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RUSLE and SDR Model Based Sediment Yield Assessment in a GIS and Remote Sensing Environment; A Case Study of Koga Watershed, Upper Blue Nile Basin, Ethiopia

Habtamu Sewnet Gelagay

Information Network Security Agency, Spatial Data Infrastructure, Addis Ababa, Ethiopia

***Corresponding author:** Gelagay HS, Geospatial Data Analyst, Spatial Data Infrastructure Program, Information Network Security Agency, Spatial Data Infrastructure, Addis Ababa, Ethiopia, Tel: 251918020778; E-mail: habtamu103@yahoo.com

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Abstract

Soil erosion and the subsequent sedimentation are the major watershed problems in Ethiopia. Removal of top fertile soil, siltation of Koga irrigation reservoir, clogging of irrigation canal by sediment and reduction of irrigated land are the major threat of Koga watershed. Hence, this study was attempted to assess and map the spatial distribution of sediment yield of Koga watershed in a GIS and remote sensing environment. Sediment yield is dependent on factors of soil erosion such as rainfall erosivity, soil erodibilty, land use land cover (C and P) and topography (LS) and sediment delivery ratio of the drainage basin to the total amount of sediment yield by sheet and channel erosion. RUSLE framed with GIS and Remote sensing technique was therefore employed to assess the amount of soil loss existed in KW. Main stream channel slope based sediment delivery ratio analysis was also carried out. Soil map (1:250,000), Aster DEM (30 × 30 m), Thematic Mapper (TM) image (30 m × 30 m) of the year 2013, thirteen years (2000-2013) rainfall records from four rain gauge stations and topographic map (1:50,000) were the major data used. The estimated mean annual SY delivered to the out let of KW was found to be 25 t $ha^{-1}year^{-1}$. Most critical sediment source areas are situated in the steepest upper part of the watershed due to very high computed soil loss and sediment delivery ratio in this part. It could be therefore difficult to attain the intended goal of Koga irrigation reservoir positioned at lower part of the watershed. Sustainable land management practices have to be conducted in the upper part of the watershed by taking each stream order as a management unit to increase the storage capacity, and/or lessen the transportation capacity of the watershed. Proper drainage construction and stream bank stabilization via vegetative cover have to widely implement to safely dispose the eroded sediment.

Keywords: Sediment yield; RUSLE; SDR; Watershed management; Koga watershed; Ethiopia

Introduction

Soil erosion and the consequent sedimentation are the major watershed problems in many developing countries like Ethiopia [1]. Soil erosion and sediment yield from catchments are therefore key limitations to achieving sustainable land use and maintaining water quality in streams, lakes and other water bodies [2]. Eroded material derived from the watershed, riverbed and banks transported with the flow as sediment transport, either in suspension or as bed load. Ultimately, this sediment redeposit and often causing problems in downstream areas. On the other hand, the sediment load passing the outlet of a catchment forms its sediment yield. Sediment yield can be emanated from point source discharge (mining and construction process) and non-point sources (run off from agricultural land and bank erosion) [3]. Sediment load is reliant on factors of soil loss and sediment delivery ratio [4].

Many of Ethiopia's hydroelectric power and irrigation reservoirs such as Aba-Samuel, Koka, Angerib, Melka Wonka, Borkena, Adarko and Legedadi has been threatened by the heavy sedimentation. Thus, these dams have been suffered from reduction in their capacity and life span, quality of water and require costly operation for removal and operation and thus these dams loss their intended services [4,5].

Hydrosult Inc. et al. [6] found the Ethiopian Plateau as the main source of the sediment in the Blue Nile system. FAO [7] estimated 10% sediment delivery rate to the rivers in Abay basin. It implies that 90% of sediment remains in the land scape. This estimate is lower than 30% estimated by Hurni [8]. FAO [7] also gives a range of soil erosion from 2.3 $tha^{-1}year^{-1}$ to 212.9 $tha^{-1}year^{-1}$ and a sediment load of 19.46 t $ha^{-1}year^{-1}$ which translates into 195 t $ha^{-1}year^{-1}$ of erosion for the basin as a whole. This estimate of sediment yield is quite close to 23.5 t $ha^{-1}year^{-1}$ estimated by Kefenie [9] at Ajenie-Gojjam.

Awulachew et al. [1] reviewed that sediment transport and sedimentation are critical problems in the Blue Nile Basin. The socioeconomic development in the basin particularly in downstream areas is hampered by sediment deposition. For instances, Gilgel Gibie I hydroelectric power reservoir situated in Blue Nile basin has been threatened by sedimentation, hence it loss it's intended services [4]. Sediment yield to the stream network also poses numerous socio economic effects such as damage of recreational value of water; decreased value of water for domestic, industrial, or waste disposal function; interruptions in stream flow characteristics resulting in downstream flooding and decreased storage. In addition, excessive sedimentation clogs stream and irrigation channels and increases costs for maintaining water conveyances and have a variety of negative effects on downstream agriculture and fisheries as well as on peoples' nutritional well-being [10,11].

It is not only socio economic activities that are affected, but there is also significant damage to the environment of the Blue Nile Basin as a

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consequence of high sediment loads [1]. Siltation of water body caused by sedimentation reduces sunlight penetration and affecting water temperature, reduces photo synthesis and as a result the survival of submerged aquatic vegetation, degrades the fish habitat (muddy water fouls the gills of the fish) and upset the aquatic food chain. Sedimentation also causes eutrophication (excessive plant growth) due to excessive load of nutrients such as nitrogen and phosphorus and it's deposition at higher level creates an increased level of non-living periphyton or otherwise degrades water quality [3,12]. This problem has been recorded in Blue Nile basin particularly at Gilgel Gibie I [13,14].

