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Modeling Soil Erosion Dynamics in the Blue Nile (Abbay) Basin: A Landscape Approach

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ABSTRACT

Soil erosion is one of the prime problems that hampers agricultural productivity, threatens food security and exacerbates rural to urban migration in Ethiopia. One of the major objectives of this study is to model soil erosion potential in the Abbay Basin using modified models of soil erosion. It is also intended to characterize all areas of the Basin across soil erosion grades. Two approaches are devised to modify the Universal Soil Loss Equation (USLE) methods to the Ethiopian landscape; these are discussed as empirical and the out-scaling approaches. The empirical approach is based on earlier studies made to modify USLE to Ethiopian highlands. In contrast, the out-scaling approach uses the measured soil erosion data from Soil Conservation Research Project stations to the Abbay Basin. The results indicate that the North Eastern and South Eastern parts of the Basin are areas of extreme soil erosion where as the lowland plains of the Western and North-Western areas have very low levels of soil erosion. The results of the empirical model put the potential soil erosion in the Blue Nile Basin at 1.3 billion tons a year and an average of 67.7 t ha^{-1} yr^{-1}. The out-scaling method estimated the annual potential soil erosion at 3.2 billion tons with average of 153 t ha^{-1} yr^{-1} . In conclusion the national estimate of soil erosion at 1.5 billion tons is an underestimate (even compared with measured station records). Research in developing modified equations and tools needs to be done for the Ethiopian landscape in order to produce results which are comparable to field measurements.

Key words: Spatial modeling, soil erosion potential, Blue Nile (Abbay) Basin Ethiopia

INTRODUCTION

The Blue Nile Basin is one of the most important river Basins of Ethiopia. The Abbay[1] Basin supports over 25% of the Ethiopia population, 40% of agricultural produce and 45% of the surface water of the country (Awulachew *et al*., 2012). The Ethiopian part of the Blue Nile Basin contributes some 62% of the Nile water and is the source of huge sediment load (122 million tons $year^{-1}$) in the downstream reservoir of Rosaries dam in the Ethio-Sudan border according to Ahmed and Ismail (2008). Beyond the Nile water politics there are many crucial issues that are threatening sustainability of the natural environment and livelihoods inside the Basin. Agriculture has been practiced for centuries in many parts of the Basin but from 1950s onwards

[1]Abbay is the local name given to the major tributary of the Nile River in Ethiopia

population explosion has exerted tremendous pressure on the natural resources leading to extreme degradation. Various research findings have highlighted the unprecedented land use change from natural vegetation to cultivation over the last half a century (Zeleke, 2000; Gumindoga, 2010). The population boom also expanded the boundaries of cultivated lands to steep marginal areas thereby accelerating soil erosion. Soil erosion is one of the critical problems in Ethiopia in general and the Abbay Basin in particular. Some researchers have gone as far as describing Ethiopia as one of the highest areas of soil erosion in the world. For instance, Young (1998) stated that the world's most severe soil erosion is found in Ethiopia, Lesotho and Haiti. The national soil loss is estimated to range from 1.9 billion tons a year by FAO (1986) to 7.8 billion tons a year by Hawando (1995) with an associated cost close to one billion Ethiopian birr each year (Alemu, 2005). The Abbay River Basin Integrated Development Master Plan Project (BCEOM, 1998) report also pointed out that soil erosion is a critical environmental problem in Abbay Basin calling for immediate attention. Various studies have been carried out on soil erosion/sediment load in the Abbay Basin (Claessens *et al.*, 2008; El Haj Tahir *et al.*, 2010; Easton *et al.*, 2010) but few of them have questioned the methods used to estimate the amount of soil loss. Hurni (1985) was the early study to customize generic soil loss equations to the local conditions and in particular to the highlands of Ethiopia. Many of the study are limited to reformulating equations at specific test plots and did not use spatial data analysis beyond small catchments.

The main objective of this study is, thus, to depict the alternatives in soil erosion modeling from the global context to local applications. It is intended to identify the appropriate techniques that best suit the biophysical and socioeconomic settings of the Abbay Basin. The reference approach used is the Universal Soil Loss Equation (USLE) as it provides option for erosion and sediment control (planning) as Gaffney and Lake Jr. (2003) puts it. This method is also widely used to estimate rates of soil erosion USDA in 2010[2]. Taking the existing level of knowledge and experiences into consideration the approaches used in this study are typically made to localize erosion model to the Abbay Basin through both empirical and out-scaling models.

LOCATION

The Abbay River Basin dominates the Northern highlands of Ethiopia and the river dissects the mountainous central Ethiopian highland areas and is the cause for the creation of various rugged topographic features in the long time span. The Basin extends approximately from 07°43'50" to 12°45'36" latitudes and 34°27'29" to 39°49'45" longitudes with total area of about 200,000 km^2. The Abbay River travels some 922 km starting from the mountainous areas of the Ethiopian highlands and rejuvenated by various tributaries before it crosses the Sudanese border (Fig. 1).

