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Estimating Rainfall Erosivity under Climate Change for Central Zone of Tigray Watersheds, Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The rainfall erosivity factor (R factor) is one of the six erosion factors in the Universal Soil Loss Equation (USLE). Most research on rainfall erosivity deals with the assumption that climate stationarity over time. However, a warming climate might change the behavior of hyetograph rainfall data emphasizing the need for updating the assumption with climate change conditions. Thus, this study presents a generalized framework for estimating rainfall erosivity under climate changes scenarios for Central Zone of Tigray. Twenty- six years (1990 to 2015) rainfall data were collected and used for climate change prediction. Sixteen years of hyetograph rainfall data (2000-2015) were used for the estimation of erosion index and erosivity model development based on the method suggested by Wischmeier and Smith. Three climate change scenarios (RCP2.6, RCP4.5 and RCP8.5) were considered for future climate change prediction. The current time, maximum and minimum annual erosivity index were computed as 6991.9 and 68.58 MJ mm/ha.h.year respectively at Adwa weather station. The annual average erosivity has estimated to be 1707.21 MJ.mm/ha.hr.year for the current time. The erosivity models developed at Adwa weather station

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worked reasonably well and the coefficient of determination for the best selected model was 0.955. In addition, this study indicates that future rainfall erosivity under the emerging climate change scenarios at the study site would increase. The annual erosivity index increments ranges from the minimum value (38.09%) to maximum value (46.15%) at Adwa weather stations as compared to the current time. Therefore, more erosive rainfall events would be expected for the future timelines and will have major implications on watershed planning and management activities in the study area.

Keywords: Rainfall erosivity; climate change; central zone of Tigray; watersheds.

1. INTRODUCTION

Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects. The economic implication of soil erosion is more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients. These countries have also high population growth which leads to intensified use of already stressed resources and expansion of production to marginal and fragile lands. Such processes aggravate erosion and productivity declines, resulting in a population-poverty-land degradation cycle. Man-made soil erosion is as old as agriculture and causes major environmental problems Worldwide. Water erosion is the main cause of land degradation. Rainfall and runoff induced soil erosion can be severe, particularly in humid tropics , especially from the marginal lands with steep slopes and poor structure [1].

In Ethiopia, the problem of soil erosion is widely perceived to be a major environmental threat. Utmost the highlands of Ethiopia that accounts 45% of the countries land area characterized by dissected terrain with slopes ranging from very steep to almost plane became severely degraded mainly due to human induced factors such as deforestation and the old farming practices which give little attention to the land resources [2]. The average crop yield from a piece of land is very low according to international standards, which are mainly due to soil fertility decline associated with removal of top soil by erosion [3]. This upper part of the soil removal always implies nutrient loss, loss of water by runoff, reduction of rooting depth, and water and nutrient storage capacity and sooner or later reduced crop production. Measurements from experimental plots and micro-watersheds showed that the highest rate of soil loss occurs from cultivated fields, which is 42 tons/ha/year, that cost to the national economy about USD 1.0 billion per year [4].

Soil erosion in Tigray region has a long history as aged as the ancient civilization in the area. The severity of the problem in the region is apparent from gullies cutting arable lands, exposure of stones and rocks on cultivated lands and grazing areas, heavy run-off during the rainy season, and declining yields. If any region in Ethiopia would need an environmental first aid, that would be Tigray [5]. Despite the severe land degradation, more than 85 percent of the population depends on agriculture for its livelihood. The high rate of soil erosion in the region and in northern Ethiopia in general, is the result of the mountainous and hilly topography, intense nature of rainfall and low degree of vegetation cover. For the last three decades as a response to catastrophes such as the 1984 famine, huge efforts put on regional scale to control soil erosion, for instance through the construction of stone bunds and rehabilitation of steep slopes [6]. Even though the massive soil and water conservation activities undergoing in the region are remarkably interesting, the establishment is merely depending on guided intervention. The planning of effective and efficient soil and water conservation technologies require an appropriate study of the extent, magnitude and rate of soil erosion.

Precipitation is a major cause of soil erosion, given the extraordinary importance of soil detachment processes due to drop impact and runoff shear. Compared to other natural factors such as the relief or the soil characteristics, rainfall erosivity has very little or null possibility of modification by humans, so it represents a natural environmental constrain that limits and conditions land use and management. Rainfall erosivity is the most important among natural factors affecting soil erosion. Separate study of those factors is the right method to have a good estimate of soil erosion. Rainfall erosivity (R) is one of the six factors in the Universal Soil Loss Equation (USLE)[7]and the Revised Universal Soil Loss Equation (RUSLE) for erosion prediction. Hence, estimating rainfall erosivity is central to the assessment of soil erosion risk. For a storm, this is defined as a product of the storm's total kinetic energy (*E*) and its maximum 30-min rainfall intensity (I_{30}).