Koga watershed (KW), with its outlet to small dam (Koga irrigation and fishery dam) is threatened by the above problems. Ministry of Natural Resources and Environmental Protection stipulated that the rate of soil loss in the furthest upstream portions of the watershed exceeds the soil formation rate [15]. Similarly, loss of top fertile soil, sedimentation or siltation of reservoir (Koga irrigation and Fish dam), clogging of irrigation channels, reduction of irrigated area and decreases in crop productivity due to reduction in the quality as well as quantity of irrigation water are the major problems in KW [16]. The extension of these problems will particularly threaten Koga irrigation reservoir in particular and jeopardize the farmers' agricultural production and productivity of the irrigable land in the watershed. This problem may make the people in the watershed to be food in secured. Furthermore, the life supporting system may be worsened and ultimately reach in an irremediable condition. The generated sediment yield from the catchment could also affect the ecosystem of Lake Tana.

The quantification of spatially distributed sediment yield and precise identification of sediment source and erosion vulnerable areas is noteworthy for watershed conservation prioritization and for reduction of the socio-economic and environmental cost posed by sedimentation on various irrigation and hydropower reservoirs, channels and conservation areas as stated by Tenaw and Awulachew [17]. Sediment yield information is therefore a critical factor in identifying non-point source pollution, comprehensive control of small and medium sized watershed as well as in the design and maintenance of the construction of hydro structures such as dams and reservoirs. The knowledge of the quantitative and spatial distribution of soil erosion and sedimentation is thus required to Control the sediment load and has important implication for the study of offsite environmental impact due to exported sedimentation and onsite erosion control.

Various previous studies have been conducted in Koga irrigation and watershed management project specifically to know the potential loss of capacity in the Koga reservoir due to sedimentation over the design life of the project by employing different bathy metric survey and empirical and mathematical sediment estimation method. But, those studies did not consider the spatial patterns of sediment yield and sediment delivery ratio of the Koga watershed and any one of the previous study were not simulate sediment yield using GIS and remote sensing techniques with geospatial processing capabilities. Besides, Chalachew [18] recommends further detail empirical sediment yield estimation because of the discrepancy between the measured and simulated volume of sediment in Koga reservoir. Likewise, Nigusie and Yared [19] recommend advanced studies to monitor siltation rate in the watershed. Therefore this study was attempted to assess and map the spatial distribution of sediment yield using Sediment deliver ratio (SDR) and Revised Universal Soil Loss Equation (RUSLE) of Koga watershed in a GIS and remote sensing environment. Specifically, an effort was made to map and assess the sediment delivery ratio and soil loss of Koga watershed and to identify sediment hotspot areas for conservation prioritization.

Research Methods

Study area description

The geographic location of the Koga watershed extends from 11.16N to 11.41N Latitude and 37.03° E to 37.28° E longitude. A total area of the watershed is about 28,000 hectare (Figure 1). Topography of the area exhibits distinct variation and contains flat low-laying plains (0% slope) surrounded by steep hills (70% slopes) and rugged land features. Thus, Koga catchment can be divided in to a narrow steep upper catchment draining the flanks of Mount Adama range and the remainder on relatively flat plateau sloping gently west wards. The altitude ranges from 1885 to 3131 m.a.s.l. The nature of the topographical features has made the area very liable to heavy gully formation and extensive soil erosion. The Koga River is a tributary of the Gilgel Abay River in the head water of the Blue Nile catchment. The Gilgel Abay flows in to Lake Tana. The river is 64 km long flowing into Gilgel Abay River. Koga irrigation and fish reservoir is located in the north western confluence point of the watershed. Its mean annual precipitation is 1628.2 mm with a maximum and minimum mean annual temperature between 17.10C and 28.4C. The area experiences the main rainy season 'me her' which commences in June and extends to September. There are about seventeen (18) kebeles (smaller administrative unite) in the watershed. The total population of the watershed excluding the local capital Merawi town was estimated to be around 57,155 (33475 male and 23627 female) [20]. Majority of the population is engaged in agriculture. Koga large scale irrigation and watershed development project is implemented within this watershed territory since 2009. The Koga Irrigation and Watershed Development Project cover about 7,000 ha of irrigable land and 22,000 ha of land watershed management in the upstream part of the watershed. Only 1,000 ha of the irrigation command area are located within the catchment territory. The remaining 6,000 ha are irrigation command area outside of the watershed boundary to the North direction.

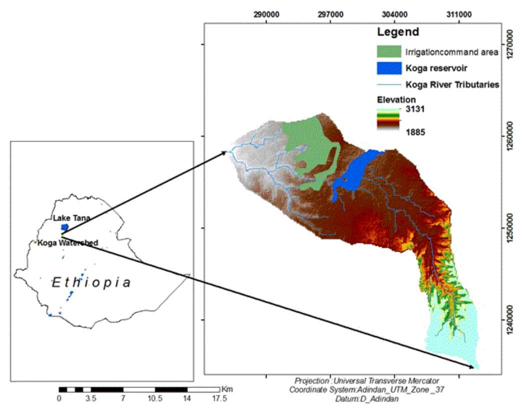

Figure 1: Study area map.

Sources and techniques of data collection

Both primary and secondary data sources were use. Once, the watershed was stratified into upper catchment, middle catchment and

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lower catchment based on their relative location; primary data such as ground control points (GCPs) were collected using global positioning system (GPS) in each strata of the watershed for each major land use or land cover types to train the image using supervised image classification and to produce thematic land use land cover map. Ground control points (GCPs) for each major land use/cover types were also collected for accuracy validation. Intensive field observation were concurrently conducted to assess the state of the watershed and to identify where and what kind of support practice had been constructed in the watershed (Figure 2).

Likewise, secondary data such as the soil map (1:250,000) obtained from Nile river basin master plan, Aster Digital Elevation Model (30 m × 30 m) downloaded from Global land cover facility (www.landcover.org) which was resampled to 20 × 20 meter spatial resolution, Thematic Mapper (TM) multi spectral image with spatial resolution of 30 meter of the year 2013 down loaded from global land cover facility topographic map (1:50,000) taken from Bureau of Agriculture and thirteen years (2000-2013) rainfall records from four rain gauge stations (Merawi, Meshenti and Bahir Dar and Durbetie) obtained from National Meteorological Agency were used to estimate the mean annual soil loss, sediment delivery ratio (SDR) and sediment yield of KW. The Google earth image was also used to digitize and produce water body (Koga reservoir) map of the study area. Other published and unpublished materials such as research reports, census reports and journal obtained from different sources were also employed.

