Efficiency test of adapted EGEM model in predicting ephemeral gully erosion around Mubi, Northeast Nigeria

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Abstract

A field adaptation test of the Ephemeral Gully Erosion Model (EGEM) to predict ephemeral gully (EG) erosion was carried out in the 2008 and 2009 farming seasons in the Mubi area, NE Nigeria. Land use, conservation practices, and EG channel features were measured and/or noted at each site. Soil loss varied among the sites and seasons. The measured area, volume, and mass of soil loss were used to test the standard EGEM\textsubscript{std}, and the adapted models' (EGEM\textsubscript{Ad} and EGEM\textsubscript{AI}) prediction efficiencies. The result showed that EGEM\textsubscript{std} could not predict the area of soil loss adequately. Both EGEM\textsubscript{Ad} and EGEM\textsubscript{AI} were efficient and better adapted to predicting area, volume, and mass loss from EG erosion. The adapted models are therefore strongly recommended for implementation in the study area.

Keywords: Ephemeral gully; EGEM; Soil loss; Prediction; Semi-arid Nigeria

1. Introduction

The recent recognition of ephemeral gullies (EG) in the context of global erosion has limited the availability of both sufficient models and data sets to test EG prediction since its recognition as an erosion class (Capra, Mazzara, & Scicolone, 2004; Foster, 1986). Thus, local adaptation of scarce process-based models and erosion results from one region may not apply to another, due to differences in study methods, making data accuracy, reliability, and credibility debatable (Lal, 2001). Not many predictive studies have been carried out in Africa to assess the extent of EG erosion problems. Development of suitable erosion models that can adequately predict the extent of soil loss has been a challenge to most scientists since the 1930s (Lal, 2001), and particularly to conservationists, erosion specialists, field workers, and policy makers in the study area. Thus, the present work is designed to produce effective erosion models that could predict EG erosion and also be used to evaluate plausible erosion control measures in the study area.

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In the past, several water erosion prediction models such as the universal soil loss equation (USLE) (Wischmeier & Smith, 1978) were widely used to estimate soil erosion and to select conservation and management practices for erosion control, but USLE technology does not estimate EG erosion. Other models patterned after the USLE such as the soil loss estimation model for South Africa (SLEMSA) (Elwell, 1977; Elwell & Stocking, 1982) were not capable of estimating soil erosion occurring in concentrated flow channels where EG occurs. The Ephemeral Gully Erosion Model (EGEM) developed in the US for use by the USDA-NRCS (Woodward, 1999) remains the most reliable tool specifically developed for EG erosion prediction (Capra et al., 2004; Gordon, Bennett, Bingner, Theurer, & Alonso, 2007). The EGEM model was reported to have been tried in Italy (Capra & Scicolone, 2002), Europe (Poesen, Nachtergaele, Verstraten, & Valentine, 2003), Spain (Casali, Lopez, & Giraldez, 1996), Iran (Nasri, Feiznia, Jafari, & Ahmadi, 2008), Portugal and Belgium (Nachtergaele, Poeson, Vandekerckove, Oostwoud, & Roxo, 2001; Nachtergaele et al., 2001), and in some parts of America (Franti, Laflen, & Watson, 1985; Woodward, 1999).

The Mubi region in NE Nigeria is particularly prone to water erosion due to its terrain and its climate, with long dry periods that are followed by heavy rainfalls acting on steep slopes with low vegetation cover, with fragile and erodible soils (Ekwue & Tashiwa, 1992). There are no reports of EGEM trials in the sub-Saharan Africa, particularly Nigeria, and therefore the need to perform evaluation trials on EGEM under local conditions in order to provide scientific document on EG erosion development in this area.

2. Materials and methods

2.1. Description of the study area

The study was carried out at 6 sites in the Mubi area (Digil, Vimtim, and Muvur, Gella, Lamorde, and Madanya). The study area is located between Latitudes 10°00′ and 10°25′ N and between Longitudes 13°00′ and 13°35′ E (Fig. 1), in the northern part of Adamawa state (Nwagboso & Uyangga, 1999). The 6 sites were selected based on watershed topography (elevation) and/or terrain, agricultural activities, field drainage, erosion activity (severity), soil type and cover conditions. Major drainage sources include the rivers Muvur, Koma, Chaba, Njairi, Gerewol, and Yedzaram, in addition to other streams that drain away surface water in the study area (Fig. 1).

The climate of the study area is characterized by a dry season spanning about 5–6 months (November–April), and a wet season from April to October. The average annual rainfall ranges from 700 to 1050 mm, and was 874 mm for the 2008 and 2009 seasons (Adamawa State University (ADSU), meteorological station, Mubi). The driest months are March and April, when the relative humidity is about 13%. The average minimum temperature is 15.2°C in the months of December and January, with a maximum temperature of up to 42°C in April (Adebayo & Tukur, 1999).

The dominant vegetation is comprised of a few grasses and shrubs, which is typical of a savannah region with scattered trees, mainly shea-butter, acacia, eucalyptus and locust bean trees, while the dominant grass species include panicum maximum, arista longiflora and andropogon gayanus (Adebayo & Tukur, 1999; Adebayo, 2004; Tekwa & Usman, 2006). The EG sites occurred on cultivated lands, and there were fewer grasses and trees observed at Vimtim and Digil, while the other sites had fewer shrubs with a few grasses and trees.

