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# Spatio-temporal Soil Loss Estimation of Mayo Inne Catchment of Jada Local Government Area of Adamawa State, Nigeria

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**Abstract**

*This research applied the Revised Universal Soil Loss Equation (RUSLE) model to quantify the mean annual soil loss within the study area and proffered the means to curb the menace. The False Color Composite (FCC) was generated using a Sentinel 2 satellite image of Inne catchment 2021; the composite band for this research was bands 7, 5, and 2 and was classified into 9 different classes, namely, thick vegetation, farmland, rock outcrop, grazing land, irrigated land, bareland, grassland, water body, and built-up area, in conjunction with other RUSLE factors such as the C-cover management factor and the P-support practice factor within the study area. The soil factor (K) and rainfall (R) factor were converted to raster by the use of geographic information system (GIS) spatial analyst tools. The digitized maps and the classified images were reclassified by assigning the index factors value onto each, as stated in RUSLE handbook 703. Data such as (R), (K), topography Digital Elevation Model (DEM), (C), and (P) were utilized for soil modeling using the integration of RUSLE and (GIS); the average annual soil loss of the Mayo-Inne was predicted to be 1,800,000 tons/acre/year for 2021. From this study and this prediction, the soil loss is expected to increase with time if agricultural activities, deforestation, and land clearing continue to take place within the research area, which in turn will subject the environment to soil fertility reduction, habitat degradation, water cycle disruption, and water quality decline.*

**Keyword:** Erosion, Soil loss, Slope Length, Management Cover, Factors, topography

## Introduction

Remote sensing and geographic information systems (GIS) have been in use for decades with the launch of LandSat 1 imagery for soil erosion research through photo interpretation, both for detecting erosion features and mapping erosion assessment in several ways (Morgan and Napela, 1982;

Akash Pal et al., 2025; Teku & Derbib, 2025). The consequence of soil erosion can be detected directly by the use of satellite imagery by assessing large erosion features, intensity, and identification of eroded areas based on empirical relationships, including the damaged effects due to major erosion events (Morgan and Napela, 1982; Akash Pal et al., 2025; Teku and Derbib, 2025). Satellite data has the capacity to detect extensive eroded areas being mapped by photo interpretation methods on optical image composites of many sensors (Ijafiya & Yonnana, 2018; Bocco, Palacio, & Valenzuela, 1991; Dwivedi & Ramana, 2003; Kumar & Bhagavanulu, 1996). Erosion classes can be differentiated based on vegetation cover as acknowledged from the visual interpretation or the topography and vegetation characteristics acquired from different sources of data (Dwivedi and Ramana, 2003; Sujatha et al., 2000). The demarcation of areas eroded on multitemporal images triggers the rise in critical observations compared with the aerial photograph and satellite imagery, but eroded land was found on aerial photographs to be better at identifying ravine types than the satellite imagery (Fadul et al. 1999; Karale, Saini, and Narula 1988).

Dregne (1987) and Thapa and Weber (1991) highlighted factors that mostly affected soil erosion as climatic variables, topographic features, vegetation cover, and soil characteristics. They also ascertained that large-scale urban development and human activities alter vegetation cover, in which surface runoff can conveniently wash away the topsoil from cultivated lands. This surface erosion reduces land elevation and increases flood intensity of the Inne catchment (Dregne 1987, Thapa and Weber 1991). The lack of judicious use of land resulted in the increased rate of soil erosion and discharge of sediment into rivers.

The recent assessment of spatial soil erosion by integrating spatial data of erosion factors and the Revised Universal Soil Loss Equation (RUSLE) has become widely used by professionals (Wischmeier and Smith, 1978). Though spatial mapping of erosion has models that exist, the models are developed for a particular region and scale, which makes the transfer of a model from one scale or region to another a difficult task of operation and application straightforward and may give poor or erroneous results by either introducing errors.

Moreover, erosion models require a large amount of integrated data from different

parameters: rainfall, slope, soil, vegetation, and slope. Where data are not readily available, like in developing countries, the integration of data that enhance flexibility in selection and combinations of erosion factors that produce a good alternative to the models are region-specific, depending on the processes that occur and the key parameters that explain the variability of these processes within the region. Local or expert knowledge can provide important input to such qualitative approaches (De la Rosa et al., 2001; Sonneveld, 2003). The results of these models are generally a substantial quantity of erosion risk, which depicts that the erosion occurrence of relative risk in a location is compared with erosion in other locations in the mapped areas. Based on the spatial data needed for erosion models and applications, it is dependent on the scale and the resolution of these data in use (Woodcock and Strahler, 1987).

