Open Journal of Ecology, 2022, 12, 483-498
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Effects of Slash-and-Burn Practices on Soil Quality at Different Landscape Positions in the Raumoco Watershed, Municipality of Lautem, Timor-Leste

Delfim Da Costa[1], Decibel V. Faustino-Eslava[2], Rico C. Ancog[2]

[1]National University of Timor Lorosae, Dili, Timor-Leste
[2]University of the Philippines Los Baños, Laguna, Philippines
Email: delfimdacosta915@gmail.com

How to cite this paper: Costa, D.D., Faustino-Eslava, D.V. and Ancog, R.C. (2022) Effects of Slash-and-Burn Practices on Soil Quality at Different Landscape Positions in the Raumoco Watershed, Municipality of Lautem, Timor-Leste. *Open Journal of Ecology*, **12**, 483-498.
https://doi.org/10.4236/oje.2022.127026

Received: June 15, 2022
Accepted: July 24, 2022
Published: July 27, 2022

Abstract

Slash-and-burn practices used by farmers in prior growing periods could affect soil quality, particularly topsoil properties. This study aimed to assess soil biophysical and chemical properties at different landscape levels within the watershed site. Soil samples were collected by a core method in the topsoil layer in slash-and-burn sites. Field analysis was on bulk density and porosity by the gravimetric method, while laboratory analysis was done on organic matter by the Loss on Ignitions Method and other macronutrients for crops (total nitrogen, phosphorus availability, and potassium availability) followed standard analytical methods. To see if there was a significant difference between sites, DMRT 5% was used. The results of the study showed slash-and-burn practice affects soil physical properties such that high bulk density in upstream, midstream, and downstream ranged from 1.55 g/cm^3 to 1.71 g/cm^3, 1.55 g/cm^3 to 1.80 g/cm^3, and 1.38 g/cm^3 to 1.79 g/cm^3 respectively. Poor porosity in upstream, midstream, and downstream ranged from 33.91% to 40.06%, 30.38% to 41.75%, and 30.91% to 46.65%, respectively. Organic matter content was low in the upstream, midstream, and downstream areas, ranging from 2.86% to 3.39%, 2.58% to 3.88%, and 2.91% to 3.88%, respectively. However, soil pH remains neutral, and nitrogen levels are low but near-optimal in the upstream and very low in the midstream and downstream. Phosphorus is extremely high upstream but very low in midstream and downstream. However, potassium remains at a low level close optimum level in the entire watershed.

Keywords

Timor-Leste, Raumoco Watershed, Slash and Burn Farming

1. Introduction

The Raumoco watershed is located in the municipality of Lautem, in the eastern part of Timor-Leste, where a majority of the population are subsistence farmers. Slash-and-burn practices widely practiced by farmers in the Raumoco watershed to grow crops have been started a long time ago by their ancestors and imitated through generations till now. Periods of doing are when the dry season is coming, usually starting from June until early November every year [1] [2] [3] [4]. These practices involve the opening up of new lands in forest areas. Start cleaning from the ground parts, followed by understory parts, then leave them under trees for more or less one month to be dried. Proceed with cutting down branches of trees by leaving the trunk to stand alone on the ground. At this stage, all material being cut should be left until dry. Farmers will have to burn if there is a sign of rain or one week before the first raindrop falls. The trunks that are left intentionally are reserve materials to be burned in the next coming year. These methods are being practiced mostly by farmers in the upstream area and some farmers in the midstream. However, downstream farmers are experiencing less forest area, so slash-and-burn is being practiced in weed sites, usually farmers looking for a Siam Weed (*Chromolaena odorata*) area to cut down, then leaving them to be dried before burned. Because this weed is flammable, farmers tend to burn it one or two days before it rains. This area seems to give high productivity during the first or second year of using it, then decrease afterward until the soil ground has eroded and no more weeds grow on it.

Slash-and-burn practices with high frequency prior to the growing season by farmers caused the soil to lose its productivity. Shifting cultivation had been observed to have caused soil degradation, yet it was not clear whether there was a direct or indirect impact. In Timor-Leste, soil loss was recorded at [6] reaching 26 tons/ha/year, a massive number compared to the average data of soil lost in the world at around 10 tons/ha/year.

Other sites by the National Government of Timor-Leste in 2009 reported that shifting cultivation was practiced by 60% of farmers in slope areas with a total area of about 912,605 hectares (61.1% of the total territory) susceptible to being eroded [7]. [8] has reported a summary of land cover changes in Timor-Leste within 10 years from 1989 to 1999. The most critical changes happened in Woodland. It was covered by 31% in 1989 but after 10 years had a deep reduction that reached 19% of the total area in the year of 1999. According to [9], based on satellite image analysis, forests lost nearly 30 percent from 1972 to 1999.

No specific study yet in the Raumoco watershed area or even in the entire municipality of Lautem on soil quality under burning treatment by subsistence farmers, while a series of studies in other countries have been done. A comparison between burning and no burning areas, as reported by [10], found that bulk density (BD) responded to burning in peat lands after combustion. Meanwhile, [11] found the effects of burning with and without burning on soil nutrients. The study revealed that burning practices could reduce organic carbon from

4.69% to 1.17% and nitrogen from 1.33% to 1.08%. However, burning can increase phosphorus availability, which increases from 5.3 mg/kg to 7.61 mg/kg. However, [12] found a contradictory result, where the organic carbon significantly increased after burning, with a mean of 15.97 g/kg soil compared to 9.29 g/kg soil in the unburnt plot.

2. Materials and Methods

2.1. Study Area

The study was carried out in the Raumoco watershed, located in the municipality of Lautem in the eastern part of Timor-Leste, and has a total area of 13.904 ha. situated between latitude 8˚35'40" and 8˚24'3"S and longitude 126˚46'10" to 126˚52'42"E (**Figure 1**). The site is dominated by slope area, with a mean slope of 19% and covered by soil types inceptisol and vertisol. The agro-climate zone is categorized as climate C (5 to 6 wet months) based on the Oldeman classification, with the rainfall ranging from 1500 to 2000 mm/year.

