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The Impact of Forest Fires on Soil Properties in Lainea District, South Konawe Regency

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ABSTRACT

Forest and land fires are a form of disturbance that has the potential to significantly change the physical, chemical, and biological properties of the soil. This study aims to determine the impact of forest fires on soil properties in the burned area in Lainea District, South Konawe Regency, by comparing soil conditions in the ex-fire area and intact forests as a comparison. Soil sampling was carried out in each area of ±10 ha, with analysis of physical properties including texture, lintan density, pore space, moisture content, and permeability; Chemical properties include N, P, K, C-organic, Al, KTK, and pH; biological properties in the form of total soil microorganisms; and erosion estimation using the Universal Soil Loss Equation (USLE) method. The results showed that forest fires increased porosity, moisture content, and soil permeability, but decreased the density of sand and particle density. In chemical properties, the content of N, P, K, and KTK was observed to be higher in the area of the fire excerpt with a more neutral pH, although this increase is suspected to be temporary because it depends on the nutrient supply from the ash, while the C-organic content and organic matter that determine long-term fertility decreased. The total number of soil microorganisms observed decreased in the area of the fire ex. The erosion potential in fire-savage areas was also observed to be much higher than that of intact forests, although this difference may also be influenced by the different slope conditions between the two areas, so it cannot be attributed solely to the loss of vegetation due to fire. The study concludes that the impacts of fire on soil properties are diverse, with some chemical changes appearing beneficial in the short term but not reflecting structural improvements in soil fertility..

Keywords: *forest fires; physical properties of the soil; chemical properties of the soil; biological properties of the soil; soil erosion.*

INTRODUCTION

Land is a natural resource that is very important for human life. Of the total area of the earth's surface, only about 25% is in the form of land that can be inhabited by around 6 billion people, while the rest is in the form of oceans. The land area is about 14,800 million ha, and about 1,400 million ha of it is covered with ice, so that only about 13,400 million ha remain that can be used for all human activities on earth (Wasis, 2002).

Soil is the top part of the lithosphere and the thinnest layer of the entire lithosphere, but its role in the survival of life on Earth is crucial. The process of soil formation that exists today takes thousands to millions of years (Wasis, 2002), in line with the succession process of wet tropical forests, for example that took place in Central Kalimantan Province. The general public often misinterprets that the high biomass and diversity of wet tropical forest types is an indication of high soil fertility, even though the two things are not always correlated.

As a natural resource, land has four distinctive properties: (1) as land or space, land is the parent of all other natural resources; (2) as a place where living things, land is not uniform in value and limited in number; (3) as a location, the land is definite and cannot be moved; and (4) as a forum for human activities, land is permanent (Wasis, 2002). Based on the 1945 Constitution and the Basic Agrarian Law No. 5/1960, land, water, and space are controlled by the state within the framework of the archipelago's vision, with the aims, among others, of prohibiting excessive land ownership, requiring the government to plan the allocation and use of land, affirming the social function of land over personal or group interests, and requiring land rights holders to maintain it so that damage does not occur.

The use of land that does not pay attention to its carrying capacity can trigger damage to the soil and the ecosystem on it. One of the most destructive forms of land use is forest and land burning, which can quickly destroy wet tropical forest ecosystems whose succession process takes a very long time to reach the climax stage. In fact, about 90% of the world's medicines come from wet tropical forests, in addition to their function as a source of germplasm, food, water, and buffer for the global climate system.

In mineral soils such as yellow-red podsolics, burning can damage the aggregate structure of the soil, decrease permeability, and increase the rate of erosion and surface flow, ultimately removing the fertile top soil. Although the practice of burning this kind of old soil is generally carried out for the purpose of improving fertility, the long-term impact is detrimental because it kills the soil microscopic bodies due to extreme temperatures during fires (Harjowiogeno, 1989; Soepardi, 1992; Saharjo, 1995; Murtinah et al., 2017).

In peatlands, the relationship between burning and fertility is two-sided and needs to be understood carefully. In the short term, burning can indeed increase a number of nutrients such as C-organic, N, P, K, Ca, Mg, Na, as well as soil pH and cation exchange capacity (KTK), considering that peatland is naturally classified as less fertile (Soepardi, 1992). However, this increase in nutrients is temporary and does not cover the fundamental damage caused: burning removes the organic matter of the peat itself as well as the vegetation that makes it up, so that the process of formation of new peat comes to a complete halt. Restoration of peat that has been damaged by fire takes hundreds to thousands of years (Holisudin, 2002; Saharjo & Al-Fauzan, 2021). In other words, short-term chemical gains are not proportional to long-term structural losses that are almost irreversible.

