1}$ for most of west Africa (Lal, 1995 cited in Igue, 2002). In Tanzania, soil erosion was estimated in Shinyanga region, which found soil erosion rate up to 70 Mg $ha^{-1}y^{-1}$ in some areas (Stocking, 1984). There is still dearth of information on soil erosion estimates, particularly by using soil erosion models such as USLE and others in Tanzania and KEA in particular, despite long-term implementation of soil conservation activity in the area.

Therefore, it was important to conduct this study to contribute to rather limited literature on soil erosion in Tanzania and Africa using a case study of an area subjected to large scale soil conservation such as KEA to determine the important role of long-term soil conservation activities in controlling soil erosion. The objectives of this study are to: (1) monitor changes of soil erosion condition associated with HADO soil conservation activities, and (2) identify the socioeconomic determinants of reduction of soil erosion in KEA.

MATERIAL AND METHODS

Study area

Kondoa eroded area is located between $4^{0}30'$ to $5^{0}00'$S latitudes and $35^{0}30'$ to $36^{0}00'$E longitudes in Tanzania (Figure 1). This study was conducted in KEA and its surrounding area, which are covered by Irangi hills rising from 900 to 2190 m.a.s.l. Temperature ranges between 16 to 26°C while annual rainfall is between 400 to 1000 mm. Vegetation is dominated by grassland, short trees and shrubs savanna and woodland savanna (Kangalawe, 2010). Dense Miombo woodland forest occupies most of highlands in the northeast, whereas short trees and shrub lands are found in dry part of western and southwestern side (Mung'ong'o, 1995). Major soil types are *Chromic luvisol*, *Ferralic cambisols*, *Haplic phaeozems* and *lithic leptosol* (United Republic of Tanzania and United Nations Department of Technical Cooperation and Development, 1984). Farmers grow crops and also raise animals, such as cattle, sheep and goat. Main crops grown in the area include maize, sorghum, millet, beans, sunflower, tomatoes, pigeon peas, cabbage and groundnuts.

This study involved the use of several data types generated from various sources. The sequential step of research methodology is shown in Figure 2. Each major step of data generation and analysis are described in the following sections.

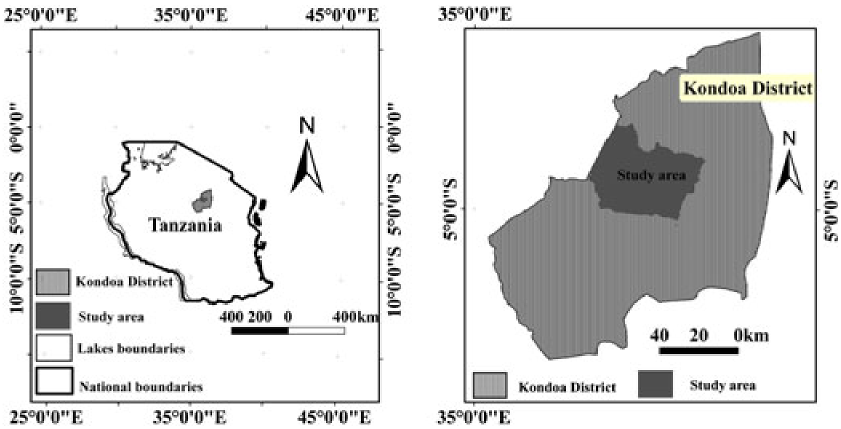

Figure 1. Location map of the study area.

Fieldwork

Field survey and direct observations of condition of soil erosion and land use/cover were conducted from August–October 2010. During fieldwork, measurements of sampled slope length under different land use/covers were taken. Household level interviews of 240 households (equivalent to 10% sample size of households in the study area) were conducted by administering a structured questionnaire. Cluster sampling, which divided each village into clusters of lower, middle and high elevation, was used; then, from each cluster, a systematic sampling was applied to select every 10th household for interview. Villages selected for household interview were Baura, Haubi, Mafai and Ntomoko. Data collected included household condition such as age, education, household size, land holding, perception on extent of soil erosion, awareness on HADO, access to extension services, participation in soil conservation, perception on reduction of soil erosion, access to markets for selling crops, forest products and livestock, income from crops and participation in tree planting. Information on soil conservation measures,

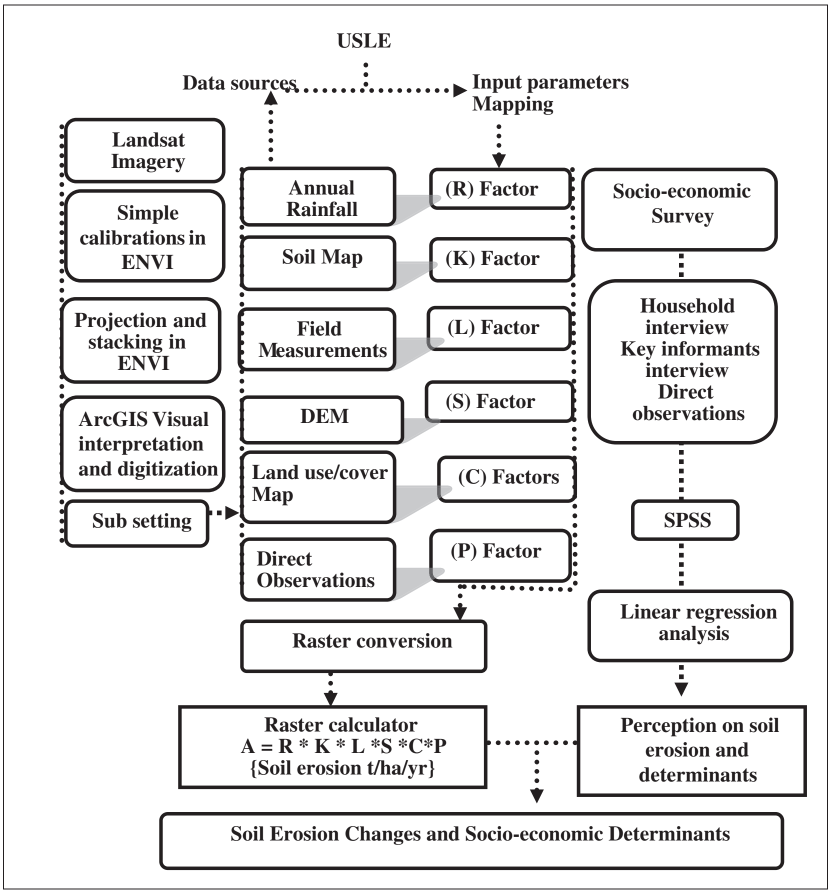

Figure 2. Research methodology.

conservation strategies and achievements and challenges on soil conservation were collected through key informants' interview with group of village elders, village executive officer and HADO and Kondoa district council officers. Literature review was conducted in HADO main library in Kondoa district and also at the Institute of Resources Assessment in Dar es Salaam to obtain information on HADO activities and previously reported achievements. Direct observations were also conducted to gather knowledge of land use cover, which is necessary before carrying out visual interpretation of Landsat images (Global Land Cover Facilities, USA) (Puig *et al*., 2002).

