Vol. 14(2), pp. 69-77, 10 January, 2019
DOI: 10.5897/AJAR2018.13076
Article Number: 73EDF8E59805
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Assessment of technical conformity of bench terraces for soil erosion control in Rwanda

Eric Derrick Bugenimana[1]*, Emmanuel Mhache Patropa[2], Charles Karemangingo[1] and Theoneste Bimenyimana[1]

[1]Department of Agricultural Engineering, Faculty of Agriculture, University of Kibungo, P. O. Box 6, Ngoma, Rwanda.
[2]Department of Geography, Faculty of Arts and Social Science,Open University of Tanzania, P. O. Box 23409 Dar es Salaam, Tanzania.

Received 23 February, 2018; Accepted 16 March, 2018

The purpose of this paper was to evaluate technical conformity of bench terraces in the Eastern Province of Rwanda. A sample of 180 actual bench terraces from 12 sites located in this Province was tested against technical standards and models provided for by the Ministry of Agriculture of Rwanda and Food and Agriculture Organization of the United Nations. The results showed that many sites have been constructed with no consideration of these technical guidelines. Terraces were built on land slopes lower or higher than standards while terrace riser slopes above 90% and height above 2.9 m were frequent. Findings indicated weak correlation coefficient (r=0.314), although very significant, between field-measured and Agriculture Organization model-computed vertical intervals, and very weak but significant correlation coefficient (r = 0.194) between terrace measured and model-derived widths. In such circumstances, land terracing might have increased risks of landslide and erosion with no sustainable benefit for soil erosion control and crop production.

Key words: Bench terraces, soil erosion, technical efficacy, Eastern province.

INTRODUCTION

More than 80% of the world's agricultural land suffer moderate to severe soil erosion. Worldwide, the mean annual soil erosion loss on cropland has been estimated at about 30 Mg/ha, while reported values vary from 0.5 to over 400 Mg/ha per year (Pimentel and Kounang, 1998). Recent soil erosion loss estimates from the intensively cultivated highlands of the upper Akagera River indicated average amounts of 35.1 tons/ha in southern Rwanda and 19.2 tons ha^{-1} in northern Burundi (Karemangingo et al., 2014). The history of bench terraces in Rwanda is linked to policies and regulations by the Government and to interventions by Non-Government Organizations (NGOs) (Bizoza and de Graff, 2012). A unique method of back-slope terracing was originally introduced by missionaries growing wheat. Other soil and water conservation techniques had been established earlier, such as hedgerows and slow-forming terraces (progressive terraces). In order to maintain the top soils, which are rich in nutrients, and to keep the riser of the terrace intact, a bench terrace is constructed by breaking up the 25 to 55% slope gradient into several shorter and levelled segments (Posthumus, 2010).

*Corresponding author. E-mail: isimbiella@gmail.com.

