

An Assessment of the Socio-economic and Soil Chemical Impact of Afforestation and Terracing on Sustainable Watershed Management: A Case Study of Mwache Watershed, Kwale County—Kenya

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Abstract—Mwache watershed, which had undergone a high degree of degradation, was put under conservation management using afforestation and terracing practices from 2018 to 2023. To find out the socio-economic, ecological and chemical effectiveness of the two conservation techniques, nine villages where the techniques were implemented were studied. Four sites were purposively selected to determine their ecological and chemical effects whereas ninety-two (94) farms were randomly selected. Mixed research design was employed for which experiments, questionnaires and interviews were used in data collection while also utilizing secondary data. Study results indicate that 53.74 acres of initially degraded land were restored with two villages; Mavirivirini Asili and Maweu achieving outstanding conservation rates of 92 and 64 % respectively. Soil tests revealed that organic matter and moistures were in high concentrations in farms where afforestation was performed while pH was higher at the control sites where neither afforestation nor terracing was performed. Extensive land restoration and vegetation renewal was observed in land under afforestation, including resurgence of vegetation such as *Tephrosia villosa* (kabalazi which had previously been depleted. Data analyses which were done using Microsoft excel, SPSS version 29 and charts revealed that produce of *Zea mays* increased 6-fold from 2018 to 2023 as a result of performing terracing with the watershed achieving an overall 37% conservation rate.

Keywords—afforestation, conservation, effectiveness, Mwache, micro-watershed, terracing, watershed

I. INTRODUCTION

Management of watersheds across the world experiences numerous challenges stemming from anthropogenic factors, governance structures, and policy instruments. Watersheds are ideal management units representing a multidisciplinary approach to resource management, geared towards supporting natural resources such as land and water [1]. The growing concern has focused minds of policy makers, NGOs and civil society organs to identify the most effective conservation techniques for efficient watershed management. Efforts have been made across the world to deploy various conservation techniques such as afforestation, terracing, contour ploughing, gabion construction, stone bunding and conservation pits. Four main variables need to be considered in determining the effectiveness of conservation techniques in watershed management; size of watershed conserved, impact of conservation techniques on socio-economic factors, impact of conservation techniques on soil chemical properties and impact on vegetation cover. These factors

could have a direct impact on the effectiveness of afforestation and terracing conservation techniques to realize effective watershed management. According to Robertson and Nielsen-Pincus [2], enhancing sustainability in watershed management requires integration of four main elements; natural resources, technology, institutions, and economics or costs.

Whereas conservation of watersheds through afforestation and terracing have been practiced for several decades across the world, no study is directly linked to evaluating their socio-economic, ecological and chemical effects on watersheds.

In Kenya, there is evidence of widespread land degradation [3], as manifested in high rates of soil nutrient loss, soil erosion, and compaction and water logging [4]. Socio-economic factors, including poverty, land fragmentation; low standard of living and earning are cited as drivers contributing to the increased risk of watersheds due to differences in land uses and land utilization types [5]. Watersheds are managed through public institutions like the Water Resources Authority [6, 7] which builds the capacity of land owners organized in Water Resources Users' Associations (WRUAs) to develop and implement Catchment Management Plans (CMPs).

The objective of this study was to investigate the extent to which afforestation and terracing conservation techniques were effective in managing Mwache watershed.

II. LITERATURE REVIEW

Healthy watersheds provide essential ecological services such as nutrient cycling, carbon storage, erosion control, and sedimentation management. These commodities and services are crucial for the societal, ecological, and economic wellbeing. According to United States' Environmental Protection Agency [8], intact healthy ecosystems minimize costly restoration and ecosystem service replacement, and in turn, provide long-term economic opportunities and jobs such as improved water quality.

Food and Agriculture Organization (FAO) [9] report on the state of the world's land and water resources estimated that the total world land area is 13.2 billion hectares out of which 12% (1.6 billion hectares) is dedicated to the production of agricultural crops and 28% (3.7 billion hectares) is covered by forests. Forests provide numerous environmental services such as watershed protection, nutrient cycling, pollution control, climatic regulation, carbon sequestration, flood

mitigation, protection from storms, landslides and soil erosion [10]. Degradation of forest resources is likely to cause adverse effects on the world economy and environment. 25% (4.6 billion hectares) of the global land area consists of grasslands and woodland ecosystems.

A study by Nyamekye *et al.* [11] on Soil and Water Conservation Management (SWCM) was reviewed to provide insight on the level of success of the conservation measures in the 1970s in Burkina Faso. SWCM commonly used to control soil erosion and to rehabilitate the land productivity in the country were stone bunds, improved traditional planting pits (zai), mulching, half-moons and agroforestry. The study revealed that implementation of the techniques by the Government and Non-Governmental Organizations failed due to lack of consideration of the preferences, skills, and involvement of the local farmers in planning. In its amelioration measures, the Government changed tact and involved the expertise of the local community in order to ensure sustainable development of the SWCM. An assessment study by Tibebu *et al.* [12] on efficiency of land management practices in Ethiopia revealed that the implementation of sustainable land management practices substantially transformed Ethiopia's smallholder farming landscape. About 70% of the landscape of the study watersheds was covered by physical Soil and Water Conservation measures. The study further notes that impacts of the techniques varied considerably across the study watersheds due to variation in techniques applied, and quality of implementation based on the experience, skill, and commitment of the implementing experts and communities.