Landsat Image processing and mapping of land use/cover

Land cover for the year 1973, 1986 and 2008 was prepared by visual interpretation through onscreen digitization in ArcGIS software. Remotely sensed data used included Landsat image scenes of path 181 row 63 dated 22 September 1973 (MSS sensor) and path 168 and row 63 of 18 September 1986 (TM sensor) and 6 September 2008 (ETM + sensor), respectively, which were downloaded from the Global Land Cover Facilities website. For 1973, the northeast part was mapped with substitute MSS image of path 180 row 63 dated 25 December 1972 because the area overlaps outside path 181 rows 63. In such case, radiometric calibrations of the different date images were needed, and it was done using ENVI software as suggested (Chandler & Markham, 2003) before classification process so that outputs from different years can be comparable. Images were resampled at 30 m resolution to match them with 30 m digital elevation model (DEM) (United State Geological Survey Bureau). Grouping of land cover includes the following classes with respective percentage of canopy cover (cc): (1) forest and woodland labelled as forest with 70% cc, (2) bushed/wooded grassland 40–50% cc, (3) grass land 20–30% cc, (4) water and swamp in lake Haubi 100% cc with assumption that all the rain is intercepted by water, (5) bare soil 0% cc, (6) croplands 36–45% cc (Leenaers, 1990) and (7) built-up area 60% cc. Maize, cowpeas, pigeon peas, millets and sorghums, which are the main crops in KEA, have their cc range from around 40–80% (Morgan, 1995). However, poor stand of such crops in the area with relatively low yield potential made cc to be allocated a value of 36–45% (Leenaers, 1990).

Soil erosion modelling method by USLE

Soil erosion prediction by USLE gives the potential soil removal by running water as results of splash, sheet and rill erosion (Welle *et al*., 2007, Hui *et al*., 2010). According to Wall *et al*. (2002), USLE computes the average annual soil erosion expected on hill slopes by multiplying several factors together. which includes: rainfall (*R*) factor in $\mathrm{Mg\,mmha^{-1}h^{-1}}$; soil erodibility (*K*) factor in ($\mathrm{t\,h\,MJ^{-1}mm^{-1}}$); slope length and steepness (*LS*); crop management factor (*C*) and support practice factors (*P*). The results are average annual soil loss (Equation 1). The predicted volumes of soil erosion are provided in $\mathrm{t\ ha^{-1}y^{-1}}$ on the basis of original USLE calculation and for easily comparison with the 'tolerable soil loss limits' (Wall *et al*., 2002).

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

Soil erosivity factor (*R*) is determined by calculating the kinetic energy for each equal intensity period of a rainstorm multiplied by the rainfall amount for that period; then, these are added together and multiplied by the maximum 30-min intensity of the storm to obtain average annual soil loss (Alnoldus, 1977). The annual rainfall data (Tanzania Meteorological Agency) for 27 years (1973–1990 and 2000–2008) used in this study were obtained from Tanzania Meteorological Agency, which provided rainfall data recorded from three weather stations of Bereko village, Haubi village and Kondoa town. The rainfalls recorded from the three weather stations were interpolated to obtain continuous grids, which covered all parts of the study area. In most part of Africa including KEA, lack of widespread high density of rain gauge stations make great difficulties to calculate erosive index (*R*). Several alternative approaches have been designated to calculate (*R*). This study calculated R factor using regression analyses presented in Equation (2) (Van der Knijff *et al*., 1999 cited in Gimm *et al*., 2002)

$$R = \alpha \cdot Pj \quad (2)$$

Where: P_j = Annual rainfall (mm) and $\alpha = 1{\cdot}3$ (Van der Knijff *et al*.,1999 cited in Gimm *et al*., 2002); however, α in Equation 2 was substituted by 0·5, which was previously applied in west Africa (Roose, 1975 cited in Morgan, 2005). The 0·5 was used in this study because both KEA and West Africa experience tropical climate. A similar approach to obtain *R* factor was also applied in Nigeria (Adediji *et al*., 2010). The *R* indexes in American units were multiplied with 17·3 to change it to $\mathrm{Mg\,mmha^{-1}h^{-1}}$ (Wall *et al*., 2002).

Soil erodibility factor *K* is defined as the resistance of soil to erode with different soil types having different rate of erosion by detachment and transport (Morgan, 1995). Unlike *R*, which is given in $\mathrm{Mg\,mmha^{-1}h^{-1}}$, *K* is calculated in $\mathrm{t\,h\,MJ^{-1}mm^{-1}}$. When USLE is applied to predict soil erosion, *K* often represents soil loss per unit of *R*; therefore, if *K* is $\mathrm{Mg\ ha^{-1}}$ for one unit of metric *R*, then multiplying the value of *R* will give the value of total soil loss in t/ha (Morgan, 1995). Five important soil parameters, that is, % silt + very fine sand, % other coarse sand, % organic matter, structure and permeability are used as inputs in calculating soil erodibility (Wischemeier *et al*., 1971 cited in Morgan, 1995).

In Africa, soil maps (Ministry of Agriculture and Food Security, Tanzania) often do not contain detailed information on soil texture because soil survey emphasizes on classification schemes rather than interpretation of soils in terms of land evaluation, which limit estimation of *K* factor (Veihe, 2002). This situation also occurred in KEA as existing soil map lacks some information on soil texture. On the basis of soil texture described in the soil survey report (Detail report of Land resources survey for Dodoma Region by United Republic of Tanzania and United Nations Department of technical cooperation and Development 1984) of the study area, the soil erodibility *K* factor was generated according to *K* value ranges given in the literature (Wall *et al*., 2002). The estimated *K* values included 0·03 for chromic luvisols and ferralic cambisols containing high proportion of sandy loam soil, 0·04 for haptic phaeosem characterized by silty clay loam and 0·007 for lithic leptosols, which contains high proportion of sand soil. Table I provides range of K value for different soil types that were applied in this study (Wall *et al*., 2002).

Slope length, which is the distance between the origin of runoff to a point where deposition occurs (Patriche *et al*., 2006), was obtained by field-based measurements. Representative slope length from each land cover types and in various topographical terrains was measured and recorded during fieldwork (Welle *et al*., 2007, Hickey, 2000): (1) for crops land, a sampled slope length taken was 180 and 120 m in low land and middle elevation, respectively; (2) 80 m in grassland; (3) bush/wooded grassland 110 and 170 m in medium hills and in mountains range, respectively; (4) 210 m in highland forests; (5) built-up area 40 m; (6) swampy area 15 m and (7) 150 m in the bare soil. In ArcGIS, slope length in metre for all the study sites were converted into raster layer, and the slope length were computed using the following equation (Saroinsong *et al*., 2006).

$$L = (X/22)^{0.5} \quad (3)$$

Where: X is the slope length obtained from actual field's measurements

On the other hand, calculation of slope angle (S) was done by using DEM with 30 m spatial resolution downloaded from the website of the United State Geological Survey Bureau. The most prominent control factor in assessment of soil erosion is the slope angle (Angima *et al*., 2003; Patriche *et al*., 2006). The slope angle S in percentage was firstly derived from DEM using 3D analyst extension in the ArcGIS. Then, using spatial analyst extension, slope angle S in percentage was computed using Equation (4) (Šurda *et al*., 2007).

$$S = 0 \cdot 0138 + 0 \cdot 0097s + 0 \cdot 00138s^2 \quad (4)$$

Where: S is the overall adjusted slope angle, and s is the slope angle in percent. The topographical factor, LS, combines two variables. These include slope length (L) factor and slope steepness (S) factor. Raster map of slope length (L) was multiplied with raster map of slope steepness (S) calculated by Equations (3) and (4), respectively, to obtain topographical factor, LS, using the raster calculator in ArcGIS spatial analyst extension.