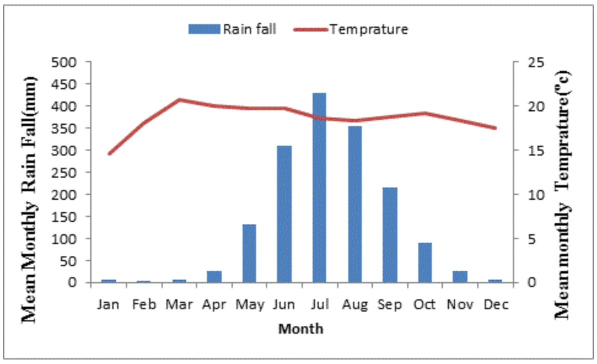

Figure 2: Mean monthly Rainfall and Temperature of KW.

Method of data analysis

RUSLE parameterization: Revised Universal Soil Loss Equation (RUSLE), which is an empirical model developed by Renard et al. [21], framed with GIS and remote sensing techniques were employed to compute the mean annual soil loss of KW. Laflen and Molden [22] inveterate the possible application of RUSLE on every continent on earth where soil loss by water is a problem. Therefore examined the application of the RUSLE in the Ethiopian highlands (Tigray Region) after Hurni effort to adopt USLE [23]. Flow convergence and divergence in a complex terrain were not considered by RUSLE in this study; however it can be applied in many circumstances even on steep and undulating terrain. A gain it was conducted at regional scale, hence didn't consider the spatial variability of soil loss process at catchment or watershed level. The study by Zhang et al. [24] and Van Remortel et al. [25] confirmed the limitation of the USLE and RUSLE method of soil loss estimation at regional scale in considering the spatial dynamics of soil loss process and in extracting slope length and gradient (LS) factor. Thus, here in this paper, RUSLE was employed at intermediate watershed or catchment level by incorporating the advanced LS factor computation approach. RUSLE is empirically expressed as:

SE (metric tons $ha^{-1}year^{-1}$)=R*K*LS*C*P (1),

Where SE is the mean annual soil loss (metric tons $ha^{-1}year^{-1}$); R is the rain fall erosivity factor [MJ mm h^{-1} ha^{-1} $year^{-1}$]; K is the soil erodibility factor [metric tons $ha^{-1}MJ^{-1}mm^{-1}$]; LS is the slope length-steepness factor (dimensionless); C is the cover and management factor (dimensionless, ranges from zero to one); and P is the erosion support practice or land management factor (dimensionless and ranges from zero to one). This model was simulated by GIS and remote sensing techniques as shown in the Figure 3 below.

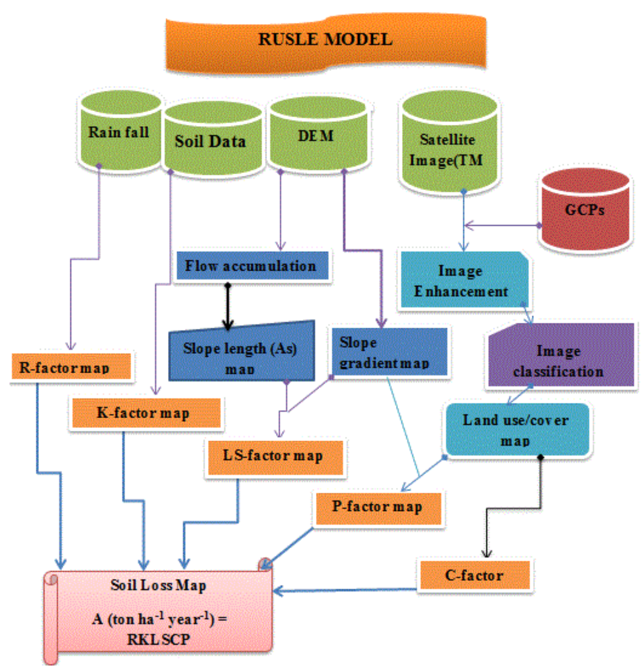

Figure 3: Conceptual Frame work of Soil Loss.

As in Figure 3, once all the RUSLE parameter had been surveyed and calculated, each raster layer of the RUSLE parameter was discretized to a resampled DEM grid size of 20 m × 20 m resolution. The layers were then multiplied pixel by pixel using Equation one and raster calculator geoprocessing tool in Arc GIS 10.1 environment to compute and map the spatial pattern of the mean annuals soil loss in KW.

Rainfall erosivity (R) factor: The rainfall erosivity (R) factor quantifies the effect of rainfall impact and reflects the amount and rate of runoff likely to be associated with precipitation events [26]. In a case of insufficient rainfall records appropriate regression equation can be employed to predict rain fall erosivity value [27]. The erosivity factor (R) in this study was therefore calculated based on the equation given by Hurni [23] derived from a spatial regression analysis [28] for Ethiopian conditions due to the absence of rain fall kinetic energy and intensity data in the study area. The model adapted by Hurni [23] for

Ethiopian condition is based on the available mean annual rainfall data and the equation is expressed as;

R=-8.12+(0.562 × P) (2),

where R is rain fall erosivity factor and P is the available mean annual rain fall data.

Inverse distance weighted (IDW) method was employed to produce uninterrupted rain fall data from point mean annual rain fall data obtained from four rainfall station for each grid cell in Arc GIS10.1 environment. From this continuous rainfall data, the R-value of each grid cell was calculated using Equation (2) and raster calculator geo-processing tool (Table 1).

No	Station Name	Location		Altitude	Mean Annual Rain fall (mm)
		Latitude (Y)	Longitude (X)		
1	Bahir Dar	11.59	37.388	1800	1371.743
2	Merawi	37.164	2000	2000	1570.87
3	Meshenti	11.5	37.3	1969	1287.74
4	Durbetie	11.359	36.956	1984	1696.74

Table 1: Rain Gauge Stations around the Study Area.