Terracing has been one of the most important systems for preventing soil erosion, conserving water, and increasing agricultural production [13]. Terraces are created to intercept surface runoff, encourage it to infiltrate, evaporate or be diverted towards a predetermined and protected safe outlet at a controlled velocity to avoid soil erosion [14]. Terracing are contour bunding which divides hill slopes and ridges into numerous small slopes, checks the flow of water, promotes absorption of water by soil and saves soil from erosion.

Land degradation and rehabilitation efforts in Kenya started in earnest in the 1970s through a programme on National Soil and Water Conservation started by the government under the Ministry of Agriculture and Rural Development through bilateral assistance from the Swedish Government. The programme involved conservation of soil and water in degraded water catchment areas and sloppy areas. It included capacity building for agricultural extension services personnel and farmers who were involved in the implementation.

As identified in Mwache watershed, soil erosion is principally caused by overgrazing, deforestation, charcoal burning, poor and continuous cultivation [15] Community-based Integrated Watershed Management efforts such as Farmer Field Schools [9] are promoted to manage the watersheds. In the approach, the community is trained on soil and water conservation and tree conservation.

III. MATERIALS AND METHODS

A. Study Area

Mwache watershed which served as the study area lies

along Mwache River Basin covering 3647 km² in 19 administrative locations stretching from Taita hills to the west and Kilifi County to the east. It is in an elevation of between 0 metres to 300 metres above mean sea level [16]. Due to watershed vastness, the study was centred on a smaller Makutano micro-watershed—which is part of the larger Mwache watershed and the epicentre of conservation practices. Administratively, the micro-watershed is in Mwatate sub-location and Mwavumbo ward of Kwale County. It is located to the eastern side between geographic position 3°57.38–3°54.21'S and 39°26.54'–39°29.08'E covering about 100 km².

The total population of Kwale County was estimated at 866,820 with a gender aggregate of 49.04% male and 50.96% female (KNBS, 2019). Population of study area (Mwavumbo ward) was 20,607 with 2946 households during the study period in 2023 [17].

B. Sampling

Given the finite population and number of households in the study area and different study items as described by Onyemaechi *et al.* [18], Taro Yamane method for sample size calculation, $n = N / (1 + N(e)^2)$, was used,

where:

n signifies the sample size

N signifies the population under study

e signifies the margin error

Total number of households in the 9 sampled villages was 1628 [17].

Using 0.1 as the margin of error, e , the estimate sample size of households was obtained as follows:

$$n = 1628 / (1 + 1628(0.1)^2)$$

$$n = 94.$$

C. Sampling Procedure

Two levels of sampling were used to select the study site. In the first level, nine (9) villages were purposively selected from the fifteen (15) villages in the micro-watershed to ensure that they, as listed in Table 1, were those which participated in implementation of the conservation techniques. Thereafter, simple random sampling was used to select the specific households from among lands conserved using afforestation and terracing. Ninety-four ($n = 94$) households (Table 1) representing farms within the nine villages were selected and interviewed using well-structured household questionnaires to capture their perceptions on the socio-economic effects of adoption of afforestation and terracing conservation techniques.

Similarly, purposive sampling was used to select four sites (Table 2) with different forms of conservation to determine the ecological and chemical effect of conservation techniques on the watershed. Three of the sites were conserved through afforestation and terracing while the fourth site was the control site where no conservation was applied.

A combination of techniques—afforestation, terraces and gabions were implemented at study site 1. Study site 2 (Kwa Ndurya) is a riparian land which was conserved through afforestation while study site 3 (Kwa Mbeyu) is a farmland conserved using terracing. Study site 4 (Mshenga Farm), was the control site with no conservation techniques implemented on it. As determination of impact of conservation techniques on soil chemical parameters would require soil analysis to be

conducted soil sampling was carried out [19]. Locations for collecting soil samples were identified in each study site through random stratified sampling along a 200-metre transect line. Beginning with point 0 metres along the transect line, soil samples were collected at every 50 metres point hence each of the four study sites had a total of five (5) sampling points.

