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Spatial Variability of Soil Moisture in Newly Implemented Agricultural Bench Terraces in the Ethiopian Plateau

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Abstract: In arid areas prone to desertification and soil erosion, the effectiveness of radical bench terracing in reducing drought risk is dependent on its correct implementation. However, the relationship between proper terracing implementation and the landscape capacity of holding soil moisture is still not understood. Moreover, spatial patterns of Soil Water Content (SWC) within the same terraced hillslope are weakly studied. The present paper analyses SWC variations in four newly implemented terraced sites in Tigray Region, Ethiopia. In all sites, terraced areas show SWC significantly higher than non-terraced ones, with the lower part of the terraced hillslope more humid than the others. A Multiple Linear Regression (MLR) analysis highlighted significant dependency of SWC from the date of analysis, the position in the terraced slope, and its significant positive correlation with the percent of Water Stable Aggregates (WSA) analyzed at the study sites. Since high soil disturbance induces low soil aggregates stability, this result shows how low soil disturbance can significantly increase SWC of radical terraces. Overall, the results of the present paper testify the good performances of bench terraces in Northern Ethiopia in terms of soil water conservation, and can represent a benchmark study informing future terracing implementation in some arid and semi-arid agricultural areas of the world.

Keywords: drought risk; dry stone walls; terracing; terracing implementation; soil water content; land degradation; arid areas; Tigray; Ethiopia

1. Introduction

In many arid and semi-arid areas of the world, water conservation in agricultural soils is key for increasing food security and combating land degradation [1–3]. Moreover, in such agricultural systems, soil erosion represents one of the most serious threats to agricultural development and food security, especially in developing countries [4–6].

Among others, implementation of bench terracing, also known as radical terracing, has long been considered as one of the most effective measures for soil and water conservation [7,8]. Implementation of bench terraces transforms sloppy landscapes into stepped agro-ecosystems in many mountainous regions of the world. The main objective of bench terraces is to increase the usefulness of areas with a steep slope which are very difficult for agricultural practices. Moreover, by reducing plots steepness, terraces can trigger multiple ecosystem services, including erosion control, runoff reduction, and soil water recharge [7].

Especially in arid and semi-arid regions, it is drought that represents the most common hydrological hazard, posing at risk agricultural productions and more in general rural livelihoods [9,10]. Here, the water conservation function of bench terraces is fundamental for sustaining agricultural production under rainfed conditions [11–14].

The impact of bench terracing on increased Soil Water Conservation (SWC) is well documented in scientific literature [7,15] as well as the consequent enhancement of soil fertility and food production [16,17]. Implementation and maintenance of new bench terraces systems still represent technological and scientific issues, given the multiple dynamics associated with those landscapes modifications [7,18], that in worst cases can induce shallow landslides, as well as soil fertility depletion. Most of the research on issues connected with terraces implementation focuses on terraces dimensioning [7,19,20] and, since terracing involves earth movement and thus soil disturbance, on soil fertility management [21–23].

In the framework of drought hazard mitigation, it should be considered that soil disturbances, such as the ones involved with terracing operations, can have an evident impact on soil properties, influencing soil water retention capacity [24–26]. Despite this, studies addressing the relationship between proper and/or improper terracing implementation works and the terrace capacity of holding soil moisture are still lacking. In addition to this, at a detail scale, few studies have been realized on the spatial variability of soil moisture within a hillslope treated with terracing, and limited to East Asian context [27]. More specifically, soil moisture variations within terraced hillslopes have been analyzed focusing only on the variations induced by terrace bench length and riser height [12] and by different soil types within the same terraced system [28]. Although it is evident how spatial variability of soil (and soil moisture) conditions along terraces may imply different management strategies [23], more complex analyses, such as an assessment of soil moisture variations in the upslope-downslope transect of a terraced hillslope, have not been realized. In this framework, we concentrated our attention to Ethiopia, where a large number of terracing projects have been carried out in last years, offering numerous case studies.