2.2. Determination of site elevation and topography

A semi-detailed survey of selected EG sites was conducted to develop digital maps of the watershed sites. The digital terrain models, digitized drainage pattern, and watershed run-off velocity were determined using a global positioning system (GPS) and a 3-D software analysis as suggested by Nachtergaele et al. (2001) and Nasri et al. (2008).

2.3. Determination of EGEM model input data

The location, climate, topography, altitude, soil map, vegetation, agriculture and human activities constitute the identification components of the EGEM input data. The EGEM program provides entry of data on client, county, state, cultural practice, date and name of the researcher as identification parameters (Foster, 1986). The drainage area was computed by EGEM using the furnished curve number (CN) values.
The particle density and particle diameter of each soil textural class, and Manning’s number was also computed by EGEM using EGEM’s Manning’s values for tropical soils and based on observed soil type, clay content, and tillage practices (manual, ox-drawn or motorized plow) in the study area. The detachment rate of eroding soil particles and volume of run-off water received at the watersheds were computed by EGEM from rainfall data supplied to the program.

Fig. 1. Map of the study area showing villages, where EG occurred on farm lands. Adapted from Tekwa, Lafren, and Yusuf (2014)
Watershed data such as watershed length was determined using a field survey with a GPS modem (Nasri et al., 2008), while watershed slope was determined using an Abney level device as described by Tolu (2002). The concentrated flow length (actual length of EG) was determined using a measuring tape in the field, while the EG maximum depth was obtained using a measuring tape in line with estimated tillage depth, which limits EGEM application (45 cm). The depleted width was determined in terms of the difference between the initial and maximum EG widths (Capra et al., 2004). The hydrologic soil group was determined in accordance with the United State Department of Agriculture (USDA) method of mapping soil hydrological groups (Philips & Joubert, 2009).

The critical hydraulic shear was computed in accordance with the expression described by Laflen, Watson, and Franti (1986), given as

\[ \tau_c = 0.0065 \times 10^{0.0182 \times \%\text{clay}} \]  

where \( \tau_c \) = critical hydraulic shear.

The rainfall data was the 24-h rainfall events during the study period. However, EGEM originally used rain storm distribution available in the United States of America (USA). These include types 1, 1A, II and III for different climates (Capra et al., 2004).

The 24-h rainfall was the amount of rainfall received using a manual rain gauge between 9.00 am (the first day) and 9.00 am (the next day) totaling 24 h duration. The 2 year 24-h and 25 year 24-h rainfall events were computed from the expression described by the Pennsylvania State Climatologist (PSC) (2009), expressed as

\[ X = \psi - \beta \ln[-\ln(F)] \]

where \( X \) = extreme rainfall value, \( \psi = \text{average} - \gamma \beta \) (where \( \gamma \) is Euler's constant, approximately 0.557), \( \beta = 0.78 \sigma \) (where \( \sigma \) is the standard deviation), \( F = (n - 1)/n \) (where \( F \) is the rainfall event period, and \( n \) = number of years) and \( \ln \) = natural log.

The PEI was determined in accordance with the method described by Lal (1983). The PEI for each EG site was computed in terms of percentage of days with erosive 24-h rainfall (\( > 20 \) mm and \( > 25 \) mm) over the total rainfall days in a season, expressed as

\[ \text{PEI} = \frac{\text{Number of erosive} \ 24-h \ \text{rainfall} (> 20 \text{ or } 25 \text{ mm}) \ \text{days}}{\text{Total number of rainfall days in a year}} \times 100 \]

The EGEM model software (EGEM version 2.0) estimated soil loss in the study area in terms of voided area (acres) and eroded volume (tons).

**EGEM model input variable adaptation**

The present study replaced and/or adapted few EGEM input variables such as present land use (arable agriculture) and cover conditions, local rainfall distribution data (daily 24-h rainfall), soil data (soil bulk density, shear strength, and erodibility), and site topographic data. EGEM is widely reported as being unable to predict area loss adequately (Nachtergaele, Poeson, Vandekerckove, Oostwoud, & Roxo, 2001; Capra et al., 2004), and therefore the need to make model adaptations in this study. Adaptation trials using variables that affect EGEM efficiency such as depth, length, and rainfall amounts were made on the EGEM model by adjusting EG depth, EG length and \( > 25 \) mm as erosive rainfall as against the 8 mm rainfall depth adapted by Nachtergaele et al. (2001) for the Mediterranean areas. A common CN of 79 was adapted for the land use types at all sites, except Gella and Lamorde, being the sites with mountainous terrain which were assigned each, a CN of 70.

**2.4. EG depth and length adjustments**

Adjustment ratio of EG depth and length

\[ \text{EG depth adjustment ratio} = \frac{\text{Observed EG depth}}{\text{Average depth}} \]

\[ \text{EG length adjustment ratio} = \frac{\text{Observed EG length}}{\text{Average length}} \]
Adjustment of EG depth and length

Adjusted EG depth = EG depth adjustment ratio \times \text{Average depth} \quad (6)

Adjusted EG length = EG length adjustment ratio \times \text{Average length}. \quad (7)

2.5. Determination of measured (actual) erosion

The actual soil loss was determined using mathematical expressions for computing channel erosion in relation to EG length, width, depth, and shape (cone or cylinder like) of each EG channel as follows.