METHODOLOGY

Many of the data layers used in this research have been obtained from the Abbay River Basin Integrated Development Master Plan Project (BCEOM, 1998). These data are the largest scale (1:250,000) available for the Blue Nile Basin. Extensive field data collection has also been undertaken to collect some of the primary data used in the models. This includes GPS based field verification and data collection, visit to three of the Soil Conservation Research Project (SCRP, 2000a) stations namely Anjeni, Maybar and Andit Tid, landscape and extensive interviews with different stakeholders (officials, experts and farmers). The rainfall data for ten years

[2]http://www.ars.usda.gov/Research/docs.htm?docid=5971

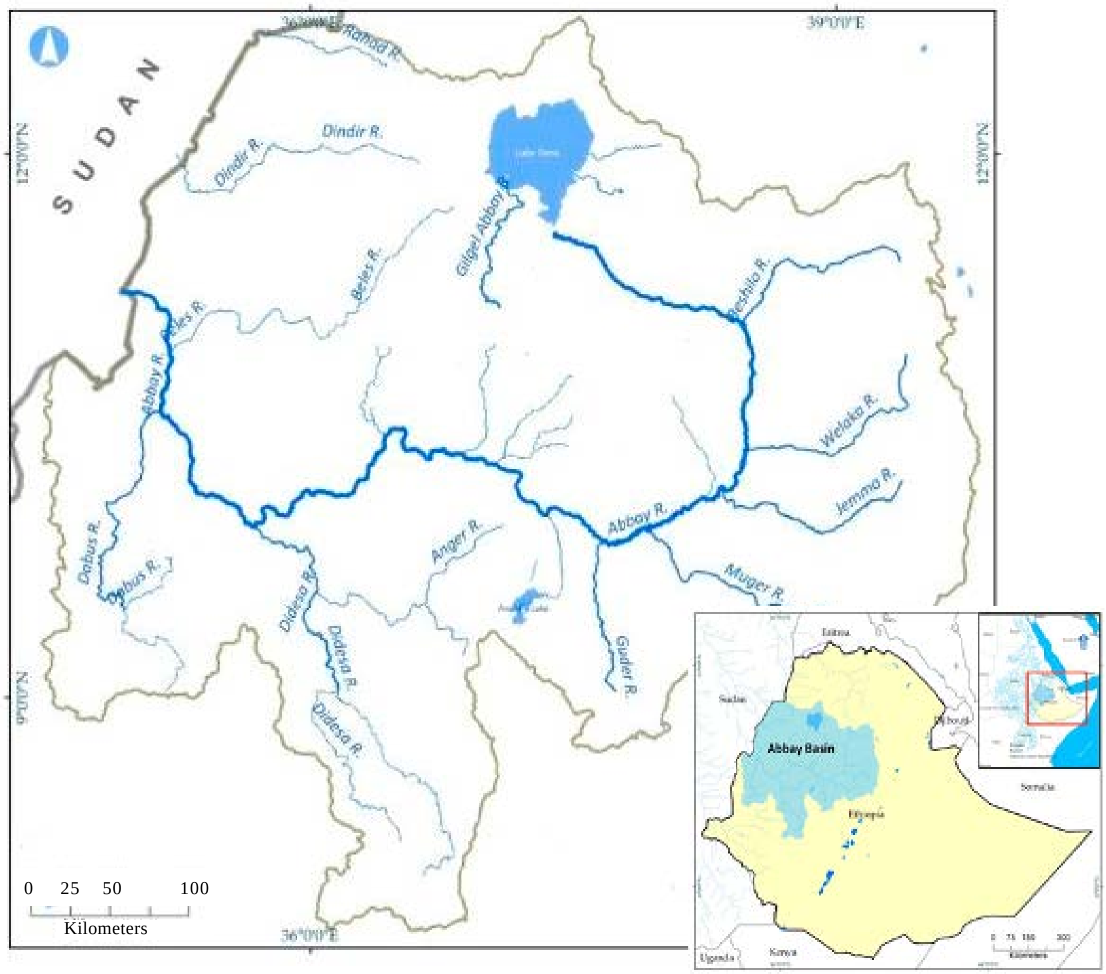

Fig. 1: Location map of the Abbay River Basin

(2001-2010) are obtained from the National Meteorological Agency (NMA, 2009) for 171 stations inside or in close proximity to the Abbay Basin. However these stations are not evenly distributed to produce realistic continuous raster data on rainfall distribution over the nearly 200,000 km^2 wide Basin. Thus, data from Worldclim[3] (Hijmans *et al.*, 2005) are used as they are found to be more realistic and consistent with the station readings in Ethiopia (Beyene and Meissner, 2009). This data layer is used in the model to predict the rainfall erosivity (R) factor. The soil data from (BCEOM, 1998) is used to produce the soil erodebility factor. The landsat TM image based land use/land cover data at 1:250,000 scales are used for representing the land cover factor of the soil erosion model. The slope length and steepness factors are derived from the modified SRTM digital elevation model version 4[4]. The GPS based field data collection and verifications are also parts of consolidating the data for the soil erosion modeling.

Theories and calculations: The Universal Soil Loss Equation (USLE) is hailed as one of the most significant developments in soil and water conservation. It is a technology that is applied on

[3]http://www.worldclim.org/
[4]http://srtm.csi.cgiar.org/

every continent on earth where soil erosion caused by water is a problem Laflen and Moldenhauser (2003). It is this evolutionary process that has continued for years and even today to produce the revised universal soil loss equation that is widely used to estimate soil erosion worldwide. However this transcontinental application is questionable as the biophysical conditions and human activities in different parts of the world can never be identical to the realities where USLE is developed, namely the United States. Research and application has continued on soil erosion modeling leading to the revisions and calibrations of the models to better estimate the amount of soil loss close to the field measurements. Some custom made procedures are being developed by various institutions and researchers (Like EUROSAM, CREAMS, AGNPS and others)[5]. The RUSLE is given in Eq. 1:

$$A = R*K*L*S*C*P \tag{1}$$

where, A is the annual soil loss per hector per year, R is the erosivity factor, K is erodebility factor, L is slope Length, S is slope steepness factor, C is the cover factor and P is the intervention and management factor.

