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Efficiency test of modeled empirical equations in predicting soil loss from ephemeral gully erosion around Mubi, Northeast Nigeria

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ABSTRACT

A field study was carried out to assess soil loss from ephemeral gully (EG) erosion at 6 different locations (Digil, Vimtim, Muvur, Gella, Lamorde and Madanya) around the Mubi area between April, 2008 and October, 2009. Each location consisted of 3 watershed sites from where data was collected. EG shape, land use, and conservation practices were noted, while EG length, width, and depth were measured. Physico-chemical properties of the soils were studied in the field and laboratory. Soil loss was both measured and predicted using modeled empirical equations. Results showed that the soils are heterogeneous and lying on flat to hilly topographies with few grasses, shrubs and tree vegetations. The soils comprised of sand fractions that predominated the texture, with considerable silt and clay contents. The empirical soil loss was generally related with the measured soil loss and the predictions were widely reliable at all sites, regardless of season. The measured and empirical aggregate soil loss were more related in terms of volume of soil loss (VSL) (r^2=0.93) and mass of soil loss (MSL) (r^2=0.92), than area of soil loss (ASL) (r^2=0.27). The empirical estimates of VSL and MSL were consistently higher at Muvur (less vegetation) and lower at Madanya and Gella (denser vegetations) in both years. The maximum efficiency (M_{se}) of the empirical equation in predicting ASL was between 1.41 (Digil) and 89.07 (Lamorde), while the M_{se} was higher at Madanya (2.56) and lowest at Vimtim (15.66) in terms of VSL prediction efficiencies. The M_{se} also ranged from 1.84 (Madanya) to 15.74 (Vimtim) in respect of MSL predictions. These results led to the recommendation that soil conservationists, farmers, private and/or government agencies should implement the empirical model in erosion studies around Mubi area.

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1. Introduction

Studies on soil erosion have a long scientific history and are still ongoing with increasing focus on detailing erosion processes and their modeling. Development of suitable erosion models that can adequately predict the extent of soil loss have been a challenge to scientists since the 1930s (Lal, 2001). Though numerous erosion models have been developed using different methods and modeling approaches in the past, the concepts governing such erosion models differ widely and thereby, consistent modeling has not been established (Lal, 2001). For instance, the universal soil loss equation (USLE) (Wischmeier & Smith, 1978), its revised version (RUSLE) (Renard, Foster, Weesies, McCool & Yoder, 1997), and the modified universal soil loss equation (MUSLE) (Williams, 1982) were first used to estimate soil erosion and to select conservation and management practices for erosion control. However, these technologies did not estimate ephemeral gully (EG) erosion. Other models which were patterned after the USLE such as the soil loss estimation model for South Africa (SLEMSA) (Elwell, 1977; Elwell & Stocking, 1982), areal non-point source watershed environment response simulator (ANSWERS) (Beasley, Huggins & Monke, 1980), chemical, runoff, and erosion from agricultural management systems (CREAMS) (Knisel, 1980), and kinematic runoff and erosion model (KINEROS) (Woolhiser, Smith & Goodrich, 1990), among other empirical and physically-based models, were not capable of estimating soil erosion occurring in concentrated flow channels, where EG erosion occurs. EG erosion is a recently recognized class of water erosion (Foster, 1986), which causes irreversible and colossal losses of fertile agricultural land resources (Lal, 2001). It is a significant factor in soil erosion by water, whose visible damage is usually obliterated by farming operations. The magnitude of EG erosion is largely influenced by climate, topography and vegetation (Poesen, Nachtergaele, Verstraten & Valentine, 2003; Capra & Scicolone, 2002; Oygarden, 2003). Hence, selection of compatible conservation methods remains difficult, unless the type and magnitude of the erosion processes are correctly assessed.

Previous studies on ephemeral gully (EG) erosion under different climates and land use conditions reported between 10% and 100% of soil loss on agricultural lands in Europe (Poeson et. al., 2003), with annual soil loss ranging from 2 to 90 m^3 ha^{-1} in the Mediterranean areas (Capra & Scicolone, 2002). Qualitative estimates of the effects on soil productivity losses from water erosion were also reported for several regions of Africa (Dregne, 1990), Asia (Dregne 1992), Australia and New Zealand (Dregne, 1995) and North America (Den Biggelaar, Lal, Wiebe & Breneman, 2001). Despite the volumes of reports on EG erosion predictions around the World, there is still a dearth of information on this subject in the whole of the sub-Saharan Africa, and particularly Nigeria. At present, there are no formulated or tested indigenous erosion models for predicting soil loss from such EG or concentrated flow channels in this African sub-region. Hence, local adaptation of 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). Despite this limitation, there have been no EG studies in Nigeria, except for the studies of Tekwa and Usman (2006), Tekwa, Alhassand and Chiroma (2013) and Tekwa, Laflen and Yusuf (2014).

In light of these limitations, local efforts were first made to develop empirical erosion models (Tekwa et al. 2013, 2014), that are well simplified and representative of natural processes and field observations, and which would be useful and serve as suitable alternatives to the foreign-based sophisticated physically-based or conceptual models. Therefore, it was the lack of sufficient erosion models that necessitated the modeling of these empirical equations for possible implementation around the Mubi area. It is strongly hoped that the developed empirical models shall serve as a guide to conservationists, erosion specialists, field workers, and policy makers in their drive to curb erosion problems in the study area. Thus, the present work is aimed at testing the prediction efficiency of the locally developed empirical models and to provide plausible erosion control measures in the study area.

2. Materials and methods

2.1. Description of the study area

The selected sites are located in the Mubi North (Digil, Vimtim, and Muvur) and Mubi South (Gella, Lamorde and Madanya) local government areas of Adamawa state in northeast Nigeria (Fig. 1). The sites were selected based on their land use, topography, vegetation cover and soil type. Mubi South generally has higher topography, rockiness, and denser vegetations compared to Mubi North, which has more arable than grazing activities (Table C1). The climate of the Mubi area has two seasons, a wet and a dry season. The dry season spans from November to April, while the wet season runs from May to October. The annual rainfall in the area ranged between 700 mm and 1050 mm (Udo, 1970; Adebayo, 2004). The average minimum temperature is 15.2 °C in December and January, while the average maximum temperature of 42 °C occurs in the driest months of March or April (Adebayo & Tukur, 1999). The dominant vegetations are grasslands with scattered trees typical of a savannah region (Adebayo & Tukur; 1999; Adebayo, 2004; Tekwa & Usman, 2006). Land use types in the area are mixed farming: cattle rearing and arable farming that are confronted by erosion hazards each year. The hydrological data representation is adequate for the study sites, which are situated within 30–50 km as acceptable distances for hydrological data representation reported by the World Meteorological Organization in 2003.

2.2. Soil sampling and analysis

Representative composite soil samples were collected during the 2 growing seasons. A disturbed soil sample was collected from each of the 3 EG channels selected at each of the 6 sites. Soil samples (0–15 cm depth) were collected using a bucket auger, when the soils were relatively moist. Each composite soil sample was stored in a well labeled plastic bag. The samples were air-dried, crushed and sieved through a 2 mm sieve before laboratory determination of selected physical and chemical properties that have been found to be related to water erosion.

2.3. Determination of selected soil properties

The particle size distribution was determined using the Bouyocous hydrometer method (Trout, Garcia-castillas & Hart, 1987). The Atterberg limit (plasticity limit) was determined using a fall cone penetrometer method (Head, 1992). Bulk density was determined using the clod method (Wolf, 2003). The soil erodibility index (SEI) was