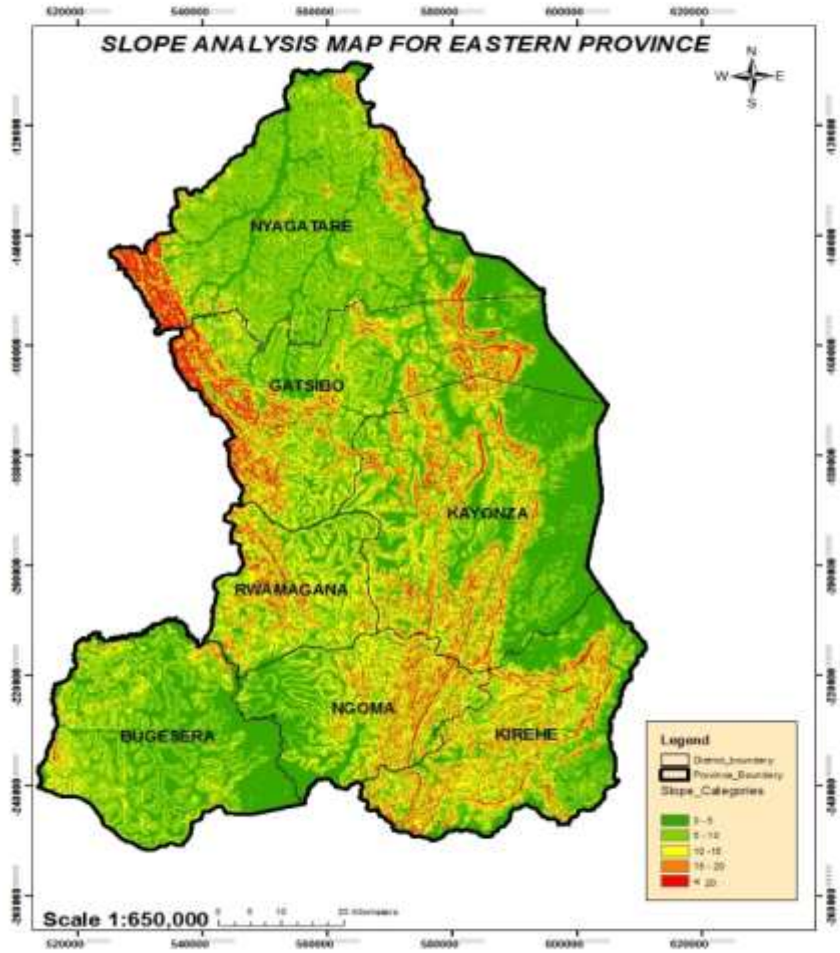

Figure 1. Slope analysis map of the Eastern Province.

In Rwanda some of the bench terraces are constructed on slopes or cuts with sandy or rocky soils, shallow soils, non-cohesive or highly erodible soils, or decomposing rocks including moraines and high slopes. In addition, all soils are not reorganized and fertilized by organic manure and lime after bench terracing as recommended by both Ministry of Agriculture and Animal Resources of Rwanda (MINAGRI) and Food and Agriculture Organization (FAO) norms. Consequently, several areas of the country have experienced floods and landslides on some constructed bench terraces while some terraced lands have been abandoned by farmers after terracing. Around 23.55% of terraced land at national level is not under exploitation (Pimentel and Kounang, 1998). Since land terracing is very expensive but profitable (Pimentel and Kounang, 1998), it was very important to understand the causes of soil infertility, frequent terrace riser destruction, and abandoning of terraced land. This research therefore aimed at analyzing technical efficacy of bench terraces vis-a-vis the standards established by both FAO and MINAGRI (Land and Water Husbandry Service) of Rwanda.

METHODOLOGY

The research was carried out in Eastern Province of Rwanda. The land surface of Rwanda is 26388 km^2 and the country has a population of about 11.78 million (National Institute of Statistics Rwanda (NISR), 2012). The least densely populated districts are found in the Eastern Province. The country is very hilly with steep slope lands and devastating soil erosion exacerbated by over stripping, deforestation, and inadequate use of land improvement techniques (National Institute of Statistics Rwanda (NISR), 2012). The soils of the eastern Province are naturally fragile. They result from the physical and chemical alteration of schistose, quartzite, gneiss, granite, which forms the surface geology of the country. The general geomorphology is a plateau characterized by localized steep slopes (Figure 1) which causes erosion and landslide (Ministry of Lands, Environment, Forests, Water and Mines 2004).

Four Districts were selected out of seven Districts of this Province to host the study as in Table 1. Selected terraced terrains were 25 ha wide or more. Three sites were identified by agro-ecological zones by District for a total of 12 sites. In addition, each selected site must have been terraced under the supervision of either Land

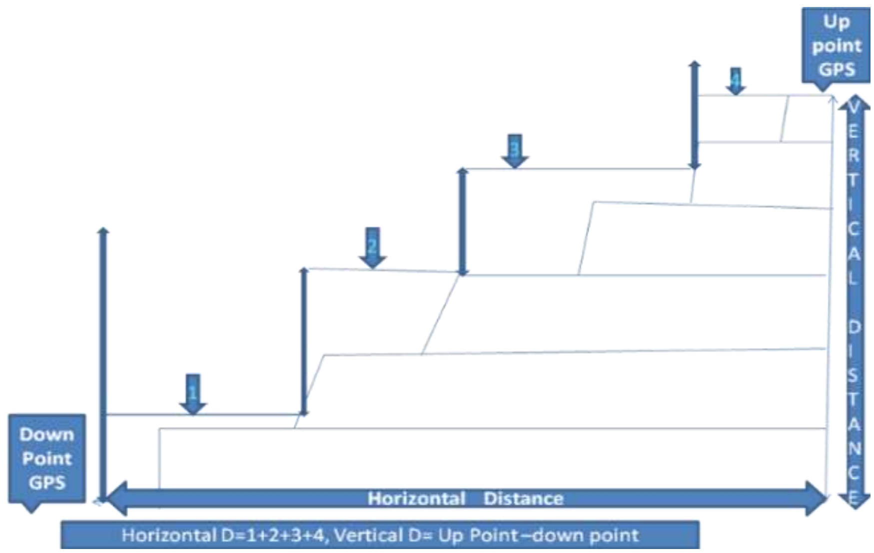

Figure 2. Site slope measurement

Table 1. Selection of study sites in the Eastern Province.