Table 1. Number of farmers sampled per village and their percentage distribution

Village Name	No. of farmer households in the village	No. of farmer households sampled	% of farmers sampled in the village against total sample
Mavirivirini Asili	175	19	20
Mavirivirini Plain	174	16	17
Mwangani	328	12	13
Maweu	106	11	12
Mwashanga	275	9	10
Changa	120	7	7
Kaluweni	116	7	7
Mdune	256	7	7
Luweni	78	6	6
Total	1628	94	100

Table 2. Description of the four study sites

Site Description	Site 1	Site 2	Site 3	Site 4
Site Name	Makutano Demonstration Farm	Kwa Ndurya Farm	Kwa Mbeyu Farm	Mshenga Farm
Village located	Mavirivirini Asili	Maweu A	Mdune	Mavirivirini Asili
Conservation technique	Afforestation and Terracing	Afforestation	Terracing	No form of protection
Soil type	Clay	Silty loam	Silty loam	Clay
Land size (Acres)	20	5	4	20

D. Data Collection

Respondents of the household questionnaires were mainly farmers spread across nine villages of Makutano Micro-watershed where conservation practices were implemented. Conservation in the watershed started at Mavirivirini Asili village before adoption by other villages; Mavirivirini Plain, Maweu A, Mwangani, Changa, Kaluweni, Mdune, Mwashanga and Luweni. Three respondents represented institutions: Mavirivirini Polytechnic, Mwashanga Primary, and Kaluweni Primary, all of which implemented afforestation. Data collection was carried out between May–October 2023, a period which crops were in the farms until they were harvested. Data on crop yields over a five-year period was collected on the randomly sampled farms and from the County Agriculture office. Responses on the questionnaires sufficiently addressed the specific objective of socio-economic effects of conservation practices used.

Unit sizes of land conserved were matched against unit sizes of the land initially eroded to attain the conservation rate. Similar measurements and observations were made of the study site where no particular conservation technique were applied (control site). Data on the area conserved was recorded in unit acres while conservation rate was recorded in percentages (Table A1).

Soil samples were collected inside a 5 m×5 m quadrant using a soil auger to determine the effectiveness of conservation techniques on the chemical properties of soils under conservation and the control site. Vegetation was first

cleared after which a panga was used to loosen the ground to ease soil scooping. A plastic spoon was used to scoop 100 g of soil from a depth of 6 inches from the land surface and carefully emptied into a clean 300 mL plastic jar. A total of 20 soil samples were collected from the four study sites. To increase test accuracy, two sets of samples were collected from each sample point and placed in two different jars. Samples were later transferred into sampling bags and taken for testing and analysis at Kenya Marine and Fisheries Research Institute (KMFRI) laboratory in Mombasa. GPS coordinates of the sample locations were recorded on a note book for reference and the sample jars accurately labelled for easy identification. Soil properties tested at the laboratory were; moisture, organic matter, nitrogen concentration, pH, phosphate concentration, potassium concentration and electrical conductivity. These variables explain the actual bio-chemical impact of conservation techniques on soils in the study sites. In addition to the seven parameters, soil texture was established to determine the effect of conservation techniques. Fig. 1 was used to classify soils into textural classes in each of the four study sites during collection of samples. Soil texture is fundamental to soil properties and their impact on plant growth and overall farm productivity. In a conserved soil, soil texture results in high water retention and availability, aeration, drainage and the supply and retention of nutrients [20].

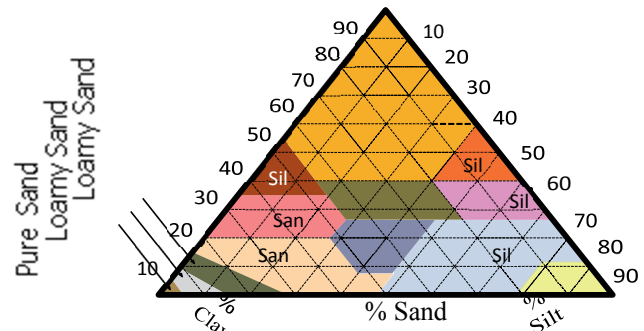


Fig. 1. Soil textural classes. (FAO, 2020).

From the study, soils at Makutano Demonstration Farm and Mshenga Farm were both observed to be clay loam while those of Kwa Ndurya and Kwa Mbeyu were of silty loam.

Soil moisture in the four study sites were determined by first weighing 5 g of wet soil samples, wrapping it in an aluminium foil, subjecting them to temperatures of 70 °C in the oven for 24 hours in a laboratory. This process led to removal of all moisture available in the soil and subsequently reducing the weight of the sample. Soil moisture was then obtained through the formula: (Weight of foil + Wet weight) – (Weight of foil + Dry sample). Differences in weights of the original soil samples from the study sites and the heated dry sample gave the value of moisture available at each sampling pint.

In determining soil organic matter, the heated soil samples were subjected to high temperatures of 450 °C for 24 h in a furnace. At these high temperatures, all the organic matter in soil were combusted leaving soil residues. The difference in the weight of dry soil sample and combusted soil residues gave the amount of organic matter in the soil as (Weight of foil + Wet weight) – (Weight after ignition). The process was repeated for each of the two sets of samples collected at every

sampling point and the mean determined to achieve accurate results.