2.6. Area of soil loss (ASL)

The area of EG cylindrical shape before and after rainy season was computed and their differences represent the net average area of soil loss for the season, and are determined as follows:

Area of EG cylinder = 2\pi rL \quad (8)

Net area of EG cylinder = 2\pi rL_2 - 2\pi rL_1 \quad (9)

where \( r \) = radius of a cylindrical EG shape, \( L_1 \) = length of EG channel before seasonal rainfall event, \( L_2 \) = length of EG channel after seasonal rainfall event and \( \pi \) = constant of proportion.

The area of EG cone shaped before and after rainy season was also computed, and their margins represent the net average area of soil loss for the season, and are determined as

Area of EG cone shaped = \pi r(r+l) \quad (10)

Net area of EG cone shaped = \pi r(r+l)_2 - \pi r(r+l)_1 \quad (11)

where \( r \) = base radius of an EG cone shape, \( l_1 \) = slant height of EG cone shape before seasonal rainfall event, \( l_2 \) = slant height of EG cone shape after seasonal rainfall event and \( \pi \) = constant of proportion.

The total ASL = Net area of EG cylinder shaped + Net area of EG cone shaped

2.7. Volume of soil loss (VSL)

The volume of soil loss was similarly computed based on the cylinder and cone shapes of EG erosion feature as follows:

Volume of soil loss (VSL) at EG headcut cone - shaped = \frac{1}{3} \pi r^2 h \quad (12)

Net volume of soil loss (VSL_2 - VSL_1) at EG cone shaped = \frac{1}{3} \pi r^2 h_2 - \frac{1}{3} \pi r^2 h_1 \quad (13)

where \( h_1 \) = perpendicular height of gully head cone-shaped before seasonal rainfall event, \( h_2 \) = perpendicular height of gully head cone-shaped after seasonal rainfall event, \( r \) = radius of an EG head-cut (cone shaped) and \( \pi \) = constant of proportion.

Volume of soil loss along gully length (cylinder shaped) before rains = \frac{1}{2} \pi r^2 L \quad (14)

Net volume of soil loss along EG cylinder shaped = \frac{1}{2} \pi r^2 L_2 - \frac{1}{2} \pi r^2 L_1 \quad (15)

where \( \pi \) = constant of proportion, \( r \) = radius of gully basin (cylinder-shaped), \( L_1 \) = length of gully basin before seasonal rainfall event, \( L_2 \) = length of gully basin after seasonal rainfall event and \( h \) = EG incision depth (cylinder shaped)

Total VSL = Net VSL (EG cone shaped) + Net VSL (EG cylinder shaped). \quad (16)
2.8. Mass of soil loss (MSL)

Mass of soil loss is calculated as follows:

\[
\text{Mass of soil loss} = \frac{\text{Total volume of soil loss (VSL)}}{\text{Soil } \delta_b} \tag{17}
\]

where \(\delta_b\) = soil bulk density.

2.9. Validation of EGEM predicted soil loss estimates

The EGEM estimates of soil loss were validated using a regression tool that compared the relationship between measured and EGEM estimates of soil loss (ASL, VSL, and MSL). The observed coefficient of determination \((r^2\text{-value})\) measured the relationship between the actual and predicted soil loss. The percentage relationship also defined the reliability of the EGEM model for predicting soil erosion in the study area.

2.10. Data analysis

The data collected were subjected to analysis of variance (ANOVA) using Statistix 9.0 version 2012. Regression analysis \((R^2\) or coefficient of determination) and Student T-test were used to respectively determine the relationships and differences between measured and predicted erosion. In addition, analysis of errors using the standardized mean error \((M_{es})\) and root mean square error \((M_{se})\) was used to assess the models’ prediction efficiencies as described by Capra et al. (2004), and expressed as follows:

\[
M_{es} = \frac{1}{n} \sum \frac{(Z_i - Z_i^*)/S)^2}{n}
\]

and

\[
M_{se} = \left[ \frac{1}{n} \sum (Z_i - Z_i^*)^2 \right]^{0.5}
\]

where \(S\) = standard deviation of the measured soil loss, \(n\) = number of observation, \(Z_i\) = predicted soil loss (EGEM estimates), and \(Z_i^*\) = measured soil loss.

3. Results and discussion

3.1. Geophysical characteristics of watersheds sites

The sites’ had different topography, soil type, vegetation, and field drainage patterns. Some of the sites such as Gella and Lamorde were typically mountainous and had little arable activity. There was denser shrub and grass vegetation at the Gella and Lamorde watersheds. Fewer grasses and trees occurred at Vimtim and Digil, which were perhaps influenced by agricultural tillage activities. The EG channels were “V” or “U” shaped by seasonal channel incisions from run-off water on a relatively flat (e.g. Digil and Vimtim), rolling (e.g. Muvur and Madanya) and hilly (e.g. Gella and Lamorde) topography (Appendix A1). Ekwue and Tashiwa (1992) and Tekwa and Usman (2006) reported similar topographic features from EG channel sites earlier studied at the Mubi area. The EG depth and drainage activities were moderated by the underlying shallow rock-basements and which could have been responsible for the observed erosion rates in the study sites, as similarly reported by Foster (2005) and Wall, Baldwin, and Shelton (2003).

3.2. Watershed elevation and rainfall characteristics

The elevation of the watershed sites was lower at Muvur (554.00 ± 0.58) and higher at Gella (652.25 ± 0.63), with corresponding run-off flow rates of 0.20–0.44 cfs and 0.20–3.00 cfs, respectively. The run-off flow rate was more variable at sites with mountainous terrain (Gella and Lamorde), than those with comparable topography (Vimtim, Muvur, Digil, and Madanya). Total rainfall amount in the sites was 859.80 and 888.70 mm in 2008 and 2009, respectively.