Ethiopia, and in particular Tigray Region, represented one of the main hotspots for land degradation and, after some high institutional efforts to revert this issue, they are now representing one of the main ones for land restoration and soil and water conservation [29–32]. Tigray Region, in the northern part of country, is mainly mountainous with a limited amount of rainfall and other water resources. The aridity index of the region varies from 0.098 to 0.652, which divides the entire Tigray into fifteen agro climatic zones, with dominant areas of hot semi-arid, warm semi-arid, tepid semi-arid, and hot arid climates [30]. Agriculture in the area is subjected to high threats of soil-water erosion, and a large number of land restoration projects has been developed in the latest 30–40 years to face this issue [29,33]. Numerous bench terraces sites were implemented in previous few years, since the government of Ethiopia has a large plan to rehabilitate and convert these mountains into hillside farming systems. Accordingly, hillside guidelines have been developed and many hilly areas have been rehabilitated with bench terraces [34]. Studies conducted in the region indicated that landless farmers who started to practice hillside farming on bench terraces are concerned about a potential threats given by low fertility and lack of soil moisture [35]. While a consistent body of literature was developed for measures widely adopted in the region, such as soil and stone bunds and progressive or slow-forming terraces [36–39], less research focused on bench terracing [40–42] which represents a relatively new technique in the area [35]. Some works inferred about the water conservation effect of multiple measures, including bench terraces, at watershed scale [43–45], but, so far, few or no direct information nor an evidence-based analysis of bench terraces effect on SWC is available in Tigray, and moreover in Ethiopia.

In the framework of advancing the knowledge of terraced systems and considering the practical need of evidence-based monitoring of bench terraces implementation in Tigray region, the present paper aims to: (1) evaluate SWC increases induced by newly implemented terracing in four sites located in the area of study, but in different climatic areas; (2) evaluate SWC variations within each single terraced plot under analysis; and (3) analyze the dependence between terraces SWC and the level of soil disturbance induced by terracing implementation at each site.

2. Materials and Methods

2.1. Study Area

Ethiopia is located in the horn Africa at 3° to 15° N and 33° to 48° E and covers an area of 1.1 million km^2 [46]. It has a considerable variation of climate due to its wide range of altitude (110 to 4620) m a.s.l. Among different climatic regions in the country, the annual rainfall and mean monthly temperature vary from 200 to 2000 mm and 10 °C to 20.8 °C, respectively.

Four terraced sites were selected for the study, namely Teshi, Ruba Feleg, Michel Emba, and Enda Chena (Figure 1), located in the northern Tigray Region. Bench terraces were realized during 2012. All terraced systems under analysis are stone walls terraces. For each site, the same number of benches was analyzed.

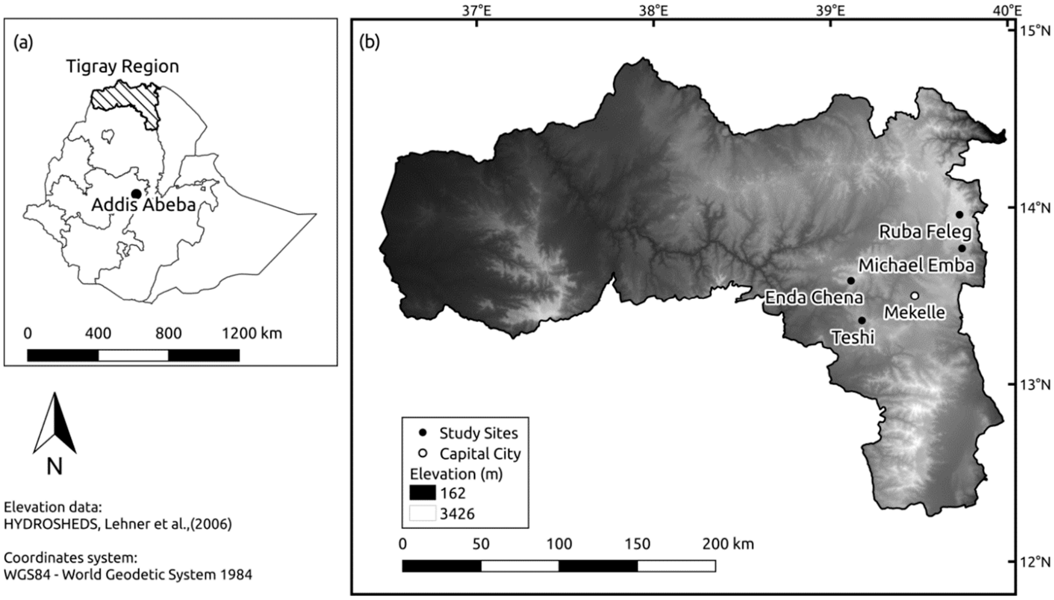

Figure 1. Study area: (**a**) Location of Tigray Region in Ethiopia; (**b**) location of study sites within Tigray Region. Elevation data from [47].

The different areas of the bench terraces are characterized by different geological formations, slope, climate, soil type, standard quality of bench terrace, this latter one evaluated—among others—as degree of disturbance of topsoil induced by terracing operations, measured by the degree of large soil aggregates destroyed by terracing [35]. Each site was divided in three sub-plots, including an upslope (Upper) portion, a middle slope (Middle) portion and a foot slope (Lower) portion (Figure 2). Although at the moment of the survey, land use of the four sites appeared not perfectly homogeneous, only scattered vegetation with large portions of bare soil covered the 4 areas, which were still not fully cultivated. Given this, for the study purposes, the assumption of considering the land cover homogeneous was made.