The land covers and crop management factor C is dependent upon the percentage of the rainfall energy intercepted by the crops in different season of a year (Morgan, 1995). In this study, C factors were obtained by weighing the percentage of cover at different season of the year with respective rainfall fractions. A year was divided into three different seasons on the basis of crops growing seasons and fraction of rainfall in each season. C values were weighted according to the percentage of the mean annual rainfall in that season and summed up to obtain the annual C value (Welle *et al*., 2007). That was performed by grouping the rainfall into subfraction of (1) January–May, (2) June–September and (3) October–December, and on the basis of that, a respective fraction of land/cover C1, C2 and C3 were assigned to each season and multiply each C values with fraction of rainfall (Rainfall 1, Rainfall 2 and Rainfall 3), respectively, to retrieve three separate cover values for three separate seasons of the year. These values were summed up to retrieve weighted C value in percentage for each land cover. The calculated land cover in percentage was then assigned C factor values on the basis of guideline on allocation of C factor values from the existing literature (Hui *et al*., 2010).

The value of C can vary from near zero for well-protected soil to 1·5 for finely till, ridge surfaces highly susceptible to rill erosion (Angima *et al*., 2003). Adediji *et al*. (2010) allocated C factor 0·02 for degraded forest, 0·11 for grassland and 0·00 for water bodies. Morgan (2005) suggested C factor range of 0·02–0·1 for maize sorghum and millet with minimum tillage, 0·001 for forest and dense shrubs, 0·01–0·1 for savannah and prairies grass and 1 for bare soil. The C factor values generated in this study were within the range of values cited in the aforementioned literatures allocated on the basis of identified cover types and weighted percentage of cover. The generated C factor comprised of areas with no visible cover, that is, bare soils that fell into 0·45 C factor, grassland 0·13, croplands 0·09, bush/wooded grassland 0·085, built-up 0·042, forest 0·012 and water 0·002 (Table II).

The support management practice for soil conservation (P) values tends to be the most difficult to determine and the least reliable factor in the USLE input factors (Renald *et al*., 1994 cited in Hui *et al*., 2010). In this study, natural vegetation areas were allocated 0·3 P factor to maintain uniformity between the three study years because of great efforts undertaken prior and after establishment of HADO in constructions of contour bunds and planting sisal strips in nonagriculture land in KEA. In KEA, British colonial administration introduced the constructions of terraces and contour bunds as early as 1930s (Christiansson, 1996). It is suggested that contour bunds can be allocated P factor of 0·3 (Morgan, 2005).

The P factor values for croplands range from 0·38 in 1986 and 2008 to 0·75 for 1973 because of limited adoption of

Table I. Range of K values for different soil texture classes (Wall *et al*., 2002).

Surface soil texture	Relative susceptibility to water erosion	K–value ranges
Very fine sand	Very highly susceptible	>0·05
Loamy very fine sand; silt loam; very fine sandy loam; silty clay loam	Highly susceptible	0·04–0·05
Clay loam; loam; silty clay; clay and sandy clay loam	Moderately susceptible	0·03–0·04
Heavy clay; sand loamy; loamy fine sand fine sand and coarse sandy loam	Slightly susceptible	0·007–0·03
Loamy sand; Sand	Very slightly susceptible	<0·007

Table II. *C* factor for 1973, 1986 and 2008

	Forest	Bush/wooded grassland	Grasslands	Croplands	Water	Bare soil	Built-up
LC1	70	50	30	43	100	0	60
LC2	70	45	20	36	100	0	60
LC3	70	50	30	40	100	0	60
1973 RF 1	0·72	0·76	0·76	0·74	0·76	0·76	0·74
1973 RF 2	0	0	0	0	0	0	0
1973 RF 3	0·28	0·24	0·24	0·26	0·24	0·24	0·26
1986 RF 1	0·75	0·78	0·78	0·75	0·75	0·58	0·58
1986 RF 2	0·1	0·03	0·03	0·1	0·1	0·1	0·1
1986 RF 3	0·24	0·21	0·21	0·24	0·24	0·41	0·41
2008 RF 1	0·82	0·65	0·65	0·65	0·65	0·65	0·82
2008 RF 2	0·2	0·00	0·00	0·00	0·00	0·00	0·2
2008 RF 3	0·16	0·35	0·35	0·35	0·35	0·35	0·16
1973-C1	50·5	38	22·8	31·8	76	0	44·4
1973-C2	0	0	0	0	0	0	0
1973-C3	19·6	12	7·2	10·4	24	0	15·6
1986-C1	52·5	39·2	23·5	32·2	75	0	34·8
1986-C2	7	1·6	0·7	3·6	10	0	6
1986-C3	16·8	10·5	6·3	9·6	24	0	24·6
2008-C1	57·4	32·5	19·5	27·9	65	0	49·2
2008-C2	14	0·0	0·0	0·0	0·0	0	12
2008-C3	11·2	17·5	10·5	14	35	0	9·6
$\sum$ C 1973	70	50	30	42·2	100	0	60
$\sum$ C 1986	76·3	51·3	30·7	45·4	109	0	65·4
$\sum$ C 2008	82·6	50	30	41·9	100	0	70·8
C-FACTOR	0·012	0·085	0·13	0·09	0·002	0·45	0·042

Note: LC = land cover percentage; RF = rainfall fraction; and C1 = LC1*RF1; C2 = LC2*RF2; C3 = LC3*RF3 for each respective year 1973,1986 and 2008; 1, 2, 3 represent seasons of the year, January–May; June–September and October–December, respectively. The *C*-Factor were allocated values based on weighed or sum of percentage of land cover and respective range of *C* value based on percentage of land cover and their respective range of *C* factor.

various land management measures, such as across slope ridges and strip cropping during 1970s. During early years of independence in 1960–1970s, most farmers were not willing to adopt soil conservation introduced since colonialism because political officials denounced the conservation measures during independence struggles, which made it difficult to enforce soil conservation by the new nation (Mung'ong'o, 1995). Allocation of *P* values for croplands were made with reference to value suggested in literature (Wall *et al*., 2002). The value of *P* ranges from about 0·2 for reverse-slope bench terraces to 1·0 where there are no erosion control practices (Wischmeier and Smith 1978 in Angima *et al*., 2003). Land use such as built-up areas and bare soils were allocated 1·0 *P* factor, whereas water was allocated 0·002 *P* factor.

Determinants of soil erosion change

The decision of land users to adopt soil conservation measures and control soil erosion is influenced by socioeconomic factors (Boardman *et al*., 2003). Factors commonly found in the literatures, which determine participation in soil conservation include: perception on soil erosion, knowledge of conservation measures, land tenure security, off-farm income and availability of land, labour and capital (Jones, 2002). Others include education level, farm size, age of farmers, family size and existence of public supports (Tadesse and Belay, 2004). Table III provides variables used in the analysis to identify the determinants of reduction of soil erosion in KEA. These are briefly discussed below.