Soil erodibility (K) factor: Soil erodibility is the manifestation of the inherent resistance of soil particles for the detaching and transporting power of rain fall [29]. The K-factor is empirically determined for a particular soil type and reflects the physical and chemical properties of the soil, which contribute to its erodibility potential [30]. Hurni and Hellden [23,28] recommended the K values based on easily observable soil color as an indicator for the erodibility of the soil in the highlands of Ethiopia. Thus, the soil map of KW was clipped from soil map (1:250,000) of the Blue Nile river master plan and the soil type of the watershed were classified based on their color as recommended by Hurni and Hellden to assign the K-value [23,28]. The water body (Koga reservoir) map of the study area was clipped from google earth image and assigned the K-value based on Erdogan et al. [31] recommendation. Koga soil map was then dissolved with Koga reservoir map clipped from Google earth image. Finally, once the vector to raster conversion of soil map of the study area was done, the grid format was reclassified into K-factor value for each soil class in Arc GIS 10.1 using reclassification geo processing tools.

Slope length-steepness (LS) factor: The (LS) factor is the ratio of soil loss per unit area from afield slopes to that from a 22.13 m length of uniform 9 percent slope under otherwise identical conditions [29]. Slope length (L sub factor) in this case represents the distance between the source and culmination of inter rill process. The culmination is either the point where slope decreases and the resultant depositional process begins or the point where concentration of flow into rill or other constructed channel such as a terrace or diversion [21,29].

In RUSLE, the three dimensional complex nature of terrain was not considered in the computation of slope length topographic sub-factor rather soil loss was tied with only with slope length [32]. However, other researchers claimed that soil loss does not depend on slope length for three dimensional complex terrains where there is flow convergence and divergence. For instance, Zhang et al. [24] condemn the USLE and RUSLE method of slope length-steepness (LS) factor calculation and develop advanced LS-tools algorithms which fill the puzzles of the USLE and (R)USLE method, even though the algorithm is not presently supported in Arc GIS10.1 environment. Hickey [33] also postulated that the limitation of slope length computation in USLE can be resolved by using the cumulative uphill length from each cell which accounts for convergent flow paths and depositional area. Similarly, studies by Desmet and Govers [34]; Moore and Burch [35,36]; Mitas and Mitasova [37]; and Simms et al. [38] indicated that slope length should be substituted by upslope contributing area. Thus, it is helpful to consider the three dimensional complex terrain geometry as well the upslope contributing area to better comprehend the spatial distribution of soil erosion and deposition process. This study was therefore employed the following advanced LS factor computation method based on up slope contributing area suggested by Desmet and Govers [34]; Moore and Burch [35,36]; Mitasova and Mitas [39]; and Simms et al. [38].

LS=(As/22.13)0.6(sin B/0.0896)1.3……………(3)

Where LS is slope steepness-length factor, As is specific catchment area, i.e., the upslope contributing area per unit width of contour drains to a specific point (flow accumulation × cell size) and B is the slope angel. LS-factor was computed in Arc GIS raster calculator using the map algebra expression in equation (4) below suggested by Mitasova and Mitas [39]; and Simms et al. [38].

POW ([flow accumulation]×cell size/22.13, 0.6)×POW (sin ([slope] ×0.01745)/0.0896, 1.3)….(4)

This study was therefore used the above modified and advanced approach of determining slope length and gradient (LS) factor. The values of S were directly derived from 20 meter resolution DEM. Similarly, flow accumulation was derived from the DEM after conducting Fill and Flow Direction processes in Arc GIS 10.1 in line with Arc Hydro tool. Flaw accumulation grid represents number of grid cells that are contributing for down ward flow and cell size represents 20 m × 20 m contributing area.

Cover and management (C) factor: It represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow [10,29]. Cover and management (C) factor is the solely factor that easily changed overtime in most cases and it regarded mostly in developing conservation strategy. Unsupervised classification was directed to identify the major land use land cover types in the watershed. Based on the information obtained from unsupervised classification, supervised classification by the help of ground control (training) points was conducted to produce thematic land cover maps of the study area. Ground control points (GCPs) collected using hand held GPs were also employed to validate the accuracy of thematic land use land cover classification process. Land use land cover raster map of KW was then converted to vector format to assign the corresponding cover and management (C) factor value obtained from different studies.

Support practice (P) factor: Support practice (P) factor is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation [29]. This factor considers the erosion control practices such as contouring, strip cropping and terracing which reduces the eroding power of rainfall and runoff by their impact on drainage patterns, runoff concentration and runoff velocity [40]. The P-factor value could be thus used for understanding the conservation practices being taken up in the study area. However, Wischmeier and Smith [29] compute the P-factor value not only by regarding the conservation practice rather by slope and general land use land cover type combination. Wischmeier and Smith [29] thus computed the P-value by categorizing the land in to agricultural land and other land major kind of land use types (Table 2). Finally, they sub-divided the agricultural land (cultivated land) in to six slope classes and assigned p-value for each respective slope class as many management activities are highly dependent on slope of the area. In this study, this method of combining general land use type and slope was therefore adopted. Values for this factor were therefore assigned considering local management practices along with values suggested in Wischmeier and Smith [29].

Land use type	Slope (%)	P-factor
Agricultural land (cultivated land)	0-5	0.1
	5-10	0.12
	1-10	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other land	All	1

Table 2: P-Value [29].

Water body, grazing, shrub and forest lands were therefore referred as other land and given the P-value regardless of the slope class they have but cultivated land of the watershed was categorized into six slope class and given P-values as discoursed by Wischmeier and Smith [29]. Lastly, the classified land use land cover and slope thematic map has been converted in to vector format and the corresponding P values were assigned to the combination of each land use land cover and slope classes.

Sediment Delivery Ratio (SDR) estimation: Sediment Delivery Ratio (SDR) is a fraction of gross erosion that is transported from a given area in a given time interval. It is a measure of sediment transport efficiency which accounts for the amount of sediment that is actually transported from the eroding sources to a catchment outlet compared to the total amount of soil that is detached over the same area above that point.