The erosion model for long-term prediction of average annual soil loss (A) is actualized by the use of the Revised Universal Soil Loss Equation (RUSLE) embedded in the runoff of specific field slopes in specific cropping and management systems with raindrop splash from rangeland. The validity and usefulness of RUSLE have been generally accepted, with the six factors used to calculate (A). Though the Universal Soil Loss Equation (USLE) was initially created to handle the soil loss within a relatively flat terrain, it calculates (A) from the hill slope. The technology for evaluating these factor values has been modified with some new data included. The computerization of the model enables the derivation of the soil loss quantities within a region. Therefore, soil loss assessment can be made for scenarios not available in the previous equation (USLE), which includes annual rainfall erosivity (R), frost-free period, monthly precipitation, temperature, twice-monthly storm erosivity (E) distributions, below-ground biomass, canopy cover, canopy height at 15-day intervals, and information on crop characteristics (Renard et al. 1997).

In recent times, the amount of rainfall intensity has resulted in significant flooding and erosion, heavy and damaging storms, and climate change increasing in temperature and frequency, which affects vegetation that is used as mulching in erosion control (Syresh 2006; Yuksel, Gundoyan, and Ahdullah 2008).

The rate at which population increase has exerted pressure on lands in urban areas and agricultural land is giving way to construction work and housing development

without proper designs; the drainage facilities are overflooded, which enables erosion problems (Ehiorobo, Osadolor, and Izinyon 2011).

The amount of soil erosion is also affected by vegetation cover, topography, climatic variables, and soil characteristics (Syresh 2006, Yuksel, Gundoyan, and Ahdullah 2008). Human activities give rise to the removal of vegetation cover, which led to an increase in the rate of soil erosion. Topographic features such as ground slope, length, and shape affect rill erosion. The main purpose of soil erosion is to make decisions in conservation planning. The RUSLE equation enhances planner's ability to deduce the average rate of soil loss for each alternative of management techniques, cropping systems, and erosion control practices over an area.

However, this paper tends to address many remote sensing-based classification lumps with diverse land uses of a mix of subsistence farming, bush fallow, grazing land, forestry, and farmland. The wrong assignment factor index values for respective classes would lead to inaccurate modeling of vegetation protection against erosion, coupled with the fact that there has being no significant research carried out by the use of remote sensing, even when RUSLE methodology of erosion mapping was highly criticized.

**Location and Extent**

The River Mayo Ine is one of the major tributaries of the River Benue that drain into the River Benue. It has a total length of about 78.3 kilometers (Federal Surveys Nigeria, 1970). It takes its source from the Gurumpawa and flows southeast to Peshi, which changes its course northward into the Benue (Ijafiya & Yonnana, 2018).

The study area is situated in Yola North, Fufore, Ganye, Mayo Belwa, and Jada Local Government Areas, the north-central part of Adamawa State, and located between latitudes 11° 75' 86" and 12° 68' 26"N and between longitudes 08° 35' 14'' and 09° 40' 04" 'E. Covering the whole area drained into the main Mayo Ine channel from the river source areas to the basin's outlet at Wuro giye (see figure 1). The catchment covers an area of 4,552 square kilometers and falls within the Yola North, Fufore, Ganye, Mayo Belwa, and Jada local government political boundaries. However, the section of the channel's middle course studied covered a length of 78.3 kilometers from Gurumpawa in Ganye to River Benue in Yola North Local Government Areas.

As stated by Aliyu, Mala, & T. (2014), Fufore, Yola, Mayo Belwa, Ganye, and Jada are regarded as low-lying plains, with about 70% of the entire area being at less than 300 m above sea level, while the remaining 30% are hills and mountains. The area is drained by a series of rivers and streams, such as the River Benue, which takes its source from Cameroon; the River Faro; the Mayo Inne; etc. (Thlakma, Ibrahin, & Iguisi, 2015), which all encourage arable cropping, livestock rearing, and fishing (Fadama II, 2008). The area experiences distinct dry and wet seasons, with temperature and humidity varying with the season. The wet season is between April and October, with average annual rainfall of 750 to 1000 mm. The dry season period is between December and March and characterized by dry, dusty, and hazy northeast trade winds that blow over the area from the Sahara Desert. Temperatures are relatively high almost all the year round. The temperature of the area ranges from 30°C to 42°C, with cold, dry winds that reduce the temperatures to about 15°C during the Harmattan period, with the hottest months being April and May, with a mean average temperature of 34°C (Adebayo, 1999).