Age of respondents (X_1); the aged farmers who benefited from past conservation are more likely to invest more on conservation and reduce soil erosion (de Graaff *et al*., 2008). The effect of age on soil conservation is associated with experiences and long-term planning horizon (Bewket, 2007). Access to extension services (X_2) may provide knowledge on conservation measures and make farmers increase adoption of measures. Awareness on HADO project (X_3); this was an important tool and component of HADO that intended to ensure widespread acceptance and adoption of soil conservation measures by farmers in the past. Household size (X_4); with increase household sizes, there is great possibility to increase supplies of labour, which is essential for soil conservation (Jones, 2002). Crop income (X_5); agriculture and livestock must generate income for farmers to invest on soil conservation measures (Kessler, 2007).

Rate of participation in soil conservation (X_6) such as long-term investment in soil and water conservation is likely to produce good results of soil conservation measures (de Graaff *et al*., 2008). Benefits from material support (X_7) existence of incentives for conservation, such as granting land tenure right influenced farmers to implement soil conservation measures (Gebremedhin, 2004). Access to market for sale of crop products (X_8); it is suggested that combining high-valued crops and improve market access may increase implementation of soil conservation measures (Posthumus 2005 cited in de Graaff *et al*., 2008). Length of time of land ownership (X_9); whereby people with long-term land ownership are more likely to have soil erosion control

Table III. Variables used in bivariate correlation and stepwise linear regression analysis

Name of variable	Values labels	Value	Measurement level
Dependent variable			
Y = Reduction of soil erosion rate	No	0	Dummy
	Yes	1	
Predictor variables			
X_1 = Age of respondents		Number of years	Continuous
X_2 = Access to extension services	Yes or No	1 or 0 respectively	Dummy
X_3 = Awareness on HADO	Yes or No	1 or 0 respectively	Dummy
X_4 = Household size	1–5; 6–10; <10	1; 2; 3, respectively	Discrete
X_5 = Crop income per year Tshs		Amount	Continuous
X_6 = Rate of participation	<10 years ago	1	
	10–15 years ago	2	Discrete
	15–20 years ago	3	
	20–25 years ago	4	
	>25 years ago	5	
X_7 = Material supports	Tree seedlings; improved cow; instruments; work for food; cow and tree seedlings; instruments and tree seedlings	1;2;3;4;5;6, respectively	Discrete
X_8 = Access to market for sale of crops	Yes or No	1 or 0 respectively	Dummy
X_9 = Length of land ownership		Number of years	Continuous
X_{10} = Has planted trees	Yes or No	1 or 0 respectively	Dummy

structures, such as cutoff drains constructed since the active stage of HADO compared with new generation. Tree planting (X_{10}) may also protect the soil from erosion through root-binding and reduce soil detachments because of protection from plant litters and leaf interceptions.

Multiple linear regression analysis was performed to determine the relation between reduction of soil erosion rate and the above 10 Independent variables (Table III). First, relationship between dependent and independents variable were analysed by bivariate correlation to omit independent variable that does not correlate with dependent variable before performing stepwise linear regressions analysis.

RESULTS AND DISCUSSIONS

Soil erosion changes in KEA

Estimated soil erosion indicates positive change by overall decrease of very high soil erosion category (50–80 Mg $ha^{-1}y^{-1}$), which declined by 5% of the study area throughout the study period. It occupied 30%, 26% and 25% of total land in KEA during 1973, 1986 and 2008, respectively. Maintaining permanent vegetation cover is considered the most important measure to control very high and severe erosion (Wall *et al*., 2002). The reduction of very high soil erosion in KEA is attributed to past efforts in planting tree and grasses cover, prevention of tree cutting and prohibiting farming in forested area especially in steep slope lands. Recently, the situation has changed drastically as results show that 45% of farms in the area occurred in middle elevation, 19% in the upper elevation, 18% in lower elevation, 9% in the middle and lower elevation, 8% in the hill top and 1% in the top and lower elevation (Figure 3). This implies that in KEA, nearly one-third of farms are located on erosion prone areas of hilltop and upper elevation similar to what Kangalawe (2010) reported about crop cultivation on land with slope above 10% in the area.

This study also observed destructive farming in closed highland forested area with more inclined slope (Figure 4). The finding in this study is similar to previously reported increased incidence of illegal grazing and tree cutting for fuel wood and timber, which have been observed since 1995 despite the government's continuation of recognizing the protected area in KEA (Dallu, 2002). Increased market for cabbages, tomatoes, maize and beans in Kondoa town and municipality of Arusha and Dodoma also increased deforestation in Irangi hills part of KEA. High slope gradient contributes significantly to high soil erosion rate as reported by Welle *et al*. (2007) in Ethiopia. Deforestation in steep slope areas of Irangi hills for crop cultivation may lead to further increase of very high soil erosion, which was indeed declining in the past few decades because of past initiatives in soil conservation.

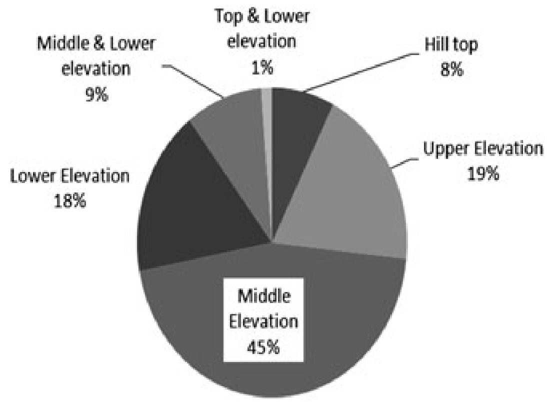

Figure 3. Proportion of farm lands distribution by location in the watershed.

Figure 4. Deforestation in slopping land for crop cultivation in Mafai village.

On the basis of the study conducted in neighbouring Zimbabwe, the rate of soil loss that ranges from 50–80 Mg $ha^{-1}y^{-1}$ could complete destroy productive land within 30 years (Elwell, 1984). With significant proportion of land (30%) of KEA suffering with soil erosion, which ranges from 50–80 Mg $ha^{-1}y^{-1}$ in 1973, it justified the efforts on soil conservation that was carried out over the last 40 years in the area. High soil erosion for some specific areas of KEA predicted in this study is almost equal to soil erosion rate amounting to 70 Mg $ha^{-1}y^{-1}$ measured in Shinyanga region in Tanzania (Stocking, 1984). However, it is lower than the results of prior measurement in the same area during 1960–1965, which showed erosion rate of 105 Mg $ha^{-1}y^{-1}$ (United Republic of Tanzania, 2009). Lack of preventive measures caused historical severe land degradation in Shinyanga region, which is contributing to environmental stress and socioeconomic hardship until today. Despite the establishment of Shinyanga region soil conservation project in 1986, the severity of the problem persisted. Severe soil erosion in the area pushed majority of people to migrate with their livestock to distant places such as Usangu plain in Mbeya region and Kilombero valley in Morogoro region and contributing to increasing land degradation and natural resource uses conflicts in the destinations' areas.

However, in KEA, prolonged soil conservation activities in the area also contributed to limited expansion of area affected by high soil erosion (25–50 Mg $ha^{-1}y^{-1}$), which increased by only 3·1% since it covered 46% in 1973 then was stabilized at 49% from 1986–2008 (Table IV and Figure 5 a, b, c). Despite less increase, the fact that a large part of KEA is affected by high soil erosion constitute great threat to agriculture development and ecosystem sustainability because this rate of soil loss is only slightly lower than the most destructive very high erosion category. The rate of soil loss ranging from (25–50 Mg $ha^{-1}y^{-1}$) demands timely and effective controls to prevent increases of its severity towards very high erosion. Some suggested measures to control high soil loss amounting to 30 Mg $ha^{-1}y^{-1}$ include zero (no) tillage, terraces and cross slope or contour strip cropping (Wall *et al*., 2002). Adoptions of these measures are within economic capability of majority of farmers in KEA, but this study found that implementation of these measures is not widespread currently. Findings also show that measures such as no tillage and contour ridges cultivation are practiced by only 21·3% and 20% of the respondents, respectively, and 41% practices minimum tillage and none of them constructed terraces. Low level of implementation of these measures contributes to high proportion of area, that is, about half, experiencing high soil erosion in KEA.