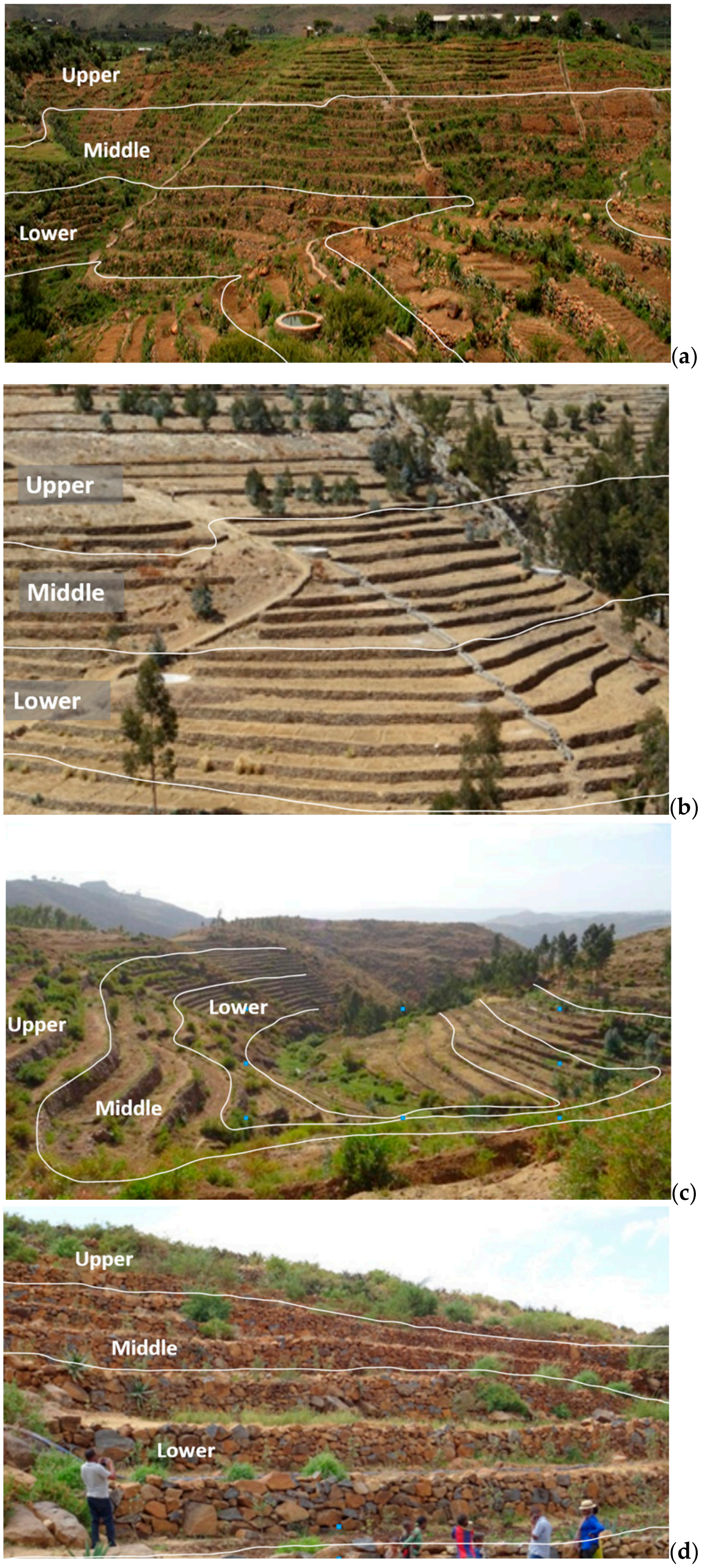

Figure 2. Location of soil sampling sites at the upper, middle, and lower positions of the four hillside farming sites: (**a**) Teshi, (**b**) Ruba Feleg, (**c**) Michael Emba, and (**d**) Enda Chena.

Data about the terraced hillslopes under study were generated in the preliminary study by Mesfin et al. [35] and reported in Table 1, including the characteristics of non-terraced control areas, used as benchmark for checking SWC increases with respect to the standard hillslope setting.

Table 1. Characteristics of the hillside farming positions and adjacent control sites, where: LSD = Limestone with some dolerite, PMSAS = Precambrian meta-sediment and Adigrat Sandstone, AS = Adigrat sandstone, VR = volcanic rock, L = Leptosols, C = Cambisols, R = Regosols, SL = silt loam, L = loam, SCL = sandy clay loam. For further detail, refer to reference [35].

