Original Research Article

Performance Evaluation of Constructed Bench Terraces in Southern Zone of Tigray Region

ABSTRACT

In the varying climate and weather environments and fast-growing population, the production of feed that could meet the demand of this ever-growing population will be challenging with limited land, soil, and water resources. In many developing countries, terraces have been constructed in sloppy, hilly and valley areas to rectify their shortage of cultivated land and severe water erosion problems to meet livelihood demands. In the southern zone of Tigray region, various labor-intensive bench terraces (BTs) have been constructed and are on the way of construction. Despite its coverage and labor intensiveness, these terraces are facing problems such as malfunctioning and collapse of structures leading to unsustainability, unproductiveness and additional labor and material costs. Thus, this study was designed to identify the basis of the above-mentioned problems and to put real solutions for the problems. A multi-disciplinary evaluation of BTs from natural resources and socioeconomic researchers was conducted to identify observational gaps in the stability and sustainability of the terraces and to put ways forward. Technical assessment and measurement of BTs were conducted onsite to evaluate and compare the specification with the recommended specification. Inappropriate site selection, water scarcity, free-grazing and neglected maintenance, poor buffer zone, and stone placement were directly or indirectly major reasons for the failure of bench terrace (BT) structures. Most of the BTs were not supported with biological soil and water conservation materials. Site selection and technical standards of BTs should be done based on recommended specifications with continuous follow-up.

***Keywords**: Bench terrace, Cultivable land, Evaluation, Malfunctioning, Stability, Standard*

1. INTRODUCTION

1.1 Background and Justification

In the varying climate and weather environments and fast-growing population, the production of feed that could meet the demand of this ever-growing population will be challenging with limited land, soil, and water resources [1]. In many developing countries, terraces have been constructed in sloppy, hilly and valley areas to rectify their shortage of cultivated land and severe water erosion problems to meet livelihood demands[2].

The agricultural sector is the main determinant factor in the Ethiopian economy. More than 80 percent of the population is living in rural areas based on agriculture productivity. This agricultural productivity is determined by moisture availability and soil fertility status. However, numerous studies have shown that wide areas of Ethiopian topography especially in the Tigray region have been and are facing severe and accelerated soil erosion [3]; [4]. Soil erosion can seriously impact agricultural production and the well-being of small-scale farmers with small landholding in Ethiopia and most developing countries.

The decline in landholding could lead to lower food production and farm income. Making productive farmers owing very small landholding is very challenging even with the support of improved technology and extension services and programs. As a result of the more susceptibility to food and income uncertainty, farmers having too small farm holdings tend to the trading of crop residue and animal manure as a source of fuel, instead of applying for soil quality and fertility enhancement. The growing decline in farm size could face to degradation of soil, a decline in soil fertility and quality[5]; [6]; [3].

The decreasing land size has affected both the profitability and level of technology use as well as the sustainability of rural livelihoods and their incomes. To resolve the shortage of cultivated land erosion hazards and livelihood demands various bench terraces (BTs) have been constructed in Ethiopia in general and in Tigray particularly. BTs are soil and water conservation structures used to enhance the use of sloppy agricultural land technology. Once the BTs are constructed, they could be shared among landless and unemployed youths in the region. BTs could also be considered as a method of taking land to the water potential area which is the opposite of the approach of taking water to cultivable land[7]; [3]; [5][8].

Bench Terraces (BTs) have been practiced and introduced to the region and the country. However, unlike other soil and water conservation practices it is not well distributed and managed in many areas of the Tigray region. Despite its distribution, BTs are found to be very important structures to create land and job for landless people and reduce run-off and to minimize soil erosion in many countries. But, the construction of BTs is labor, capital, and time-intensive. In Tigray, the intensive labor requirement of bench terrace (BT) construction requires 800 man-days/ha/yr to construct on 49% slopes of the land. In the case of Rwanda and Sierra Leone 708 man-days/ha/yr is needed to construct BT in a 31% slope of the land. The maintenance material and labor costs of BTs are also too challenging[9]; [10][11].