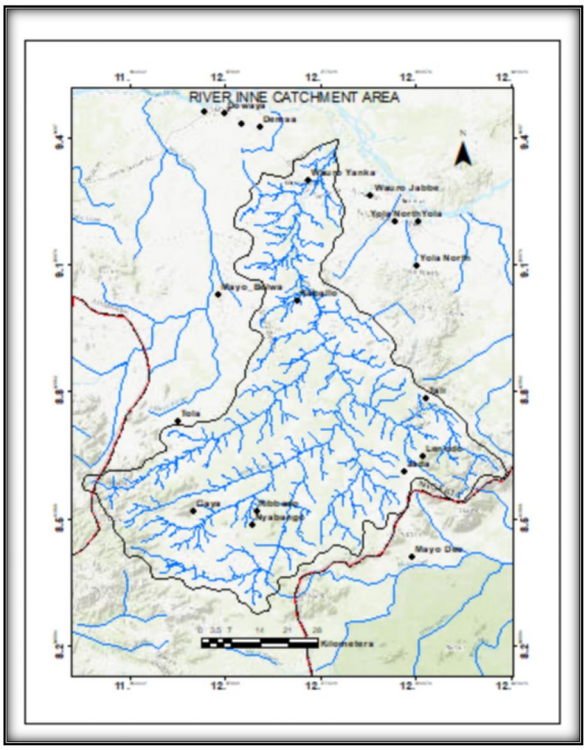



Figure 1: Mayo- Inne and its tributaries Google Image (2020)

**Methodology**

The methodology of this research involved the use of the Revised Universal Soil Loss Equation (RUSLE) using the Geographic Information System (GIS) platform. The use of soil loss erodibility factors (K), land cover factor (C), slope length factor (SL), rainfall factor (R), and conservation practice factor (P) ascertains the multi-criteria approach of quantifying the soil loss of the River Inne catchment of the Jada Local Government Area of Adamawa State, Nigeria. The GIS layers for each of the factors were generated by the use of ArcGIS 10.7.1. The Sentinel 2 satellite image bands

7, 5, and 4 were used to create the False Color Composite (FCC) of the masked imagery to interpret the spectral reflectance of the composite. The land use image was classified into nine (9) different classes, namely, thick vegetation, farmland, rock outcrop, grazing land, irrigated land, bare land, grassland, water body, and built-up area, through the maximum likelihood of the supervised method. The weighted overlay Spatial Analyst tool was incorporated to evaluate the factors class of importance. The ground truthing was also used to ascertain that the emerged classes depict the real land use as spatially distributed in the study area by integrating classified images with the visual interpretation techniques. All indexes of the factors (P. K. S. L. C. and R) were assigned to each to represent their respective affiliations. Thus, the raster calculator was used to derive the quantity of soil loss of the Mayo-Inne catchment of Adamawa State by multiplying these factors together, i.e., A = R K P CSL, to measure the soil loss of Mayo-Inne.

**Cover Management (C-factor)**

The land cover reduces the rainfall energy (thick vegetation, farmland, rock outcrop, grazing land, irrigated land, bare land, grassland, water body, and built-up area) with infiltration, which is the ratio of soil loss of the same consequence as bare fallow condition (Renard, Foster, Weesies, Mc Dool, and Yonder, 1997). The parameters of the C-factor, influenced by anthropology, in turn improve the erosion development within any area of study.