Soil electrical conductivity in the four sites was determined in the laboratory using Yellow Springs Instruments (YSI) Professional Plus meter. Other nutrients; nitrogen concentration, phosphate concentration and potassium concentration nutrients were first dissolved in distilled water to make sediment solutions using a standard dilution formula. Potassium chloride (KCl) solution was then used to extract nutrients from the soil solution. Each soil parameter was determined using a specific reagent. Values of each soil parameter obtained were recorded in Microsoft excel for analysis. Soil pH was determined in a ratio of 1:1 soil: water (w/v) suspension using a pH meter. pH levels of each sample point of the study area was recorded to measure the acidity and alkalinity of the soils.

IV. RESULTS AND DISCUSSION

A. Socio-economic Effectiveness of Conservation Techniques

The results of descriptive statistics indicate that majority of the farms in the watershed were subjected to afforestation (97.91%; $n = 94$) as compared to terracing (78.72%; $n = 74$) and the initiative was mainly spearheaded by male farmers (64.89%; $n = 61$) as opposed their female counterparts (35.10%; $n = 33$). Notably, all individual farmers who practiced terracing also practiced afforestation. One of the factors that influenced farmers' engagement in watershed management activities as described by Upadhaya and Arbuckle [21], were stakeholders who were versatile in various modes of conservation. Their level of influence varied from Coast Development Authority (41%; $n = 38$), County Agriculture Extension Officers (32 %; $n = 30$) and Non-Governmental Organizations (20%; $n = 19$). However, there were challenges encountered by farmers in implementing the conservation techniques.

The challenges as presented in Fig. 2 could compromise achievement of efficient land conservation and minimize benefits accruing from agricultural farms. Water scarcity ranked as the main challenge encountered by majority of farmers implementing afforestation ($n = 86$; 89.58%) due to the watershed falling within the semi-arid areas which receives minimal rainfall of between 550–850 mm per annum [22]. Other challenges which compromised afforestation included pest infestation ($n = 59$; 61.45%) and human and livestock destruction ($n = 34$; 35.42%). Challenges relating to lack of appropriate tools (38.54%; $n = 37$) and rocky soils (26.04%; $n = 25$) were associated with terracing while those relating to labour intensiveness and capital were challenges bedevilling both conservation techniques at a rate of 16.67% ($n = 16$) and 14.58% ($n = 14$) for afforestation and 29.17% ($n = 28$) and 33.33% ($n = 32$) for terracing respectively. These findings are consistent with those of Barbier [23] that soil conservation requires access to labour and capital; inputs which are largely unreachable by poorer farmers, particularly female-headed households which often lack access to one or more of these inputs.

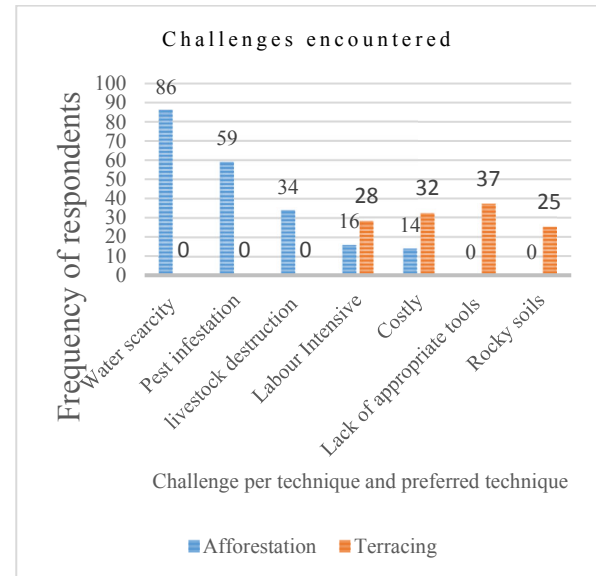


Fig. 2. Challenges encountered while implementing conservation techniques.

Effectiveness of terraces in the watershed was largely noted in its impact on yields in agricultural farms.

As examined in Table 3, yields of three crop varieties; *Zea mays* (maize), *Vigna radiata* (greengrams) and *Vigna unguiculata* (cowpeas) exhibited noteworthy improvement in the five-year period of terraces implementation from 2018 to 2023 potentially increasing food and revenue, hence improving farmers' socio-economic status. This is in concurrence with the assertion by Branca *et al.* [25] that implementation of soil and land conservation practices increases the productivity of land and provides good economic returns on investment. Crop yields realized in 2020, 2021 and 2022 were comparatively low during the period due to low amount of rainfall received in the watershed in the months of April–October as shown in Table 4 below.