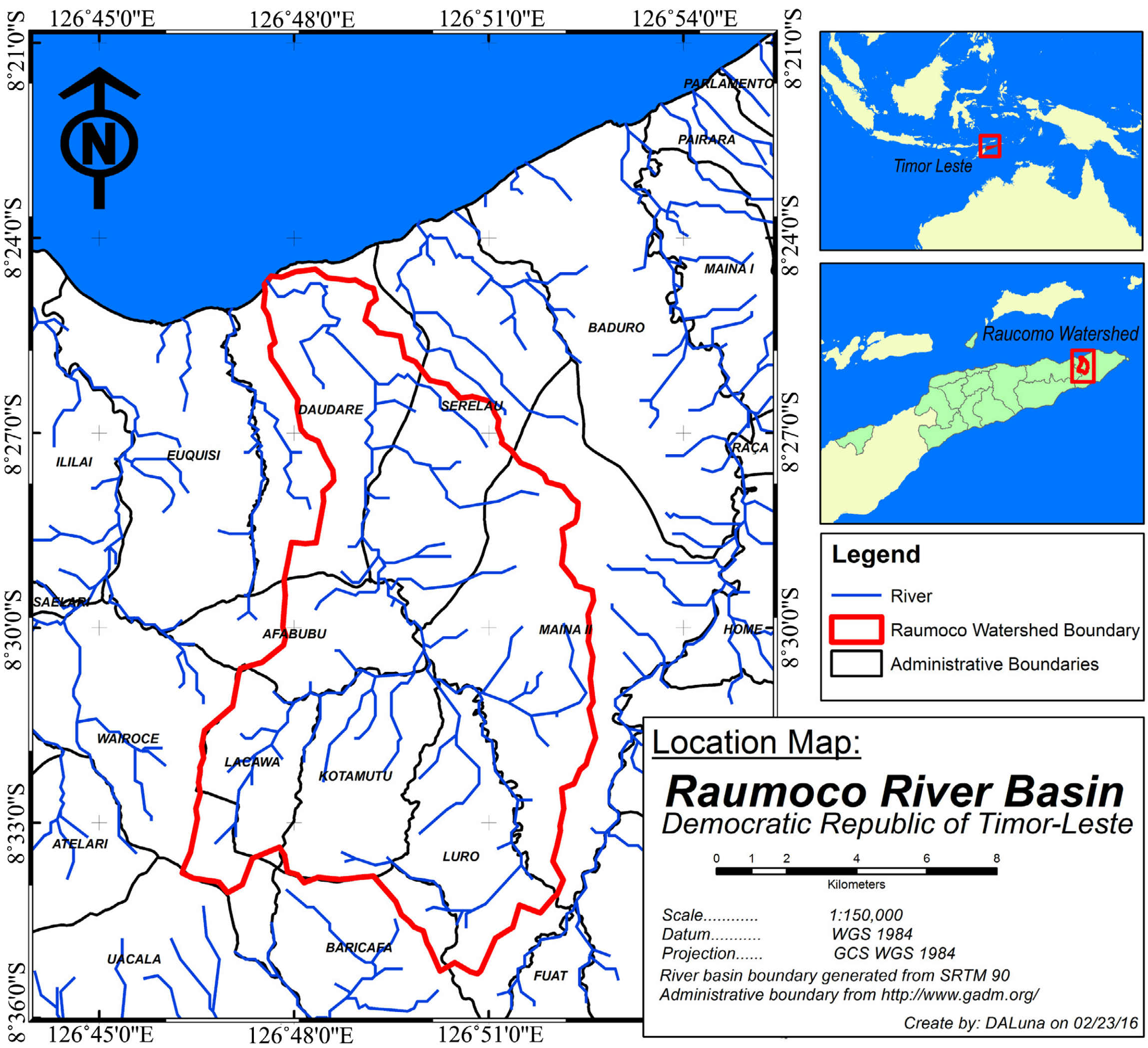

Figure 1. Location of study area (Raumoco Watershed).

2.2. Field Study

Soil samples were collected in slash-and-burn practices areas in the upstream, midstream, and downstream zones. Villages were then identified within each zone. The number of sites in the upstream area was 36 samples from twelve sites within three village zones (Kotamuto, Lakawa, and Luro); in the midstream area it was 24 samples from twelve sites within two village zones (Afabubo and Maina II); and in the downstream area it was 24 samples from twelve sites within two village zones (Daudere and Serelau). Soil samples were collected by the core method. Each site had three sampling points that were 100 to 150 m apart.

The total number of sampling points for bio-physical analyses was 84. From these, 21 were selected for analysis of their chemical properties. Field measurements were taken of soil bio-physical properties, namely soil bulk density, soil porosity, and soil organic matter. Undisturbed soil samples were collected by using stainless steel core rings. The core rings were placed inside a ring holder and then inserted into the soil surface by hammering the ring holder with an impact-absorbing hammer [13]. The sample is then removed from the soil, and the excessive soil is cut with a sharp knife before weighing to record the wet weight. After weighting, samples are segregated into plastic bags with proper labels from the field (site name, sample number, and GPS point) and then transferred to the soil laboratory.

2.3. Laboratory Tests

Soil bulk density and soil porosity were measured by the gravimetric method, while soil organic matter was measured by the loss on ignition method in the soil laboratory of the National University of Timor Lorosae, Faculty of Agriculture, Timor-Leste. In addition, soil chemical properties for soil fertility status were hand-sieved through a 2-mm screen to remove roots and other remains of vegetation from the soil. The soil was then packed into plastic and transported to the Soil Laboratory of Udayana University in Bali, Indonesia for nitrogen, phosphorus, and potassium analysis. Total nitrogen was determined by N Kjeldhall, while phosphorus and potassium were determined by the Bray-1 method.

2.4. Data Analysis

Complete Random Design (CRD) was used to figure out soil quality within the watershed, while The Duncan's Multiple Range Test (DMRT) at 5% was used to detect differences between the means of soil variables at the landscape level.

3. Results

3.1. Biophysical Properties of Soils

Biophysical data is composed of bulk density, soil porosity, and soil organic matter. In the upstream bulk density, porosity, and organic matter differ statistically (DMRT 5%) between sites; soil bulk density in Lakawa is significantly higher than bulk density in Kotamuto, but bulk density in Luro does not differ statistically (**Figure 2**). Overall, bulk density is classified as high while soil porosity is low (**Figure 3**). As shown in **Figure 4**, soil organic matter is significantly highest in Kotamuto and lowest in Lakawa, while organic matter content in Luro is neither high nor low (falling in adjacent points).