Other than the limited expansion of high soil erosion particularly in the early year of HADO project 1973–1986, success has been shown by 2·4% increase of area occupied by moderate soil erosion (11–25 Mg $ha^{-1}y^{-1}$), which increased from 15%, 16% and 18% in 1973 to 1986 and 2008, respectively. The moderate soil erosion predicted in this study match with reported annual average soil losses amounting to 10–25 Mg $ha^{-1}y^{-1}$ for Eastern Africa (Lal, 1995 cited in Igue, 2002). Major expectation could have been high proportion of land in KEA be covered by moderate soil erosion but in reality less than one-fifth of the land fell into that category of erosion severity. Despite significant investment in soil conservation success in controlling soil erosion has been very minimal especially during 1973 to 1986. Even more threatening situation was observed by high increase of soil erosion between 1973 and 1986, which showed that average annually soil erosion had changed from 14·7 to 23 and 15·7 Mg $ha^{-1}y^{-1}$ for 1973, 1986 and 2008 respectively.

Major explanation for increasing trends of erosion severity in the early years of HADO soil conservation project was due to slow progress in afforestation activities. Among the important factor for rehabilitation of degraded semiarid land is attributed to the increase of vegetation cover

Table IV. Differences in soil erosion area and severity between 1973, 1986 and 2008

Erosion severity	Low		Moderate		High		Very high		Total	
Soil loss ($Mg\ ha^{-1}y^{-1}$)	0–11		11–25		25–50		50–80			
Area	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
Erosion area 1973	150	9·0	255	15	762·2	46	507·4	30	1675	100
Erosion area 1986	156	9·3	263	16	823·1	49	432·8	26	1675	100
Differences 1986–1973	5·9	0·4	7·7	0·5	60·9	3·6	−74·5	−4		
Erosion area 2008	139	8·3	295	18	814·3	49	425·9	25	1675	100
Differences 2008–1986	−17·2	−1·0	33·0	2·0	−8·8	−0·5	−6·9	0		
Differences 2008–1973	−11·3	−0·7	40·7	2·4	52·1	3·1	−81·4	−5		

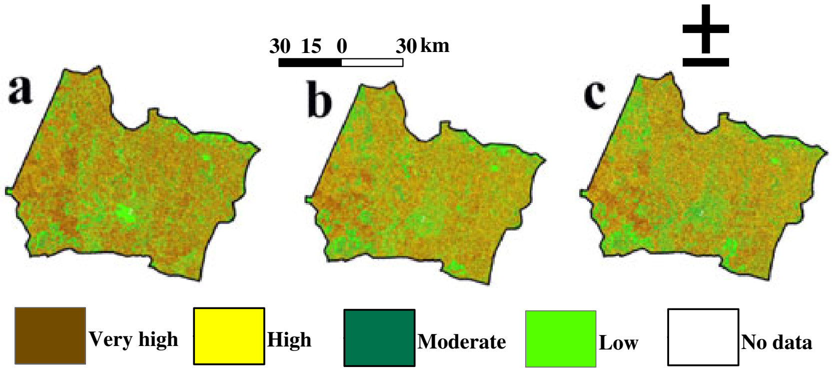

Figure 5. a, b, c. The condition of soil erosion in KEA during 1973, 1986 and 2008, respectively.

(Coxhead and Øygard, 2007). But during the initial stage of HADO restoration of grasses occurred quickly following destocking of 1979 but woodland expansion went slowly. It is argued that localized and specific high erosion in Africa can best be controlled by improvement of vegetation cover rather than relying on physical erosion control structures (Stocking, 1984). Contrary to that suggestion by 1983, out of 126,000 ha of the enclosed area of KEA, only 10,000 ha (8% of the area) was rehabilitated with woodland instead of 50,000 ha of woodland needed to meet restoration target (Nshubemuki and Mugasha, 1985). Very high rate of soil erosion in 1986 in KEA is similar to measurement done in Shinyanga regions in Tanzania where erosion jumped from average annual soil loss of 2·6 Mg $ha^{-1}y^{-1}$ from mid-1960 to 22 Mg $ha^{-1}y^{-1}$ in 1984, which is nearly tenfold increase of soil erosion in the area (Stocking, 1984).

Low performance of HADO in controlling soil erosion until mid-1980s had also been attributed to top-down and nonparticipatory conservation measures (Dejene *et al.*, 1997). Lack of consultation caused inability to focus on local needs that made the project to concentrate on physical land rehabilitation without targeting improving farmland conservation, which also constituted significant area of degraded land (Nshubemuki and Mugasha, 1985). Use of heavy machines, such as tractors instead of preparing the farmers to construct erosion controls structures with simple and affordable tools, such as shovels and hand hoes also reduced adoptions of measures. Key informants in this study stated that in the long run, tractors had to be inevitably replaced by manual labour because of maintenance problems and high-running cost. Although destocking contributed to increase natural vegetation, it also hauled back rehabilitation in degraded agriculture land and contributed to abandonment because of lack of manures to improve soil fertility, which are important inputs in rehabilitation of degraded land. It is suggested that improvement of soil fertility may enhance vegetation cover, which is the best controller of soil erosion in Africa (Stocking, 1984).

The annual average rate of soil loss ranging from 14·7 to 23 Mg $ha^{-1}y^{-1}$ estimated in this study was high compared with the soil loss tolerance level of 5–11 Mg $ha^{-1}y^{-1}$, which can occur, but still, high agriculture productivity continues to be maintained, given existence of deepest and most fertile soil (Wall *et al.*, 2002). The worse situation in KEA is that it is mostly characterized by thin soils and estimated results show that low erosion category (0–11 Mg $ha^{-1}y^{-1}$), which is equivalent to the stated soil loss tolerance occupied very small areas. Such areas as classified were 9% and 9·3% of the study area in 1973 and 1986, respectively, and then declined to 8·3% in 2008. The low erosion hazards covering 9% of total land predicted in this study was even bigger than the past assessment by expert judgement, which showed that only 5% of total land of KEA had low soil erosion during 1984 (Mbegu and Mlenge, 1984). The low eroded areas mainly occurred in noncultivated area in Mafai closed forest reserves and Kolo forested area and also in area surrounding Lake Haubi and patches of closed forest in the South of KEA.

Failure to reduce soil erosion is highly rooted to limited success in tree planting activities since the early stage of HADO, and recent increased return of illegal overgrazing animals after withdrawal of donor supports to HADO activities since 1996 and subsequently declining project activities since 1997. Recent poor implementation of soil conservation is also attributed to the tendencies to stick to external interventions, which does not even create linkage to local production systems and often does not support environmental management by increasing capacity of local institutions and community groups in adoption of conservation measures (Mungo'ng'o, 1995). This is because although HADO top down interventions by state and donors enabled physical rehabilitation of degraded land, little was performed to support soil conservation on farmland because of weak past linkage between HADO project activities and agriculture production systems. Some of the cutoff drains and areas of improved vegetations started to be degraded again because of poor management after withdrawal of donor supports and limited participation of local communities and their institutions in soil conservation (Mung'ong'o, 1995, Catterson and Lindahl, 1999). Therefore, major challenge is how to ensure sustainability of the positive achievements in controlling soil erosion in the area particularly after withdrawal of HADO project.