Districts	Sites	Location /Sector
Ngoma	3	Jalama/Musera/Rurenge
Kirehe	3	Kirehe/Mahama/Gatore
Rwamagana	3	Musha/Gahengeri/Mwurire
Kayonza	3	Murund and Mukarange
Total	12	

and Water Husbandry service (LWH), private companies (PC) or Village Umurenge Program (VUP), a national program for local development. Data collection consisted of field observations and technical measurements of implemented bench terraces and their comparison to FAO and LWH standards. Collected data included bed slope, terrace width, vertical interval, heights of risers, and riser slope.

(i) Slope of land was measured as the ratio of the horizontal distance of the land (Figure 2), and the vertical distance as follows:

$$\textbf{Slope}\ (\%) = \frac{\textbf{Vertical Ditance}}{\textbf{Horizontal Distance}}\textbf{x100} \quad (1)$$

(ii) The width terrace: The width terraces were measured in order to find the average width of benches for selected terraces, the total length of the terrace was firstly measured. Therefore, the average width of the bench was calculated by taking different width measurements along that terrace at 5 m interval. The actual mean width is then compared to the expected width as per FAO and MINAGRI models calculated as follows:

$$\boldsymbol{Wb = VI \times (100 - (S \times U))/S} \quad (2)$$

Where VI: vertical interval, in m;
S: slope in percentage (%);
Wb: Width of bench (flat strip), in m;
U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers)

(iii) The vertical interval: Based on LWH, the vertical interval for slopes between 16% and 40% is 1.5 m (Sheng, 2002). For FAO, the width of benches on a specific slope category is equal to the vertical interval. Using this approach, the vertical intervals corresponding to the widths of benches were calculated and compared to LWH guidelines using 1.5 m of vertical interval. Using the below formula, the vertical interval was calculated as follows:

$$VI = \frac{S \times Wb}{100 - (S \times U)} \quad (3)$$

Where VI: vertical interval, in m;
S: slope in percentage (%);
Wb: Width of bench (flat strip), in m;
U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers. The 0.75 value was used because the bench terraces of our case study were hand-made by human labor.

(ii) Heights of riser: After vertical interval was obtained it is easy to figure out the height of riser of the terraces. For level terrace, *VI* equals the height of the riser. For reverse sloped terraces, the *VI* needs to add a reverse height to get the total height. The reverse height was calculated by the following equation:

$$Hr = \text{Wb x0.05} \quad (4)$$

Where *RH* is reverse height;
Wb is width of bench;
5% is the reverse slope.

(iii) The slope of risers: The slope of risers were measured on 15 terraces of the up as the samples, the medium terraces and the lower terraces means 5 terraces for each level and the mean was made for each site and calculated. Figure 3 shows the procedure used in measuring of slope of risers.

$$\textbf{Slope}\ (\%) = \frac{\textbf{Vertical distance of riser}}{\textbf{Horizontal distance of riser}}\boldsymbol{x}\textbf{100} \quad (5)$$

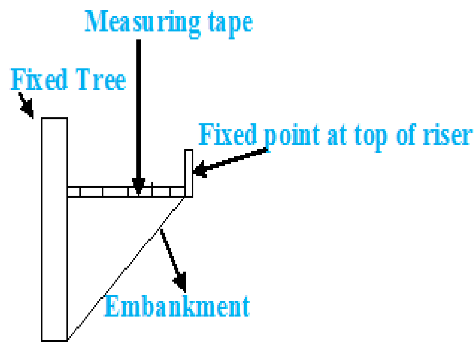

Figure 3. Measurement of embankment slope.

Figure 4. Mean slope of the study sites as monitored for each implementer by District

RESULTS

Land mean slope

Land slope determination is the imperative criteria in selecting soil conservation and management practices for soil erosion control. In that regard, Figure 4 illustrates the study site mean slopes for each implementer (LWH, VUP and PC) by district. The results refer to the measured mean slope of terraced sites in eastern Rwanda by implementer for each one of the four Districts.

Slope of bed and height of embankment

The results in Table 2 represent field-measured terrace parameters by District and by implementer.