Table 3. Cumulative crop yields in Mwache watershed (in 90Kgs bags). Source: Kinango sub-county crop production, 2018–2023 [24]

Year	<i>Zea mays</i>	<i>Vigna radiata</i>	<i>Vigna unguiculata</i>
2023	4800	3900	2700
2022	450	150	110
2021	300	150	140
2020	760	670	540
2019	800	680	220
2018	720	610	250

Table 4. Rainfall received in Mwache watershed in 2018–2023

Rainfall total (mm)	April	May	June	July	Aug.	Sep.	Oct.	Total
2023	176.2	115.8	37.6	82.6	31.4	12.4	106.4	562.40
2022	39.8	56.6	66.4	39.2	42.1	17	11.4	272.5
2021	49.6	42	57.2	27.6	25.8	35.8	18.8	256.8
2020	199.4	170	35.6	46.6	0	22.4	91.2	565.2
2019	55.8	305.3	2.8	21.2	44.8	150.2	35.5	615.6
2018	48.2	148	122	69.2	15.4	84.6	295.2	782.6

Rainfall received in 2023 facilitated optimum growth of crops. Although rainfall contributed to increased crop yield, the increase was higher in farms with terraces as shown in Table 3. Combined with terraces constructed, crop yields harvested in the 2023 was higher than in 2018 when the farms lacked terraces.

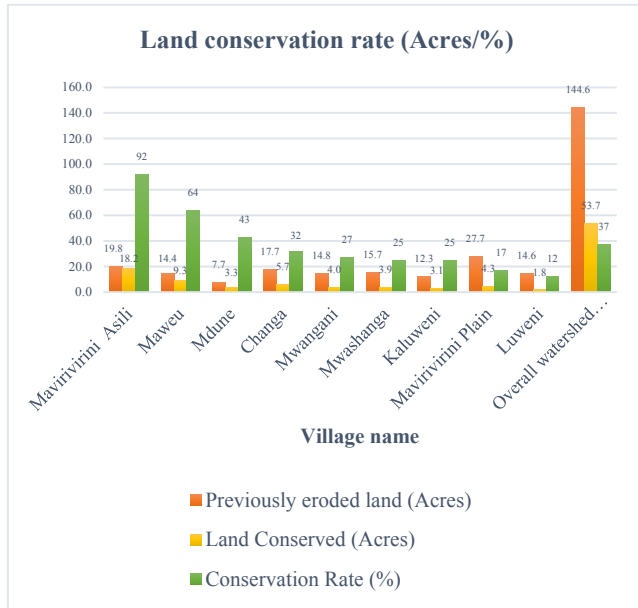


Fig. 3. Land conservation rate.

The two conservation practices caused varying impact. Out of the 222.5 acres (109 hectares) owned by the sampled farmers, a total of 144.6 acres (58.043 hectares) were initially in a degraded state. As a result of applying afforestation and terracing for about 5 years, 53.74 acres (21.50 hectares) was restored. Considering variables such as technique applied, size of land conserved and the period over which the technique was implemented, management of conservation resulted in the watershed achieving overall conservation rate of 37% as shown in Fig. 3. Mavirivirini Asili village and Maweu were the most conserved as they recorded a 92% and 64% conservation rates for conserving 18.2 acres and 9.3 acres respectively from the 19.8 acres and 9.3 acres which were initially eroded (Fig. 3). Notably, all farmers in the two villages engaged in both terracing and afforestation to conserve their lands. At Luweni village which had the least conservation rate of 12%, only 1.8 acres out of 14.6 acres were put under conservation, a very little proportion to make any meaningful impact in the highly degraded watershed. This was compounded by the short period of conservation as some farmers implemented conservation techniques for only

3 years.

B. Effectiveness of Conservation Techniques on Soil Chemical Properties

1) Soil moisture and organic matter

Investigation of the effectiveness of afforestation and terracing on the soils chemical properties revealed that Makutano Demonstration Farm which was subjected to afforestation and terracing intervention exhibited the highest moisture content among the four sites with a mean moisture of 12.993%. The control site which did not receive any conservation intervention had a very low moisture content with a mean of 6.496%. Mean moisture contents at Kwa Ndurya and Kwa Mbeyu Farms which were subjected to afforestation and terracing were 10.777% and 11.118% moisture contents respectively, marking a relatively moderate moisture content.

Table 5. Moisture content in the study area

Quadrant (m)	Makutano	Mshenga	Kwa Ndurya	Kwa Mbeyu
0	13.419	6.833	11.175	11.005
50	12.315	6.122	10.185	11.142
100	12.938	6.377	11.756	10.84
150	12.774	6.39	10.073	11.093
200	13.517	6.706	10.696	11.5093
Mean	12.993	6.496	10.777	11.1178

At Makutano Demonstration Farm, implementation of afforestation and terracing along with safeguarding to prevent human and animal interference, had a substantial role in enhancing moisture retention. Conversely, the insufficient adoption of afforestation and terracing at the control site-Mshenga Farm may be identified as the primary cause of the low moisture content recorded (Table 5). The unregulated movement of livestock within the site significantly contributed to the depletion of indigenous flora, which would have facilitated soil moisture retention. These challenges are further compounded by the absence of terraces, so exposing the land to effects of erosion. Kwa Ndurya and Kwa Mbeyu, (Sites 3 and 4) characterized by moderate moisture levels (Table 5), were subjected to conservation practices involving the use of *Bambusa vulgaris* trees and terraces, respectively. Despite the implementation of conservation methods, the sites were consistently subjected to tilling for agricultural reasons, therefore exposing the soil to evaporation which minimized their moisture retention capabilities. Afforestation and terracing performed intrinsically had an effect on the soil parameters.