The layout and specification requirements of BTs can be complex for the farmers in Tigray. Development agent and support is very necessary to solve the complexity of BT construction. Clearing of vegetation from the sloppy land during BT construction is also another negative dimension of BTs. In the southern zone of Tigray region, various labor-intensive BTs have been constructed and are on the way of construction. Despite its coverage and labor intensiveness, these terraces are facing problems such as malfunctioning and collapse of structures leading to unsustainability, unproductiveness and addition labor and material costs. Thus, this proposal is generally designed: 1) To evaluate the performance of bench terraces by assessing the major specifications and sustainability of bench terraces (BTs) and 2) To identify the basis of the above-mentioned problems and put real solutions for the problems that could assist in future management, development, and utilization of bench terraces.

2. MATERIALS AND METHODS

2.1 Study area

The study was carried out in the southern zone of the Tigray region specifically at Zatta, Embahasti, and Wegelen watersheds in the districts of Ofla, Endamekoni and Alaje respectively where BTs are mostly practiced. The study areas range from midland (2184 m.a.s.l) to highland (2858 m.a.s.l). The study areas are characterized by undulating topography with an average slope ranging from 36% to 78%. The map and location of each study area are shown in the following figures.

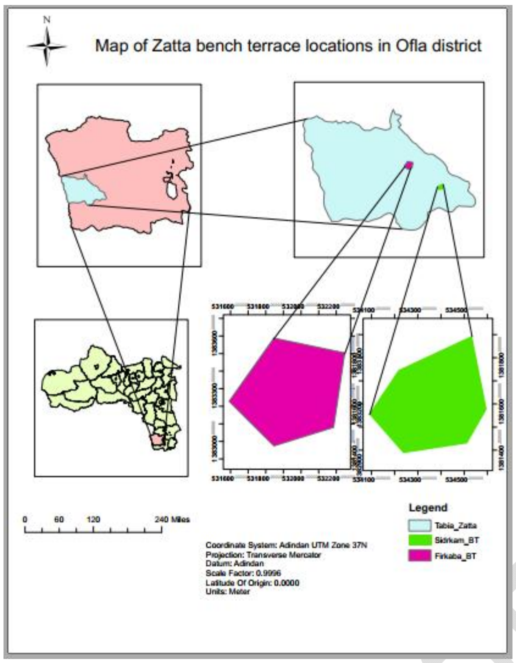

Figure 1 Map of Zatta BT locations

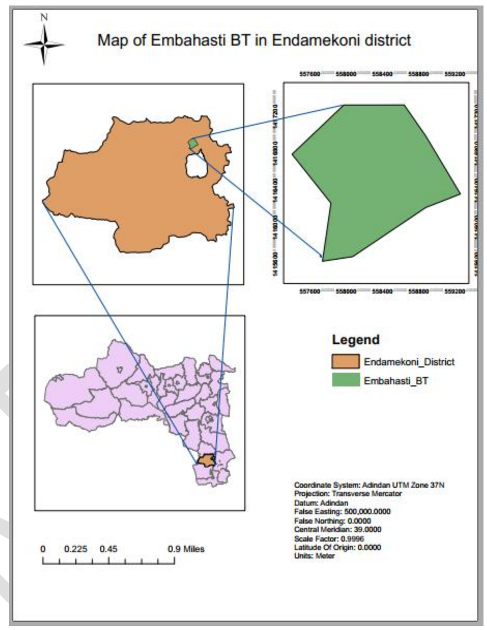

Figure 2 Map of Embahasti BT

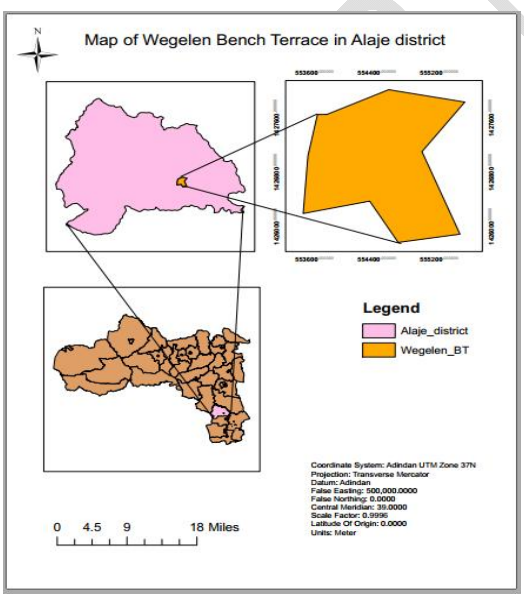

Figure 3 Map of Astela_wegelen BT

2.2 Materials

The following table clarifies the materials used for the study and their specific purpose.

Table 1 Materials used during the research and their purpose

Materials used	Purpose
GPS	To record location data of the study area
Clinometer	To measure the slope of the study area
Meter	To measure BT specifications to compare with recommended specifications
Plastic bugs	To collect soil samples for soil texture analysis
Camera	To take important pictures of BTs

2.3 Methods

This study was applied to constructed BTs in Ofla, Endamokoni and Alaje districts. A multi-disciplinary evaluation of BTs from natural resources and socioeconomic researchers was conducted to identify observational gaps in the stability and sustainability of the terrace and to put ways forward. Technical assessment and measurement of BTs was conducted onsite to evaluate and compare the