Parameter	Unit	Terrace Position and Control	Teshi	Ruba Feleg	Michael Emba	Enda Chena
Elevation	m a.s.l.	-	2261	2803	2359	2607
Mean Rainfall	mm	-	558	745	715	726
Average Temperature	°C	-	23	16	16	17
Bench width	m	Upper	2.8	6.3	3.6	4.7
		Middle	3.7	5.4	4.7	5.9
		Lower	3.7	4.6	4.9	4.9
Wall height	m	Upper	1.4	0.7	1.8	1.4
		Middle	2.0	1.2	2.3	1.3
		Lower	3.5	1.1	1.9	1.5
Slope	%	Upper	61.3	35.5	44.3	33.0
		Middle	53	25.4	40.7	31.3
		Lower	46	23.3	36.6	23.3
		Control	51.3	27.6	39.4	32.2
Bulk density	g cm^{-3}	Upper	1.23	1.34	1.19	1.09
		Middle	1.23	1.35	1.21	1.11
		Lower	1.24	1.36	1.21	1.10
		Control	1.34	1.24	1.23	1.19
Water stable aggregates	%	Upper	42.5	38.3	33.0	22.0
		Middle	46.3	45.6	42.0	24.0
		Lower	52.7	46.0	43.7	31.0
		Control	39.4	38.9	48.0	31.0
Soilorganic carbon	%	Upper	1.73	1.28	2.04	1.48
		Middle	1.60	1.21	2.00	1.78
		Lower	1.48	1.06	1.81	1.94
		Control	1.80	0.72	1.23	1.13
Soil nitrogen	%	Upper	0.09	0.08	0.13	0.12
		Middle	0.08	0.07	0.11	0.12
		Lower	0.07	0.06	0.09	0.12
		Control	0.10	0.12	0.08	0.10
Soil available phosphorous	ppm	Upper	4.50	3.02	1.57	1.99
		Middle	5.20	2.01	4.22	2.70
		Lower	6.78	1.15	7.31	3.59
		Control	22.30	0.91	1.19	1.14
Exchangeable potassium	ppm	Upper	9.00	0.73	3.45	4.05
		Middle	6.57	0.95	2.75	4.25
		Lower	4.40	1.15	2.25	4.45
		Control	4.90	17.95	4.05	3.55
Geology	type	-	LSD	PMSAS	AS	VR
Soil type	type	-	L&C	L&R	L,R&C	L,R&C
Soil texture*	type	Upper	SL	SL	L	SCL
		Middle	SL	SL	L	SCL
		Lower	SL	SL	L	SCL
		Control	SL	SL	SL	SL

*USDA classification.

Considering rainfall distribution, it should be noticed how Ethiopian highlands exhibit a bimodal rainfall pattern with two peaks: a first minor rainy season (*Belg*), from March to April, and a major rainy season (*Kiremt*) from June to September. However, overall, the whole study area is characterized by elevated rainfall seasonality with more than 80% of the rainfall being concentrated during the main rainy season with long term annual average rainfall ranging from 558, in Teshi site, to 745 mm, in Ruba Feleg site [35]. In any case, farmers in the area use to plant cereal crops during early March and to crop vegetables and cash crop only during the *Kiremt* season [48]. Thus, soil moisture residual in the months of March and April is of a particular importance for the dry season crops cultivated in the area. Moreover, since bench terraced areas are also partially planted with fruit trees and fodder, farmers use this residual moisture for retaining such cultivations and for land preparation for the next cropping season.

2.2. Experimental Setting, Soil Sampling, and Soil Moisture Estimation

Considering that the period ranging from January to April represents one critical spot, when residual soil moisture is particularly needed, the collection of soil moisture data was carried out in three separated dates: 15.02.2017, 15.03.2017, and 15.04.2017. For each day of analysis, eight composite soil samples were collected from each terrace position (upper, middle and lower) areas and adjacent control sites. Soil samples were collected at 0–20 cm of the soil depth for each position, for a total of 384 soil samples.

Soil moisture was calculated through the gravimetric method. Soil samples were oven dried at 105 °C for 24 h. Finally, SWC was calculated as the ratio of weight difference between wet and dry soil to the weight of dry soil. Soil moisture was determined on a dry-weight basis (g water per g dry soil) as:

$$\text{SWC} = (\text{fresh weight} - \text{dry weight})/\text{dry weight} \tag{1}$$

2.3. Data Analysis

2.3.1. Statistical Analysis of Soil Moisture Data

The experiment was conducted in a scheme of sub-subdivided parcels, with tree factors (position, with four levels; site, with four levels; and date, with tree levels; Table 2) and eight repetitions for each treatment. Data were tested after a “log (x) + 10” transformation, showing a normal distribution for the Lilliefors test and a homogeneous variance according to the Cochran and Bartlett test, both with a *p*-value of 0.05. The ANOVA and the test were then applied to compare the means.