Table 6. Correlation of moisture with other parameters at Makutano Demonstration Farm

Soil parameter	Organic Matter	PH	Electrical Conductivity	Nitrogen Conc.	Potassium Conc.	Phosphate Conc.
Corr. Coefficient	0.46936	0.46905	0.33010	-0.29482	0.73391	0.02654

Correlation analysis performed (Table 6) established that as moisture content increased at site 1, potassium concentration increased at a high rate as evidenced by a strong positive coefficient of correlation, 0.73391 while phosphate concentration increased at a very slow rate of correlation coefficient 0.02654. This also explains the strong negative correlation of -0.62110 between moisture content

and potassium concentration at the control site which, empirically, had low moisture content. A positive correlation between soil moisture and organic matter (correlation coefficient 0.46936) and pH (correlation coefficient 0.46905) shows the relationship of soil parameters. However, a negative correlation between soil moisture and nitrogen concentration (correlation coefficient -0.29482) was

observed at the site, albeit weak.

Anova ($p < 0.05$) indicates that terracing and afforestation significantly improved the degraded land. A weak negative correlation of coefficient -0.29482 observed between moisture and nitrogen concentration implied that as the former increases in the soil, the latter decreases at a slow rate.

Table 7. Soil organic matter (%)

Quadrant (m)	Makutano	Mshenga	Kwa Ndurya	Kwa Mbeyu
0	11.91	3.78	8.70	9.075
50	10.25	5.33	8.50	8.15
100	11.63	4.58	9.38	9.78
150	11.98	4.95	8.82	9.63
200	11.04	5.07	8.37	9.70
Mean	11.36	4.77	8.75	9.27

As can be seen in Table 7, the control site had comparatively the lowest organic matter content averaging 4.77%. Kwa Ndurya and Kwa Mbeyu Mrira sites which were both cultivated farms had medium organic matter of averagely 8.75% and 9.27% respectively. Makutano Demonstration Farm had the highest organic matter averaging 11.36% signifying that soil has the ability to restore its life-support processes if sufficient time is allowed for such recovery [26].

2) Soil nitrogen concentration

Nitrogen concentration varied in all the four study sites as illustrated in Table 8. Kwa Ndurya and Kwa Mbeyu Farms with 0.119 % and 0.113 % nitrogen concentration respectively falling within the nitrogen thresholds range of 0.1–0.15 % for silty soils [27] thus maximising nitrogen availability for plant uptake and minimising the risk of nitrate leaching [28]. Afforestation and terracing conservation carried out in both sites contributed to nitrogen fixation to the soils. Additional nitrogen was contributed by inorganic fertilizers containing nitrate which were applied on the agricultural lands to boost crop produce. Makutano

Demonstration Farm had a low nitrogen concentration of 0.0927%. The vegetation deficient Mshenga Farm which served as the control site had the least nitrogen concentration of 0.0725% among the four study sites as neither afforestation nor terracing was carried out.

3) Soil pH

As indicated in Table 9, near neutral pH levels of average 6.986 recorded at the control site (site 2) illustrates the effect of lack of vegetation on soil pH. In contrast all sampling points at sites 1, 3 and 4 had moderate acidic soils averaging pH 5.440, 5.872 and 5.848. These acidic conditions are attributable to conservation techniques implemented, more so tree planting and natural regeneration which was implemented at Makutano Demonstration Farm resulting in low pH values and more acidic soils [29]. In consonance with Kaushal *et al.* [30], breakdown of leaf litter deposition in the sites where conservation practices were implemented may have resulted in low pH, with the control site remaining high. Kaushal *et al.* [30], points out that application of nitrogen and sulphur fertilizers over time lowers soil pH elucidating the reason behind the acidic nature and corresponding pH values of the soils of Kwa Ndurya and Kwa Mbeyu, which are farmed annually. Although plants have different nutrient needs, pH affects the availability of nutrients within the soil [31] further affecting the continuous availability of soil chemical properties. For instance, nitrogen, is readily available in soil when the pH value is above 5.5 and may consequently turn into gas with a pH value above 7.2. These findings are corroborated by the works of Tajamul and Gupta [32] on assessment of soil pH and electrical conductivity in different land use systems in India which showed lowest average pH value in forest land systems attributed to acidic nature of decomposing biomass litter while barren land showed highest average pH value (6.93) which was attributed to the accumulation salts.