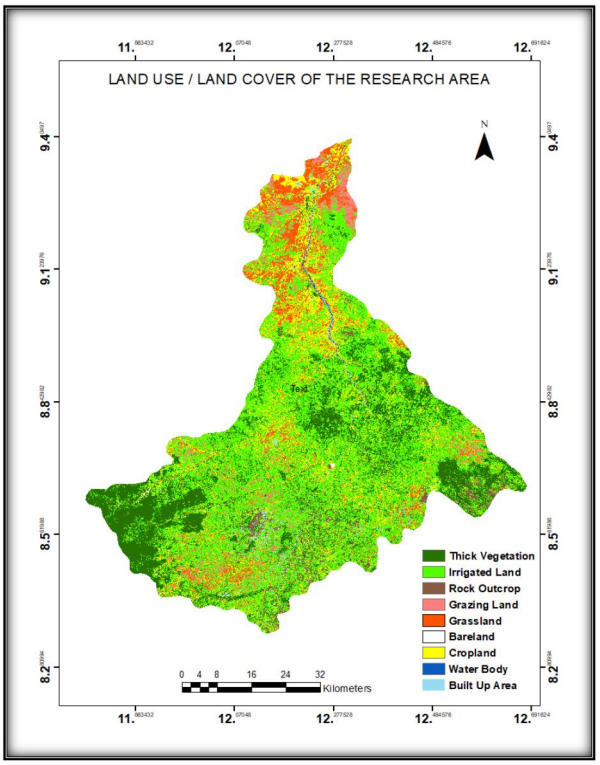



Figure 3: Land Use Land Cover Map of Mayo-Inne (C-Factor)

***Soil Erodibility (K-factor)***

The rain factor (K) depicts how susceptible the soil is to the erosion and the rate at which the sediment is transported, the quantity, and the quality of the runoff. The K factor image was prepared using the same classified image by reclassifying the image into relative soil type and assigning the index parameter of the respective soil type. For the purpose of this research, the area covered has a heterogeneous type of soil, such as chromic luvisol, pellic lithosol, glevic luvisol, and lithosol. Therefore, the K-value selected for the Inne catchment ranges from 0.02 mm to 0.35, based on the Standard Unit Plot of Environment for soil types.

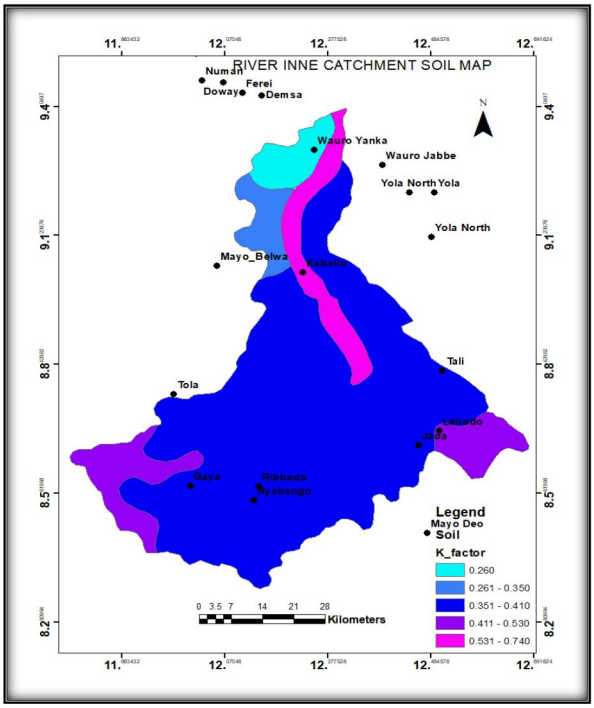



Figure 4: Soil Map of Mayo-Inne (K-Factor)

***Rain Erosivity (R-factor)***

The quantity of rain in an environment determines the modification of the R-factor; soil erosivity is the annual summation of the energy and the intensity (EI) value of a normal year's rain. When other factors remain constant, the storm losses from rainfall are directly proportional to the kinetic energy of the storm (E), multiplied by the maximum 30-minute intensity (I). The annual rainfall of the Inne catchment ranges from 1100 mm to 1300 mm.