Climate change is expected to alter the intensity, duration or frequency of climatic extremes over time. Today, the atmosphere of planet Earth is undergoing changes unprecedented in human history. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change [8], “Warming of the climate system is unequivocal, and many of the observed changes are unprecedented over decades to millennia. This report also concludes with very high confidence that the period from 1983 to 2012 was the warmest 30-year period of the last 1400 years. According to World Meteorological Organization [9], temperatures in 2015 were about 1°C above the pre-industrial era for the first time on records. In the context of climate change, the effect of altered rainfall characteristics on soil erosion is one of the main concerns of soil conservation studies [10].

Studies on soil erosion started in the first decades of the 20th century, and have increased in number and variety since then. Even though it is lately started in Ethiopia, a considerable number of studies have been conducted regarding soil erosion at national and local level. However, all studies in the past were based on one important assumption (i.e. climate change do not affect rainfall intensities and rainfall erosivity for the future soil loss prediction periods). Nonetheless, under the current ‘warning symptoms’ of climate change, rain fall intensities and hence rainfall erosivity values today can not represent future values. Therefore, it is imperative to relate rainfall erosivity index with climate change conditions to account the future impacts of climate change and variability. Therefore, the specific objectives of this research is 1) to estimate rainfall erosivity value under the current and future climate change conditions and 2)to develop iso-erodent map of the study area under the current climate condition. .

2. METHODS AMD MATERIALS

2.1 Study Area

Central zone is one of the five administrative zones of Tigray located on the central part of Tigray. The total land area is about 22133.87km^2. Globally, it is located between 13^0-14.8^0 N latitude and 38.5^0-39.6^0E longitude. The topography is mainly an extension of the central Ethiopian highlands. The Annual rainfall of the study area ranges from 539 to 942.3 mm with significant spatial and temporal variability. Most of the precipitation falls within the three months of June, July and August, with high intensity. The annual temperature ranges with 15C^o to 27C^o.

2.2 Data Sources and Collection Process

Rainfall data were collected from Ethiopian National Meteorological Agency (ENMA). Adwa meteorological station equipped with first class self-recording rain-gauge was selected for annual erosivity index estimation and erosivity index model development. Twenty-six years (1990 -2015) were used for prediction of future climate change, whereas sixteen years (2000-2015) rainfall data was used for estimation of rainfall erosivity index and rainfall erosivity model development. During the processes of data collection, storms of less than 12.7 mm were excluded and rainfall periods separated by more than six hours were considered as separate rainfall events [7]. Maximum 30-minute rainfall events were abstracted from the continuous rainfall charts (rainfall mass curves) at Adwa weather station. For the development of iso-erodent map to the whole study area, rainfall recordings from eight additional meteorological stations have been collected. The location of the weather stations in the study area is indicated in Fig. 2.

2.3 The Climate Change Scenario Data

Climate change scenarios data were obtained from Global Circulation Model (GCM) simulation outputs. For this study, among the different GCM models, the second-generation Canadian Earth System Model (CanESM2) for the African window was used. The nearest grid boxes to the study area (Adwa meteorological Station) containing three emission pathways (RCP8.5, RCP4.5&RCP2.6) which are freely available at the Canadian Climate data and scenarios website(http://www.cccsn.ec.gc.ca/?page=download-intro) was obtained and downscaled to the site level. The CanESM2 is a global climate model of earth system category developed by Canadian Centre for Climate Modeling and Analysis. The resolution is uniform along the longitude with 2.8125° and nearly uniform along the latitude of roughly by 2.8125°.