There were 64 days with 24-h rainfalls, and 17 days with > 20 mm, while 11 days with > 25 mm depths in 2008. Also, 66 days had 14 days with > 20 mm and 11 days with > 25 mm rainfalls in 2009. The PEI was 23% and 26%
in 2008 and 2009 respectively. In addition, the 2 year 24-h rainfall events were 11.95 mm and 40.51 mm in 2008 and 2009 respectively, while the 25 year 24-h rainfall events were 11.85 and 36.01 mm in the respective years.

3.3. Measured versus EGEM<sub>std</sub> predicted annual soil loss estimates

EGEM underestimated ephemeral gully erosion at 4 sites including Muvur (300.65 m<sup>2</sup>), Gella (284.30 m<sup>2</sup>), Lamorde (73.15 m<sup>2</sup>) and Vimtim (50.40 m<sup>2</sup>). Only Digil and Madanya had their ASL over predicted by 168.73 m<sup>2</sup> and 91.40 m<sup>2</sup> respectively in 2008. Conversely, in 2009, the measured ASL ranged from 70.02 to 426.78 m<sup>2</sup>, while empirical ASL ranged from 158.42 to 437.98 m<sup>2</sup>. The EGEM estimates comparably had a higher range of 152.44–349.39 m<sup>2</sup>. The empirical ASL was generally over predicted at all sites, except at Gella (172.80 m<sup>2</sup>). Similarly, the EGEM estimate was generally over predicted at Lamorde (90.51 m<sup>2</sup>), Madanya (70.56 m<sup>2</sup>), Digil (19.93 m<sup>2</sup>) and Muvur (6.27 m<sup>2</sup>). It was Gella (274.34 m<sup>2</sup>) and Vimtim (56.80 m<sup>2</sup>) that had their ASL under predicted by EGEM. It was noted that erosion (ASL) was generally greater at Muvur than at the other sites. Also, Lamorde and Gella had the least ASL in terms of EGEM and actual erosion in this study. The noticed over prediction was however, still not unusual with EGEM, especially with the rocky nature of the Mubi area, a limiting factor reported in EGEM studies, especially when tried in the Mediterranean area (Capra et al., 2004; Nachtergaele, Poeson, Vandekerckove, Oostwoud, & Roxo, 2001).

The EGEM under predicted the VSL at all sites, except at Madanya, where it was over predicted by 56.74 m<sup>3</sup> in 2008. There was generally no significant (P > 0.05) differences between the actual erosion and EGEM predicted erosion in the study area in 2008. This was earlier observed by Nachtergaele, Poeson, Vandekerckove, Oostwoud, and Roxo (2001) and Nachtergaele et al. (2001), that comparing EGEM predicted volume with measured generates a spurious self-correlation. The measured VSL ranged from 90.06 to 311.91 m<sup>3</sup>, compared to a range of 45.09–312.97 m<sup>3</sup> predicted by EGEM in 2009. On the other hand, the VSL was under predicted at Vimtim, Gella, Digil, and Lamorde by 108.91, 106.15, 51.91 and 40.92 m<sup>3</sup> respectively. Both Muvur (1.06 m<sup>3</sup>) and Madanya (28.79 m<sup>3</sup>) had their VSL slightly over predicted by EGEM in 2009. EGEM estimates differed from the measured VSL at both Vimtim and Lamorde in 2009. The erosion (VSL) severity was relatively intense at Muvur, compared to that at other sites. Such under prediction of VSL by EGEM was reported in other similar works (Capra et al., 2004; Capra & Scicolone, 2002; Nachtergaele, Poeson, Vandekerckove, Oostwoud, & Roxo, 2001; Nasri et al., 2008).

The EGEM mass (MSL) estimates were generally under predicted at all sites, except at Madanya, where the MSL was over predicted by 80.25 kg/ha. There were no significant (P > 0.05) differences between measured and EGEM estimates of MSL in 2008. Actual erosion (MSL) severity occurred in the order: Vimtim (446.33 kg/ha) > Muvur (400.19 kg/ha) > Digil (227.50 kg/ha) > Lamorde (196.20 kg/ha) > Gella (154.23 kg/ha) > Madanya (98.78 kg/ha) within a range of 98.78–446.33 kg/ha. This observed trend was perhaps due to the low efficiency of physically-based models such as EGEM, as earlier reported by Capra et al. (2004), Foster (2005), Nasri et al. (2008), Nachtergaele, Poeson, Vandekerckove, Oostwoud, and Roxo (2001) and Nachtergaele et al. (2001), in addition to other authors.

3.4. Effect of adapted EGEM using EG depth and length on predicted ASL estimates

The results of EG depth and length adaptation on EGEM predicted ASL estimates are presented in Table 1. The results showed that both EG depth and length adjustments influenced the extents of erosion to be generally under predicted across the sites, compared to those estimated by the EGEM standard version, which over predicted ASL at only the Madanya site. The results of adjusted EG depth’s (EGEM<sub>Ad</sub>) influence on EGEM predictions showed that the ASL was not over predicted at any of the sites in both years, except at Muvur and Lamorde in 2009. The erosion (ASL) estimates ranged from 90.38 m<sup>2</sup> (at Lamorde) to 454.62 m<sup>2</sup> (at Muvur) in 2008, while it was from 75.54 to 399.30 m<sup>2</sup> respectively at these same sites in 2009. This result implies that even with inputting low EG depths in EGEM<sub>std</sub> it over predicted soil loss at these sites. This observation concurs with those mentioned by Capra et al. (2004) that even though inputting a maximum depth using a ratio of 0.36 instead of the standard EGEM maximum depth for improving the estimation, it still over estimates.