The sediment delivery ratio value in a given watershed indicates the integrated capability of a catchment for storing and transporting the eroded soil. It compensates for areas of sediment deposition that become increasingly important with increasing catchment area and therefore, determines the relative significance of sediment sources and their delivery [41]. It is affected by many highly variable physical characteristics of a watershed such as drainage area, slope, relief-length ratio, runoff-rainfall factors, land use land cover and sediment particle size [2]. The amount of floodplain sedimentation occurring and the presence of hydrologically controlled areas such as ponds, reservoirs, lakes and wetlands also affect the rate of sediment delivery to the watershed mouth.

Numerous Sediment Delivery Ratio (SDR) relationships have been developed based on combinations of the variable physical characteristics of a watershed [42]; but, their application is limited to only small catchments with adequate data [2]. Williams and Berndt [43] found that the average stream channel slope is more significant than other parameters in estimating sediment delivery ratio, which is expressed as a function of percent slope of main stream channel. Empirically, Sediment Delivery Ratio in this case is expressed as;

$SDR = 0.627 \times (SLP)\ 0.403$…………………………………………… (5),

Where, SLP is percent slope of main stream channel. Onyando et al. [44] confirmed that Williams and Berndt [43] method of main stream channel slope gradient based sediment delivery ratio estimation provides reasonable result in a case of in adequate data. This empirical equation was therefore used in this intermediate watershed (Koga watershed) where there is no adequate data as illustrated in the following diagram (Figure 4).

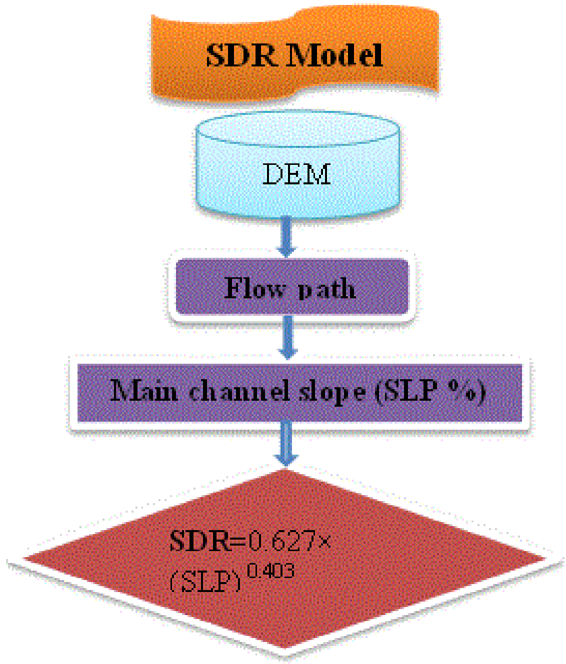

Figure 4: Diagram of Sediment Delivery Ratio Analysis.

Digital Elevation Model (DEM) was corrected for sink as well grids of flow direction, flow accumulation and stream network were determined. After conducting terrain preprocessing, the flow path was generated using Arc GIS extension of HEc GeoHMS 10.1. By taking the flow path and raw DEM, the average mainstream channel slope (SLP) values in percentage for each cell in the flow path was computed for the estimation of the SDR value for that cell amount upstream from that cell as indicated in the above diagram. Each cell in the flow path can be considered as the outlet of its upstream catchment. Therefore, the SDR value of that cell measures the sediment delivery capacity of its upstream catchment as stated by Li et al. [45].

Sediment Yield (SY) estimation: Sediment yield is the sediment load at the end of the slope length, at the outlet of the terrace diversion channels, or sediment basins that are considered by RUSLE. It is the sediment load normalized for the drainage area and is the net result of erosion and deposition processes within a basin. Thus, it is controlled by those factors that control erosion and sediment delivery, including local topography, soil properties, climate, vegetation cover, catchment morphology, drainage network characteristics and land use [46,47]. Given that, sediment yield is usually not available as a direct

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measurement in watershed lacking adequate sediment regime like Koga watershed as stated by Benedict and Andreas [2]; accurate estimation of sediment delivery ratio is an important and effective approach. Therefore, for this study sediment yield was computed by superimposing the raster layer of mean annual soil loss obtained by RUSLE model analysis and the channel slope based sediment delivery ratio using equation (6).

$$Sy = \sum_{i=1}^{n} SDR \ x \ SE \ (6)$$

Where n is the total number of cells over the catchment, SE is the amount of soil erosion produced within the ith cell of the catchment estimated using Equation (1) and SDR is the fraction of SE that ultimately reaches the nearest channel computed by. In a GIS framework, the raster layer of sediment yield for the watershed (SY) was estimated by overlaying the raster layer of mean annual soil loss and sediment delivery ratio using raster calculator geo-processing tools (Figure 5).

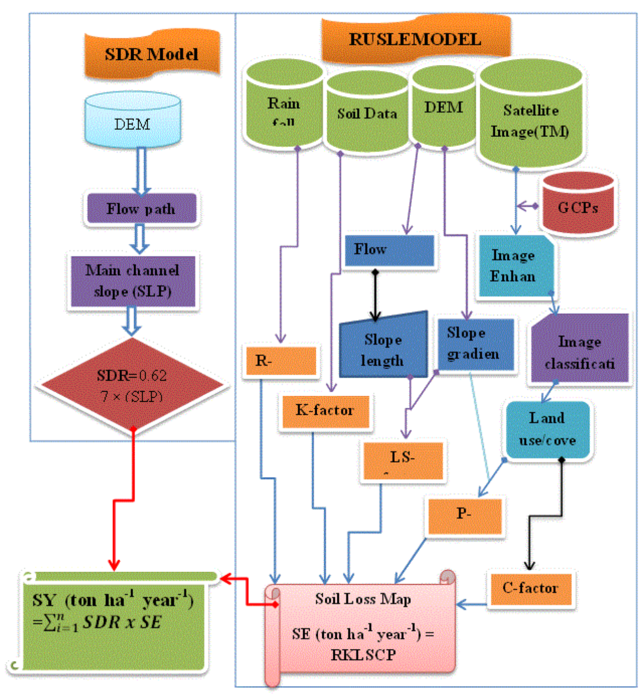

Figure 5: Diagram of Sediment Yield Estimation.