Bulk density, soil porosity, and organic matter are not significantly different between sites in midstream. Bulk density ranged from 1.51 to 1.80 (**Figure 5**), Soil porosity ranged from 30.38 to 41.75 (**Figure 6**), and organic matter ranged from 2.42% to 3.88% (**Figure 7**).

Biophysical properties downstream have significant differences between sites (DMRT 5%). Sr_2 has the highest bulk density and Dr_4 has the lowest, while Sr_4 and Dr_1 have the same bulk density as Dr_4 (**Figure 8**). Soil porosity is significantly higher in Dr_4 and lowers in Sr_2 (**Figure 9**), but soil organic matter downstream is not significantly different (**Figure 10**). Sr_4 is the highest and Sr_2 is the lowest. Upstream is the highest and midstream and downstream are the lowest.

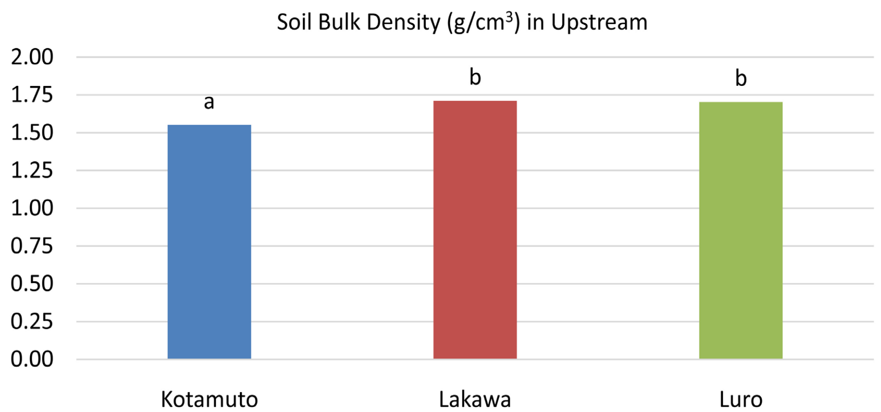

Figure 2. Comparison of soil bulk density in upstream. The same letters bars are not significantly different (DMRT 5%).

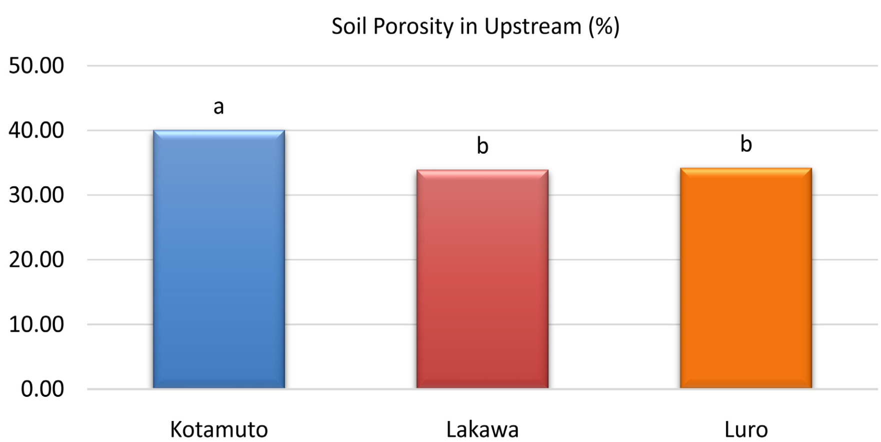

Figure 3. Comparison of soil porosity in upstream. The same letters bars are not significantly different (DMRT 5%).

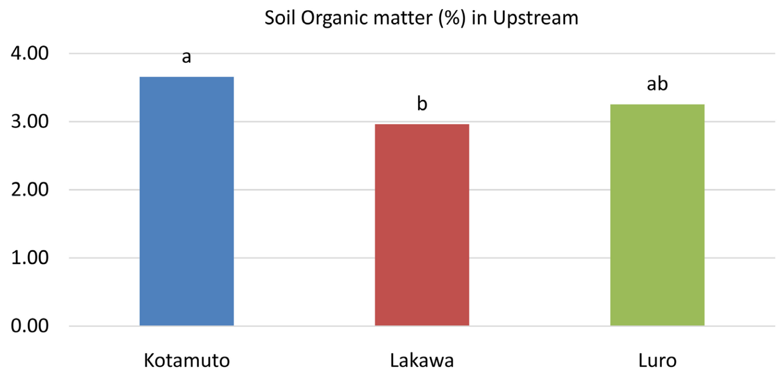

Figure 4. Comparison of soil organic matter in upstream. The same letters bars are not significantly different (DMRT 5%).

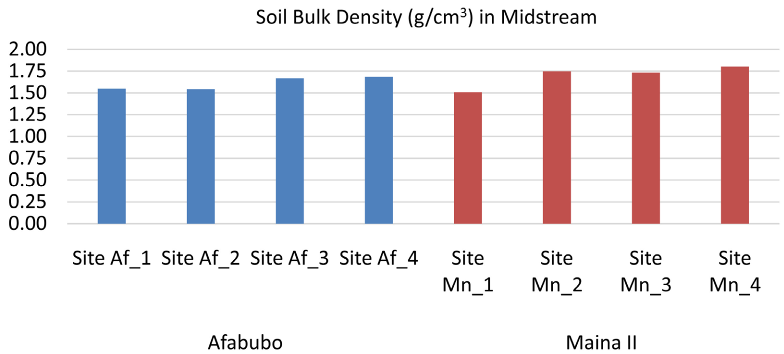

Figure 5. Comparison of soil bulk density in midstream.