In modeling soil erosion in the Abbay Basin there needs to be an understanding of the ground realities both in the natural and human aspects. Based on this premises it is difficult to take the results of universal models for grant that suits all places and local settings of the Abbay basin. Thus, in order to customize USLE (at factor level) to the Abbay Basin and Ethiopian conditions at large two approaches are devised in this study. These are discussed afterwards as empirical and the out-scaling modeling approaches.

Empirical modeling approach: This approach focuses on the earlier works made to customize the USLE to the Ethiopian highlands. In this regard Hurni (1985) have made a remarkable contribution based on measurements from five small catchments under the Soil Conservation Research Project (SCRP, 2000b). This study suggested specific equations to determine the erosion factors in the highlands of Ethiopia and these are given as follows:

Erosivity factor (R): Erosivity is the detaching power of the rainfall which is obtained from the rainfall intensity. The National Meteorological Agency never produced data on erosivity (R) in all the meteorological stations in Ethiopia. Due to this fact Hurni (1985) suggested to use, as an alternative, the mean annual rainfall in the following regression Eq. 2 which is found to have strong correlation to erosivity (Juliette, 2007):

$$0.55x\text{-}4.7 \tag{2}$$

where, x is the monthly precipitation in mm.

Erodebility factor (K): Erodebility refers to the susceptibility of the soil to erosion agents. In this regard Hurni (1985) suggested using soil color as an indicator for the erodebility of the soil in the highlands of Ethiopia. Accordingly suggestions are given in Table 1.

Slope length and steepness factors (LS): In this regard Hurni (1985) adopted the Wischmeier and Smith (1978) method of calculating the topographic components of soil erosion model. However,

[5]http://www.soilerosion.net/doc/models_menu.html

Table 1: Estimated K values for some soils in the Ethiopian highlands

Soil color	Name/class	Estimated K value
Black	Andosol, Vertisol... etc	0.15
Brown	Cambisol, Phaeozem... etc	0.20
Red	Lixisol, Nitosol... etc	0.25
Yellow	Fluvisol, Xerosol... etc	0.30

Table 2: Estimated C values for some land cover classes in the Ethiopian highlands (Hurni, 1985)

Land cover	C factor
Dense forest	0.001
Other forest	0.05
Badlands hard	0.05
Badlands soft	0.40
Sorghum, maize	0.10
Cereals, pulses	0.15
Dense grass	0.01
Degraded grass	0.05
Fallow hard	0.05
Fallow ploughed	0.60
Ethiopian 'teff'	0.25
Continuous fallow	1.00

the continued improvement in computing give rise to some advanced approaches to determine the LS factors. One of such software oriented equations is that of Simms *et al*. (2003) that suggested the Eq. 3:

$$T = (A/22.13)^{0.6}\ (\text{Sin B}/0.0896)^{1.3} \tag{3}$$

where, A is the upslope contributing factor and B is the slope angle.

For use in ArcGIS raster calculation, (Simms *et al*., 2003) proposed the following map algebra expression (Eq. 4):

$$\text{Pow}\left(\frac{\text{(Flow accumulation)*cell size}}{22.13}\right)^{0.6} \times \text{Pow}\left(\frac{\text{Sin(Slope)*0.01745}}{0.0896}\right)^{1.3} \tag{4}$$

This method is used as it produced more logical outputs in the Abbay Basin conditions.

Cover management factor (C): Techniques for estimating the cover management factor was also given by Hurni (1985) which was found to be practical in the Ethiopian highlands. Hurni presented the estimates for each of the major land cover types (Table 2).

Support practice factor (P): Support practice factor (P) is also estimated by Hurni (1985) based on the SCRP stations data and field observations. However, such detailed data is not available for the whole Abbay Basin and thus Wischmeier and Smith (1978) method of combining general land use and slope is adopted for this section (Table 3).

Out scaling method: In modeling soil erosion to estimate soil loss in the Blue Nile Basin the second approach used for this research is the out-scaling method. This approach is more of a process model as it seeks to up-scale the measured station database from the SCRP stations to the Abbay Basin though homogeneity analysis. In order to upscale and use data from SCRP test plots some ground rules are set that can objectively relate station records to the study area. First, out of the available seven SCRP stations only those considered relevant and appropriate (from the biophysical point of view) are selected. Secondly, in depth analysis is made on SCRP database to explain the sites and the soil loss records for more than a decade. Thirdly careful up scaling work is done on the bases of each of the erosion controlling factors rather than the total soil loss. Finally, the results are examined using the calibration curve method. The selected stations are Anjeni (Gojam), Maybar (Wollo), Andit Tid (Shawa) and Dizi (Illubabor) (Fig. 2, 3).

Under each of these stations there are four Test Plots (TP) depicted as Test Plot 1 (TP 1), Test Plot 2 (TP 2), Test Plot 3 (TP 3) and Test Plot 4 (TP 4). The test plots are installed in different parts of Ethiopia representing various land use, slope and management factors. The homogeneity analysis for up scaling is done based on the database from a total of 16 TPs (Table 4).