Pearson correlations between the parameters

A correlation matrix was calculated between field and expected parameters using the existing FAO models, and the results are presented in Table 3. The parameters include vertical interval measured on field (VIF), vertical interval calculated using the FAO formula (VIFAO), width measured on field (WBF), and width calculated using FAO formula (WBFAO). The results notably represent correlation coefficients between field-measured vertical interval (VIF), model-estimated vertical interval (VIFAO), field-measured bench width (WBF), and model-estimated bench width (WBFAO). The correlation coefficient of 0.314 (with $P < 0.01$) between vertical interval measured on the field and vertical interval calculated using the FAO formula indicates a weak but significantly positive relationship. In the same way, the correlation coefficient of 0.194 (with $P < 0.05$) between field measured width and width calculated using the FAO formula represents a very weak positive correlation between the two variables.

DISCUSSIONS

Land slope and embankment

The land slope is key in selecting the type of soil conservation and management practices. In particular, the slope gradient is important for choosing bench

Table 2. Slope of bed and height of risers.

District	Implementer	Slope of bed (%)	Slope of riser (%)	Height of riser (m)
Ngoma	LWH	3.5	61.4	1.7
	PC	4.1	61.3	1.1
	VUP	2.2	66.0	2.7
Mean		**3.26**	**62.9**	**1.83**
Kayonza	LWH	4.4	68	1.2
	PC	3.47	90	0.88
	VUP	3.07	74.5	2.9
Mean		**3.64**	**77.5**	**1.6**
Kirehe	LWH	2.6	68.87	2.23
	PC	N/A	N/A	N/A
	VUP	2.0	69.63	2.44
Mean		**2.3**	**69.25**	**2.3**
Rwamagana	LWH	4.0	65.1	1.2
	PC	1.8	74.1	1.3
	VUP	2.7	70.6	2.1
Mean		**2.83**	**69.9**	**1.53**

Table 3. Correlations between parameters.

		VI-FAO	VIF	WB-FAO	WBF
VI_FAO	Pearson Correlation	1.000			
	Sig. (2-tailed)				
	N	165			
VIF	Pearson Correlation	0.314**	1.000		
	Sig. (2-tailed)	0.000			
	N	165	165		
WB_FAO	Pearson Correlation	-0.071	-0.080	1.000	
	Sig. (2-tailed)	0.364	0.310		
	N	165	165	165	
WBF	Pearson Correlation	-0.172*	0.065	0.194*	1.000
	Sig. (2-tailed)	0.028	0.407	0.013	
	N	165	165	165	165

terraces. The study results in this paper as presented in Figure 4 indicated that bench terraces were chosen regardless of the land slopes for some sites. Land slope steepness is above or below recommended levels for terraces. That is notably true for terraces located in Kayonza district where some were constructed on 44% slope gradient while others were established on 11% slope gradient. The success of terraces above 40% slope gradient is doubtful because of high risk for riser collapse while cheaper and equally efficient conservation measures such as soil bunds are available below 15% slope gradient. According to Azene (2011), soil bunds must be implemented on soils with slope ranging between 10 to 15% whereas bench terraces must be established on soils having between 16 to 40% slope gradient and forestation is appropriate for the land above

Plate 1. (1) The embankment started cracking few weeks after terracing, (2) abandoned terraces are actually used as pasture land
Source: Field Data (2015)

40% slope gradient. However, FAO (2013) stated that the bench terraces are only recommended for sites whose slope categories range between 12 to 47% and stated that it depends on construction materials used in construction (tractors or hand). Hence, all the terraces in Rwanda have been constructed by hand.

Concerning the riser slopes and heights, the results field-measured or calculated from field collected data showed that about 85% of investigated terraces have not complied with the established norms. In general, the inclination of riser slope between 30 and 60% results in stability and sustainability of terrace embankments while steeper risers should be planted with grasses to give them same stability (FAO, 2013). The assessment results indicated that, for most of sites constructed by private companies and VUP program, terrace risers are beyond recommendations established by LWH and FAO. Embankment slopes of 77 and 90%, instead of 60 to 70% as recommended by LWH and 30to 60% recommended by FAO, were surveyed in some sites of Rwamagana and Kayonza. Thus, steeper riser is runoff-prone or subject to land slide. It is also an indicator of poor quality embankments which in the future can lead to sudden embankment collapse and destruction. , The embankment gets more fragile as the riser height increases (Sheng, 2002). Tied closely with slope gradient is the gentle slopes receiving storm runoff from above which may have a much higher erosion hazard than very steep slopes near a ridge top. Brian (1990) stated that the experience shows the overall height of a riser should not exceed 1.8 to 2 m; above which the maintenance work will become difficult (Azene, 2011).