Table 2. Description of the factors and levels of the experiment.

Factor	Levels
Position	Upper Middle Lower Control
Sites	Teshi Ruba Feleg Michael Emba Enda Chena
Date	February March April

2.3.2. Multiple Linear Regression

In order to further evaluate the response of SWC to variations of specific variables within a single site and across sites, a Multiple Linear Regression (MLR) analysis was carried out by using the statistics toolbox of the open source software LibreOffice Calc (The Document Foundation, Berlin, Germany). To perform MLR, a single SWC value was obtained for each level of the experiment described in Table 2, averaging the 8 repetitions and obtaining a single SWC value characterized by the site, its position and the date (48 entries). In order to compare the weights of the different variables considered for MLR, both SWC (dependent variable) and independent variables values were normalized.

Semi-quantitative normalized values were calculated for the Position on the slope (Pos_n) and for the date (Date_n). Pos_n values were ordered considering their average SWC value as No terracing, Upper, Middle, Lower; Date_n values were ordered and normalized chronologically (Table 3).

Table 3. Normalized position and date values for Multiple Linear Regression (MLR) (Pos_n and Date_n respectively).

Parameter	Original Value	Normalised Value
Position (Pos_n)	Control	0.000
	Upper	0.333
	Middle	0.667
	Lower	1.000
Date (Date_n)	15/02/2017	0.000
	15/03/2017	0.500
	15/04/2017	1.000

For quantitative parameters, normalized values were calculated as:

$$\text{Val\_n} = [\text{Val} - \min(\text{Val})]/[\max(\text{Val}) - \min(\text{Val})] \quad (2)$$

where Val_n is the normalized value and Val, min(Val), max(Val) are respectively the value correspondent to Val_n, the minimum of all Val values and their maximum.

Soil Organic Carbon (SOC) and Water Stable Aggregates percent (WSA) were included in the analysis, and normalized to SOC_n and WSA_n with Equation (2). WSA parameter was included considering that a reduction of soil aggregation can be generated by high soil disturbance, while high WSA percent can represent an indicator of the level of soil aggregation able to increase soil water retention capacity [49]. SWC was also normalized to SWC_n.

2.4. Rainfall Data of 2016–2017 Season

In order to compare soil moisture data with the rainfall conditions that occurred before the sampling, remote sensing data were retrieved by the Climate Hazards Group InfraRed Precipitation with Station dataset (CHIRPS) [50]. In particular, CHIRPS Daily 2.0 version data were retrieved from Google Earth Engine platform [51] for the study areas. Considering that CHIRPS data performs better than other datasets for East-Africa at decadal and monthly time-scales [52], rainfall cumulates for the period 15/11/2016–14/04/2017 (dry season before the sampling) and for the period 15/04/2016–14/04/2017 (year before the sampling) were considered. Data were collected by considering the centroid of the terraced areas under study as target of the remote sensing analysis.

3. Results

3.1. Statistical Analysis

SWC content average values at each site are presented in Figure 3, showing the value for each position and for each date. Table 4 presents the result of the *t* test, comparing the sites with the position on the bench terrace.

SWC diminished with the time, coherently with the climatology of the area and it is always higher in the terraced area, if compared with the control site. On average, in all sites, terracing determined an overall 110% increase of SWC with respect to non-terraced control plots. These differences are statistically significant in each site.