Homogeneity analysis: The test plots of the four SCRP stations are characterized in terms of the six soil erosion model equation parameters of RUSLE and homogeneous areas of the Abbay Basin are identified using advanced spatial analysis in GIS. This method of homogeneity matching seems to be more reasonable compared to the direct application of the USLE and also some conventional techniques discussed at plot level. The main goal of this homogeneity assessment is to out scale the measured values from the 16 test plots to the wider Abbay Basin. Accordingly, the slope length and steepness, soil type, agro climatic condition and general land cover and use categories are characterized for the test plots. The homogeneity is made on factor bases (RKLSCP) rather than the total soil loss (A). This is preferred for two reasons. First, it is more rationale to match sites based on their pieces than the whole biophysical components. Secondly, it is impractical to find similar areas in the Abbay Basin that practically matches the 2 by 15 m test plots of the SCRP stations. The measured values of the factors from the SCRP database used for homogeneity analysis are presented under Table 5.

Table 3: The practice factor (P) (Wischmeier and Smith, 1978)

Land use	Slope (%)	p-factor value
Cultivated lands (Agricultural)	0-5	0.11
	5-10	0.12
	10-20	0.14
	20-30	0.22
	30-50	0.31
	50-100	0.43
All other types (Non-agricultural)	All slope categories	1.00

Table 4: Amount of soil loss across stations and test plots (SCRP, 1988)

	SCRP stations															
	Maybar				Anjeni				Andit Tid				Dizi			
Test plot	TP1	TP2	TP3	TP4	TP1	TP2	TP3	TP4	TP1	TP2	TP3	TP4	TP1	TP2	TP3	TP4
Annual soil loss	75	3	15	25	150	189	13	282	145	222	176	30	145	17	25	41

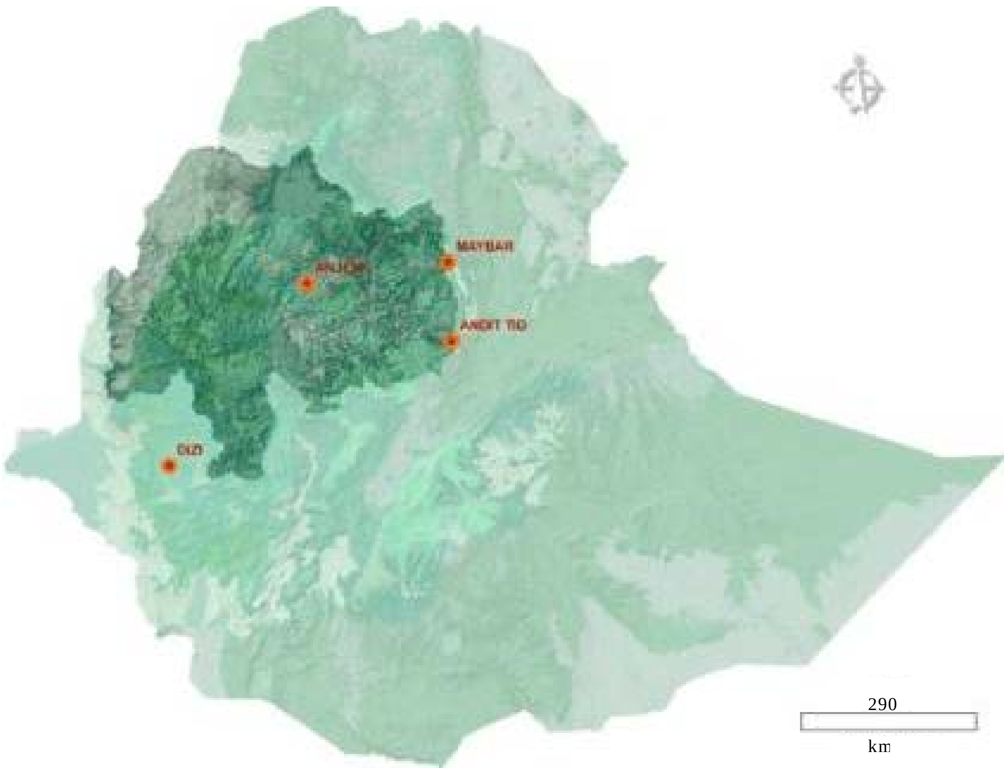

Fig. 2: Location of the four SCRP stations in relation to the Abbay River Basin

Fig. 3: Anjeni Station Test Plot (TP) 1

Table 5: SCRP stations and the RUSLE variables (Source: SCRP, 2000c)

Test plot	Measured average erosivity (R)	Measured average erodebility (K)	Slope length and steepness (LS)	Land cover and practice (CP)	Average soil loss (t ha^{-1} yr^{-1} (A)
Anjeni station					
TP 1	633.4	0.14	2.62476	0.45	170.0
TP 2	633.4	0.17/0.16	0.94392	0.45	131.4
TP 3	633.4	0.23/0.25	6.18480	0.03	4.7
TP 4	633.4	0.12	8.33580	0.45	134.3
Andit-Tid station					
TP 1	502.0	0.27/0.25	2.11680	0.30	168.7
TP 2	487.4	0.33	3.67885	0.30	212.4
TP 3	487.4	0.27/0.25	4.47016	0.15	120.7
TP 4	487.4	0.25	4.47016	0.45	86.5
Maybar station					
TP 1	408.9	0.31	1.38299	0.05	35.8
TP 2	408.9	0.31	5.70768	0.01	15.7
TP 3	408.9	0.31	4.04079	0.01	21.3
TP 4	408.9	0.19	3.48679	0.05	31.8
Dizi station					
TP 1	646.0	0.23	1.59511	0.01	145.0
TP 2	646.0	0.23	3.01760	0.05	17.0
TP 3	646.0	0.23	3.94706	0.01	25.0
TP 4	646.0	0.23	3.94706	0.001	41.0