Despite the withdrawal of HADO soil conservation project in KEA, soil conservation activities have prevented further increase of area affected by different soil erosion severity. Major success is the reduction of very high erosion and the increased area with moderate soil erosion. Continued participation of farmers in soil conservation is also attributed to policy changes since mid-1990s, particularly related to land tenure security, appropriate extension services on agriculture and livestock development, continued supply of subsidized improved cattle replacing destructives larges herds of the past and favourable market for crops, which provided incentives for soil conservation. Households' survey also confirms a decline of soil erosion (Figure 6). On the basis of the results of household survey, 28·3% of respondents said they experience very high soil erosion in 1973–1986 followed by high soil erosion 14%, no erosion 13%. No respondents mentioned about very high soil erosion during 1986–1996. High soil erosion severity was experienced by 22% of the respondents, 48·3% experienced low soil erosion, 18% had no soil erosion on their farms and 11·7% did not know. In 1997–2010, no erosion was reported by 31% of the farmers, 53% had low erosion and 14% experienced high soil erosion. These observations indicate the declining rate of soil erosion as perceived by the farmers.

According to the farmers, reduction of soil erosion is highly pronounced in the middle elevation; this may be attributed to moderate sloping land. While in top elevation, small proportion of farmers said they experienced reduction of soil erosion. Results also show that there is also considerable reduction of soil erosion in upper elevation and that may be attributed to implementation of soil conservation measures, such as contour ridging and cut off drains (Table V). Numbers of studies have also documented the overall benefits of HADO including improvement of vegetation cover, reduction of soil erosion and gullies' sizes and increase forest products, such as firewoods (Mungo'ng'o, 1995, Dejene *et al*., 1997, Kangalawe *et al*., 2008). Natural vegetation cover increased from 30% in 1986 to 80% of the total area in 1998 (Nkwilima, 2001). Stall-feeding practice also replaced destructive open gazing and increase supply of manure for organic matter build up in soils. Report also shows that agriculture land has been increased by restored former gullies (Nshubemuki and Mugasha, 1985, Kangalawe *et al*., 2008). Extension services from HADO and other sources have contributed to better land uses and land management to a greater extent (Nshubemuki and Mugasha, 1985). Some of improved

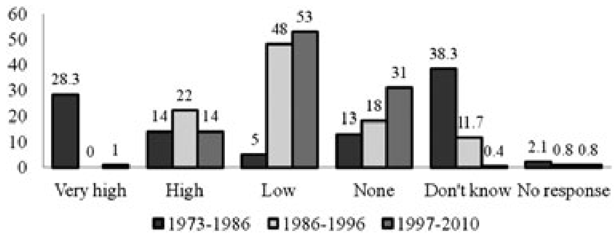

Figure 6. Farmers' perception about soil erosion severity 1973–1985, 1986–1996 and 1997–2010.

land uses are agroforestry practices, ox-plough, zero grazing, use of manure, crop diversification, mixed cropping, crop rotation and maintaining useful traditional methods, such as the use of compost and farmyard manure (Kangalawe *et al*., 2008).

Determinants of reduction of soil erosion

Results from household survey show that 68% of farmers said soil erosion had declined and 32% said there was no reduction of soil erosion (Table V). This implies that initiatives to control soil erosion through HADO soil conservation projects with participation of local communities and supports from other stakeholders, such as Kondoa District Council (Kondoa District Council, 2009) has contributed significantly in reduction of soil erosion in KEA. A total of 10 covariates tested by bivariate correlation analysis all have significant correlation with dependent variable the reduction of soil erosion (Table III). When those 10 correlated variables were tested by stepwise multiple linear regression analysis as predictor variables, three of them appeared to have significant relationship with reduction of soil erosion as shown in Equation (5) and in Table VI.

$$Y = 0 \cdot 066 + 0 \cdot 003X_6 + 0 \cdot 009X_{10} + \cdot 0 \cdot 033X_1 \quad (5)$$

Where: Y = reduction of soil erosion rate and X_6 = rate of participation in soil conservation; X_{10} = tree planting and X_1 = age of respondents. In the above model, all variables were significant at 0·01 confidence level. The obtained multiple correlation coefficients (R^2) of 0·21 indicate that there is moderate association between predictor variables and reduction of soil erosion rate. As included in the model, all predictor variables have positive correlation with the dependent variables

Table V. Reduction of soil erosion rate by location of land in the watershed

	Hill top		Top and lower elevation		Upper elevation		Middle elevation		Middle and lower elevation		Lower elevation		Total	
	F	%	F	%	F	%	F	%	F	%	F	%	F	%
No	10	56	2	67	14	30	24	22	6	27	20	48	76	32
Yes	8	44	1	33	32	70	84	78	16	73	22	52	163	68
Total	18	100	3	100	46	100	108	100	22	100	42	100	239	100

F = frequency and % = percentage

Table VI. Linear regression model summary coefficients[a]

Model	Unstandardized coefficients		Standardized coefficients		
	B	Std. error	Beta	t	Sig.
(Constant)	0·066	0·099		0·669	0·504
Rate of participation	0·300	0·099	0·177	3·032	0·003
Tree planting	0·157	0·060	0·168	2·618	0·009
Age of respondent	0·223	0·104	0·126	2·148	0·033

[a]Dependent variable: reduction of soil erosion rate

Critical analysis of regression model results shows that number of factors contributed to influence each independent variable to have significant relationship with reduction of soil erosion. As shown in the model, as people grew older above 50 years, they experienced reduction of soil erosion on their farms. This may be attributed to the past HADO soil conservation measures, which ensure erosion control through planted trees and grass cover, cutoff drains, drainage channels and contour bunds but also aged people might still have knowledge of soil conservation impacted to them when the project was still active compared to young farmers. The presence of conservation programme often influence long-term investment in soil and water conservation because of knowledge provided by the project (de Graaff *et al*., 2008). Rate of participation in soil conservation also has positive relationship with reduction of soil erosion. Major factor for majority of farmers to adopt soil conservation over extended period of time in KEA includes universal acceptance of farmers on danger of soil erosion in the area (Kangalawe *et al*., 2008) and also because of long-term implementation of HADO soil conservation project, which provided numerous supports on soil conservation activities. Key informants stated that HADO staffs were supported through funding, communication skill and technical training to improve their capacity in providing extension services and educating the farmers in soil conservations. The absence of supports from either the government or nongovernment organization increased the number of nonadopters of soil conservation elsewhere (Tadesse and Belay, 2004). This implies that HADO soil conservation project contributed significantly as important policy instrument ,which increased participation of people in soil conservation. With defunct of HADO project in KEA, alternative approaches need to be identified to ensure sustainability in adoption of soil conservation measures in the area. Soil conservation activities can be carried out through community-based conservation programmes and by supporting farmers to increase conservation activities on farmlands.