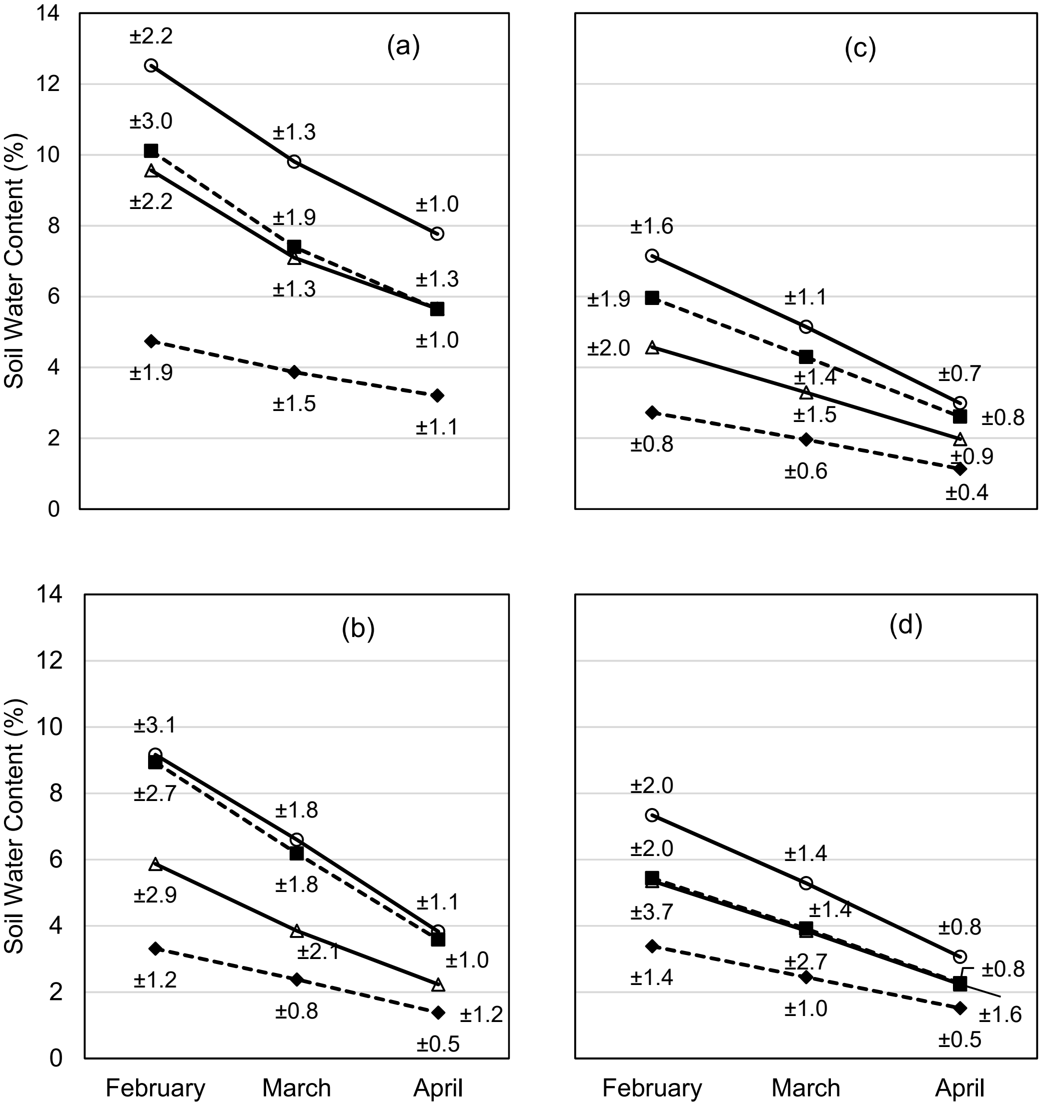

Figure 3. Soil water content (SWC) on the four sites: (**a**) Teshi; (**b**) Ruba Feleg; (**c**) Michael Emba; and (**d**) Enda Chena. The numbers close to the points indicate the standard deviation.

Table 4. Average SWC (in kg/kg) of the four sites evaluated in the four different position of soil samples collection. The same lower-case letters on the columns and upper-case letters on the rows indicate that there is no statistic difference between the means for the t test by the level of 5% of probability.

Position	**Sites**							
	Teshi		**Ruba Feleg**		**Michael Emba**		**Enda Chena**	
Upper	7.44 ± 2.81	bA	3.99 ± 2.58	bB	3.28 ± 1.57	bB	3.82 ± 1.91	aB
Middle	7.72 ± 2.82	bA	6.24 ± 2.92	aAB	4.28 ± 1.95	abBC	3.87 ± 1.95	aC
Lower	10.03 ± 2.50	aA	6.53 ± 3.03	aB	5.09 ± 2.27	aB	5.23 ± 3.22	aB
Control	3.94 ± 1.59	cA	2.36 ± 1.16	cB	1.94 ± 0.9	cB	2.45 ± 1.28	bB

SWC reaches its highest values in the lower terraced portion in each site. In particular, comparing the positions on the terraced area of Teshi, Ruba Feleg, and Michael Emba it can be noticed that the lower part of the terrace has a higher SWC with statistical difference when compared with the upper part. Teshi site has a higher SWC for all the positions when compared with Michael Emba and Enda Chena, while, if compared with Ruba Feleg the SWC in Teshi are statistically higher in all positions, except on the middle of the terrace. Aggregated results shown in Table 4 confirm the decreasing of the SWC through the time, with statistic difference for all positions.

By analyzing the factor position versus date in Table 5, it is possible noticing that there is statistical difference between all the positions when the average of the four sites is considered. This additional analysis confirms the positive effect not just of the bench terrace, but also of the position on the terrace, where the lower part has a higher SWC.