On the other hand, the adjusted EG length equally influenced the ASL to be fairly under predicted at all sites, except at Muvur in 2009. The EGEM<sub>AI</sub> estimates ranged from 75.54 to 441.12 m<sup>2</sup> in 2008, while it was from 63.40 to 376.37 m<sup>2</sup> in 2009. The mean differences between the adapted EGEM<sub>AI</sub> estimates and actual erosion ranged from 93.39 to 255.97 m<sup>2</sup> in 2008, while it also ranged from 5.27 to 324.25 m<sup>2</sup> in 2009, and without wide differences from the actual erosion estimates. EG length expressed a better relationship (r<sup>2</sup>-value) with the actual erosion than both EGEM<sub>Ad</sub> and EGEM<sub>std</sub> predicted ASL estimates. However, the reason for the EGEM<sub>std</sub>’s inability to adequately
predict soil erosion could be linked to the underlying theory of EGEM (Capra et al., 2004). EGEM has inbuilt data on stoniness, erodibility and critical shear stress, which may not be applicable to the study area.

3.5. Effect of adapted EGEM using EG depth and length on predicted VSL estimates

The results of adjustments in EG depth and length on EGEM prediction of VSL estimates in the area are presented in Table 2. The results on EGEMAd estimates of VSL indicated that it was over predicted at the same Digil, Muvur, and Madanya sites. The EGEMAd estimates however, ranged from 100.81 to 670.07 m$^3$ in 2008, while it ranged from 99.58 to 652.42 m$^3$ in 2009. It was observed that there were still no wide differences between these estimates and the measured VSL in both study years. The over estimation by EGEM could have also been due to the assumption that EG depth equals to the depth of a soil layer that may be similar for the entire length, thereby limiting the EGEM prediction potentials. EG length on the other hand, is a good determinant of eroded volume, and as such, EG length showed a better correlation with eroded volume, than with EG depth in this study. Nachtergaele et al. (2001) similarly mentioned that comparing estimated and measured volumes generates a spurious self-correlation, because both EGEMstd and field measurements used measured EG length to calculate eroded volume.

Conversely, the adapted EG length also influenced the EGEMAl to over predict the VSL at Muvur by 366.95 m$^3$ and at Madanya by 45.70 m$^3$, compared to the EGEMstd, which over predicted the VSL at Madanya in 2008. The adapted EGEMAl estimates ranged from 93.16 to 666.01 m$^3$ in 2008, and from 86.46 to 628.25 m$^3$ in 2009. The mean difference between these estimates and the actual erosion was between 2.64 and 366.95 m$^3$, and which did not differ significantly ($P < 0.05$) from the actual erosion in the various sites in both study years. The adjustment in depth perhaps does not represent the actual incision behavior at these sites, and therefore the sudden occurrences of such over prediction by the EGEMstd model. Capra and Scicolone (2002) reported similarly for the Mediterranean areas.

3.6. Effect of adapted EGEM using EG depth and length on predicted MSL estimates

The results of effects of adapted EG depths and lengths on EGEM prediction of MSL estimates are presented in Table 3. The results indicated that the adapted EGEMAd estimates of MSL were as well over predicted at the same Digil, Muvur, and Madanya in both years and at Vimtim in 2009. The estimate ranged from 135.67 to 912.64 kg/ha in 2008, and was

<table>
<thead>
<tr>
<th>Study site</th>
<th>Area of soil loss (m$^2$)</th>
<th>Measured</th>
<th>EGEMstd</th>
<th>$T$-test</th>
<th>Measured</th>
<th>EGEMAd</th>
<th>$T$-test</th>
<th>Measured</th>
<th>EGEMAl</th>
<th>$T$-test</th>
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<tr>
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<td>-168.73</td>
<td>0.01**</td>
<td>214.38</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Digil</td>
<td>266.06</td>
<td>285.99</td>
<td>-19.93</td>
<td>0.01**</td>
<td>266.06</td>
<td>118.71</td>
<td>147.35</td>
<td>266.06</td>
<td>138.95</td>
<td>127.11</td>
</tr>
<tr>
<td>Vimtim</td>
<td>306.37</td>
<td>249.57</td>
<td>56.80</td>
<td>0.01**</td>
<td>306.37</td>
<td>227.98</td>
<td>78.39</td>
<td>306.37</td>
<td>116.01</td>
<td>190.35</td>
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<tr>
<td>Muvur</td>
<td>343.12</td>
<td>349.39</td>
<td>-6.27</td>
<td>0.01**</td>
<td>343.12</td>
<td>399.30</td>
<td>-56.18</td>
<td>343.12</td>
<td>376.37</td>
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<tr>
<td>Gella</td>
<td>426.78</td>
<td>152.44</td>
<td>274.34</td>
<td>0.01**</td>
<td>426.78</td>
<td>124.11</td>
<td>302.67</td>
<td>426.78</td>
<td>102.53</td>
<td>324.25</td>
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<tr>
<td>Lamorde</td>
<td>70.02</td>
<td>160.53</td>
<td>-90.51</td>
<td>0.01**</td>
<td>70.02</td>
<td>75.54</td>
<td>-5.52</td>
<td>70.02</td>
<td>64.75</td>
<td>5.27</td>
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<tr>
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<td>133.14</td>
<td>203.70</td>
<td>-70.56</td>
<td>0.01**</td>
<td>133.14</td>
<td>86.34</td>
<td>46.80</td>
<td>133.14</td>
<td>63.40</td>
<td>69.74</td>
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</table>