Result and Discussion

RUSLE based soil loss valuation

Rainfall Erosivity (R) factor: Rain fall erosivity (R) value ranges from 715 (in the outlet part) to 945 (inlet part) were estimated using equation (2) and raster calculator geo-processing tool. The R-value of 874 at Merawie station (nearest station to watershed) has great weight to the R-value of the watershed. Thus, the R-value in most part of the watershed was found to be 874 except a little variation at the lower and north western part of the watershed. This implies that the influence of rain fall erosivity is nearly similar in the study area with a little exception at the lower and north western part of the watershed.

Soil Erodibility (K) factor: Eutric Vertisols (Black), Eutric Regosols and Haplic Luvisols (Brown), Haplic Nitosols and Ali sols (Red) soil classes were identified and given the K-value of 0.15, 0.2 and 0.25 for Black, Brown and Red soil color respectively based on Hurni and Hellden soil color based K-value recommendation [23,28]. The K-value of zero [31] was assigned for water body (Koga reservoir). Haplic Nitosols and Ali sols (0.25), which are highly susceptible for the eroding power of rain fall, are dominant in the upper part of the watershed; as a result this part could be seriously affected by soil loss by water. On the other hand, the lower and middle part of the watershed are dominated by less erodible (Vertisols) and moderately erodible (Regosols and Luvisols) soil class, hence this part could have minimal soil loss contribution.

Slope length-steepness (LS) factor: The slope length-steepness (LS) value ranges from 0 (flatter lower and middle part) to 109 (steepest upper part) was estimated using the map algebra expression (equation 4) in raster calculator Arc GIS geo-processing tools. The topographic (LS) factor of RUSLE has therefore significant influence in the upper part of the watershed and vice versa in the lower and middle part.

Cover and management (C) factor: The C-factor value taken from different studies were given for the major land use land cover types of the study area identified by supervised image classification in ERDAS imagine 10 environments (Table 3).

Land use land cover type	C-factor value	References
Water body	0	Erdogan et al. [31]
Cultivated land	0.1	Hurni [8,25]
Forest land	0.01	Hurni [8,25]
Shrub land	0.014	Wieshmier and Smith [29]
Grazing land	0.05	Hurni [8,25]

Table 3: C-Factor value of the watershed adopted from different studies.

Maize and millet are the major crops cultivated in most of the middle and lower part of the watershed with the cover and management factor value of 0. The soil loss in the middle and lower part of the watershed could be therefore high due to the predominance of cultivated land (maize and Millet).

Support practice (P) factor: As discussed in the method section, the Wieshmier and Smith [29] method of P-value computation was employed. The P-value of 1 was therefore assigned for water body (Koga reservoir), shrub, grazing and forest lands irrespective of the slope class they have by grouping them into other land major kind of land use type. On the other hand, the P-value of 0.1, 0.12, 0.14, 0.19, 0.25 and 0.33 were given for cultivated land use type with slope gradient class of 0-5, 5-10, 10-20, 20-30, 30-50 and 50-100 percent respectively. The P-value of 1 was found in most of the upper part of the watershed. On the contrary, the P-value of 0.1 was found in the lower part of the watershed. Hence, the support practice factor in the upper part of the watershed where steep slope class are dominated and support practices were not yet constructed has substantial soil erosion contribution.

Finally, each layers of RUSLE parameter was organized in a grid format with a cell size of 20 m × 20 m and the soil loss map of the watershed was produced (Figure 6). The computed mean annual soil loss of the study area was therefore found to be 47.4 ton ha^{-1}year^{-1} with a range of 0 (lower par, specifically at Koga reservoir) to 265 ton ha^{-1}year^{-1}. On annual bases, the total soil loss of the watershed was found to be 255283 tones. Topographic (LS) and soil erodibility (K) factors were found to be the major soil loss parameter.

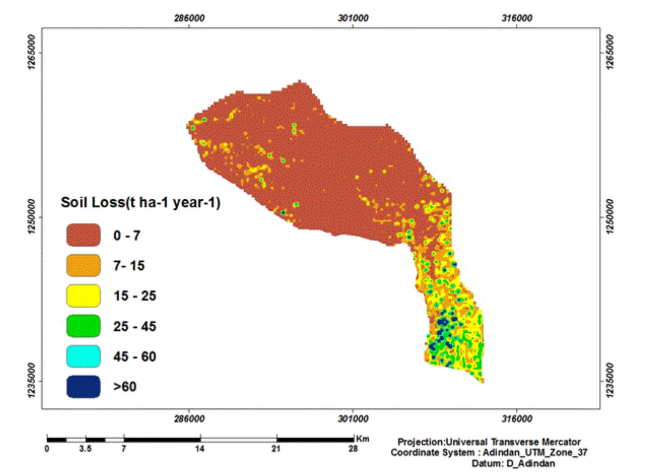

Figure 6: Soil Loss Rate Map.

Sediment delivery ratio (SDR) assessment

Spatially distributed Sediment Delivery Ratio (SDR) map was produced by computing the average channel slope value in percent for each cell in the flow path using HEc GeoHMS 10.1 in a GIS environment (Figure 7). Hence, as shown in Figure 7 (left) below, main stream channel slope of Koga watershed ranges from 0.0007 (the lower catchment) to 0.08 percent (steepest upper catchment).

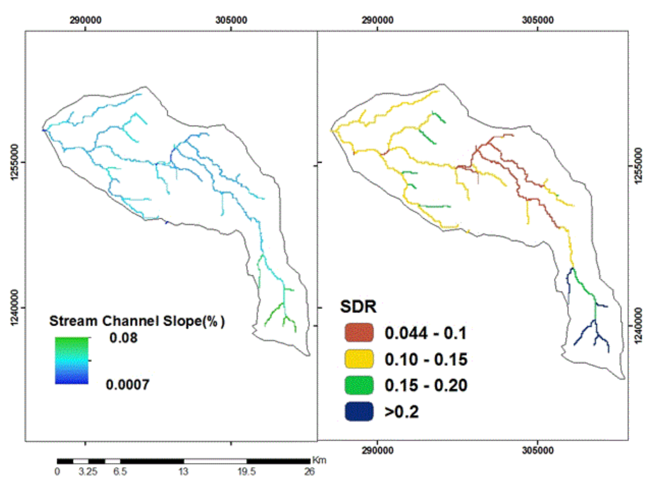

Figure 7: Stream Channel Slope (left) and Sediment Delivery Ratio (right) Map.