The predictor variable tree planting also has positive relationship with reduced soil erosion in KEA. Afforestation and prohibiting degraded land from other uses have been widely implemented in many countries to control soil erosion (Morgan, 1995). In KEA, development of tree nurseries and tree planting went simultaneously with destocking measures and later on controlling stock of herds by establishing stall-feeding cattle with legal provision of a herd size of not more than four cattle per household to reduce the pressure of overstocking. Trees and grasses cover minimized surface erosion and enhanced slope stability. Major challenge in KEA is that past efforts in tree planting and controlled grazing have not been met with similar undertaking currently because of limited supply of tree seedlings and lack of surveillance against deforestation after withdrawal of donor in 1996 and HADO project being dormant since 1997. With increasing vegetation clearance for agriculture and illegal grazing, there is great danger of reoccurrence of more deforestation and severe soil erosion in most part of KEA in the near future.

CONCLUSIONS

Overall outcome of long-term adoption of soil conservation measures has brought positive results by preventing further expansion of area affected by high soil erosion severity in KEA, and there was an increase of moderate erosion in some area. Number of measures put in practice, such as tree planting, cutoff drains, drainage channels, contour bunds, contour ridges, mixed cropping, strip cropping, crops diversification, ban of livestock-keeping and later zero grazing have contributed to reduced expansion of soil erosion. Erosion modelling showed that soil erosion initially increased during earlier stage of HADO implementation mainly because of slow progress in improvement of vegetation cover by top-down intervention, but subsequently, the change of management in favour of more local community participation resulted significant reduction of soil erosion during the period of 1986 and 2008. However, computed soil loss rates were still two times higher than soil erosion tolerance level. The modelling result is substantiated by the households' survey, as respondents perceived lesser erosion in the recent past compared with earlier. Age of farmers, long-term participation in soil conservation and tree planting by the households are the major factors contributing to reduced rate of soil erosion as indicated by the regression analysis.

Observed challenges for further progress in soil conservation by reducing soil erosion were dependency on external interventions, top-down conservation approach, bias towards physical land rehabilitation activities and low participation of local people in soil conservation. Also, there has been weak mechanism in aligning soil conservation activities, local agriculture production systems and local institutional mechanisms for environmental management. HADO used hired labour to construct cutoff drains, manage trees nurseries, demonstration woodlots and surveillances. One option was to use village governments to enforce laws, which provide for standard of sustainable farm management to ensure environmental protection and optimum production in the farm and protection of nonfarmland resources. That would have reduced the likelihood of recurrence of land degradation in former restored areas particularly after withdrawal of resources and support from donors and central government.

The farm land could have been better sites for tree planting to address declining efforts in tree planting by integrating trees in crop lands as provided in the recent Kondoa District environmental by-laws. Farmers may also be supported to establish woodlots in degraded land outside their farms with agreements to allocate such lands to the farmers. Activities such as overgrazing should be discouraged and replaced by controlled or zero grazing. Similarly, research and extension services to introduce technologies that are less destructive to environment, for instance, using cattle manure as fuel, introduction of high quality cattle breeds and sustainable agriculture production practices, would further help achieve soil conservation and environmental management. There is also a need for increasing monitoring and assessment on status of land cover and soil erosion. This study only applied simplified USLE model and limited socioeconomic information as part of encouraging use of simplified tools for monitoring of land degradation in Tanzania. Regular monitoring using advanced erosion models along with their field-based validation to improve the accuracy of soil erosion prediction for formulating better land management strategies in the future is suggested.

ACKNOWLEDGEMENTS

We thank the Ministry of Livestock Development and Fisheries in Tanzania and the World Bank for providing funding support to carry out this study through the Marine and Coastal Environmental Management project (MACEMP) and the Asian Institute of Technology for providing academic platform. We would like to express our appreciation to the Global Land Cover Facilities, which provided Landsat data, and USA Bureau of Geological Survey for providing DEM. Thanks are also due to the support during field work by HADO and Kondoa district council staffs and respondents in the study area who kindly cooperated in giving the sought information necessary for the study. Constructive and critical comments of the anonymous reviewers, which were very valuable for improving the manuscript, are also highly acknowledged.

REFERENCES

Adediji A, Tukur AM, Adepoju KA. 2010. Assessment of Revised Soil Loss Equation (RUSLE) in Katsina Area, Katsina State of Nigeria using Remote Sensing (RS) and Geographic Information System (GIS). *Iranica Journal of Energy and Environment* **1** (3): 255–264

Alnoldus H. 1977. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Moroco. In [FAO] Food and Agriculture Organization 1977: *Assessing soil degradation* Soil Bulletin No **34** :39–48

Angima SD, Stott DE, O'Neill MK, Ong CK, Weesies GA. 2003. Soil erosion prediction using RULSE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment* **97**: 295–308.

Bewket W. 2007. Soil and water conservation with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. *Land Use Policy* **24**: 404–416.

Boardman J, Poesen J, Evans R. 2003. Socio-economic factors in soil erosion and conservation. *Environmental Science and Policy* **6**: 1–6.

Catterson J, Lindahl C. 1999. *The sustainability Enigma*: *aid dependency and phasing out of projects*: *the case of Swedish Aid to Tanzania* expert group on development issues EGDI 1 Nortedts Tryckeri AB

Chakela QK. 1992. *Problems of monitoring erosion and sediments yields in southern Africa*. Erosion and Sediment transport monitoring programmes in river basins: Proceedings of the Oslo Symposium August 1992; IAHS Publication, No. 210.

Chandler G, Markham B. 2003. Revised Landsat-5 TM radiometric calibration procedures and postcalibration dynamic ranges. IEEE *Transactions on Geoscience and Remote Sensing* **41**(11): 2674–2677.

Christiansson C. 1996. Linking landscape and societies: glimpses from ongoing studies in the man land interrelations research programme. In. Christiansson C, Kikula I. 1996. *Changing Environments research on Man –Land Interrelations in Semiarid Tanzania*, No. 13. Swedish International Development Cooperation Agency: Regional Soil Conservation Unit: Nairobi, 7–14.

Coxhead I, Øygard R. 2007. *Land degradation*: Paper submitted for Copenhagen Consensus 2008. [online]. Available from: http://www.copenhagenconsensus.com/ [Access date 29 October 2012].

Dallu AIM. 2002. Tropical secondary forest management in Africa: reality and perspectives. *Tanzania Country Paper. Workshop on tropical secondary forest management in Africa FAO/EC LNV/GTZ in collaboration with ICRAF and CIFOR Nairobi Kenya 9–13* December 2002.

de Graaff J, Amsalu A, Bodnar F, Kessler A, Posthumus H, Tenge A. 2008. Factors influencing adoption and continued use of lang-term soil and water conservation measures in five developing countries. *Applied Geography* **28**: 271–280.

Dejene A, Shishira E, Yanda P, Johnsen F. 1997. *Land degradation in Tanzania: perception from the village*. Technical Paper No 370: World Bank Washington DC.

Elwell HA. 1984. *Sheet erosion from arable lands in Zimbabwe*: *prediction and control. Challenges in African hydrology and water resources*: Proceedings of the Harare Symposium, 1984: IAHS Publication. No, **144**.

Eriksson MG, Christianson C. 1997. Accelerated soil erosion in central Tanzania during the last few hundred years. *Physical Chemical Earth* **22**(2–4): 315–320.