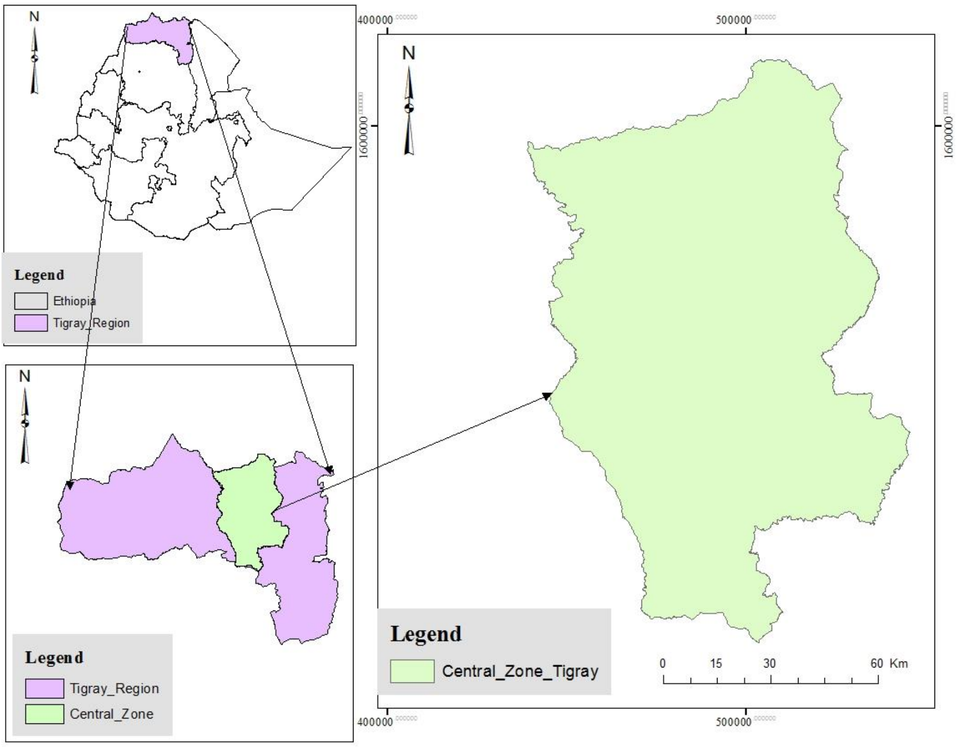

Fig. 1. Map of Study Area

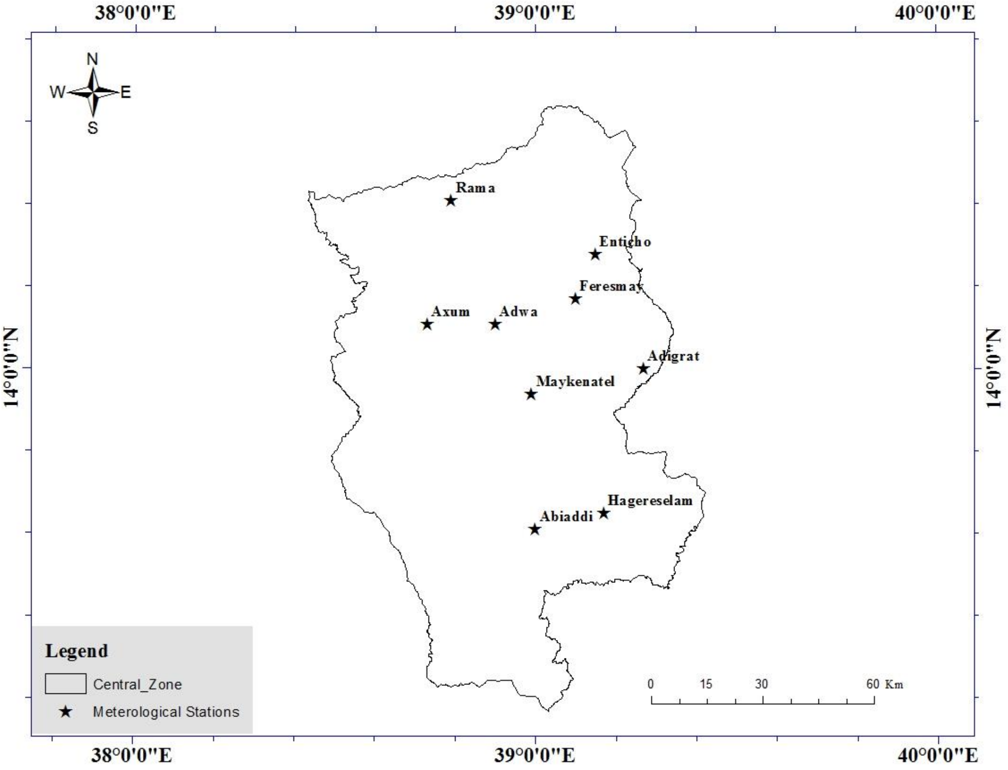

Fig. 2. Location of selected meteorological stations

2.4 Downscaling Daily Precipitation

In this study to bring the course resolution (2.8125^0x2.8125^0) of CanESM2 outputs to a point scale resolution, Statistical downscaling model (SDSM 4.2.9) was employed using daily predictor-predictand relationships. SDSM has been used in different regions of the world and is widely accepted in climate change impact studies. The SDSM is best described as a hybrid of stochastic weather generator and regression based in the family of transfer function methods. It permits the spatial downscaling through daily predictor-predictand relationship using multiple linear regressions and generates predictand that represent the local weather.

2.5 Computation of Rainfall Erosivity

Rainfall charts obtained from Ethiopian National Meteorological Agency (NMA) was used for rainfall intensity records. Analog traces of rainfall depth versus time were read from the chart at each point where the slope of the pen line changes. These breakpoint rainfall data were processed to obtain rainfall intensity in millimeters per hour (mm/hr) for each increment. The I_{30} (maximum 30 minutes rainfall intensity) was calculated by selecting the maximum amount of rainfall for any consecutive 30 minutes duration during the rainstorm. The I_{30} was multiplied by 2 to obtain the hourly values. Maximum 30 minutes intensity was limited to 64 mm/hr. According to [7] explains limiting the I_{30} component of EI_{30} to 64 mm/hr improves the prediction accuracy of the storm. Daily rainfall erosivity refers to individual or multiple storm erosivity and dry periods of six hours or longer is considered to separate storm events [7]. Monthly erosivity is the sum of EI_{30} of all storm events in the month and the annual erosivity is the sum of all storm EI_{30} values within the year. Computation of the rainfall erosivity using the rainfall intensity information obtained from the selected stations, and annual rainfall amounts obtained from stations with non-recording type of rain gauge as independent variables was done. A rainfall threshold of 12.7 mm was considered to calculate erosivity. Rainfall of less than 12.7 mm, and separated from other rain period by more than 6 hrs was not included. For the computation of EI_{30} [7] was used and kinetic energy were calculated using [11] method. Eosivity values for future climate change were calculated by using monthly and annual erosivity models which were developed from the relationships of current erosivity and rainfall values.