EGEMstd = predicted soil loss by standard version of EGEM program.
EGEMAd = predicted soil loss by adapted EGEM program using adjusted EG depth.
EGEMAl = predicted soil loss by adapted EGEM program using adjusted EG length.
n.s = difference between means are not significant ($P < 0.05$).
*Difference between means are significant ($P < 0.05$).
from 129.45 to 867.75 kg/ha in 2009. The mean differences between the adapted EGEMAd estimates and the actual erosion ranged from 1.46 to 512.45 kg/ha in 2008, and from 0.84 to 469.86 kg/ha in 2009. It was, however, observed that there were still no differences between these estimates of MSL from those of actual erosion in the various sites in both study years. On the other hand, the influence of adapted EG length on EGEM prediction of MSL estimates

<table>
<thead>
<tr>
<th>Study site</th>
<th>Volume of soil loss (m³)</th>
<th>Measured</th>
<th>EGEMstd</th>
<th>T-test</th>
<th>Measured</th>
<th>EGEMAd</th>
<th>T-test</th>
<th>Measured</th>
<th>EGEMAl</th>
<th>T-test</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>135.21</td>
<td>26.14ns</td>
<td>161.35</td>
<td>232.39</td>
<td>−71.03ns</td>
<td>161.35</td>
<td>130.44</td>
<td>30.91ns</td>
<td>130.44</td>
</tr>
<tr>
<td>Vimtim</td>
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<td>162.58</td>
<td>166.03ns</td>
<td>328.61</td>
<td>187.84</td>
<td>40.77ns</td>
<td>328.61</td>
<td>141.96</td>
<td>186.64ns</td>
<td>141.96</td>
</tr>
<tr>
<td>Muvur</td>
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<td>272.80</td>
<td>26.26ns</td>
<td>299.06</td>
<td>670.07</td>
<td>−371.01ns</td>
<td>299.06</td>
<td>666.01</td>
<td>−366.95ns</td>
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<tr>
<td>Gella</td>
<td>115.34</td>
<td>27.57</td>
<td>87.77ns</td>
<td>115.34</td>
<td>114.12</td>
<td>1.23ns</td>
<td>115.34</td>
<td>112.70</td>
<td>2.64ns</td>
<td>112.70</td>
</tr>
<tr>
<td>Lamorde</td>
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<td>128.69</td>
<td>16.15ns</td>
<td>144.84</td>
<td>100.81</td>
<td>44.03ns</td>
<td>144.84</td>
<td>93.16</td>
<td>51.68ns</td>
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<tr>
<td>Madanya</td>
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<td>130.16</td>
<td>−56.74ns</td>
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<td>73.42</td>
<td>119.12</td>
<td>−45.70ns</td>
<td>119.12</td>
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<table>
<thead>
<tr>
<th>Study site</th>
<th>Mass of soil loss (kg/ha)</th>
<th>Measured</th>
<th>EGEMstd</th>
<th>T-test</th>
<th>Measured</th>
<th>EGEMAd</th>
<th>T-test</th>
<th>Measured</th>
<th>EGEMAl</th>
<th>T-test</th>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digil</td>
<td>161.35</td>
<td>135.21</td>
<td>26.14ns</td>
<td>161.35</td>
<td>232.39</td>
<td>−71.03ns</td>
<td>161.35</td>
<td>130.44</td>
<td>30.91ns</td>
<td>130.44</td>
</tr>
<tr>
<td>Vimtim</td>
<td>328.61</td>
<td>162.58</td>
<td>166.03ns</td>
<td>328.61</td>
<td>187.84</td>
<td>40.77ns</td>
<td>328.61</td>
<td>141.96</td>
<td>186.64ns</td>
<td>141.96</td>
</tr>
<tr>
<td>Muvur</td>
<td>299.06</td>
<td>272.80</td>
<td>26.26ns</td>
<td>299.06</td>
<td>670.07</td>
<td>−371.01ns</td>
<td>299.06</td>
<td>666.01</td>
<td>−366.95ns</td>
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</tr>
<tr>
<td>Gella</td>
<td>115.34</td>
<td>27.57</td>
<td>87.77ns</td>
<td>115.34</td>
<td>114.12</td>
<td>1.23ns</td>
<td>115.34</td>
<td>112.70</td>
<td>2.64ns</td>
<td>112.70</td>
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<tr>
<td>Lamorde</td>
<td>144.84</td>
<td>128.69</td>
<td>16.15ns</td>
<td>144.84</td>
<td>100.81</td>
<td>44.03ns</td>
<td>144.84</td>
<td>93.16</td>
<td>51.68ns</td>
<td>93.16</td>
</tr>
<tr>
<td>Madanya</td>
<td>73.42</td>
<td>130.16</td>
<td>−56.74ns</td>
<td>73.42</td>
<td>212.57</td>
<td>−139.14ns</td>
<td>73.42</td>
<td>119.12</td>
<td>−45.70ns</td>
<td>119.12</td>
</tr>
</tbody>
</table>