Fan JR, Zhang JH, Zhong XH, Liu SZ, Tao HP. 2004. Monitoring of soil erosion and assessment for contribution of sediments to rivers in a typical watershed of the Upper Yangtze River Basin. *Land Degradation and Development* **15**: 411–421, **DOI**: 10.1002/LDR.622

Gebremedhin B. 2004. Economic incentives for soil conservation in the east African countries. Paper No 1026 presented in 13th International soil conservation organization conference (ISCO) on conserving soil and water for society sharing solution. International Livestock Research Institute (ILRI), Addis Ababa Ethiopia.

Grimm M, Jones RJA, Rusco E, Montanarella L. 2002. *Soil Erosion Risk in Italy: a revised USLE approach*. European Soil Bureau Research Report No 11, EUR 20677 EN, 28pp. Office for official Publications of the European Communities, Luxembourg

Hickey R, 2000. Slope angle and slope length solutions for GIS. *Cartography* **29**(1): 1–8.

Hui L, Xiaoling C, Lim JK, Xiaobin C Sagong M. 2010. Assessment of soil erosion and sediment yield in Liao watershed, Jiangxi province, China using USLE, GIS and RS. *Journal of Earth Science* **21** (6): 941–953

Igue AM. 2002. *The Qualitative Assessment of water erosion risk in moist savanna of Benin*. 12th ISCO Conference Beijing

Igwe CA, Akamigbo FOR, Mbagwu JSC. 1999. Application of SLEMSA and USLE erosion models for potential erosion hazard mapping in south-eastern Nigeria. *Int. Agrophysics* **13**:41–48

Jones S. 2002. A framework for understanding on-farm environmental degradation and constraints to the adoption of soil conservation measures: case studies from highland Tanzania and Thailand. *World Development* **30**(9): 1607–1620.

Kangalawe RYM. 2010. Changing land use/cover patterns and implications for sustainable environmental management in the Irangi Hills, central Tanzania. *Environment, Development and Sustainability* **12**: 449–461. DOI: 10.1007/s10668-009-9204-5.

Kangalawe RYM, Christiansson C, Ostbergy W. 2008. Changing land-use patterns and farming strategies in the degraded environment of the Irangi Hills, central Tanzania: *Agriculture*, *Ecosystem and Environment* **125**: 33–47.

Kessler CA. 2007. Motivating farmers for soil and water conservation: a promising strategy from Bolivian mountains valleys. *Land Use Policy* **24**: 118–128.

Khity M, Csaplovics E. 2007. Appropriate methods for monitoring and mapping land cover changes in semi-arid areas in North Kordofan (Sudan) by using satellite imagery and spectral mixture analysis. Institute of Photogrammetry and Remote Sensing, University of Dresden Mummsenstr 13, 01062 Dresden Germany

Kondoa District Council. 2009. *Kondoa district environmental by-laws of 2009*. Kondoa District Council Dodoma Tanzania

Leenaers H. 1990. Estimating the impact of land use changes on soil erosion hazard in the Zambezi River Basin. Working paper 90–024 International Institute for Applied Systems Analysis A-2361 Laxenburg, Austria

Mbegu AC, Mlenge WC. 1984. Ten years of HADO 1973–1983. Forest Division Ministry of Natural Resources and Tourism: Dar Es Salaam.

Merritt WS, Letcher RA, Jakeman AJ. 2003. A review of erosion and sediments transport models. *Environmental Modelling and Software* **18**: 761–799.

Morgan RPC. 2005. Soil erosion and conservation. (*3rd.edn*). Blackwell Publishing Malden USA, Oxford UK, Victoria Australia .

Morgan RPC. 1995. Soil erosion and conservation (2nd edn). Longman: Malaysia TCP

Morgan .PC, Rickson RJ, McIntyre K, Brewer TR, Altshul HJ. 1997. Soil erosion survey of the central part of the Swaziland Middleveld. *Soil Technology* **11**: 263–289

Mung'ong'o CG. 1995. Social processes and ecology in the Kondoa Irangi hills, central Tanzania. Ph.D. Dissertation. Stockholm University. Stockholm.

Nkwilima EMS. 2001. Proposal for handling HADO soil conservation project to the local government authority. Paper presented at the stakeholder meeting in Kondoa District Council January 2001. Forest Division Ministry of Natural Resources and Tourism: Dar Es Salaam.

Nshubemuki L. Mugasha A.G. 1985. The modifications to traditional shifting cultivation brought about by the forest development project in HADO area, Kondoa, Tanzania: In. FAO 1985. Changes in shifting cultivation in Africa, seven case studies. No. 50/1 Forestry Department. FAO. 141–162.

Pagiola, S. 1999. The global environmental benefits of land degradation controls on agriculture land, Global analysis programme. *World Bank Environmental Paper* Number 16 WB: Washington DC.

Patriche CV, Capatana V, Stoica DL. 2006. Aspects regarding soil erosion spatial modeling using the USLE/RULSE within GIS. *Geographia Technica No* **2**.

Puig, C.J. Hyman, G., and Bolaños, S. 2002. Digital classification vs. visual interpretation: a case study in humid tropical forests of the Peruvian Amazon. International Center for Tropical Agriculture (*CIAT*). Cali. Colombia

Saroinsong F, Harashina K, Arifin H, Gandasasmita K, Sakamoto K. 2006. Practical application of a land resources information system for agricultural landscape planning. *Landscape and Urban Planning* in press

Stocking M. 1984. Rate of erosion and sediment yield in the African environment: challenges in African hydrology and water resources: Proceedings of Harare Symposium, July 1984. IAHS Publication. No. **144**

Šurda P, Šimonides I, Antal J. 2007. A determination of area of potential erosion by geographic information systems. *Journal of Environmental Engineering and Landscape Management*. **XV**(**3**):144–152

Tadesse M, Belay K. 2004. Factors influencing adoption of soil conservation measures in Southern Ethiopia: The case of Gununo area. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* **105** (1): 49–62

United Nations. 2009. Monitoring policy making at the United Nation Global Policy Forum. NY, USA.

United Republic of Tanzania. 2002. Natural resources aspects of sustainable development in the United Republic of Tanzania [online]. Available from: http://www.un.org.esa/agenda21/natlinfo/countr/tanzania.natur, htm [Access date 9 November 2012].

United Republic of Tanzania. 1995. National Land Policy of Tanzania 1995, Ministry of Land Housing and Human Settlements Development, United Republic of Tanzania.

United Republic of Tanzania. 1986. HADO second master plan 1986–1996. Ministry of Natural Resources and Tourism, United Republic of Tanzania

United Republic of Tanzania and United Nations Department of Technical Cooperation and Development. 1984. Integrated development plan Dodoma region: land resources survey. Agrar-UND HYDROTECHNIK GMBH Esse Germany

Veihe A. 2002. The spatial variability of erodibility and its relation to soil types: a study from Northern Ghana. *Geoderma* **106**: 101–120.

Wall GJ, Coote DR, Pringle EA, Shelton IJ (editors). 2002. RUSLEFAC—Revised Universal Soil Loss Equation for Application in Canada: a handbook for estimating soil loss from water erosion in Canada. Research Branch, Agriculture and Agri-Food Canada. Ottawa. Contribution No. AAFC/AAC2244E. pp 117.

Welle S, Chantawarangul K, Nontanandh S, Jantawat S. 2007. Prediction of soil loss in the northern part of Somali region of Ethiopia using empirical soil erosion models. *Kasetsart J. (Nat.Sci.)* **41**:109–122.