2.6 Rainfall Erosivity Modelling

Rainfall erosivity is mainly influenced by the amount and intensity of rainfall. Since rainfall variability across the study area was found very high, to establish different regression models two third of the data (2000-2010) were used for model development and fitted to the annual rainfall amounts against annual erosivity values at Adwa weather station. The selection of the best regression equation was done based on highest coefficient of determination (R^2), the smaller standard error of estimate (MSE), residuals mean squares error (RMSE), percent bias (PBIAS) and RMSE-observations standard deviation ratio (RSR) was used for all selected stations.

2.7 Testing and Validation of the Models

During the processes of model validation, out of the total available data one third of the data (2011-2015) of rainfall-erosivity index data that was not used during model development were used for model validation. After fixing the value of each model parameters using the remaining data set, the model was evaluated whether it represents the actual value or not. The performances of the selected models were tested by model validation measures such as coefficient of determination (R^2), standard error of estimate (MSE), residuals mean squares error (RMSE), percent of bias (PBIAS) and standard deviation ratio (RSR).

2.8 Development an Iso Erodent Map

To map erosivity in the study area, rainfall erosivity values were computed at locations where continuous pluviographic data were available using the erosivity model developed at Adwa weather station. Then the points with known rainfall erosivity values were used to estimate values at unknown points through spatial interpolation techniques. The Iso-erosivity maps represented to obtain spatial distribution of erosivity, with which rainfall erosivity information can be obtained at any location of the study area map with and without rainfall observations. The map was developed with the application of GIS (Arc GIS version 10.1) using Kringing interpolation method.

3. RESULTS AND DISCCUSION

3.1 Estimation of Current Annual Erosivity index (EI_{30} or R-factor)

The erosive rainfall shows a considerable variation for the current estimation years. The highest and the lowest rainfall erosivity index were recorded to be 6991.9 and 68.58 MJ.mm/ha.hr.year respectively. The average annual rainfall for the current time was estimated to be 1707.21 MJ.mm/ha.hr.year (Table 1). As shown from Table 1, the effective rainfall has been a direct relationship with erosion index.

3.2 Annual Erosivity Model Development

As pointed out by [12], the ideal data for at-site estimation of erosivity is high temporal resolution data, such as 30-min interval data [13,14]. Conversion factors are generally used to adjust the *R* factor based on the different intervals of rain data to that based on the hyetograph data [15,16,17].

However, there are fewer recording rain gauges with higher time resolution, and the high-resolution data tend to have greater rates of missing data and shorter record lengths A general technique used for erosivity estimation is to develop simple empirical relationships between erosivity from limited finer resolution data and coarse-resolution rainfall, such as daily, monthly, and annual rainfall, and then to extend the relationship to wider areas with coarser temporal resolution rainfall data.

Hence in this study, different regression models relating annual erosive rainfall values and annual erosion index values were developed for Adwa weather station. Out of these, the best model was selected based on model performance criteria. The coefficients of determination for Adwa were found to be 0.955. Linear relation type erosivity index predictive equations were best performed for Adwa weather station. As shown from Fig.3 and Equation (3.1), the annual erosivity factor (Ra) is linearly related with the annual mean rainfall (Pa) at Adwa weather station. The Annual erosivity model is indicated in equation 3.1.

$$Ra = 1.831 * Pa + 133.3 \quad , R^2 = 0.955 \ldots (3.1)$$

Where, Ra, Mean Annual Rainfall index (MJ.mm/ha.hr.year) and Pa, Mean Annual Rainfall (mm).

3.3 Model Performance Evaluation

The relationship between rainfall and erosivity values was determined. Accordingly, using a scatter diagram the best fitting curve was selected based on the highest coefficient of determination (R^2). Additional statistical performance measures such as Nash-Sutcliffe coefficient of Efficiency (NSE), Percent of bias (PBIAS), Root Mean Square Error (RMSE), Root mean square error standard deviation ratio (PSR) and residual mean square (RMS) were also used. The best models were selected based on their performance. The annual predictive models have a very good performance in explaining the relationship between annual rainfall and erosivity index.