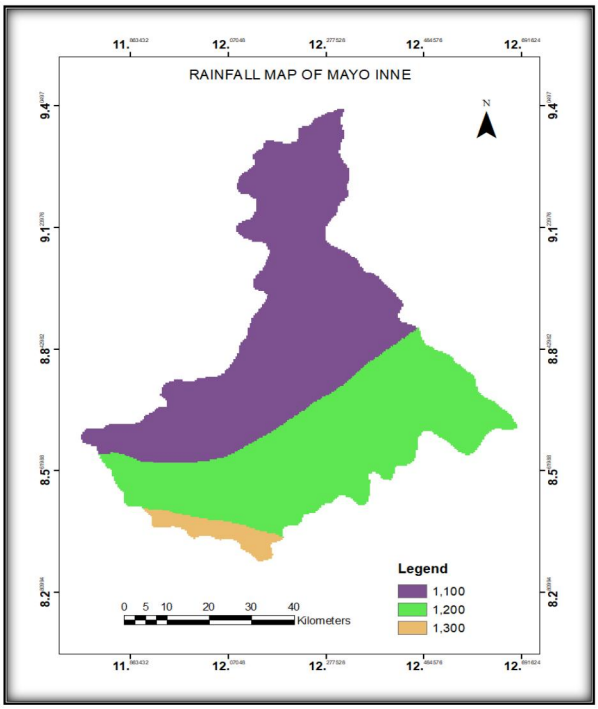



Figure 5: Rain Erosivity of Mayo-Inne (K-Factor)

***Slope Length***

The digital elevation model represents the topography of an area; it shows the nature of either undulating or flat terrain. A DEM is a numeric representation of the spatial variation in the land surface elevation, which represents the land surface as a matrix of elevation values (Z), implicitly located by their geographic coordinates (X, Y, Z).

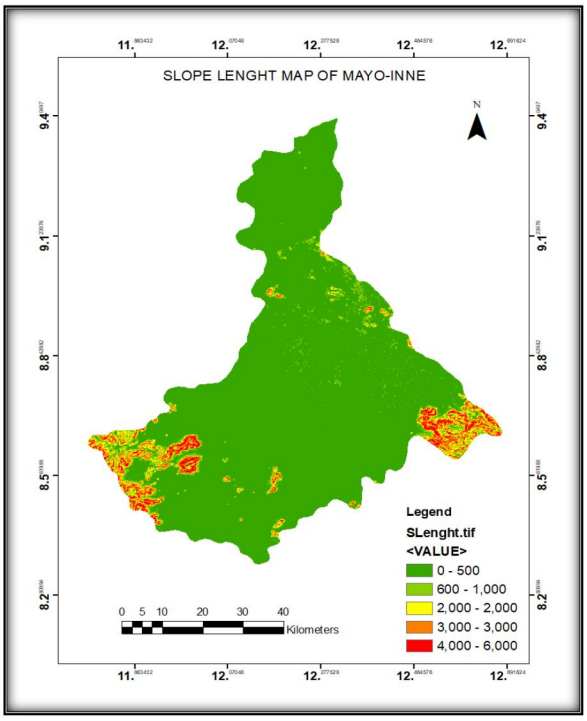



Figure 6: Slope Length of Mayo-Inne (SL-Factor)

**Support Practice (P) Factor**

It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up-and-down slope. As with the other factors, the P-factor differentiates between cropland and rangeland or permanent pasture practices within the Mayo-Inne catchment, which contributes to a precise estimation of flow accumulation.

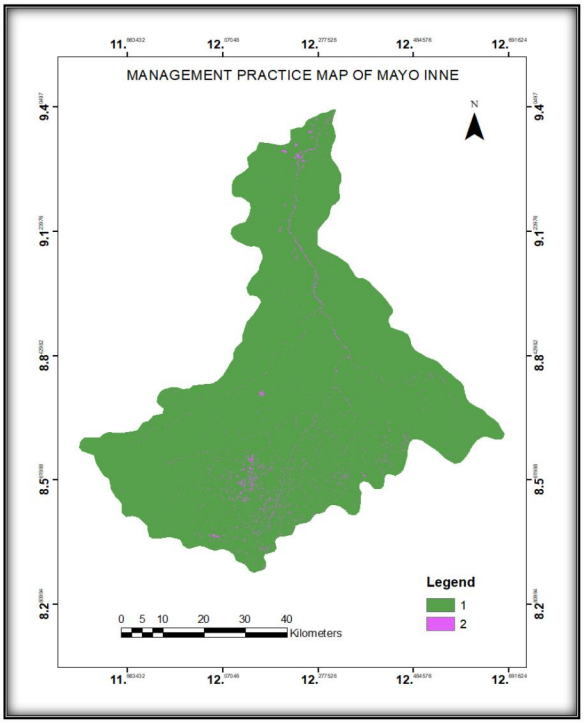



Figure 7: Support Practice of Mayo-Inne (P-Factor)