specification with recommended specification starting from site selection to each specification criteria's such as type of bench, average bench width, length of the bench, net area of the bench, riser height, riser width, riser stand, slope of the terraced area, stone placement, availability of water and maintenance of the BT. Ten samples of each measurement were taken to record the average values of each specification for better accuracy and the slope of each BT were classified into three and recorded three times to take the average value for better estimation.

3. RESULT AND DISCUSSION

3.1 Evaluation of Sidrkam BT in Zatta, Ofla district

For suitable BT selection, the maximum slope for handmade BT is from 12% to 60% and should not exceed 30 degrees (60%) [12]; [13]; [14]. If the terraces are done by hand, the fitting slope range is from 7 degrees to 25 degrees (12.3% to 46.6%) [13]. However, the site in Sidrkam BT was selected on a very steep slope of an average 78% and in sandy and very fragile soil which is beyond the recommendation for the construction of BTs. The steep slope, single line BT, the sandy soil texture and large stone placement at the top of BTs resulted in the collapse of the terraces. The terraces were not supported with biological SWC measures, no buffer zone left, free grazing and no maintenance activities were done. Almost all structures were collapsed forming gullies and changing to degraded land. There was no water source for the terrace and eucalyptus was planted on the terraces which were not the target of constructing BTs. It takes a long time to get benefits from the perennial crops thus raising questions of economic feasibility and the maintenance and sustainability of the BT could be at risk.

Figure 4 Collapse of terraces due to steep slope and fragile soil

Figure 5 Collapse of terraces due to single line stone placement, no buffer zone and not support with biological SWC practices

Figure 6 Eucalyptus tree planted on BT, no waterway and source

3.2 Evaluation of Firkaba BTs in Zatta, Ofla district

The BT in Firkaba has no waterways, no buffer zone in some BTs and there is a collapse of structures in some steep slope (80% slope) areas. Avocado and chili were planted but production was not started yet since the water source is not sustainable and fully functional. However, BT was supported by local biological SWC practices such as '*Oleo berhana*' and '*Becium grandiflorum*.

Figure 7 Collapse of the terrace due to not recommendable slope

Figure 8 BT supported with local biological soil and water conservation practices, chili and avocado planted.