Model efficiency evaluation for annual estimate: There are many methods of evaluating predictive models and one of the famous ways is the one given by Nash and Sutcliffe (1970) called Model Efficiency (ME) evaluation. The ME is used to assess the predictive accuracy of any model against the observed/measured values. One application of ME is demonstrated by Zeleke (2001) to determine the efficiency of runoff and soil loss estimation model, WEEP in the Ethiopian highlands. It is stated that in addition to basic regression analysis, ME was also used to determine goodness of fit between model prediction and measured values. The equation is given as:

$$\text{ME} = \frac{\sum_{t=1}^{n}\left(Y_o - Y_p\right)^2}{\sum_{t=1}^{n}\left(Y_o - Y_m\right)^2}$$

where, ME is model efficiency, Y_o and Y_p are measured and predicted values for event t and Y_m is the mean value of measured values for all selected events, i.e., n.

The consistency of the results of the soil erosion models are compared with the measured values from four SCRP Test Plots (TP) data. For this purpose out of the four stations only Anjeni station is used as it lays inside the Basin and also recent data is available for the comparison (2008/2009/2010). The ME is run for the four test plots in Anjeni station against both 'empirical' and 'out-scaling' soil erosion prediction approaches and the result is given in (Fig. 4 and 5) (Table 6).

The results of the model efficiency between measured soil losses in four test plats are compared with the predicted results both for empirical and out-scaling approaches. However, there are some instances like the case in test plot 3 where the measured values are zero for the whole year

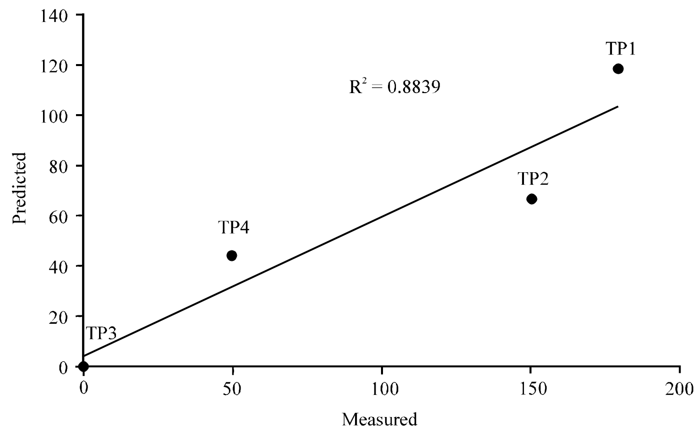

Fig. 4: Comparing measured (2008) and predicted values for four Anjeni test plot using empirical approach

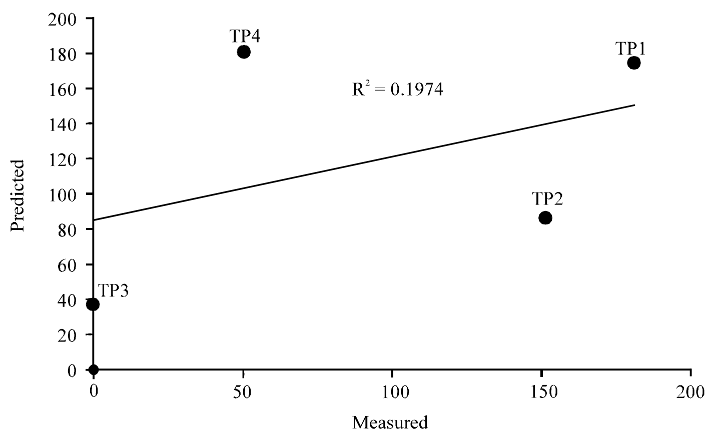

Fig. 5: Comparing measured (2008) and predicted values for four Anjeni test plot using out-scaling approach

Table 6: Model Efficiency (ME) for Anjeni station test plots

Test plot (TP)	Measured*	Predicted (empirical)	ME	Predicted (out-scaling)	ME
TP1	90	118	0.535	175	0.446
TP2	78	66	2.325	87	1.334
TP3	0	0	0.000	37	0.000
TP4	27	44	0.018	182	0.421
Average	48.8 57		0.719	120	0.558

*Measured values are obtained from SCRP station reading 2008

(this figure is rechecked from the station office) where the model predicted higher values and as a result the model efficiency at this particular plot is quite low. This also makes the model evaluation a complex exercise for this particular year (2008).

The comparison between the measured and predicted (empirical approach) values under the entire four test plot in Anjeni station shows that the predicted amount is lesser than what is measured in TP1 and TP2 while the values for the measured exceed the model on TP2. The ME results revealed that slightly over 70% of the empirical model values can be explained by the test plot readings from Anjeni station. This might not necessarily imply the overall efficiency of the model but gives some ideas about the predictive accuracy of the model in Anjeni area. The soil erosion patterns across the test plots significantly vary as they are installed deliberately at different slope and land cover/land use settings. One of the weak points of this validation is that there are few test plots (only four) to compare with the model outputs produced for the whole Basin. The results at this scale between the model and the measured values however, are comparable indicating the efficiency of the extrapolation to certain extent.