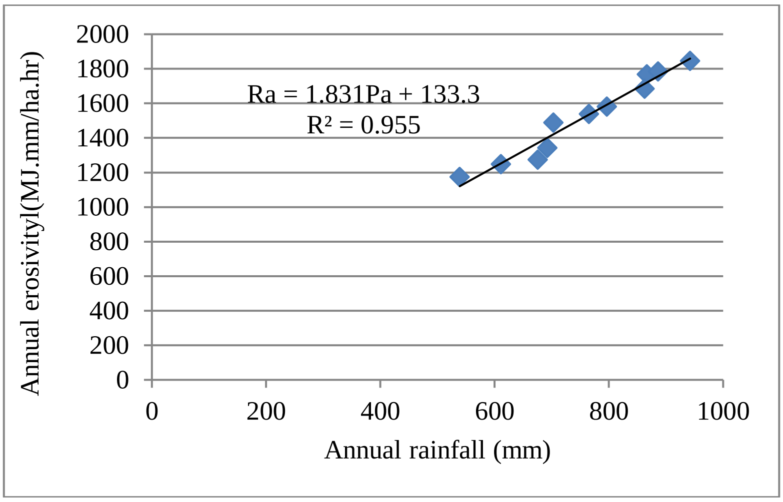

Fig. 3. Regression model for predicting annual rainfall erosivity at Adwa

Table 1. Mean Annual rainfall (mm), Erosive rainfall (mm) and erosion index (EI_{30}) in at Adawa weather station

Year	Rainfall(mm)	Effective Rainfall(mm)	Erosivity, EI30 (MJ.mm/ha.hr.year)
2000	764.9	83.76	1139.46
2001	692.4	133.82	3223.04
2002	539	25.69	153.25
2003	866.4	92.46	722.34
2004	702.9	76.98	613.11
2005	796.4	104.45	791.85
2006	862.8	115.64	1685.89
2007	886	268.5	3358.26
2008	675.6	75.00	575.36
2009	610.8	65.34	548.38
2010	942.3	471.75	6991.9
2011	609.6	49.48	418.98
2012	929.2	508.13	5687.26
2013	565.3	31.88	571.96
2014	911.48	83.85	765.81
2015	794.64	620.57	68.58
Mean Annual	759.35	175.45	**1707.21**
Maximum	942.3	620.57	6991.9
Minimum	539	25.69	68.58

Table 2. Annual predictive models and their performance at Adwa weather station

Station	Equation	Model performance					
		R^2	NSE	MSE	RMSE	RSR	PBIAS (%)
Adwa	Ra= 1.831(Pa)+133.3	0.960	0.940	2243.63	47.37	0.200	-4.0

Table 3. Selected atmospheric predictors for Adwa Weather Station

Atmospheric Predictors	Notation
Specific Humidity at 500 hPa	ncephs500gl
500 hPa Zonal velocity	ncephp5-ugl
500 hPa Geo-potential height	ncephp500gl
Mean Sea level Pressure	ncephmslpgl
wind direction	ncephplthgl
850 hpa airflow strength	ncephplthgl850-fgl

According to [18],the minimum criteria set as >0.5 for NSE and R^2, ≤ 0.7 for RSR, ±0.25 for PBIAS was satisfied at all selected stations and hence the developed annual erosivity predictive models perform to a good accuracy in explaining the relationship of annual rainfall amount and annual erosivity values.

3.4 Rainfall Erosivity under Future Climate change

Selected atmospheric predictor variables: The NCEP-NCAR reanalysis data sets, contains twenty six atmospheric variables called predictors. Among those twenty six predictor variables, predictor variables that produce better partial correlation at 5% significance level with the observed rainfall (predictand) variable were chosen to establish predictand/predictor relationship for the calibration and generation of the future climate change scenario outputs. The screened variables during downscaling process are described in (Table 3). Six predictor variables were found to be appropriate for Adwa weather station based on their partial correlation values.

Daily synthetic rainfall time series were generated for the whole 21st Century (2006-2100) for RCP2.6, RCP4.5 and RCP8.5 climate change scenarios. The outcome of the 20 ensembles of future climate change was averaged and divided into three-time horizons, which are the near term 2020s (2011-2040), midterm 2050s (2041-2070) and the long-term 2080s (2071-2100) for further analysis of climate change impact on erosion index.

Rainfall Erosivity Index (EI30 or R- factor): Based on the annual erosivity model developed from the current period, annual erosivity values for the future time period under RCP2.6, RCP4.5 and RCP8.5 climate change scenarios were estimated. Tables (4-6) illustrate the mean annual rainfall erosivity value under RCP2.6, RCP4.5 and RCP8.5 for different projection time horizons. In the case of RCP2.6, near term (2020s) time horizon the maximum and minimum erosivity value would be 2819.6 and 2183.04 MJ.mm/ha.hr.year respectively. For the mid-term (2050s) time horizon the maximum and minimum value would be 2819.67and 2290.84 MJ.mm/ ha.hr.year respectively and for the long term (2080s) time horizon, the maximum value 2772.97 MJ.mm/ha.hr.year and minimum value 2283.26 MJ.mm/ha.hr.year would be expected.

Under RCP4.5 intermediate emission scenarios for 2020(2011-2040) time horizon the maximum and minimum value would be 2725.03 and 2228.20 MJ.mm/ha.hr.year respectively. In the mid-tern (2050s) time horizon 2806.90 and 2227.17 MJ.mm/ha.hr.year would be expected as the maximum and minimum erosivity values respectively. In the long-term (2071-2100) time horizon maximum and minimum value would be 2892.23 and 1124.04 MJ.mm/ha.hr.year respectively.