Forest and land fires have continued to recur as land has been cleared for plantations, transmigration, livestock, and forestry in the past two decades. Major fire disasters were recorded in 1982/1983, 1994/1995, and 1997/1998, and continued to recur in the following years, with most of the causes coming from human activities and not natural factors (Wulandari & Fitriasari, 2022). Forest and land fires can damage the physical and chemical properties of the soil (Purbowaseso, 2004), and as a dynamic system, the soil is constantly changing due to climatic factors as well as due to human actions that can accelerate these changes (Sutedjo & Kartasapoetra, 2005). Findings from a number of fire sites in Indonesia in Kutai National Park (Murtinah et al., 2017) and Mount Panderman (Wibowo et al., 2024) consistently show an increase in bulk density as well as a decrease in porosity and soil permeability after fires, even up to a dozen years after the incident.

However, most studies on the impact of fire on soil properties are still concentrated in Kalimantan and not many have integrated the physical, chemical, and biological properties of the soil simultaneously in a single post-fire fertility evaluation framework, especially in South Konawe Regency. This emptiness is the basis for this research to be conducted, with the hope that the results can make it easier to determine the type of plants that are in accordance with the characteristics of the post-fire land in recovery efforts. Based on this description, the problem raised in this study is: how does the impact of forest fires on the physical, chemical, and biological properties of the soil in the burned area. Therefore, this study aims to determine the impact of forest fires on soil properties (physical, chemical, and biological) in the burned area.

METHODS

This study uses a quantitative method with comparative descriptive analysis carried out in Lainea District, South Konawe Regency, in January-March 2013, by comparing post-fire land (±10 ha) and normal forest as a comparison (±10 ha). In each area, composite soil samples were taken from 15 points in a zigzag manner at a depth of 0–20 cm, while intact soil samples for physical properties analysis were taken using a ring sample at 3 points in a zigzag manner. All samples were dried before being analyzed in the laboratory.

The physical properties of the soil observed include texture (hydrometer method), lindak density, pore space, moisture content (field capacity, permanent wilting point, available moisture content), and permeability following Sarief (1988); chemical properties including total nitrogen (Kjeldahl method), phosphate, potassium, C-organic, aluminum, cation exchange capacity, and soil pH biological properties in the form of total soil microorganisms analyzed by agar cup method (plate count); and erosion allegedly using the Universal Soil Loss Equation (USLE) model following the Dephut of the Director General of RRL (1990). The data were analyzed in a descriptive histogram to compare soil properties between burned land and normal forests.

RESULTS AND DISCUSSION

Chronology of Fire Incidents

Forest fires are a form of disturbance to forest ecosystems that cause losses from various aspects, including loss of vegetation, destruction of animal habitats, air pollution, and other long-term ecological impacts. This disturbance is not only momentary at the time of the occurrence, but also leaves traces of changes in various properties of the soil that can last over a long period of time, as will be described in the following sections.

Physical Properties of Soil

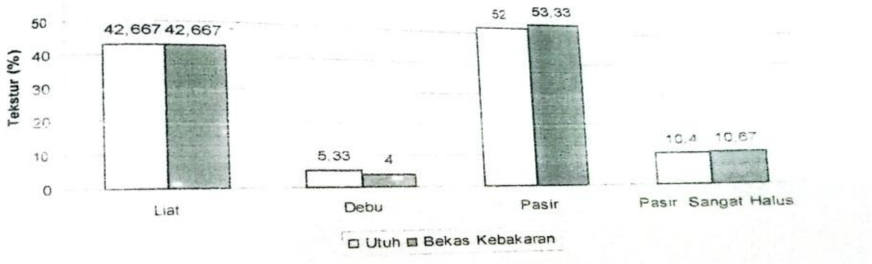

Figure 1. Soil Texture Analysis

Texture analysis showed that the soils in intact forests and fire-stricken forests were both sandy loam, based on the USDA texture triangle in Sutanto (2005). Based on Gmabar 1. The percentage change in the sand, dust, and clay fractions between the two conditions was relatively small. The small size of these changes is consistent with the properties of soil texture that are naturally stable over short periods of time, as texture is determined by the composition of soil-constituent minerals formed in long-term geological processes, in contrast to soil structures that are more sensitive to momentary disturbances such as fire. The remaining ash and charcoal from burning is suspected to still affect soil structure at the micro level, in line with Gumailina et al. (2003) who stated that the supply of charcoal into the soil can reduce the bulk density even though it does not change the overall texture class.