**Result**

The RUSLE equation A A= C*P*LS*K*R was *used* to determine the annual average soil loss rate in ton/ha/year by the use of the raster calculator of ArcGIS 10.8. The resulting image shows the rate of vulnerability in respect to the locations in degree of environmental effects. The red portion of the map depicts the area with the highest vulnerability effect due to the runoff

rate taking place on the slope of the mountain, and the effects gradually transcend to other areas, and if not mitigated or controlled, the rill erosion will metamorphose into gully erosion in the blink of an eye. The soil loss estimation conducted for the Mayo-Inne catchment reveals a significant variation in annual soil erosion rates, ranging from 18 tons/acre/year (minimum) to 26 tons/acre/year (maximum). This variation reflects the spatial heterogeneity in land use, slope gradients, vegetation cover, and rainfall intensity across the catchment. These findings underscore the severity of land degradation processes and highlight the urgent need for targeted soil conservation strategies in vulnerable sub-watersheds.

When compared to other similar studies across different agro-ecological and climatic regions, the Mayo-Inne values are notably higher than the tolerable soil loss threshold, which is generally accepted to range from 2 to 11 tons/acre/year (4.5 to 25 tons/ha/year) depending on soil type and land use (Morgan, 2005; Lal, 1994). For example, Bewket and Teferi (2009), using the RUSLE model in the Chemoga watershed in Ethiopia, reported soil loss rates of 10 to 22 tons/acre/year, which closely align with the lower boundary observed in Mayo-Inne. Similarly, Adornado et al. (2009) in the Philippines estimated soil loss in upland agricultural areas at 16–23 tons/acre/year, further validating the high-risk erosion context in Mayo-Inne. The estimation figures from Mayo-Inne also resonate with the findings of Amsalu and Mengaw (2014), who observed up to 25 tons/acre/year in severely degraded areas in the North-Western highlands of Ethiopia. Such similarities underscore the broader pattern of land degradation in sub-Saharan Africa, particularly in regions characterized by deforestation, intensive cultivation, and poor land management.

From this comparative analysis, it is evident that the Mayo-Inne catchment falls within the upper erosion-risk category, with its maximum value of 26 tons/acre/year signaling a critical threat to soil productivity and watershed health. These estimates suggest that without immediate intervention through afforestation, terracing, conservation agriculture, and community-based watershed management, the region could face accelerated land degradation, declining agricultural yields, and downstream sedimentation challenges.

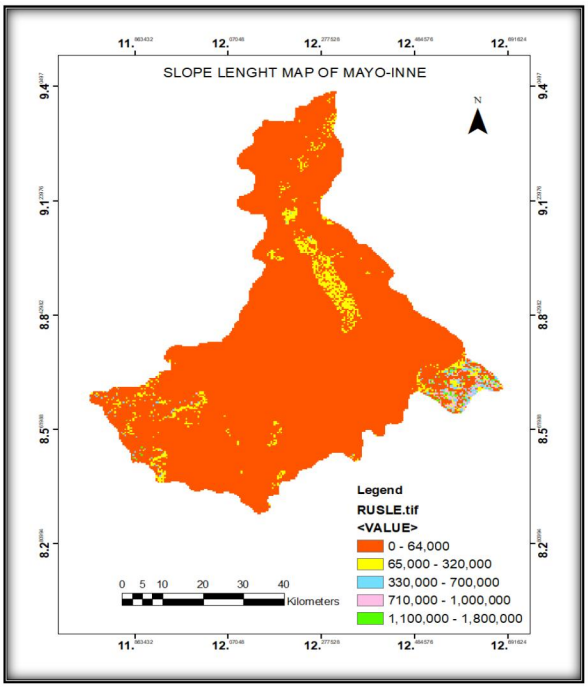



Figure 8: Soil Loss of Mayo-Inne Catchment (RUSLE)

## Conclusion

The increase rainfall in years ahead due to global warming, assert the need to mitigate the effects of soil erosion within the study area, such as good afforestation, drainage system, excavations round the mountains/borrowed pit to collect runoff water.

The soil loss values for Mayo-Inne not only mirror but in some cases exceed those observed in similarly situated tropical catchments. These findings call for integrated land management policies grounded in empirical evidence, participatory conservation planning, and robust monitoring using remote sensing and GIS tools.

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