Table 8. Nitrogen Concentration in the four sites (%)

Quadrant (Metres)	Makutano Demonstration Farm	Mshenga Farm (Control Site)	Kwa Ndurya Farm	Kwa Mbeyu Farm
0	0.093	0.073	0.11	0.1
50	0.0935	0.0715	0.13	0.12
100	0.091	0.0735	0.11	0.115
150	0.0935	0.073	0.145	0.125
200	0.0925	0.0715	0.1	0.105
Mean	0.0927	0.0725	0.119	0.113

Table 9. pH levels in the four sites

Quadrant (Metres)	Makutano Demonstration Farm	Mshenga Farm (Control Site)	Kwa Ndurya Farm	Kwa Mbeyu Farm
0	5.5	6.985	5.87	5.84
50	5.35	6.975	5.855	5.855
100	5.5	6.98	5.875	5.84
150	5.45	6.99	5.89	5.86
200	5.4	7	5.87	5.845
Mean	5.44	6.986	5.872	5.848

4) Phosphate concentration

As illustrated in Table 10, phosphate concentration of 1.35556 mg/L at Kwa Ndurya and 1.24975 mg/L at Kwa Mbeyu were above the normal range of 0.001 mg/L to 1 mg/L [33]. This phenomenon is caused by combination of decomposed crop residues and manures, organic matter and added commercial fertilizers, factors which are related to

conservation techniques implemented in the two sites. While the phosphate concentration at Mshenga Farm (0.551666 mg/L) was still within the normal range, the values were much lower in comparison with other study sites due to insufficient plant material to decompose and form phosphorus. As opposed to Kwa Ndurya and Kwa Mbeyu, the site does not have crop residues nor added fertilizer since

it is not an agricultural field and the available phosphate is largely contributed by animal waste as livestock graze freely in the field. Due to its lack of afforestation and terracing initiatives, the available phosphate is likely to be removed through erosion and leaching. Makutano Demonstration Farm's phosphate concentration of 0.927671 mg/L found within the normal range can be attributed to decomposition of its plant residues. Analysis of variance ($p < 0.005$) performed on the soil phosphate concentrations in all the four sites indicates a probability that conservation techniques improved phosphate concentration.

Table 10. Phosphate levels (mg/L).

Quadrant	Makutano Demonstration Farm	Mshenga Farm (Control Site)	Kwa Ndurya Farm	Kwa Mbeyu Farm
0	1.043675	0.5327	1.2563	1.37575
50	1.08603	0.63868	1.3511	1.2065
100	0.72295	0.50775	1.47225	1.19
150	0.8047	0.5641	1.465	1.22
200	0.981	0.5151	1.23315	1.2565
Mean	0.927671	0.551666	1.35556	1.24975

5) Potassium concentration (ppm)

Potassium (K) is an essential nutrient for plant growth and is classified as a macronutrient because plants take up large quantities of it during their life cycle. Its deficiency in soils stunts plant growth and reduces yield [34].

Table 11. Potassium concentration in the four sites of Mwache watershed

Quadrant	Makutano Demonstration Farm	Mshenga Farm (Control Site)	Kwa Ndurya Farm	Kwa Mbeyu Farm
0	74.65	52.4	83.7	84.25
50	74.295	53.1	83.35	84.12
100	74.43	52.3	83.8	84.15
150	74.61	52.25	83.5	84.12
200	74.55	52.3	83.75	84.1
Mean	74.507	52.47	83.62	84.148

Results of potassium concentration in Table 11 compared fairly to the standard provided for potassium in soils indicated in Table 12. The results reveal that the soils in the watershed contain low to moderate levels of potassium as they fall in the category of sandy loam or clay loam soils.

Table 12. Soil type and target levels of potassium (ppm)

Target levels	Sands	Sandy loams	Clay loams	Clays	Peats
Low	<50	<80	<110	<120	<250
Moderate	50–100	80–120	110–160	120–180	250–350
Ideal	101–150	121–200	161–250	181–300	351–600
High	>150	>200	>250	>300	>600

Kwa Ndurya and Kwa Mbeyu Farms which had sandy loam soils had potassium concentrations which fall in the moderate category of 80 to 120 ppm. Makutano Demonstration Farm and Mshenga Farm which had clay loam soils have potassium concentrations which fall in the mid low category of below 110 ppm.

Phosphate concentrations at Kwa Ndurya (83.62 ppm) and Kwa Mbeyu (84.148 ppm) can be considered moderate due to its sandy loam (silty) soils. Potassium content at the two

sites are highly contributed to by commercial fertilizers used to improve crop growth. Conversely, potassium concentrations at Makutano Demonstration Farm (74.507 ppm) and Mshenga Farm (52.47 ppm) are considered low in their clay loam soils which are below range. The cause of low potassium concentration at Makutano Demonstration Farm despite experiencing rapid plant regeneration as a result of afforestation and terracing should be studied further.