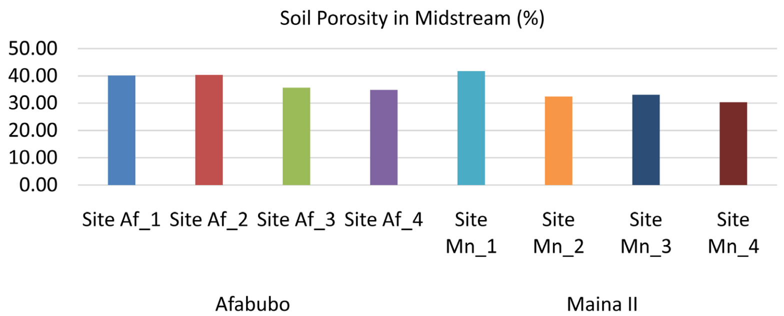

Figure 6. Comparison of soil porosity in midstream.

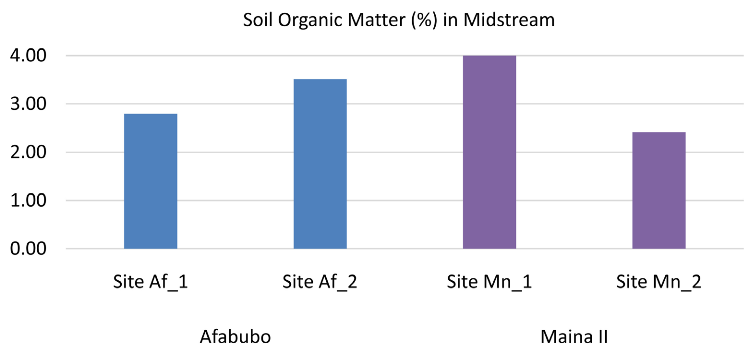

Figure 7. Comparison of soil organic matter in midstream.

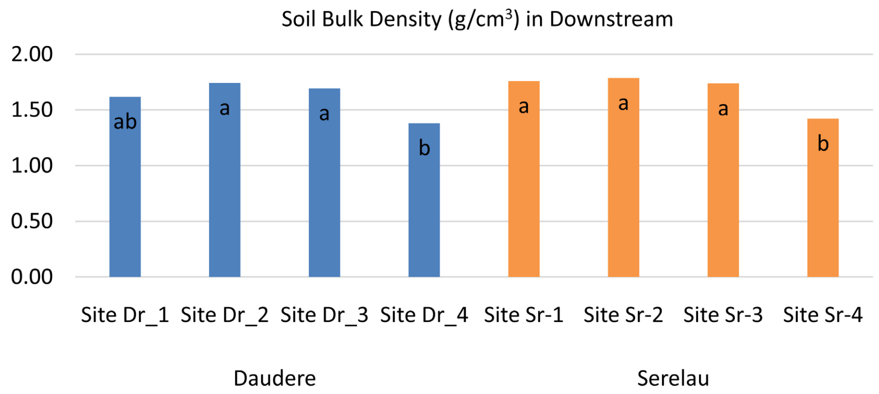

Figure 8. Comparison of soil bulk density in downstream. The same letters bars are not significantly different (DMRT 5%).

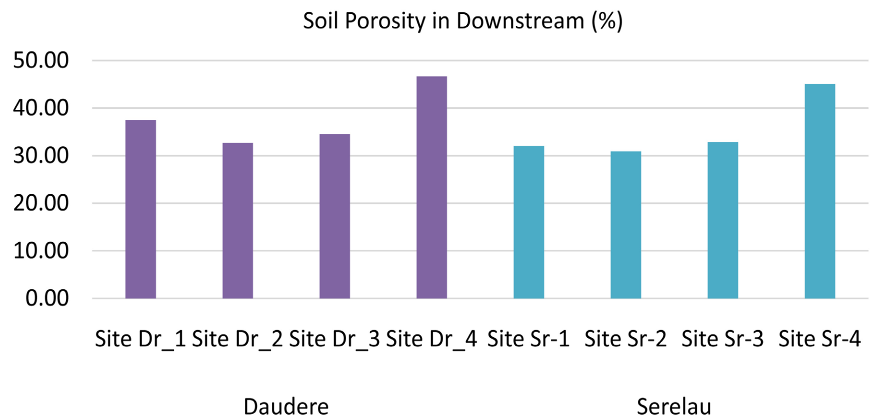

Figure 9. Comparison of soil porosity in downstream.

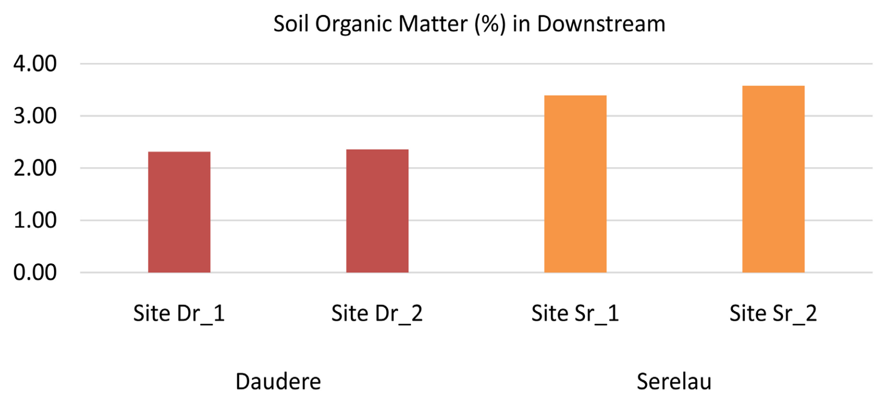

Figure 10. Comparison of soil organic matter in downstream.

3.2. Chemical Properties of Soils

The result of the analysis shows that soil chemical properties such as pH, nitrogen, phosphorous, and potassium are significantly different from one another. Upstream, midstream, and downstream soil pH is generally alkaline. Soil pH is uniform in Kotamuto, Lakawa, and Luro but different from pH in midstream and downstream, which tend to be more alkaline (**Figure 11**). The presence of nitrogen in the soil after slash-and-burn indicated a significantly different situation. In upstream, the highest nitrogen is found at the site of Luro and the lowest at the site of Kotamuto. Nitrogen in midstream and downstream was the lowest compared to nitrogen in upstream (Figure 12). Phosphorus availability is significantly different between sites, extremely highest in the site of Lakawa, followed by the site of Kotamuto and lowest in Luro (upstream), but the rest of the sites are neither high nor low (Figure 13), while the level of potassium is significantly different from each site (Figure 14).