Hence if the riser is taller, steep and poorly protected, it effectively becomes an erosion hazard in itself (Sheng, 2002). Therefore, terrace risers become a very important component of terraced hillsides, and their significance increases with steepness of the landscape. Where risers are not protected, they present a distinct erosion hazard. When height of riser is great, it can reduce the cultivable area. Therefore, farmers cut away at the base of risers, primarily to increase cultivable area as shown by Plate 1. The farmer destroyed the risers because they needed to increase the cultivable area while cultivating and planting, but this may also trigger some extra erosion through destabilization of the riser. Secondly, and significantly in certain situations, there are riser failures, where slumping occurs usually when an unstable riser becomes saturated [14]. Grasses should be grown well on the risers. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or graze the grasses. Runoff should not be allowed to flow over the risers on reverse-sloped terraces (Sheng, 2002).

It is obligatory to shape and plant grasses as soon as possible after cutting a terrace. Field observations have shown that some sites were well protected (for instance those constructed by LWH), while many terraces constructed by VUP and CP are not well protected at all. The sites constructed by LWH are well maintained, some of them are projected by fruits trees and agro-forestry trees. Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers (FAO, 2013; Sheng, 2002). Risers require regular care and maintenance. If a small break is neglected, large-scale damage will result (Sheng, 2002).

Plate 2. The old and new risers destroyed by farmers for increasing the cultivation area (photo taken on the field)

The slopes of bed

The benches (Inward Sloping Bench Terrace) are made with inward slope to drain off excess water as quickly as possible (Suresh, 2009). It is essential to keep the excess runoff towards hill (original ground) rather than on fill slopes. These inwardly sloping bench terraces have a drain on inner side, which has a grade along its length to convey the excess water to one side, from where it is disposed-off by well stabilized vegetated waterway.

From the field results, the mean inward bed slope values range from 2.3 to 3.6%. These results are in range with recommended values; but if we consider site by site, several concerns are raised: some terraces constructed by VUP and PC are subjects to destruction by farmers' activities, few of them have been made outward instead of inward slope, some are used by farmers for burning charcoal (Plate 2) and free-grazing their cattle graze (Plate 3).

The bed slope or inverse slope should be between 3 and 7% (Azene, 2011; FAO, 1985), it should be adopted because inverse slope when used for a long term did not provide a sustainable land use management, since few years after construction, this slope is almost removed due to continuous natural process such as drop and rain borne strong runoff speed, velocity and volume which quickly makes runoffs to move downhill thus destroying embankments of concerned terraces and adversely effecting terraces in its southwards path way direction (Suresh, 2009). Complying with LWH and FAO recommended bed slopes, as they play their role in breaking the run-off will result in the long-term sustainability of bench terraces as a soil erosion control practice. It is also expected that reduced runoff water will result in increased infiltration and increased water availability to crop, and ultimately sustainable bench terraces will result in increased crop yields. These suggestions are in line with FAO (1985) who reported that, interfering with runoff and its speed results in increased infiltration rate which ultimately reflect in an increasing crop yield, soil and water conservation and sustainable land use management.

Vertical interval and width of bench

Terrace spacing and width of the bench are normally expressed in terms of the vertical interval at which the terraces are constructed. They depend upon factors like slope, soil type and surface condition, grade and agricultural use. Therefore, the width and vertical interval of bench terraces are crucial parts of bench terraces as quality assessment parameters which, once inaccurately calculated, affect the position and size of terraces on sites. In that regard there is a very close relationship between both width and vertical interval of bench terrace. Terrace spacing depends mainly upon land slope (FAO, 1985). However, it also depends upon the soil and climate. While the cross section will have some effect on the horizontal spacing, the crops to be grown and the machinery that will be used should also be considered. In this respect, the results of this study are in range with the predictions with the exception for few sites. For instance, on the field we measured 1.4 m instead of 0.62 m given by FAO formula found in Kirehe sites and 1.9 instead of 2.7 m on Rwamagana site, respectively constructed by private companies and Vision Umurenge Programme.