6) Electrical conductivity

Electrical conductivity of the four sites intrinsically varied in accordance with the conservation technique implemented as demonstrated in Table 13. Soil Electrical Conductivity (EC) measures the ability of soil water to carry electrical current. Cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and NH_4^+) and anions (SO_4^{2-} , Cl^- , NO_3^- , and HCO_3^-) from salts dissolved in soil water carry electrical charges and conduct the electrical current. Consequently, the concentration of ions determines the EC of soils. While the optimal EC levels in the soil range from 110–570 milli siemens per meter (ms/m), Kwa Ndurya and Kwa Mbeyu sites having average ranges of 117.07 ms/m and 117.32 ms/m respectively demonstrate a fair ability of soil electrical conductivity. This is attributed to the soils having high amounts of soluble salts like Potassium (K^+) and Phosphates (PO_4) and which are responsible for soil electrical conductivity and are in high quantities in the sites. Afforestation increases soil moisture content which in turn increases its electrical conductivity. Electrical conductivity at Makutano Demonstration Farm (109.45 ms/m) were close to the standard range and which is likely as a result of soils having high moisture content. Due to low concentration of salts like potassium, phosphate and nitrogen in the soils at Mshenga Farm, its electrical conductivity averaged a low of 98.709 ms/m. The absence of conservation interventions resulted in absence of the essential nutrients that facilitate movement of soluble salts to plants.

Table 13. Electrical conductivity in the four sites

Quadrant (M)	Makutano	Mshenga Farm	Kwa Ndurya	Kwa Mbeyu
0	109.5	98.63	117	117.6
50	109.5	98.915	117.05	117.05
100	109.5	98.575	117.15	117.35
150	109.2	98.7	117	117.1
200	109.55	98.725	117.15	117.5
Mean	109.45	98.709	117.07	117.32

V. CONCLUSION AND RECOMMENDATION

Afforestation and terracing were notably implemented at varying levels in Mwache watershed with each technique impacting the watershed differently. Cumulatively, more farmers were involved in afforestation than terracing as the former was viewed as less labour intensive at the beginning. However, after five years of practicing afforestation, farmers experienced challenges such as water scarcity, pest infestation and livestock destruction and hence they preferred terracing to afforestation. *Azadirachta indica*, *Gmelina arborea*, *Azela quanzensis*, and *Senna siamea* are the most suitable tree species owing to their drought tolerance capabilities and fast growth rates and hence should be prioritized in arid and semi-arid (ASAL) areas like Mwache watershed. In the period of five years which conservation was

practiced, Mwache watershed achieved only 37% conservation rate. This signifies that complete conservation in a degraded watershed can only be achieved in a period between 10–15 years of active restoration. The impact of terraces was, notably, realized more in agricultural farms which recorded a six-fold increase in crop yields on the fifth year of practicing terracing thus enhancing household income and improving farmers' economic standing. This realization informs that agricultural lands within watersheds should therefore be put under well-maintained terraces in order to achieve sufficient crop yield. On the institutional front, farmers' adoption of afforestation and terracing was significantly influenced by stakeholders who had varying levels of influence but contributed an overall 93% of the technical expertise on conservation using terracing and afforestation. Therefore, stakeholders with particular conservation skills should continue to discharge them to improve farmers' knowledge on conservation. This study found out that afforestation modulates soil pH within acceptable range (pH 5.5–6.5) as observed at Makutano Demonstration Farm and in turn enhances conditions that support vegetation growth. Barren soil increase soil pH and limits vegetation growth (pH 6.9–7.0) as observed at Mshenga Farm-site 2). Afforestation similarly increases soil moisture and organic content—through root retention and leaves and plant residue decomposition. Both afforestation and terracing provide optimum conditions for vegetation regeneration, especially if left undisturbed for a period more than 1 year. Trees such as *Bambusa vulgaris* should be planted in degraded riparian lands for quick regeneration and protecting the soil against riverbank erosion.

APPENDIX

Table A1. Land conservation rate per village

Village name	Eroded land (Acres)	Land Conserved (Acres)	Mean Conservation Rate (%)
Mavirivirini Asili	19.825	18.2328	92
Mavirivirini Plain	27.65	4.3405	17
Mwangani	14.775	4.0455	27
Maweu	14.375	9.2649	64
Mwashanga	15.65	3.9012	25
Changa	17.7	5.725	32
Kaluweni	12.3	3.075	25
Mdune	7.695	3.3445	43
Luweni	14.6	1.7999	12
Total	144.57	53.73	37.44

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Author S.L.C. conceptualized the research topic and designed the manuscript. S.L.C. and B.O. conducted the research, edited the data and analyzed it. S.L.C. wrote the paper while B.O. and K.M.H.T reviewed it. All authors approved the final version.

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