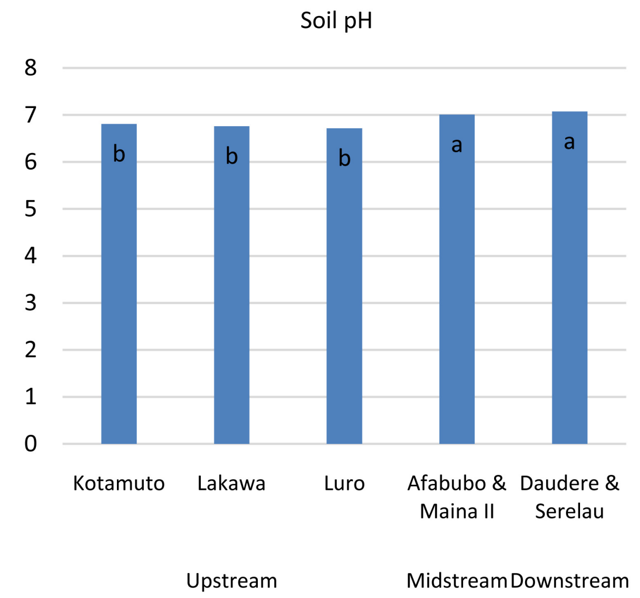

Figure 11. Comparison of soil pH. The same letters bars are not significantly different (DMRT 5%).

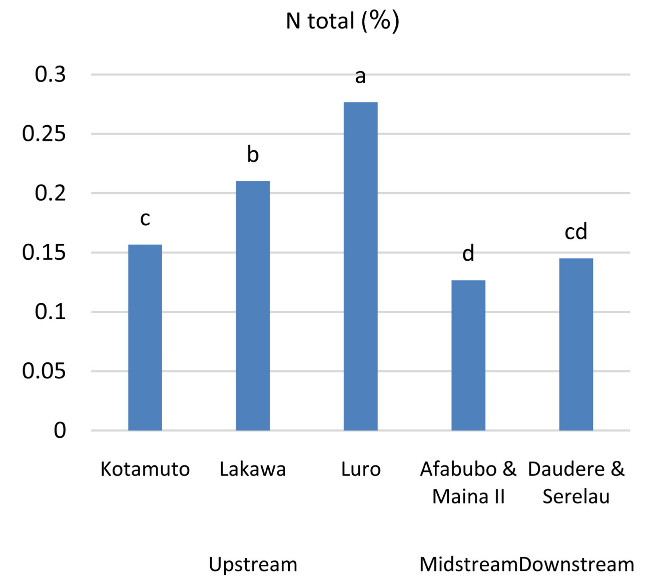

Figure 12. Comparison of soil N total. The same letters bars are not significantly different (DMRT 5%).

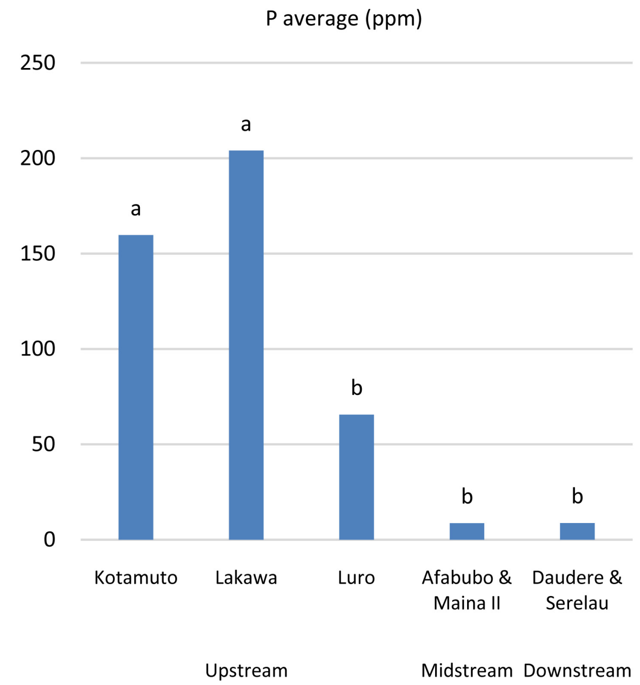

Figure 13. Comparison of soil P average. The same letters bars are not significantly different (DMRT 5%).

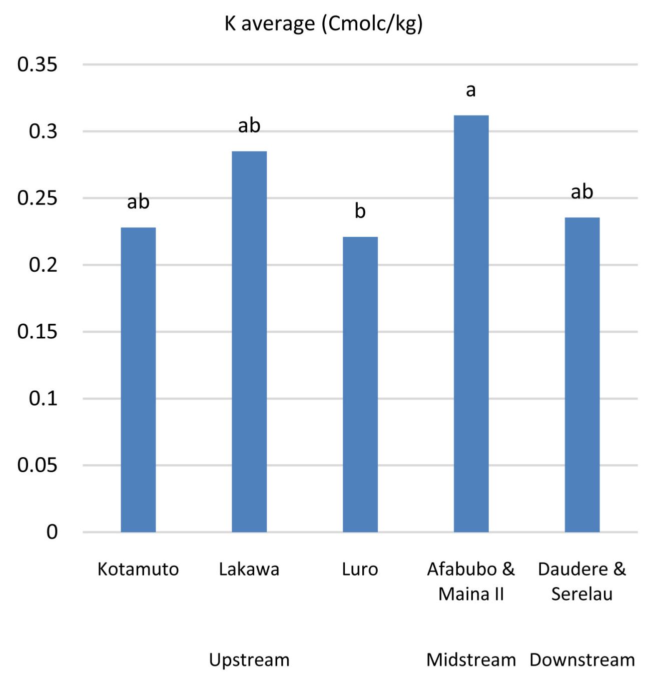

Figure 14. Comparison of soil K average. The same letters bars are not significantly different (DMRT 5%).

4. Discussions

4.1. Biophysical Properties of Soils

The soil biophysical properties in the entire watershed (*i.e.*, upstream, midstream, and downstream) are shown in **Figures 1-10** respectively. In the upstream, soil organic matter in Lakawa is significantly lower than the organic matter in Kotamuto, yet organic matter in Luro is recorded at an adjacent point in both Kotamuto and Lakawa (DMRT 5%). Organic matter in Kotamuto is higher due to less compaction of soil and has greater pores than in Lakawa. The organic matter present is determined by good air movement in the soil through sufficient pores that allow microorganisms to decompose more organic matter, which leads the soil away from its compacted status. Burning practices can heat the ground, elevating the temperature from 200˚C to 300˚C, which decreases organic matter. In addition, if the heating is increased to 500˚C, organic matter is completely destroyed [14].