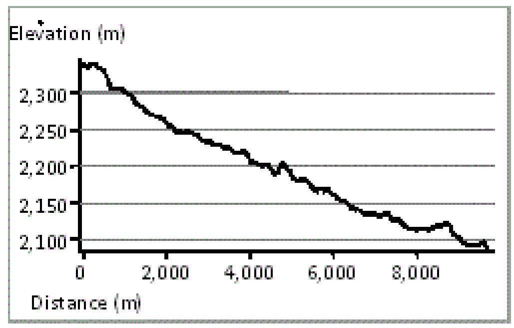

Figure 8: Main stream Channel Slope Profile.

Lastly, the Sediment Delivery Ratio (SDR) values range from 0.04 to 0.3 was computed using raster calculator geo processing tools and Equation (3) in ArcGIS10.1 environment. This implies that in Koga watershed (KW), the eroded materials which passes to the channel system and contributes to sediment yield ranges from 4.4 to 30 percent. In the steeper, narrower and upper part of the watershed, 30 percent of the eroded soil particles passes to the channel system and delivered to Koga watershed (KW) out let. It is therefore, this part of the watershed has high capability to transport the eroded material, but less storage capacity. Whereas, in the wider, flatter and lower part of the watershed only 4 percent of the gross soil loss is delivered to the outlet of Koga watershed (KW). It does mean that 96 percent of the eroded materials are redeposited in the catchment of the watershed. Hence, this part of the watershed has excellent storage capacity of the eroded soil, but streams in this part have less sediment delivery capacity.

As point up in the Figure 7 (right) and Table 4, first order streams with very high sediment delivery capacity (> 0.2) are situated in stepper and narrower parts of the upper catchment. In this part, 24.9 per cent of the eroded soil particles could be transported to the out let of Koga watershed (KW) annually. While, the second most critical sediment delivery class (0.15-0.2) are located in the gentle slope lower parts of the watershed. Fortunately, some of these second vital areas are found in the lower parts of Koga irrigation reservoir but not all. These sediment delivery classes are also located in the immediate upper part of Koga irrigation reservoir. In this part of the watershed 17 percent of the total soil losses could be delivered to the channel system and arrive at Koga river outlet. Almost all of the moderate sediment delivery capacity classes (12.5%) are positioned in the flatter lower parts of the watershed surrounding the confluence of main stream channel with higher stream order. The lower range of sediment delivery (0.044-0.1) class is situated in the nearest upper part of the reservoir.

Numeric SDR (Sediment Delivery Ratio class)	Sediment delivery capacity class	Mean SDR capacity (%)
0.044-0.1	low	7.2
0.1-0.15	moderate	12.5
0.15-0.2	high	17.5
>0.2	Very high	24.85

Table 4: Numeric SDR Class and Contribution to Sediment Yield.

On average, the sediment delivery capacity of KW is about 0.17. This indicates that a mean of 17% of the eroded soil materials (soil, nutrient and other pollutant) could be delivered to Koga watershed (KW) outlet and 82.5% of the eroded soil materials are redeposit in the catchment of the watershed. But, FAO [7] estimated 10% sediment delivery rate to the rivers in Abay basin where this study area belongs to.

Ouyang and Bartholic [42] point out that watersheds with steep slopes, smaller drainage area and the fields with short distance to the streams have a higher sediment delivery ratio than a watersheds with flat and wide valleys, large drainage area and fields with long distance to streams. In the same way, the result of this study from the above map showed that the SDR values in the steeper, fields with short distance to stream and narrower upper catchment of the watershed (upstream) are greater than those in flatter and wider middle and lower catchment(near Koga reservoir) of the watershed. This is because large areas have more chances to trap soil particles. Thus, the chance of soil particles reaching the water channel system is low. Therefore, more eroded soil in the upstream areas transported into the channels and delivered out of the watershed. Ouyang and Bartholic [42] also stipulated that the amount of floodplain sedimentation occurring and the presence of hydro logically controlled areas such as ponds, reservoirs, lakes and wetlands also affect the rate of sediment delivery to the watershed mouth. Correspondingly, the sediment delivery ratio values near Koga reservoir is quite smaller (7.2%). Besides the above, the report of Merawi woreda office of agriculture confirmed that grass strip development and alteration of the crop land into perennial fruit tree and forage land has been done around Koga reservoir by Koga watershed development project and the people jointly. Thus, reduction in sediment delivery ratio near Koga reservoir could be due to these vegetation cover increment in Koga reservoir buffer zones.

The SDR map was considered reasonable because it reflects that the ultimate nature of sediment delivery that erosion occurs in the steeper location will have more chances to be transported into the channels than to be deposited down slope.

Sediment yield estimation

Sediment yield was quantified using the channel slope based SDR model [43], expressed as the percent of annual soil erosion by water estimated by RUSLE that is delivered to a particular point in the drainage system. As a result, the mean annual soil loss in Koga watershed was estimated in the above section (3.1) and found to be 47.4 t ha-1 year-1. Likewise, the sediment delivery ratio was estimated and discussed in chapter (3.2) by taking main stream channel slope as a main parameter and on average the sediment delivery rate of 17.05 percent was estimated in Koga watershed. Thus, spatially distributed map of sediment yield was produced through cell by cell multiplication of the raster layer of sediment delivery ratio (SDR) and mean annual soil loss in Arc GIS10.1 environment (Figure 8).