Were as, in RCP8.5 higher emission scenarios the maximum value is 2801.50 MJ.mm/ha.hr.year with a minimum value of 2232.15 MJ.mm/ha.hr.year under 2020s (2021-2040) time horizon. In the mid-term (2041-2070) time horizon the maximum and minimum value would be 2957.56 and 1846.10 MJ.mm/ ha.hr.year. For the long-term (2070-2100) time horizon the maximum and minimum erosion index value would be 3007.40 and 2436.24 MJ.mm/ha.hr.year respectively.

Table 4. Estimated annual erosivity index (MJ.mm/ha.hr.year) for RCP2.6 at Adwa Weather Station

RCP 2.6					
2020s		2050s		2080s	
Year	**Erosivity index(R)**	**Year**	**Erosivity index(R)**	**Year**	**Erosivity index(R)**
2011	2787.03	2041	2695.33	2071	2464.90
2012	2646.76	2042	2640.81	2072	2699.48
2013	2336.19	2043	2645.30	2073	2732.63
2014	2462.84	2044	2720.23	2074	2290.58
2015	2590.42	2045	2438.86	2075	2614.02
2016	2377.09	2046	2528.34	2076	2656.65
2017	2527.05	2047	2595.43	2077	2305.45
2018	2234.17	2048	2290.84	2078	2291.23
2019	2497.66	2049	2669.97	2079	2699.61
2020	2649.86	2050	2709.45	2080	2632.98
2021	2619.89	2051	2449.60	2081	2494.88
2022	2448.36	2052	2463.69	2082	2587.29
2023	2475.12	2053	2524.61	2083	2386.75
2024	2183.04	2054	2443.51	2084	2363.27
2025	2468.92	2055	2495.02	2085	2429.07
2026	2698.43	2056	2598.81	2086	2570.37
2027	2669.32	2057	2648.07	2087	2283.26
2028	2642.64	2058	2648.07	2088	2563.07
2029	2674.13	2059	2735.50	2089	2680.71
2030	2531.52	2060	2791.47	2090	2772.97
2031	2343.22	2061	2666.88	2091	2546.39
2032	2424.81	2062	2566.66	2092	2492.91
2033	2579.14	2063	2754.80	2093	2617.91
2034	2589.54	2064	2525.94	2094	2673.32
2035	2484.19	2065	2819.67	2095	2500.13
2036	2706.81	2066	2717.44	2096	2455.23
2037	2628.62	2067	2704.07	2097	2591.16
2038	2564.72	2068	2446.25	2098	2433.37
2039	2284.12	2069	2348.19	2099	2528.78
2040	2650.75	2070	2496.82	2100	2764.17
Mean Annual	2525.879		2592.654		2537.418

Table 5. Estimated annual erosivity values (MJ.mm/ha.hr.year) for RCP4.5 at Adwa station

RCP 4.5					
2020s		**2050s**		**2080s**	
Year	**Erosivity index(R)**	**Year**	**Erosivity index(R)**	**Year**	**Erosivity index(R)**
2011	2229.23	2041	2433.14	2071	2665.25
2012	2436.36	2042	2641.43	2072	2608.91
2013	2498.77	2043	2557.81	2073	2732.52
2014	2536.50	2044	2511.65	2074	2575.30
2015	2563.25	2045	2571.63	2075	2633.77
2016	2633.33	2046	2671.90	2076	2892.23
2017	2442.82	2047	2615.54	2077	2716.78
2018	2245.09	2048	2227.17	2078	2259.40
2019	2555.81	2049	2616.34	2079	2737.80
2020	2607.98	2050	2785.45	2080	2534.97
2021	2645.54	2051	2550.71	2081	2711.51
2022	2491.12	2052	2519.65	2082	2559.06
2023	2586.91	2053	2802.09	2083	2391.70
2024	2539.27	2054	2471.87	2084	2613.61
2025	2683.61	2055	2775.11	2085	2708.24
2026	2597.31	2056	2381.34	2086	2753.30
2027	2606.48	2057	2624.84	2087	2418.46
2028	2388.22	2058	2709.89	2088	2820.69
2029	2606.11	2059	2779.55	2089	2811.96
2030	2725.03	2060	2610.28	2090	2680.50
2031	2479.04	2061	2688.57	2091	2815.68
2032	2509.78	2062	2458.85	2092	2722.42
2033	2627.13	2063	2806.90	2093	2675.61
2034	2515.94	2064	2796.11	2094	2674.11
2035	2675.32	2065	2495.95	2095	2607.68
2036	2717.94	2066	2459.76	2096	2579.52
2037	2627.49	2067	2625.10	2097	2582.49
2038	2228.2	2068	2716.20	2098	2769.73
2039	2627.22	2069	2670.36	2099	2673.58
2040	2630.27	2070	2673.32	2100	2664.82
Mean Annual	2541.902		2608.284		2653.053

Comparison of current and future erosivity: Erosivity values from the historic climate conditions were compared with erosivity values estimated under the emerging climate change scenarios for Adwa weather station to quantify the change in rainfall erosivity. Comparisons between the current and future rainfall erosivity values were made in terms of the relative difference given by Slobodan et.al, [19]. The mathematical expression is given by:

$$\mathrm{RD} = \left(\frac{(\mathrm{X1} - \mathrm{X2})}{\left(\frac{\mathrm{X1} + \mathrm{X2}}{2}\right)}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where: RD is relative difference (%), $x_1$is mean erosivit of rainfall under future climate change and x_2 is mean erosivity of rainfall under the current climate condition. Table 7 illustrates the relative difference in mean annual erosivity of the future climate change periods as compared to the current time.