Furthermore, FAO has established theoretical standards (which range between 12 to 32% of land slope) to refer when one does not consider the use of formula for example it is the reason why for bench width of 4 m the corresponding vertical interval was 0.94 m in our case. On some sites, the land slopes standards were not considered but the vertical interval and width of the bench

Plate 3. a) The farmers started burning charcoal on new terraces, b) the cattle grazing on bench of terraces (photo taken on Mugesera and Mushasites-Rwanda).

were calculated because few land slopes in this study comply between 10.7 of PC to 44% of VUP implementer. Unfortunately, FAO and LWH did not specify for sites with slopes categories beyond 32% and below 12% (Sheng, 2002). The area dedicated to growing crops will be reduced and it will reduce the yield which could be obtained from those terraces. Poor vertical interval affects position and sequence of bench terraces to be implemented and interfere with agriculture purpose, of which they were implemented (Sheng, 2002). The effective cultivated length of slope between terraces varies with the type of cross section; the back slope of the broad base cross section can be cultivated and therefore is a part of the effective length (FAO, 1985).

CONCLUSION AND RECOMMENDATIONS

The severity of soil erosion in Rwanda motivates the government to invest more in soil conservation for sustaining agricultural production and environment protection. Various agronomic and physical soil conservation measures have been taken and the government continues to put more efforts in soil erosion control. This research carried out in eastern Province of Rwanda evaluated the compliance level of institutions in charge of the implementation of bench terraces across the Province with regard to LWH and FAO norms for bench terrace construction.

The results revealed that some terraces have been built with no consideration of neither LWH recommendations nor FAO norms and standards. In that regard the land slopes are over or under the norms (standards) of bench terraces for some sites. For instance, one site of Kayonza was terraced although the land slope was above 40% (44% exactly) while a 10.7% slope site was terraced instead of using alternative and cheaper practices. Moreover, the slopes and heights of bench riser measured on the fields show that about 85% of sites visited had terrace risers higher than the standards. In addition, many of them were not protected with grasses for improved stabilization as recommended. Therefore, steeper riser is runoff-prone with increased risk of land slide or collapse. In general, the bed slope values are within recommended ranges from 2.3 to 3.6%. Also, vertical intervals and width of the benches were generally within recommended ranges, but few sites existed which the widths are seriously threatened by farmers looking for increased cultivable land (Plate 2) while other farmers use the beds for charcoal burning (Plate 2). Several sites have no waterways and no cut-off drains and some sites without water way and cut-off drains are located below roads and at risks of destruction by the water flow from the roads. It was noted that most of the terraces constructed by LWH were well in compliance with the norms and well protected.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

REFERENCES

Azene B-T (2011). Assessment of the quality of comprehensive of land-husbandry works at LWH project sites. Kigali-Rwanda.

Bizoza AR, de Graff J (2012). Financial cost-benefit analysis of bench terraces in Rwanda. Land Degradation and Development 23:103-115.

Brian C (1990). Terracing re-examined in the light of recent findings in Nepal and Indonesia Research Needs and Applications to Reduce Erosion and Sedimentation. In Tropical Steep lands (Proceedings of the Fiji Symposium, June 1990): IAHS-AISH Publ. No.192, 1990. Gibsons, British Columbia, Canada.

Food and Agriculture Organization (FAO) (1985). Method of erosion control. Rome, Italy.
Food and Agriculture Organization (FAO) (2013). Green manure/cover crops and crop rotation in Conservation Agriculture on small farms. Rome, Italy.
Karemangingo C, Bugenimana ED, Bimyebebe M (2014). Development of catchment management plan for Akanyaru sub-catchment, Nyaruguru district, Rwanda, Kigali-Rwanda
Ministry of Lands, Environment, Forests, Water and Mines (2004). National Land Policy, Kigali/Rwanda.
National Institute of Statistics Rwanda (NISR) (2012). Rwanda 4th Population and Housing Census, Kigali/Rwanda.
Pimentel D, Kounang N (1998). Ecology of soil erosion in ecosystems. Ithaca, New York
Posthumus H (2010). To terrace or not: the short term impact of bench terraces on soil properties and crop response in the Peruvian Andes.

Sheng CT (2002). Bench Terrace Design Made Simple, 12th ISCO Conference, Beijing.
Sheng T/C (2002). Bench Terrace Design Made Simple. Beijing Department of Earth Resources Colorado State University Fort Collins, CO 80523, USA.
Suresh N (2009). Soil and Water Conservation Engineering, Standard Publishers, New Delhi.
Van Dijk AIJM, Bruijnzeel LA (2011). Terrace erosion and sediment transport model: a new tool for soil conservation planning in bench-terraced steep lands. Environmental Modelling and Software 18:839-850.