Bulk density and soil porosity have a contrasting relationship, with both having a DMRT 5% significant difference. High bulk density and low porosity were found in site Luro, while low bulk density and high porosity were found in site Kotamuto. However, bulk density is high, as is soil porosity in the entire upstream.

Overall, soil physical properties upstream are at a critical level for agriculture requirements. Slash-and-burn results in high bulk density and less porosity, which makes the soil susceptible to increased run-off due to less infiltration during rainfall. The soil becomes less productive as well as the leaching process. High bulk density indicates the status of the soil is heavy, which is harmful to growing crops because roots cannot be well developed and it is difficult to absorb nutrients for growth and development processes. [15] observed that natural soil aeration can support crop O_2 demand and maintain aerobic and anaerobic metabolisms of soil organisms.

As per site comparison, all physical properties are significantly different in the upstream with the same treatment ("slash-and-burn"). This indicates that the intensity of burning and material on the ground (vegetation) used to burn up could be of different types. When the material to be burned is woody, but the ground cover is only shrubs, high-intensity burning must be used. Otherwise, low-intensity burning should be used. The assessment results showed that slash-and-burn sites held by a family group with a size of fewer than 2 hectares were mostly used for farming until ten years ago. Woody materials were used for building materials and fencing, while grass and shrubs burned on the land surface to generate ashes. In addition, soil physical properties were altered moderately (water repellency, porosity) to severely (water infiltration) by pile burning. As a consequence, some localized erosion may be expected in the first few years after burning before surface litter or plant cover returns [17].

Soil biophysical properties were not significantly different at DMRT by 5% on site comparison in the midstream. Soil organic matter, bulk density, and soil porosity do not have significant differences among sites. The mean of organic matter was low, as indicated by the fact that the higher point was only 3.88 found in Afabubo 1. At the same time, the lower point decreased to 2.42, which was found on the site of Maina II-2. These phenomena respectively occurred through variables of bulk density and soil porosity in the whole midstream area of the watershed. No significant differences for all physical properties, probably due to the homogeneity of soil characteristics in a given area and similar ground cover being burned. Due to continuous slash-and-burn practices being practiced for a long time in the past, now there are no significant woods to be burned or even open new land to grow crops. Overall, the midstream seems to be in similar statuary to very few trees. That leads to catastrophic microclimate status and tends to be homogeny or dominated area, which brings it to be critical for agricultural purposes. The erodibility of soil is determined by a number of factors, one of which is fire, but soil properties are also determined; slopes, ground cover types, and burn methods must all be considered and interconnected [18].

Soil organic matter has no significant differences among sites under slash-and-burn practices upstream. Yet in site Serelau-4, a higher mean value of 3.88 and lower in site Serelau-1, with a mean value of 2.91. [19] stated that soil organic carbon from burned sites decreased by 8% when compared to undisturbed sites, and nitrogen loss ranged from 5% to 11%. Soil organic matter status after burning may differ from one site to the next due to the different biomass produced at each site. [20] reported that soil organic matter status declined over time after burning biomass on the land surface.

Bulk density and soil porosity have significant differences at DMRT 5%. Site Dr. 4 is significantly lower in bulk density than Site Dr. 1, while the rate is not statistically different in Sr.4 and Dr.1. Despite that, in the rest of the sites, there is no significant difference, but overall bulk density in the downstream is high. Soil porosity, on the other hand, showed the contrast way, low porosity as a function of high bulk density, and it led to the soil being compact with less infiltration, poor microorganisms, and very little organic matter. In 2005, the World Meteorological organization recognized that the decrease in basal (the total cross-sectional area of all stems in a stand measured at breast height) cover due to fire (head fires) exposed the soil more to the natural elements and therefore to higher soil temperatures and soil compaction, in turn leading to lower soil water content and a decline in soil ability to infiltrate.

4.2. Chemical Properties of Soils

Besides the physical and biological properties of soil, its chemical properties also have an important role in agricultural practices. The quality of soil would be determined by the existence of such properties in the soil at an optimum rate for growing crops for food production purposes as well as for the lifecycle of microorganisms in the soil. A lack of such nutrients in the soil could be an indicator of decreased soil productivity.

The pH values were at normal levels, ranging from 6.72 to 7.01 either upstream, midstream, or downstream. DMRT at 5% revealed that there were significant differences by the site. The pH is normal but slightly significantly higher in Daudere & Serelau with a pH of 7.01, which is not statistically different from the pH in Afabubo & Maia II, while pH in Luro is 6.72, significantly lower in the entire watershed. The pH in Luro is not significantly different from the pH in Lakawa and Kotamuto. A slight increase in pH under slash-and-burn practices is probably due to different intensities of burning in different sites. These findings are in accordance with the results found by [21] that ash deposited would increase soil pH. There was no significant difference under slash-and-burn practices in farming sites, which was in line with the findings of [22] that slash-and-burning has effects on soil pH and organic matter. Soil organic matter declines and soil tends to become alkaline from intensive slash and burn practices.

The soil pH fell within the optimum range in the whole watershed area under slash-and-burn farming sites. Therefore, pH is not an issue of concern. Several studies in other countries have found that slash-and-burn agriculture can cause soil to become more alkaline. [23] have observed that the small particle size of wood ash might have contributed to the more rapid change in soil pH. The normal range of pH in the Raumoco watershed indicates that soil is suitable to grow any crop for agricultural purposes if other factors like nutrient retention are kept at a standard level even though the pH level could be changed if the rate of burning is continuously practiced in the farming sites due to leaching effects from erosion and runoff.