As illustrated above in Table 7, the rainfall erosivity at Adwa weather station showed an increasing trend under the future climate change scenarios. The general climate change trends were quantified by percentage difference between the current and future climate conditions. Rainfall erosivity in the near-term (2020s) for the RCP2.6 climate change scenario would be expected to increase by 38.68% as compared to the present climate condition. Alongside, the rainfall erosivity by 2050s would likely to increase over the current time by 41.18%. In association to this, the rainfall erosivity by 2080s will increase up to 39.29% .Generally rainfall erosivity for Adwa weather station would be expected to increase with varying ranges up a maximum range of 46.13% for RCP8.5 climate change scenario in the long-term period (2080s) (Table 7).

Table 6. Estimated annual erosivity values (MJ.mm/ha.hr.year) for RCP8.5 at Adwa station

RCP 8.5					
2020s		**2050s**		**2080s**	
Year	**Erosivity index(R)**	**Year**	**Erosivity index(R)**	**Year**	**Erosivity index(R)**
2011	2601.31	2041	2791.81	2071	2854.66
2012	2232.15	2042	2838.42	2072	2684.31
2013	2429.62	2043	2646.15	2073	2753.15
2014	2482.03	2044	2629.44	2074	2726.71
2015	2340.42	2045	2617.57	2075	2767.82
2016	2517.78	2046	2459.81	2076	2742.55
2017	2553.28	2047	2710.48	2077	2729.09
2018	2327.02	2048	2271.74	2078	2436.24
2019	2638.54	2049	2564.53	2079	2826.73
2020	2448.91	2050	2548.79	2080	2620.80
2021	2721.65	2051	2452.88	2081	2655.29
2022	2538.89	2052	2623.78	2082	2851.33
2023	2416.02	2053	2691.49	2083	2881.95
2024	2454.48	2054	2570.36	2084	2876.74
2025	2487.00	2055	2881.33	2085	2851.03
2026	2649.93	2056	2737.63	2086	2760.92
2027	2445.24	2057	2582.02	2087	2805.02
2028	2266.26	2058	2511.28	2088	2627.13
2029	2644.11	2059	2737.06	2089	2585.57
2030	2616.57	2060	2775.46	2090	2600.67
2031	2602.89	2061	1846.10	2091	2777.14
2032	2544.01	2062	2684.15	2092	2627.85
2033	2526.2	2063	2750.78	2093	2632.12
2034	2715.77	2064	2957.56	2094	2775.95
2035	2330.66	2065	2653.93	2095	2683.36
2036	2563.13	2066	2755.70	2096	3007.40
2037	2506.68	2067	2736.39	2097	2730.52
2038	2801.5	2068	2724.60	2098	2807.89
2039	2326.25	2069	2495.70	2099	2647.29
2040	2576.48	2070	2707.64	2100	2599.13
Mean Annual	2510.159		2631.819		2730.879

Table 7. Comparison of erosivity values between current and future climate change scenarios at adwa weather station

Climate Scenarios	Time lines	Mean Annual Erossivity (MJ.mm/ha.hr.year)	Relative Difference (%)
Current	200-2015	1707.21	-
	2020s(2021-2040)	2525.87	38.68
RCP 2.6	2050s(2041-2070)	2592.65	41.18
	2080s(2071-2100)	2537.41	39.12
	2020s(2021-2040)	2541.9	39.29
RCP4.5	2050s(2041-2070)	2608.28	41.76
	2080s(2071-2100)	2653.05	43.38
	2020s(2021-2040)	2510.16	38.08
RCP8.5	2050s(2041-2070)	2631.82	42.62
	2080s(2071-2100)	2730.88	46.13

Mapping erosivity (Iso-erodent Maps): The iso-erodent map of the study area was developed using the estimated rainfall erosivity value of nine weather stations, to show the spatial distribution of rainfall erosivity of the study area as shown in Fig. 4. However, rainfall erosivity of the study area was considered to be high, its magnitude is increasing from South-west to Eastern part of the study area. The highest value of estimated rainfall erosivity (8500 MJ. mm/ha.hr.year) is found at Eastern part of the study area (Fig. 4), on the other hand the lowest value of estimated rainfall erosivity 500 MJ.mm/ha.hr.year is found in the Southern and North-West part. Considering rainfall erosivity of each weather station 73.08%, 15.38% and 11.54% of the study area is subjected to high, moderate and low level of rainfall erosivity according to [20,21] rainfall erosion hazard classification respectively.