Figure 2. Forest Land Former Fire

Figure 3. Intact Forest Land

Based on Figure 2 and Figure 3. Visually, the color of the land from the fire was darker, which was blackish-brown, compared to the whole forest soil which was brown. This color difference is suspected to come from the accumulation of charcoal from burning on the ground surface. Darker soil color under natural conditions is generally related to higher organic matter content (Hardjo, 2003), but in the case of fire-damaged soil, the color darkness comes from carbon residues from burning, not from the accumulation of natural organic matter. This difference in color sources is important to underline so as not to be misinterpreted as an indication of higher fertility in fire-stricken soils, given that the C-organic data in the next section show the opposite pattern.

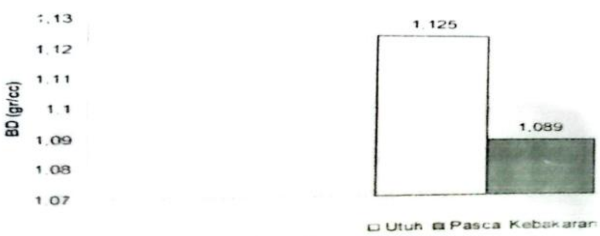

Figure 4. Lindak Density Analysis

Based on figure 4. The density of lindak and particle density in fire-ex-forest forests was recorded lower than that of intact forests, with a difference in particle density of 0.018

gr/cc. This condition is in line with the loss of soil particle-binding organic matter after the fire (Hardjowigeno, 2003), which causes soil aggregates to become less dense.

Figure 5. Pore Space Volume Analysis

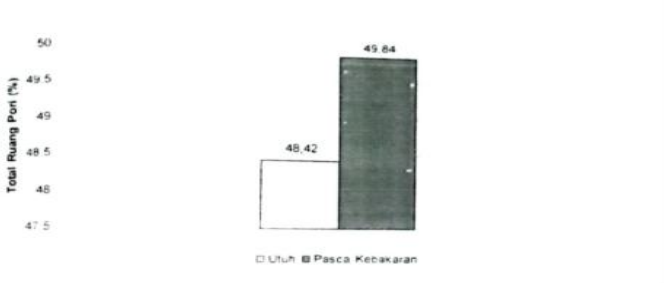

Figure 6. Total Pore Space Analysis

This decrease in lilac density correlates with higher volume and total pore space in fire-excruciated soils Figure 5 and Figure 6, in accordance with the general principle that soils with lower lilac density tend to have larger pore spaces to hold air and water. In line with these patterns, moisture content, spacing capacity, permanent wilting points, and available moisture content were also recorded higher in fire-stricken soils as a direct consequence of the larger pore space (Hakim et al., 1986) As we can see in figures 7,8, and 9.