3.3 Evaluation of Wegelen BT in Atsela, Alaje district

The BT in Wegelen was started from the top to down approach which makes it difficult to estimate the amount of earthwork required for cut and fill as well as the depth of BT[2]; [15]; [13]. Some BTs were constructed on a very steep slope (72%). There was no foundation, no buffer zone, and single-line stone placement in some BTs which makes the BT to easily collapse and unsustainable. There was a water availability problem to make it usable for the beneficiaries of that particular BT and large horizontal bed slope without waterway which can lead to damage to the BT and erosion hazard. The soil texture was inappropriate (sandy and fragile soil) leading to the unsustainability of BTS[16]; [11].

3.4 Evaluation of Embahasti BTs in Endamekoni district

This BT was relatively more stable BT than other BTs found in the southern zone of Tigray region. It is supported by biological SWC grasses such as Vetiver, Desho, Elephant grasses and acacia species which can be used as animal fodder and some local biological shrubs and grasses. There is a better sense of ownership and maintenance of the BTs compared to all other BTs constructed in the southern zone of Tigray region. Enough buffer zones were left in most of the BTs which is good for the stability and sustainability of the BTs. It can be taken as a model for other BTs. However, since the area of the buffer zone is wider it is recommended to cover with economically important grasses, shrubs, and trees rather than making it as free space[4]; [9]. In some BTs the infertile soil has been changed to the production of cash crops such as *Rhamnus prinoides*, Potato, Onion, and Carrots due to good management and soil fertility enhancement practices. Economic benefits have been started in a member of 20 groups from *Rhamnus prinoides*, Onion, Carrot and animal fodder from the acacia trees and biological grasses. Planting biological SWC grasses/measures at the top and base of the BTs is recommended for better stability of BTs. However, water availability is the major problem in almost all BTs and the acacia species are rarely used for animal forage and this has to be changed to benefits.

Figure 9 BT supported with Biological SWC practices, animal fodder trees and with a good buffer zone

Figure 10 BT planted with cash crops and supported with biological grasses, shrubs, and trees (both local and exotic species)

3.5 Technical observation and measurement of BTs

Based on the technical observation and measurement of BT specifications level BTs were constructed in all study locations. The selection of BTs was appropriate. Level BTs composed of a level top surface and are used in areas that have medium rainfall and highly permeable soils to absorb surface runoff[17]; [2]. Level BTs are also called irrigated bench terraces provided that they need to be under irrigation [12]. However, irrigation access was the main problem in almost all BTs and the available canal system in some BTs were not functional. Average bench width, Average length of the bench, Average net area of the bench, Average riser height, Average riser width were measured if they were within the recommended range. But, these specifications are dependent on each other and determined by farmer's preference, soil depth, and texture, the slope of the bench. Thus, making comparisons becomes a complex task. The riser stand in most of the BTs was perpendicular except in Embahasti BT. This is not recommended to control and sustain the collapse of terraces instead inclined riser stand is suitable [4].

Table 2 Location of BT and BT specification measurement results

Measured and observed BT Specifications	**Location of BT and BT specification measurement results**			
	Zata-sidrkam	**Zata-Firkaba**	**E/mekoni-Embahati**	**Wegelen_atsela**
Type of bench: (1. Level 2. Inward 3.Outward)	Level	Level	Level	Level
Bench width (m) : (Average Bench Width)	2.46	2.1	4.34	3.97
Average length of bench :	57.3	58.3	23.6	43
Average net area of the bench(W*L) :	140.96	122.5	102.24	170.7
Average riser height:	1.13	1.14	1.58	1.3
Average riser width:	0.24	0.23	0.62	0.38
Riser Stand: (1. Inclined 2. Perpendicular)	Perpendicular	Perpendicular	Inclined	Perpendicular
Average slope of the bench :	78.3	58.67	56	36
Stone Placement: (1. Poor 2. Fair 3. Good)	Poor	Fair	Good	Poor
Availability of Waterways (canal system) for irrigation; (1. Yes 2. No)	No	Yes	Yes	No
Maintenance of the BT: (1. Yes 2. No)	No	No	Yes	No
Soil Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam

4. CONCLUSION AND RECOMMENDATION

Inappropriate site selection, water scarcity, free-grazing and neglected maintenance, poor buffer zone, and poor stone placement are directly or indirectly major reasons for the failure of BT structures. Most of the BTs are not supported by Biological SWC materials. Site selection and technical standards of BTs should be done based on recommendations. The participation of beneficiaries in site selection and layout can reduce the failure of BT structures. BTs have to be supported with multipurpose biological SWC on the top and bottom of the bench and the water availability problem should be rectified by a responsible body. Manual and training to responsible bodies of the BT construction have to be prepared and conducted. Economic feasibility studies should be carried out for future BT practices whether it is economical or not.