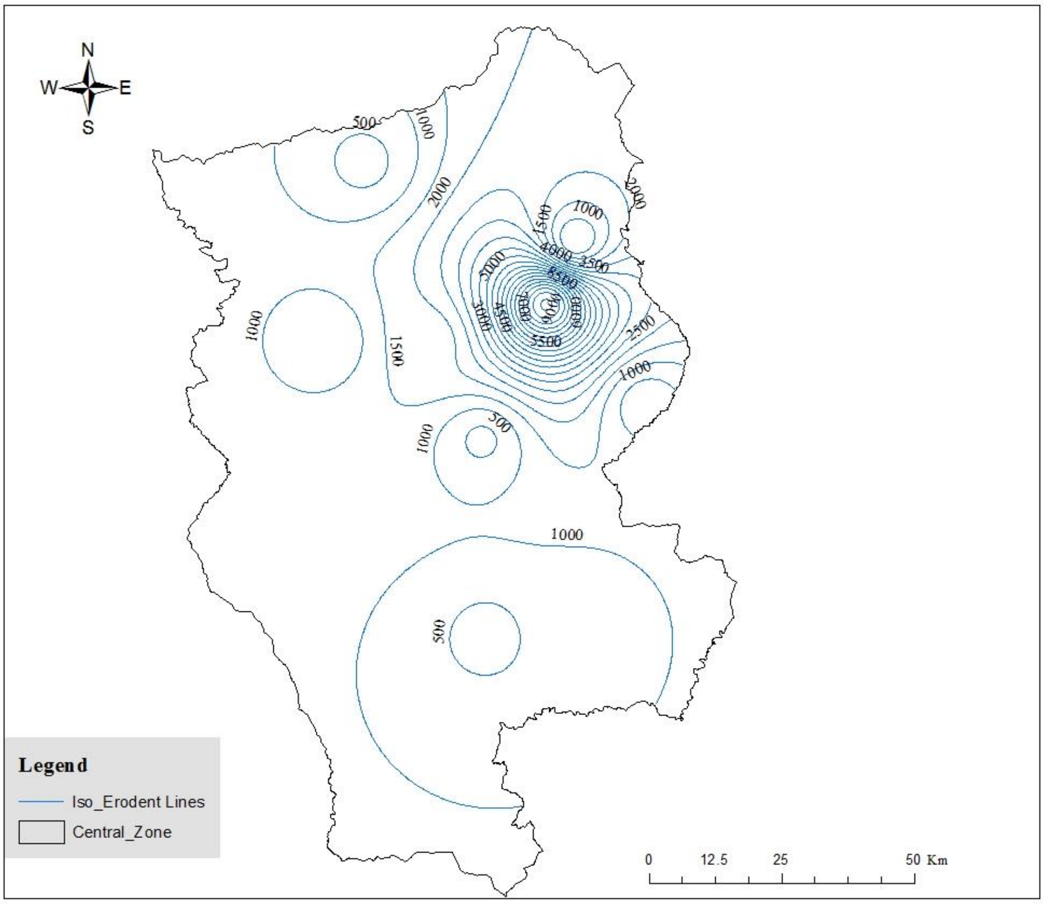

Fig. 4. Eastern part of the study area

4. CONCLUSION

This study estimates the impacts of climate change on precipitation and rainfall erosivity in the Central Zone of Tigray watersheds, Ethiopia. In this study, a single-climate model and a multi-emission scenario approach are used for the estimation of climate change impacts. The statistical downscaling method is used as a downscaling technique to generate future precipitation data. The relationship between annual precipitation and rainfall erosivity can be used to estimate annual rainfall erosivity under future climate. The results of this study indicate that rainfall erosivity changes are unidirectional and vary depending on greenhouse gas emission scenarios. The expected increase in rainfall erosivity may have significant effects on soil and water conservation planning in the study area. Thus, the presumable increase in erosion potential will make more soil conservation efforts necessary in the watershed. However, the quantity and resolution of the results of this study need to be improved by subsequent investigations. More specifically, the findings of the present study can be summarized as:

1. The mean annual rainfall erosivity (R) for Central Zone of Tigray watersheds is 1707.21 MJ·mm/ha/hr/y, with a range between 500 and 9001.90 MJ·mm/ha/hr/y, during the historical period 2000–2015. The highest values are calculated at the mountain range of Adwa and the lowest at central part of Tanqua Abergele mainland.
2. The calculated annual mean erosivity (R) values follow the spatiotemporal characteristics of precipitation depth and intensity over the study area.
3. The projected mean annual erosivity (R) as an average over the study area, follows, in general, the projected changes of precipitation from the selected GCM model.

The results about future values of erosivity (R) inherit a set of uncertainties that have to do with the limitations of climatic models and downscaling methods. This holds true, as well as for the calculated current erosivity values due to limiting and missing data values from the utilized time series. Future research will eventually provide more robust climatic models, as computational power increases and research continues, and hopefully we will also have high quality, high density, observed precipitation data for shorter durations and more stations to estimate more accurately current and projected rainfall erosivity in the study area.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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