In the slash-and-burn area, total nitrogen was recorded, yet results of DMRT at 5% show total nitrogen in Luro is significantly different from the total nitrogen in other sites. Total nitrogen in Luro is categorized as a medium level for crop production. The presence of nitrogen in the soil has a strong relationship with soil organic matter. Total nitrogen in Afabubo & Maina II is at a low level and has no different significance than total nitrogen in Daudere & Serelau but is significantly different from total nitrogen in other sites, namely Lakawa and Kotamuto. Burning practices lead the soil to become low in organic matter. Poor microorganisms in the soil are exacerbated by low soil moisture as an effect of overheating. Microorganisms in the soil have a function in decomposing and modifying litter into organic matter in the soil. If soil moisture is low, total nitrogen will decrease and it will not be absorbed by crops or for any agricultural purposes. On the other hand, less moisture is harmful to microorganisms' ability to reproduce. [24] stated that burning practices result in microbial oxidation of organic compounds and severely reduce soil organic matter and increase the negative impact on the soil.

A low percentage of nitrogen in the soil is related to leaching processes and runoff. When the ground cover is absent, it could be susceptible to leaching down by rain and removing nutrients and other organic matter. [25] stated that nitrogen may be lost during water erosion as dissolved N in runoff and N bound to eroded sediments.

Phosphorus availability in burn-and-slash farming sites shows a significant difference among sites. Phosphorus availability in Lakawa was significantly different from that in Afabubo & Maina II and Daudere & Serelau and was categorized as an extremely very high level. A similar finding was found in Kotamuto in terms of phosphorus availability. The phosphorous availability in Afabubo & Maina II and Daudere & Serelau was found at a very low level. Phosphorous availability in Luro is categorized as very high but not statistically different from the phosphorus availability in both Afabubo & Maina II and Daudere & Serelau. The high availability of phosphorus in the soil is attributed to soil samples mixed with ash from a burned area. According to [26], the soil under burned practices will have direct effects on the availability of phosphorus and calcium in the short term.

Phosphorus availability is linked directly to soil pH. If the soil pH remains in the neutral range, the phosphorus would be available and easily absorbed by the crop roots. When the soil pH is alkaline, phosphate ions tend to react with calcium (Ca) and magnesium (Mg), while when the soil pH is acidic, phosphate ions tend to react with aluminum (Al) and iron (Fe), which makes them unavailable for crops. Another factor affecting phosphorus availability could be the liming effects of ash from materials burned on the ground [27].

Potassium availability in an entire watershed is significantly different from one to another (**Figure 13**). It was found significantly higher in site Afabubo & Maina II and categorized in the optimum rate of availability for crop production. Even the potassium availability in Daudere & Serelau, Kotamuto, and Lakawa was categorized as low level, it was found to have no significant difference at 5% DMRT with the potassium availability in Afabubo & Maina II. However, potassium availability in Luro was categorized as low compared to sites.

The optimum rate of potassium is mostly in the entire watershed except in Luro, due to the effect of burning. In some studies, it was observed that potassium could be eroded caused by runoff and also declined due to burned practices [28]. However, potassium availability is indirectly affected by burning practices. It leads soil to be susceptible to erosion and leaching. Erosion causes potassium availability to decrease or at a poor level afterward. A study conducted by [29] revealed that burning or removing vegetation from the soil surface strongly increases sediment yield and soil loss.

Because K is bound to clays and organic materials, and adsorbed K is mostly associated with fine soil particles, it can be eroded with particulate material in runoff water and by strong winds. It can also be lost when crop residues are burned in the open.

5. Conclusions

The practice of slash-and-burn in land preparation prior to farming has significantly contributed to the depletion of soil nutrients. In terms of soil biophysical properties, the soil becomes low in moisture content, very compacted, and less porous. The practice also removed the vegetation on the ground, which made the soil prone to a high rate of evaporation, increased soil moisture losses, and allowed for massive and continuous soil erosion. It also eliminated soil microorganisms that have an important role in decomposing organic matter. With continuous slash-and-burn practice, the balance in the ecosystem is affected.

The study would like to recommend that the farmers adopt conservation agriculture (CA) with the principle of no-burning, minimum/zero tillage, and growing soil cover crops and Slope Agricultural Land Technology (SALT) to restore soil quality and maintain the soil ecosystem to increase crop production.

The study also recognized the limitation of the study in finding the relationship between recent soil quality and agricultural crop production in the Raumoco watershed. Therefore, further study is needed to look at the relationship between soil quality and agricultural crop production to compare slash-and-burn farming practices with proposed best agricultural practices within the watershed of Raumoco.

Acknowledgements

The researchers would like to acknowledge the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) under the Southeast Asian Ministers of Education Organization (SEAMEO), who have supported this study. I would also like to offer my gratitude to the National University of Timor-Lorosae and Udayana University for allowing me to use their soil laboratory for the samples analyzed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ministry of Agriculture and Fisheries (2018) Final Country Report of The Land Degradation Neutrality Target Setting Programme in Timor-Leste. Mission Aviation Fellowship, Dili.

[2] National Adaptation Plan (2017) Timor-Leste's National Adaptation Plan Addressing Climate Risks and Building Climate Resilience. National Adaptation Plan, Dili.

[3] Asian Development Bank (ADB) (2016) Country Partnership Strategy for Timor Leste 2016-2020. https://www.adb.org/sites/default/files/institutional-document/183715/cps-tim-2016-2020.pdf

[4] Tomás, L.F.R. (1973) Vida Rural Timorense. *Geographica*, *Ano Ix*, *Lisboa*, *Sociedade De Geografia*, No. 33, 3-26.

[5] Food and Agricultural Organization (FAO) (2019, July 6) FAO in Timor-Leste. http://www.fao.org/timor-leste/news/detail-events/fr/c/1197518/

[6] Mota, F. (2002) Timor Leste: As Novas Florestas Do Pais. Ministério Da Agricultura E Pescas, Direcção Geral De Agricultura, Divisão De Florestas.

[7] Democratic Republic of Timor-Leste (2009) National Action Plan to Combat Land Degradation "*Programa de Acção Nacional Para Combater a Degradação dos Solos*". Democratic Republic of Timor-Leste, Díli.

[8] Bouma, G. and Kobryn, H. (2004) Change in Vegetation Cover in East Timor, 1989-1999. *National Resources Forum*, **28**, 1-12.

https://doi.org/10.1111/j.0165-0203.2004.00067.x

[9] Sandlund, O.T., Bryceson, I., De Carvalho, D., Rio, N., Da Silvia, J. and Silva, M.I. (2001) Assessing Environmental Needs and Priorities in East Timor: Issues and Priorities. UNDP, Dili and Norwegian Institute for Nature Research, Trondheim.