The out-scaling approach seems to show low predictive accuracy of the model in Anjeni test plots as compared to empirical method. But this still never explain model accuracy in areas of the Basin other than Anjeni.

Rigorous field activities were carried out inside the Basin at different spots and it is observed that the model prediction is good at the level of high, moderate and low soil erosion grades but it was not possible to verify the values produced by the model. However, it was a challenge to verify the exact figures from observations as it needs to have sufficient number of measuring stations all across the Basin. The field work for sampling and verifying the results covered most of the accessible and some inaccessible areas (when found critical) in the Abbay Basin. The verification work is done all across the results of the soil erosion grades. Areas under the extreme and very low erosion grades are prioritized in order to see whether the model predicts the reality on the ground appropriately or not. The major challenges of this method are the insufficient number of stations (only two inside the basin) and the small scale outputs (1:250,000) which was challenging to compare with the 2 x 15 test plot readings. The other non-conventional strategy used as part of the verification is 'expert opinion'. Experts at the Woreda and zonal level are asked to identify hot spot location of soil erosion in their respective districts. The results indicated that 60% of the model results are in conformity with 'expert opinion'.

RESULTS

The results of the modified erosion model both from empirical and out-scaling approaches are presented in this section. Both models predicted the patterns of erosion in the Abbay basin and the respective findings are presented as follows:

Results of the empirical method: This is a model based on modified USLE made earlier for Ethiopia by Hurni (1985). The findings of this approach reveal that large area of the Basin (47%) is characterized by low erosion grade (0-2 t ha^{-1} yr^{-1}). Nearly 35% of the Basin is under moderate to high soil erosion potential. The remaining (18%) areas fell under very high to extreme areas of soil erosion potential. The North East parts of the Abbay Basin (North Wollo, South Wollo, East and West Gojam, South Gonder and North Shewa) are identified to be areas of high soil erosion belts. On the other hand the lowland areas of the Western and North Western areas are depicted as low erosion areas (Fig. 6, Table 7).

Results of the out-scaling approach: This is the out scaling results from SCRP test plots. The results of the model shows most areas of severe soil erosion are in the Eastern and North Eastern parts of the Basin which accounts over 20%. This includes North Wollo, South Wollo, East and West Gojam, South Gonder and North Shewa. Nearly half of the Abbay

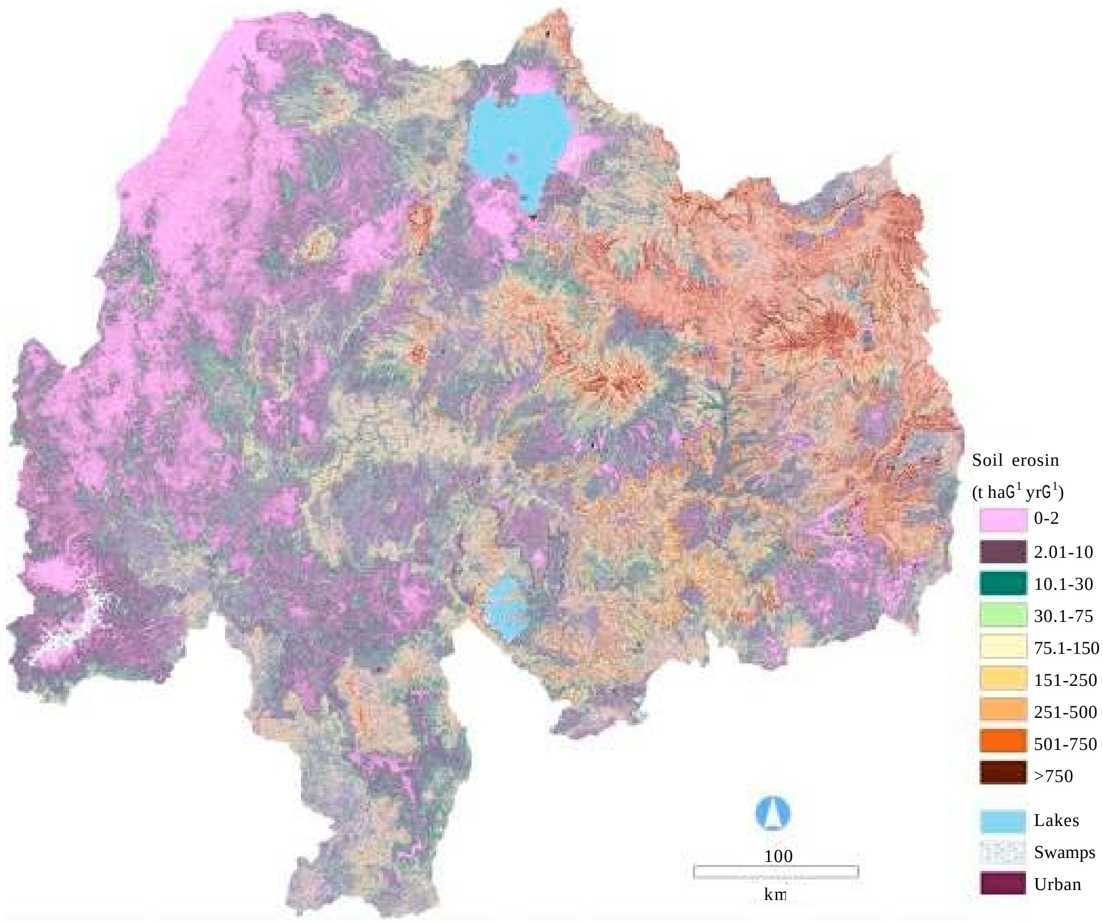

Fig. 6: Soil erosion potential map using empirical approach

Table 7: Results of soil erosion potential

Erosion potential grade (t ha^{-1} yr^{-1})	Total area (km^2)	Percent
0-2	91,225.5	47
2-10	25,440.4	13
10-30	24,834.4	13
30-75	17,659.6	9
75-150	10,828.7	6
150-250	7,051.9	4
250-500	8,058	4
500-750	3,356.1	2
>750	5,976.3	3

Basin (44%) is under low soil erosion potential grade and 33% of the land is under moderate to high soil erosion potential grades much in conformity with the empirical result (Fig. 7, Table 8).