Table 5. Average SWC on the four positions evaluated in the three different dates of soil samples collection. The same lower-case letters on the columns and upper-case letters on the rows indicate that there is no statistic difference between the means for the t test by the level of 5% of probability.

Position	**Date**					
	February		**March**		**April**	
Upper	6.34 ± 3.05	Ac	4.52 ± 2.28	Bc	3.03 ± 1.88	Cc
Middle	7.61 ± 3.07	Ab	5.45 ± 2.12	Bb	3.53 ± 1.65	Cb
Lower	9.04 ± 3.45	Aa	6.71 ± 2.66	Ba	4.41 ± 2.29	Ca
Control	3.54 ± 1.51	Ad	2.67 ± 1.24	Bd	1.81 ± 1.04	Cd

3.2. MLR Results

Table 6 presents the result of MLR analysis, with an r^2 of 0.716. Coherently with the climatology of the area, the normalized date parameter Date_n shows a negative coefficient (SWC_n decreasing in time, moving towards the driest season). As shown also by the statistical analysis, it is evident how lower positions in the terraced hillslope determine higher SWC_n. In addition to this, by the analysis of the coefficients, it is possible to infer how the spatial variation induced by the position of the terrace in the slope (MLR weight equal to 0.293) can be comparable with the one induced by a temporal evolution of 1 month during the dry season (MLR weight of −0.306).

Most importantly, SWC_n shows a significant positive correlation with WSA_n (MLR weight equal to 0.273). Since a careful implementation of terracing, inducing low soil disturbance in newly implemented terraced slopes induces a high percent of WSA [35], the present analysis highlights that a low soil disturbance is of particular importance also for terracing SWC. As a matter of fact, Teshi terraces, carefully implemented in the driest and hottest area, show the highest WSA as well as the highest SWC. The low significance of SOC_n correlation can be explained by the overall low levels of SOC in the newly implemented terraced sites.

Table 6. Results of MLR analysis. The * indicates that the effect is significant by the level of 5%.

	Coefficients	Standard Error	*t*-Statistic	*p*-Value	Lower 95%	Upper 95%
Intercept	0.163	0.069	2.372	0.022 *	0.024	0.302
Pos_n	0.293	0.056	5.249	0.000 *	0.181	0.406
Date_n	−0.306	0.045	−6.794	0.000 *	−0.396	−0.215
WSA_n	0.273	0.073	3.712	0.001 *	0.125	0.421
SOC_n	0.030	0.074	0.406	0.687	−0.119	0.179
r^2		0.716				
Adjusted r^2		0.690				
Standard Error		0.129				

3.3. Rainfall Data of 2016–2017 Season

Rainfall data calculated for the periods before the sampling, and thus directly influencing the analysis carried out in 2017, are presented in Table 7. Results showed that the rainfall amount of the 5 months before the soil moisture data collection were very low in all the areas under study, while for the whole year before the analysis, Teshi, but moreover Enda Chena, showed the higher rainfall amounts.

Table 7. Rainfall amounts from Climate Hazards Group InfraRed Precipitation with Station dataset (CHIRPS) dataset [50] (mm) for the period 15/11/2016–14/04/2017 (dry season before the sampling) and 15/04/2016–14/04/2017 (year before the sampling).

Period	Teshi	Ruba Feleg	Michel Emba	Enda Chena
15/11/2016–14/04/2017	20	39	26	11
15/04/2016–14/04/2017	786	547	566	874

4. Discussion

4.1. SWC Increase Induced by Terracing

The analysis carried out in the paper shows an overall average increase of 110% in SWC from non-terraced control plots to terraced plots, that is of particular relevance considering that data were collected in the driest period for the region. To benchmark the result of the analysis we adopted the framework introduced by Wei et al. [7] for the calculation of ecosystem services of terraced systems. Wei et al. defined key indicators (δ), each one calculated as the ratio of the value of an ecosystem service under terraced and non-terraced slopes. A δ value of 1 represents the threshold to distinguish terracing impacts, considered positive if δ value is >1.

The four sites under analysis revealed an average value of the indicator of soil water recharge ecosystem service (δ_{sw}) equal to 2.10, where the average value at global level is reported equal to 1.20 [7] (Table 8).

Table 8. Percent of increases of SWC in the four sites of analysis. In parenthesis the value of the ecosystem service for soil water recharge (δ_{sw}) calculated according to Wei et al. (2017).