[10] Global Change Biology (2016) Peat Soil Bulk Density Important for Estimation of Peatland Fire Emissions.

[11] Tabi, F., Mvondo, Z.A.D., Boukong, A., Mvondo, R.J. and Nkoum, G. (2013) Changes in Soil Properties Following Slash and Burn Agriculture in the Humid Forest Zone of Cameroon. *African Journal of Agricultural Research*, **8**, 1990-1995. https://doi.org/10.5897/AJAR2012.1713

[12] Dennis, E.I., Alphonsus D.U. and Christiana J.I. (2013) Soil Properties Dynamic Induced by Passage of Fire during Agricultural Burning. *International Journal of Advance Agricultural Research*, **2**, 111-126. https://doi.org/10.9734/IJPSS/2013/3121

[13] Holmesa, K.W., Wherrett, A., Keatingc, A. and Murphy, D.V. (2011) Meeting Bulk Density Sampling Requirements Efficiently to Estimate Soil Carbon Stocks. *Soil Research*, **49**, 680-695. https://doi.org/10.1071/SR11161

[14] Montoya, S., Marín, G. and Ortega, E. (2013) Impact of Prescribed Burning on Soil Properties in a Mediterranean Area (Granada, SW Spain). *Spanish Journal of Soil Science*, **4**, 88-98.

[15] Ganot, Y. and Dahlke, H.E. (2021) Natural and Forced Soil Aeration during Agricultural Managed Aquifer Recharge. *Vadose Zone Journal*, **20**, Article ID: e20128. https://doi.org/10.5194/egusphere-egu22-10407 https://acsess.onlinelibrary.wiley.com/doi/10.1002/vzj2.20128

[16] Jeus, M., Henriques, P., Laranjeira, P., Narciso, V. and da Silva Carvalho, M.L. (2012) Técnica Superior de Agricultura, Díli, Timor-Leste, CEFAGE e Departamento de Economia - Universidade de Évora, Ministério da Agricultura e Pescas de Timor-Leste4 Investigadora independente, ICAM e Departamento de Economia, Universidade de Évora.

[17] Busse, M.D., Shestak, C.J. and Hubbert, K.R. (2013) Soil Heating during Burning of Forest Slash Piles and Wood Piles. *International Journal of Wildland Fire*, **22**, 786-796. https://doi.org/10.1071/WF12179

[18] Ladrach, W. (2009) The Effects of Fire in Agriculture and Forest Ecosystems. International Society of Tropical Foresters, Bethesda.

[19] Abdalla, K., Chivenge, P., Ciais, P. and Chaplot, V. (2021) Long-Term (64 Years) Annual Burning Lessened Soil Organic Carbon and Nitrogen Content in a Humid Subtropical Grassland. *Global Change Biology*, **27**, 6436-6453. https://doi.org/10.1111/gcb.15918

[20] Edivaldo, T. and Rosell, S. (2020) Slash-and-Burn Agriculture in Southern Brazil: Characteristics, Food Production and Prospects. *Scottish Geographical Journal*, **136**, 176-194. https://doi.org/10.1080/14702541.2020.1776893

[21] Pantami, S.A., Voncir, N., Babaji, G.A. and Mustapha, S. (2010) Effect of Burning on Soil Chemical Properties in the Dry Sub-Humid Savanna Zone of Nigeria. *Researcher*, **2**, 78-83.

[22] Ebel, R. (2018) Effects of Slash-and-Burn-Farming and a Fire-Free Management on a Cambisol in a Traditional Maya Farming System. *CIENCIA Ergo-Sum*, **25**, 8. https://doi.org/10.30878/ces.v25n2a5

[23] Kopecky, M.J., Meyers, L.N. and Wasko, W. (2012) Using Industrial Wood Ash as a Soil Amendment. A3635. University of Wisconsin-Extension, Cooperative Exten-

sion, Madison.

[24] Tematio, P., Ertine, I.T. and Lucas, K. (2011) Effects of Tillage, Fallow And Burning on Selected Properties and Fertility Status of Andosols in the Mounts Bambouto, West Cameroon. *Agricultural Sciences*, **2**, 334-340. https://doi.org/10.4236/as.2011.23044

[25] Hartley, A., Barger, N., Belnap, J. and Okin, G.S. (2007) Dryland Ecosystem. In: Marschner, P. and Rengel, Z., Eds., *Nutrient Cycling in Terrestrial Ecosystems*, Vol. 10, Springer, Berlin, 271-307.

[26] Angelo Fachin, P., Tadeu Costa, Y. and Lopes Thomaz, E. (2020) Evolution of the Soil Chemical Properties in Slash-and-Burn Agriculture along Several Years of Fallow. *Science of the Total Environment*, **764**, Article No. 142823. https://doi.org/10.1016/j.scitotenv.2020.142823

[27] Martin, Y., Naunamo, L. and Njomgang, R. (2002) Effects of Natura Fallow on Top Soil Properties and Subsequent Crop Yieds in Forest Oxisol of Southern Cameron. *Proceedings of* 17*th World Congress of Soil Science*, Bangkok, 14-21 August 2002.

[28] Goulding, K., Murrell, T.S., Mikkelsen, R.L., Rosolem, C., Johnston, J., Wang, H. and Alfaro, M.A. (2021) Outputs: Potassium Losses from Agricultural Systems. In: Murrell, T.S., Mikkelsen, R.L., Sulewski, G., Norton, R. and Thompson, M.L., Eds., *Improving Potassium Recommendations for Agricultural Crops*, Springer, Cham, 75-97. https://doi.org/10.1007/978-3-030-59197-7_3

[29] Santos, J.C.N., De Andrade, E.M., Medeiros, P.H.A., Guerreiro, M.J.S. and de Queiroz, P.H.A. (2017) Land Use Impact on Soil Erosion at Different Scales in the Brazilian Semi-Arid. *Revista Ciência Agronômica*, **48**, 251-260. https://doi.org/10.5935/1806-6690.20170029 http://www.ccarevista.ufc.br