Comparing the two model approaches: The empirical and out-scaling models produced an immense knowledge on the spatial distribution of erosion potentials inside the Abbay River Basin.

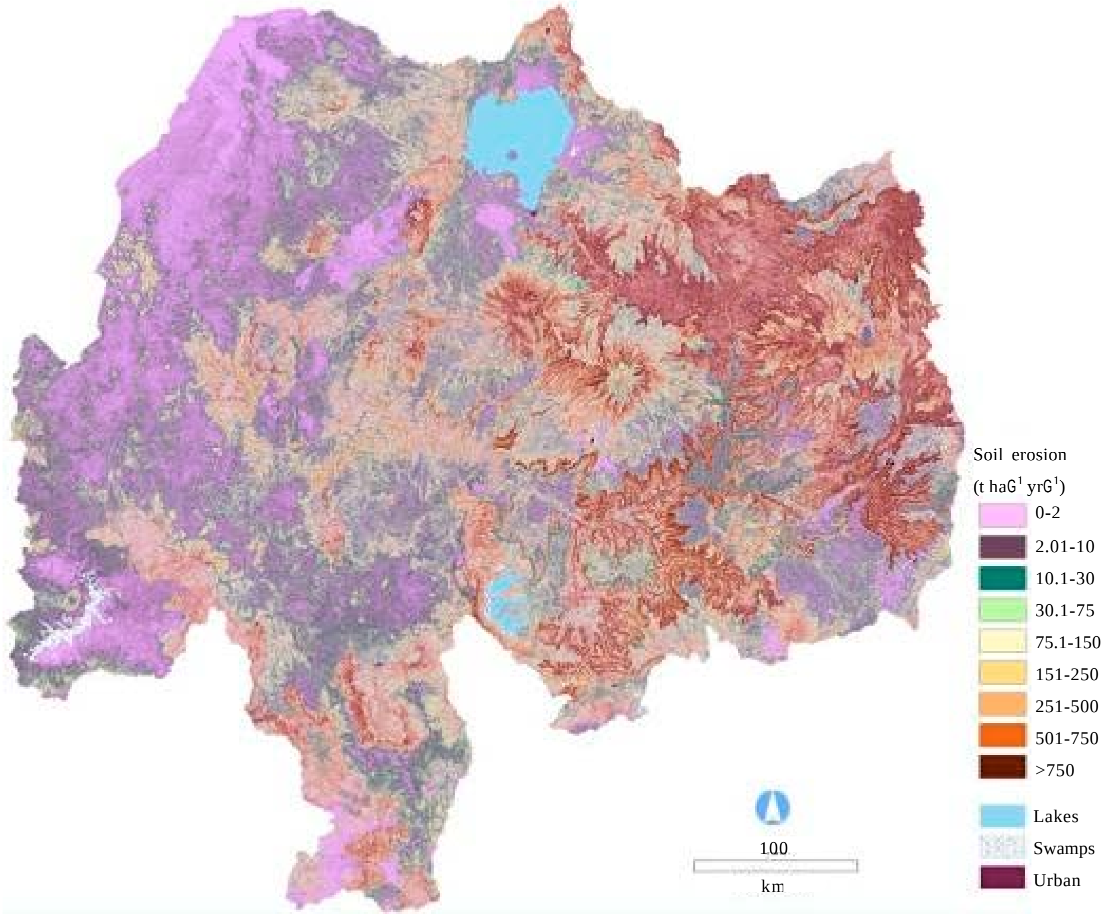

Fig. 7: Soil erosion potential map using the out-scaling approach

Table 8: Soil erosion potential result for the out-scaling method

Erosion potential grade (t ha^{-1} $year^{-1}$)	Total area (km^2)	Percent
0-2	85435.7	44
2-10	16060.8	8
10-30	17907.2	9
30-75	18463.8	9
75-150	14512.9	7
150-250	9932.7	5
250-500	12019.2	6
500-750	6034.1	3
>750	14471.5	7

It gives a chance to discuss erosion modeling at the Ethiopian landscape level. The total soil loss from Abbay Basin is estimated in the range of 1.3 billion tons (empirical method) to 3.2 billion metric tons (out-scaling model). The out-scaling put the figure higher than the adopted equations used in the empirical model. The detailed statistical examination also revealed that the mean annual soil loss in the Abbay Basin is 67.7 and 153.7 tons ha^{-1} $year^{-1}$ in the empirical and