	February	March	April	3-month Average
Teshi	126% (2.26)	109% (2.09)	98% (1.98)	111% (2.11)
Ruba Feleg	141% (2.41)	133% (2.33)	133% (2.33)	136% (2.36)
Michael Emba	116% (2.16)	116% (2.16)	122% (2.22)	118% (2.18)
Enda Chena	79% (1.79)	77% (1.77)	66% (1.66)	74% (1.74)
4-site Average	116% (2.16)	109% (2.09)	105% (2.05)	110% (2.10)

4.2. SWC Patterns Within Terraced Hillslopes

Our analysis focuses on the variation of SWC with the position of the terraces (Upper, Middle, and Lower parts of the terraced system), considering that these latter variations can be coupled with soil as well as crop productivity patterns, already detected by other studies [23,35].

When analyzing the spatial distribution of soil moisture within each terraced sites, our results revealed that SWC increases by descending the terraced hillslope, with the highest values in the lower portion of the terraced system. Our result is confirming the early work on the spatial distribution of SWC in terraced systems by Xu et al. [27], who detected the same decreasing spatial patterns, but within a single sloping bench terrace.

The spatial patterns detected can have a practical impact on soil and water management at the terraced system level, with lower SWC in the upper areas, but it can be counter-balanced, if needed, with differentiated terraced dimensioning (inducing the effects detected by Lü et al. [12]) by cover crops [53] and/or with in-situ water harvesting [54].

However, in the framework of the present analysis, in contrast with the results of Lü et al. [12], the terraced system with the smaller bench length is the one retaining more SWC at 20 cm depth. This latter phenomenon needs further investigation, being possibly linked to the differences in soil characteristics and different climatic conditions between the sites of the two studies.

4.3. Impact of Terracing Implementation on SWC

By comparing the four sites, it is evident how Teshi site has the overall SWC higher in all terraces portions. This latter result may be driven by a relatively higher rainfall amount, while, despite the lowest rainfall amount, Ruba Feleg terraces were the second ones more humid (Table 7).

The results of MLR highlight how this effect can be linked to a better soil structure, as shown by WSA percent, which impact can be comparable to the once induced by the desiccation of soil in time and by the impact of terraces positioning (Table 6). Mesfin et al. [35] conducted an extensive analysis on soil quality in the four sites investigated in the present work, determining how Teshi and Ruba Feleg sites have undergone the better practices of terracing implementation, resulting in a low level of soil disturbance. Mesfin et al. showed how large soil aggregates percent in general (not only WSA) were at the same level or increased from the control plot to the terraced site. On the other hand, Michel Emba and Enda Chena (Table 1) show the highest degree of loss of WSA, and at the same time are showing a lower average SWC (Table 4).

It can then be affirmed that low soil disturbance when implementing new terracing has a considerable impact on the capacity of the new terraced systems in retaining soil moisture. At this purpose, it can be shown how some practical guidelines realized in the framework of large-scale terracing projects [22] already recommend careful management of topsoil while implementing terraces, like, for instance, the practice of removing the topsoil and putting it apart before hillslope profiling, and then replacing it afterwards (Figure 4). These soil management practices can significantly increase the performances of terraced systems in storing soil moisture, especially in rainfall-limited areas, having the potential of reducing soil disturbance and related issues.

Figure 4. Practice of removing the topsoil and putting it apart before hillslope profiling during terraces implementation, according to Bekele-Tesemma, 2011 [22], Rwanda, photo of G. Castelli, 2017.

5. Conclusions

In the present work we analyzed the overall effect on 0 to 20 cm SWC of new bench terraces implementation in Ethiopia, as well as soil moisture distribution within a terraced hillslope.

Results revealed an increase of SWC of 110% on average between non-terraced control plots and terraced ones. Sub-plot analysis revealed an increase of SWC from upslope to downslope position, significant with a *p*-value of 0.05. A MLR analysis revealed how SWC showed a significant dependency from the date of analysis, the position of the sample in the terraced slope.

Our analysis showed also notable relationship between soil disturbance during terraces implementation and their soil water retention capacity. The comparison of the four locations revealed how Teshi and Ruba Feleg sites were retaining the highest SWC, given the best level of soil aggregation in terms of WSA and of large soil aggregates [35], induced by both pre-terracing conditions and careful soil management during terracing implementation.

It is thus evident that low soil disturbances while implementing new terracing systems plays a relevant role in determining the overall performances of the system itself, in terms of water conservation. Spatial patterns of soil moisture identified at terraced plot level can be also taken into account in the management of terraced agricultural systems, in dealing with potential upslope-downslope moisture deficits.

The results of the present paper testify the overall good performances of bench terraces in Tigray Region in terms of soil water conservation. The practical implications of the present work can represent a baseline information for the design and the practical implementation of new terracing projects, but it should be further tested, considering also deeper soil layers.

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