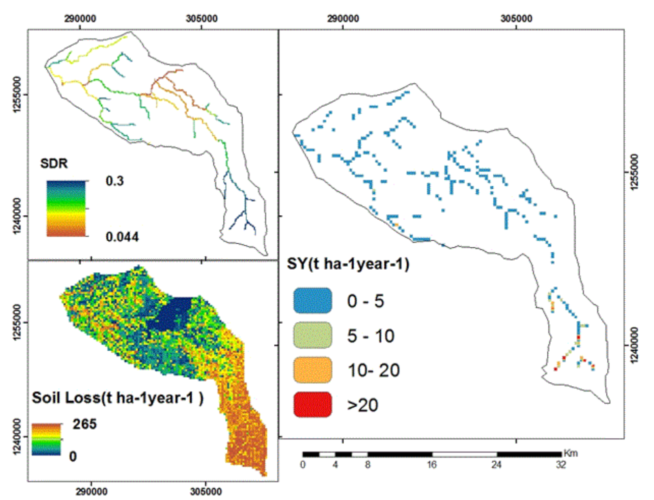

Figure 9: Sediment Loss (SE), Sediment Delivery Ratio (SDR) and Sediment Yield (SY) Map.

Recall the above figure, the Sediment Yield (SY) of the watershed ranges from 0 to 51 tone ha^{-1}year^{-1} which has a similar spatial pattern with that of soil loss and sediment delivery ratio map. For the purpose of identifying nonpoint source pollutants and the sediment load at the end of the slope length, at the outlet of terrace diversion channels, or sediment basins that are considered by RUSLE, the raster map of sediment yield was classified into four sediment load class as illustrated in Figure 9 and Table 5 below. Very high (>20 t ha^{-1}year^{-1}) and high (10-20 t ha^{-1}year^{-1}) sediment load classes which accounts 23 and 8 percent of total annual sediment yield and 2.5 and 2 percent of sediment source areas respectively are situated in the steeper, narrower and degraded upper catchment of the watershed. Accordingly, most of the critical sediment source areas are located in this part. This could be due to (I) the dominance of erosion susceptible soil type (Nitosols and Alisols) and the steepness of the slope (high LS factor value), so that very high computed soil loss as discussed in section 3.1; (II) this part is characterized by high channel slope, short distance of the field to the stream (narrowness of the watershed) and abundant first order streams with very high sediment delivery capacity, as a result very high sediment delivery ratio as discussed in section 3.2. Most of the moderate sediment load classes are found in the north western lower catchment and steeper upper catchment of the watershed. Whereas, the lower sediment load classes are spatially distributed in the middle and lower part of the watershed. This could be due to the presence of hydrological controlled area (Koga irrigation reservoir) in the lower part of the watershed. The presence of such hydrologically controlled area could there for reduce the sediment delivery rate and thus the sediment load as sediment load from the upper part of the watershed could be enter in to the reservoir. Besides this, the reduction of sediment yield in this part could also be due to the alteration of the land use land cover from cultivation to protected forage land and perennial crop land along with the development of grass strip around the buffer zone of the reservoir for the past six years.

Numeric range of SY (t $ha^{-1}year^{-1}$)	Mean SY (t $ha^{-1}year^{-1}$)	Sediment load class	Area (ha)	Percent of total area	Total annual SY	% of total annual SY
0-5	2.5	Low	1172	90.4	2930	58.7
5-10	7.5	moderate	64	4.9	480	9.6
10-20	15	High	27	2.08	405	8.12
>20	35.5	Very high	33	2.54	1171.5	23.5

Table 5: Numeric Sediment Yield Range and Sediment Load Class.

Figure 9 and statistical Table 5 informed that, the total annual sediment yield of Koga watershed was 4986 tone. The estimated mean annual SY delivered to the out let of KW was found to be 25 t $ha^{-1}year^{-1}$ which is reasonable and realistic weigh against the findings of the previous studies. For case in point that the mean annual sediment yield of 25 t $ha^{-1}year^{-1}$ was measured in Anjeni-Gojjam station by Kefeni [9]. FAO [7] also estimated a sediment load of 19 t $ha^{-1}year^{-1}$ for the Abbay river basin as a whole. But, is quite far from 140 kg $ha^{-1}year^{-1}$ which is equivalent to 1.8 t $ha^{-1}year^{-1}$ estimated by Nigusie and Yared [19] using SWAT model.

Conclusion

The findings of this study demonstrate the simulation of sediment yield in a GIS and remote sensing environment in areas where there is no sufficient sediment regime like Koga watershed. It also shows how the use of spatially capable technologies like remote sensing and GIS helps in handling spatially dynamic data easily and efficiently. The estimation of SY by integrating SDR and annual soil loss computed from RUSLE could be replicated in other part of the upper Blue Nile basin where sheet and rill erosion are dominant. Sediment yield estimation in this study therefore plays a vital role for Koga large scale irrigation reservoir in particular and for the watershed as a whole in identifying non-point source pollution, critical sediment source areas and to take site specific measures such as different drainage and water harvesting structures. An accurate prediction of SDR is also important in controlling sediments for sustainable natural resources development and environmental protection.

Nature of the watershed (steepness, drainage area and distance to stream), hydrologically controlled area (reservoir), land use land cover, channel slope and soil factors were found to be determinant for sediment yield assessment in Koga watershed.

Very high sediment load class was computed in the steeper upper part of the watershed. It could be therefore disastrous due to the fact that Koga irrigation and fishery reservoir which irrigate 7000 hectare is positioned at the outlet of the watershed, thus the aforementioned sediment load could cause siltation of the reservoir, clogging of irrigation canal, even in reduction of the quality of irrigation water. It is difficult therefore to attain the implied goal of Koga irrigation reservoir. Siltation of the reservoir also could cause reduction in crop productivity and finally affects the livelihood of the community who depend on irrigation activities.

Hence, intensive sustainable soil and water conservation practices should be carried out by taking each stream order as management unit especially in the upper part where most critical sediment source areas are situated. Each stream order should be treated uniquely and conservation prioritization should be directed from first order streams to highest order streams. In view of the fact that sedimentation could affects Koga irrigation reservoirs and channel, proper drainage construction and stream bank stabilization via vegetative cover have to widely implemented. The report of Merawi office of agriculture and field observation confirmed that soil and water conservation activities were better implemented in the buffer zone of the reservoir irrespective of watershed logic. But, conservation activities must be conducted starting from the most upper catchment of the watershed by respecting watershed logic and potential.

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