EGEMstd = predicted soil loss by standard version of EGEM program.
EGEMAd = predicted soil loss by adapted EGEM program using adjusted EG depth.
EGEMAl = predicted soil loss by adapted EGEM program using adjusted EG length.
s = difference between means are not significant (P < 0.05).
* = difference between means are significant (P < 0.05).
indicated similar pattern of prediction with those observed in terms of VSL in this study. The EGEMAl predicted MSL were still over predicted at the same Digil, Muvur, and Madanya, compared to the standard EGEM version, which did not over predict the MSL in the sites, except at Madanya in both years. The EGEMAl estimates of MSL ranged from 125.50 to 907.16 kg/ha in 2008 and from 113.36 to 830.76 kg/ha in 2009. Mean differences of between 3.27 and 506.97 kg/ha and between 21.52 and 432.87 kg/ha were recorded in 2008 and 2009 respectively. It was still observed that there were no differences between the EGEMAl estimates and the actual erosion in both study years.

3.7. Efficiency of EGEM model in predicting average EG erosion

The ASL predicted by EGEMstd was comparably less reliable than those predicted by EGEMAd and EGEMAl in this study. The EGEMstd prediction was however, efficient at Lamorde (0.0084), followed by Vimtim (0.0271). The EGEMstd predicted ASL at Digil (0.2156) and Gella (0.3885) had comparable prediction accuracy, while Madanya (13.0607) and Muvur (28.0131) experienced low prediction efficiencies. The Mes and Mse indices were fairer than the range of 0.7–4.5 and 14.8–96.4 from eroded volume reported by Capra et al. (2004) from a similar work in Sicily, Italy.

3.8. Efficiency of adapted EGEMAd to predict average EG erosion

The efficiency of adapted EGEMAd in predicting VSL in the various sites is presented in Table 4. The results indicated that the adapted EGEMAd behaved differently from the standard version (EGEMstd) in terms of its wide VSL over prediction at all sites, except at Lamorde. The results revealed lower relationship between VSL estimated by the adapted model (EGEMAd) at Lamorde, Vimtim, and Digil sites, compared to the other sites. However, the adapted EGEMAd was less efficient compared to the standard Digil model prediction efficiency. The efficiency (Mes) of EGEMAd prediction in the sites was in the order: Digil (0.01)=Gella (0.01) ≥ Madanya (0.11) ≥ Muvur (0.80) ≥ Vimtim (0.88) > Lamorde (1.47), while the maximum efficiency (Mse) of EGEMAd predicted VSL was in the order: Gella (7.77) ≥ Digil (12.14) ≥ Vimtim (27.41) ≥ Lamorde (36.68) ≥ Madanya (55.40) > Muvur (205.40). The Mes of adapted EGEMAd model in predicting the VSL estimates was not significantly (P<0.05) different from the EGEMstd version.

The adapted EGEMAd estimates were widely over predicted compared to the standard EGEMstd, which generally under predicted soil loss in this study.

Besides this, the relationship between the adapted EGEMAd and EGEMstd varied between low and high in the various sites. Similar adaptation trials on EGEMstd using EG depth adjustments could not improve EGEMstd performance especially in the Mediterranean environment (Capra & Scicolone, 2002; Capra et al., 2004; Nachtergaele, Poeson, Vandekerckove, Oostwoud, & Roxo, 2001; Nachtergaele et al., 2001).

3.9. Efficiency of adapted EGEMAl to predict average EG erosion

The prediction efficiency of adapted EGEMAl also exhibited over prediction of VSL estimates at 3 sites (Table 4). However, the variation between these estimates from those of actual erosion was lower (except at Muvur), compared to those predicted by both EGEMstd and EGEMAd. Even though, the prediction efficiency of EGEMAl was less adequate, but without wide variation between its ability and those of the EGEMstd version. Unlike the effects of adapted EG depth on EGEMstd prediction efficiency in this study, the adapted EG length (EGEMAl) exerted a better relationship, but had lower relative efficiency in predicting the VSL, than adapted EGEMAd. This result was not unconnected to the widely acclaimed fact that EG lengths are essential determinants of eroded volumes on watersheds (Gordon et al., 2007; Woodward, 1999; Zhang, Quine, & Walling, 1998). According to Nachtergaele, Poeson, Vandekerckove, Oostwoud, and Roxo (2001) and Nachtergaele et al. (2001), there is a close correlation between EGEMstd eroded volume and EG length. This explains the usually strong correlation between EG length and EG eroded volumes. In this study, it was observed that the predicted estimates of adapted EGEMAl expressed better relationship with the measured soil loss, than with standard EGEMstd estimates. This result was perhaps improved by the spontaneous correlation between EG volume and EG length as widely reported from similar works (Capra et al., 2004). On the other hand, the relatively lower prediction accuracy of EGEMstd may be attributed to the underlying theory that determines EGEM predictions, whereby soil properties such as soil erodibility, shear stress, and particle diameter were automated in the program, irrespective of place of application. Such assumptions might have affected
EGEM’s efficiency in the study area, considering the fact that some of the conditions may not apply in this part of the World.