REFERENCES

[1] N. Molyneux, G. R. Da Cruz, R. L. Williams, R. Andersen, and N. C. Turner, "Climate change and population growth in Timor leste: Implications for food security," *Ambio*, vol. 41, no. 8, pp. 823–840, 2012.

[2] D. Chen, W. Wei, and L. Chen, "Effects of terracing practices on water erosion control in China: A meta-analysis," *Earth-Science Rev.*, 2017.

[3] H. Gebreslassie, "Opportunities of Bench Terracing in Tigray, Ethiopia : Taking Land to Water Perspective," vol. 22, pp. 33–39, 2014.

[4] K. G. Hurni H, Berhe WA, Chadhokar P, Daniel D, Gete Z, Grunder M, *Soil and Water Conservation in Ethiopia: Guidelines for Development Agents*, 2nd ed. Bern, Switzerland, 2016.

[5] M. Haile, *Sustainable Land Management – A New Approach to Soil and Water Conservation in Ethiopia*. 2006.

[6] H. Hurni, "Degradation and Conservation of the Resources in the Ethiopian Highlands," *Mt. Res. Dev.*, vol. 8, no. 2/3, pp. 123–130, 2016.

[7] G. Taye *et al.*, "Effects of land use, slope gradient, and soil and water conservation structures on runoff and soil loss in semi-arid Northern Ethiopia," *Phys. Geogr.*, vol. 34, no. 3, pp. 236–259, 2013.

[8] K. S. Mushir Ali, "SOIL AND WATER CONSERVATION MANAGEMENT THROUGH INDIGENOUS AND TRADITIONAL PRACTICES IN ETHIOPIA," *Ethiop. J. Environ. Stud. Manag.*, vol. 5, no. 4, pp. 343–355, 2012.

[9] A. Mesfin, "A Field Guideline on Bench Terrace Design and Construction," 2016.

[10] A. Mekuriaw, A. Heinimann, G. Zeleke, and H. Hurni, "Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands," *Int. Soil Water Conserv. Res.*, vol. 6, no. 1, pp. 23–30, 2018.

[11] A. Balbo, A.L., Puy, "Terrace landscapes. Editorial to the special issue," pp. 1–5, 2017.

[12] A. Mesfin, "A Field Guideline on Bench Terrace Design and Construction," 2016.

[13] T. C. Sheng, "Bench Terrace Design Made Simple," in *Proceedings of 12th International Soil Conservation Organization Conference*, 2002, no. Vol. IV, pp. 500-504.

[14] K. Esser and M. Haile, "SOIL CONSERVATION IN TIGRAY, Ethiopia," 2002.

[15] Z. Adimassu, S. Langan, R. Johnston, W. Mekuria, and T. Amede, "Impacts of Soil and Water Conservation Practices on Crop Yield, Run-off, Soil Loss and Nutrient Loss in Ethiopia : Review and Synthesis," *Environ. Manage.*, pp. 87–101, 2017.

[16] T. Mequaninte, R. Birner, and U. Mueller, "Adoption of Land Management Practices in Ethiopia : Which Network Types."

[17] W. Jemberu, J. E. M. Baartman, L. Fleskens, Y. G. Selassie, and C. J. Ritsema, "Assessing the variation in bund structure dimensions and its impact on soil physical properties and hydrology in

Koga catchment, Highlands of Ethiopia," *Catena*, vol. 157, pp. 195–204, Oct. 2017.