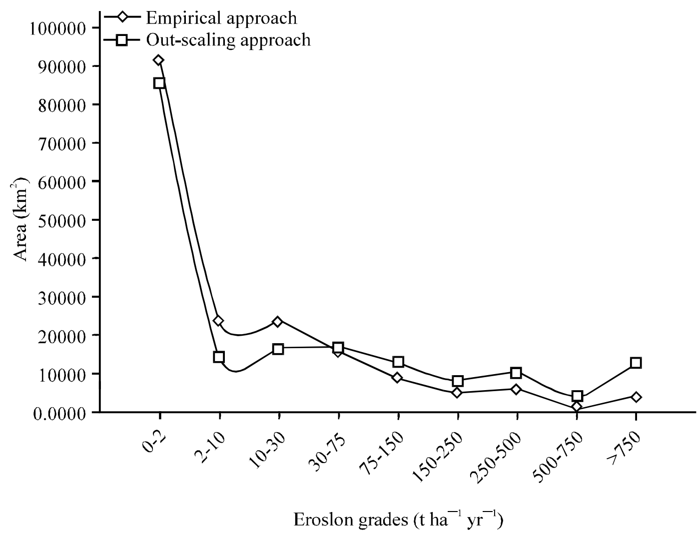

Fig. 8: Comparing the empirical and out-scaling results

out-scaling methods, respectively. One logical explanation for the large deviation from the mean is the nature of the methods. The method used in both these approaches is different but there are no contradictions on the general pattern of erosion potential at all. This shows the merit of both methods used in one hand and on the other it allows cross-referencing the results of one method to the other (Fig. 8).

From the graph it is clear that in the erosion grade 30-75 t ha^{-1} yr^{-1} both model come in closer conformity than any other grade. The results of the soil erosion model shows that over 45% of the areas in the Abbay Basin are under low soil erosion grades (0-2 t ha^{-1} yr^{-1}). Majority of the areas under this category are the flatlands, lowland woodlands, forest areas and swamps. The results of both the empirical and process based methods are in complete agreement in this regard. The land use grades from 2-10 and 10-30 t ha^{-1} yr^{-1} constitutes nearly a quarter of the land mass of the Abbay Basin and areas under this category are cultivated lands on moderate slopes and partly degraded bare lands. These are areas that are moderately affected by soil erosion due to the combination of their natural and human settings. Some of the galleys observed during the field survey are located under this category. High to very high soil erosion grade areas are mostly found on cultivated lands on high slopes and degraded bare lands. Some of these areas have been intensively cultivated over long years and sloppy areas that are abandoned and remain bare degraded lands. These portions take close to 9% of the land under the Abbay Basin. Areas that are identified under Severe to extreme soil erosion conditions are the types of landscape that are on the extreme slopes with active human interference. Areas that are prone to sliding and mass movement are also categorized in this group. Bare and extremely degraded sloppy areas of the Basin are painted as areas of extreme soil erosion. It may be good news to find out that close to 45% of the areas of the Basin are under low soil erosion grade (0-2 t ha^{-1} yr^{-1}) but the problem is not static and the continued mismanagement can accelerate soil erosion any time anywhere. Thus, the core concept is not to look at status rather on the potentials as it gives a better insight for conservation planning.

DISCUSSION

In Ethiopia where over 85% of the population depends on subsistence agriculture, the threat posed by soil erosion is extremely high. The active soil erosion is turning many of the once fertile and surplus production areas in to badlands. The findings of this research study shows that the amount of soil loss at national level has been underestimated as all of the models done so far adopt the universal methods both at equation and process levels. This created two important problems so far; first it hampers the attention due to the problem from policy and decision makers. Second, misinforms most of the interventions made so far to improve agricultural productivity and natural resource conservation. The densely populated fertile highland areas are identified as high soil erosion belts in the Basin and this makes the problem much significant. In addition to the huge annual soil loss in the Basin some of these areas are extremely affected which can be seen from continuous land conversion and livelihood deterioration. This not only intensifies poverty but also accelerate out migration and mass resettlement of the predominantly agricultural population. The findings of the soil erosion modeling revealed that there is an urgent need of intervention in soil conservation and land management. This is also pivotal in reducing siltation on the ongoing 'grand renaissance' dam the country is venturing for mega-hydropower project in the far downstream areas of the Abbay Basin. The erosion grade map and zonal statistics are some of the vital works that can support intervention decisions and a wide range of conservation planning activities. Most important of all it helps to prioritize areas and identify optimal conservation techniques based on the nature and severity of the identified soil erosion grades. The other point worth mentioning is the importance of customizing 'universal' models to fit in to the local conditions. In this regard both the empirical and out-scaling methods adopted in this study better predicted the realities in the extent and spatial distribution of soil erosion.

CONCLUSION

The Abbay River Basin is highly affected by severe soil erosion and this has an impact both in the livelihoods and natural environment inside the Basin and even beyond. A single universal method of soil erosion modeling is a challenge to understand the extent of soil erosion in all regions of the world. Thus, custom-made approaches might better work to show the soil erosion conditions like the case in the Abbay Basin. The results of the empirical models show that the potential soil erosion in the Abbay Basin is 1.3 billion tons a year. The out-scaling method estimated the annual potential soil erosion at 3.2 billion tons. The findings not only reveal the spatial distribution and variations but also the intensity of soil loss which is quite important to prioritize conservation interventions. It has a significant input in environmental reclamation, management, livelihood assessment and conservation planning works in the Abbay Basin. After the findings of this study it can be said that the amount of soil loss in the Abbay Basin and in Ethiopia at large is underestimated. In many of the discussions of soil erosion rough extrapolations or direct application of 'universal' models are used and this might cause the problem. Further researches needs to be done to fine-tune the customizing efforts towards automated national soil erosion prediction tools.

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