4. Conclusion

EGEM estimates of VSL and MSL were significantly \((P < 0.05)\) higher at Muvur and respectively lower at Madanya and Gella in both the years. Hence, the measured estimates were consistently higher at Vimtim and lower at Madanya conserved with vegetative barriers. In addition, the EGEM\textsubscript{std} model efficiency in predicting erosion was reliable at most of the study sites in terms of annual VSL and MSL, but was unsuited for ASL prediction. The adjusted EG length improved EGEM\textsubscript{Al} predictions than both adapted depth (EGEM\textsubscript{Ad}) and standard EGEM\textsubscript{std} in this study.

5. Recommendations

The observed EGEM\textsubscript{std} weakness for ASL prediction is recommended for deterministic modeling in order to establish the root causes of its inability. The adapted EGEM\textsubscript{Al} was more efficient and is recommended for
implementation within and outside the Mubi environment as a suitable alternative technology to the very rigorous field measurement of EG erosion. Agronomic and cultural practices such as ridging, terraces, sand bags/stone lines, and vegetative barrier establishments that could reduce EG depths, lengths, and erosion processes are strongly recommended in the host environment. Future research works are recommended to compare the prediction efficiencies of \( \text{EGEM}_{\text{Ad}} \) and \( \text{EGEM}_{\text{Al}} \) aggregate estimates of ASL and MSL estimates.

Appendix A

See Table A1.

Table A1
Physical properties of soils of the study area.
(Source: Tekwa et al. (2014))

<table>
<thead>
<tr>
<th>Study location</th>
<th>Particle size distribution (%)</th>
<th>Texture</th>
<th>Bulk density (Mg m(^{-3}))</th>
<th>WHC (%)</th>
<th>Site slope</th>
<th>Shape of EG</th>
<th>DA size (ha)</th>
<th>Conservation practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digil</td>
<td>53.61 19.92 26.47 SCL</td>
<td>1.41</td>
<td>28.75</td>
<td>5</td>
<td>U</td>
<td>1.61</td>
<td>Few vegetative barriers, tied-ridging</td>
<td></td>
</tr>
<tr>
<td>Vimtim</td>
<td>59.19 18.05 22.76 SCL</td>
<td>1.38</td>
<td>21.92</td>
<td>15</td>
<td>V</td>
<td>1.63</td>
<td>Rough surface tillage, tied ridging</td>
<td></td>
</tr>
<tr>
<td>Muvur</td>
<td>51.88 22.16 25.96 SCL</td>
<td>1.35</td>
<td>26.94</td>
<td>13</td>
<td>U</td>
<td>2.80</td>
<td>Tied-ridging</td>
<td></td>
</tr>
<tr>
<td>Gella</td>
<td>62.41 18.06 19.53 SL</td>
<td>1.34</td>
<td>19.09</td>
<td>15</td>
<td>V</td>
<td>1.20</td>
<td>Terraces, sand-bags, stone lines</td>
<td></td>
</tr>
<tr>
<td>Lamorde</td>
<td>51.96 24.57 23.47 SCL</td>
<td>1.35</td>
<td>26.59</td>
<td>21</td>
<td>U</td>
<td>1.18</td>
<td>Terraces, sand-bags, stone lines</td>
<td></td>
</tr>
<tr>
<td>Madanya</td>
<td>50.30 24.29 25.41 SCL</td>
<td>1.33</td>
<td>25.47</td>
<td>10</td>
<td>U</td>
<td>1.51</td>
<td>Vegetative barriers, tied ridging</td>
<td></td>
</tr>
</tbody>
</table>

SCL = sandy clay loam; SL = sandy loam; WHC = water holding capacity; EG = ephemeral gully; DA = drainage area.

Appendix B

See Table B1.

Table B1
Chemical properties of soils of the study sites.
(Source: Tekwa et al. (2014))

<table>
<thead>
<tr>
<th>Chemical parameter</th>
<th>Digil</th>
<th>Vimtim</th>
<th>Muvur</th>
<th>Gella</th>
<th>Lamorde</th>
<th>Madanya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon (OM (%))</td>
<td>0.76</td>
<td>0.91</td>
<td>1.13</td>
<td>0.88</td>
<td>1.31</td>
<td>1.17</td>
</tr>
<tr>
<td>Potassium – K(^+) (C mol(+)/kg)</td>
<td>0.36</td>
<td>0.24</td>
<td>0.33</td>
<td>0.37</td>
<td>1.00</td>
<td>0.46</td>
</tr>
<tr>
<td>Calcium – Ca(^{2+}) (C mol(+)/kg)</td>
<td>15.65</td>
<td>14.35</td>
<td>15.82</td>
<td>9.49</td>
<td>16.78</td>
<td>19.68</td>
</tr>
<tr>
<td>Magnesium – Mg(^{2+}) (C mol(+)/kg)</td>
<td>2.44</td>
<td>4.28</td>
<td>4.69</td>
<td>3.96</td>
<td>6.98</td>
<td>10.59</td>
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<tr>
<td>Sodium – Na(^+) (C mol(+)/kg)</td>
<td>0.79</td>
<td>1.01</td>
<td>0.85</td>
<td>0.85</td>
<td>1.16</td>
<td>0.97</td>
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<tr>
<td>Total exchangeable bases – TEB (C mol(+)/kg)</td>
<td>19.24</td>
<td>19.88</td>
<td>21.69</td>
<td>14.67</td>
<td>25.92</td>
<td>31.70</td>
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</tbody>
</table>

Appendix C

See Fig. C1.
Fig. C1. Total amount of 24-h rainfall received in May–October each year (2008 and 2009) in Mubi area.
Source: Tekwa et al. (2014)

References