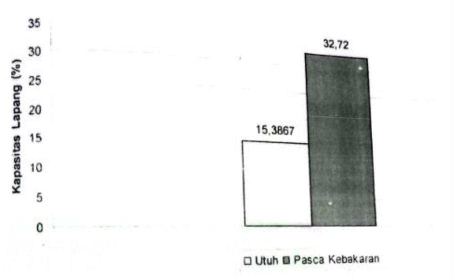

Figure 7. Field Capacity Analysis

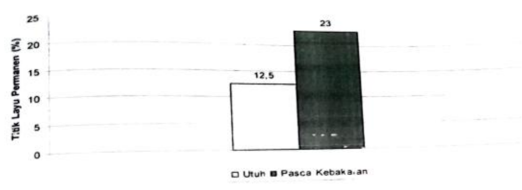

Figure 8. Field Capacity Analysis

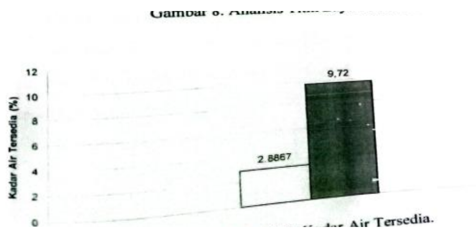

Figure 9. Field Capacity Analysis

So that the permeability in both conditions is relatively fast according to the classification used, with the value of fire-damaged soil slightly higher than that of intact forest as shown in Figure 10. consistent with the previously described porosity pattern. It should be noted that this increase in permeability and porosity, although at first glance beneficial for water infiltration, also has implications for an increased risk of leaching of dissolved nutrients into deeper soil layers in the fire-excruciated area.

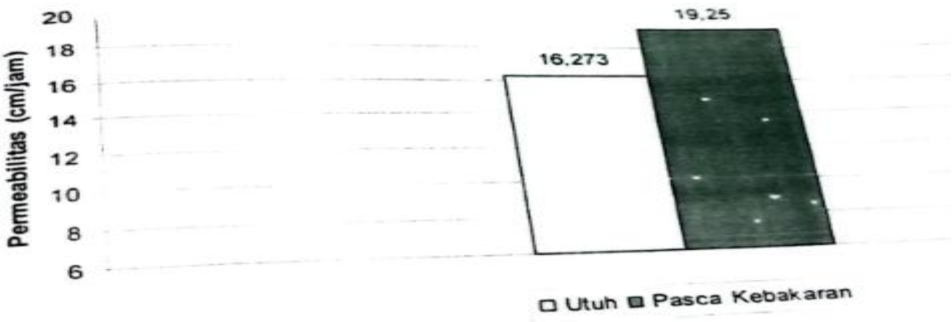

Figure 10. Permeability Analysis.

Chemical Properties of Soil

The total N-content of fire-extinguished land was recorded to be higher than that of intact forests, although both are still relatively low **Figure 11**.

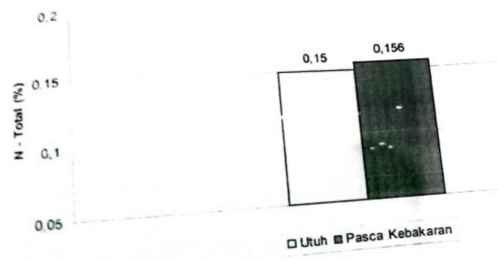

Figure 11. N-Total Analysis.

These findings need to be read carefully considering that the content of C-organic and organic matter is actually lower in fire-damaged soils, while organic matter is known as the main source of soil N (Hardjowigeno, 2003). At first glance these two findings seem contradictory, but the increase in N in this case does not actually come from the remaining organic matter reserves, but from two mechanisms that are conceptually independent of the total organic matter stock. First, the direct release of nutrients from ash and charcoal from biomass combustion (Chandler et al., 1983 in Priandi, 2006). Second, the acceleration of the mineralization of the remaining organic matter due to the increased soil temperature after the loss of the cover vegetation cover (Daniel et al., 1987 in Marjenah, 2007). The increase in pH due to alkaline deposits from the ash also stimulates microbial activity and the nitrification process, so that nitrate levels in the burned area tend to be higher than the condition before burning. Thus, the observed increase in N is short-term and dependent on the nutrient supply from the ash, rather than an indication of structural improvement in soil fertility.

Figure 12. P- analysis is available

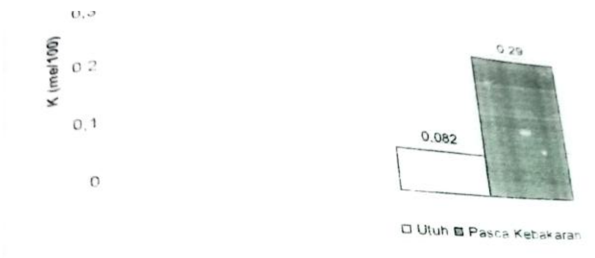

Figure 13. Potassium Analysis

A similar pattern occurs in phosphorus available in Figure 12 and potassium in Figure 13, both of which are higher in fire-damaged soils although they are relatively low to moderate. This increase is consistent with the alkaline release mechanism from the combustion ash that raises the pH of the soil and increases the availability of phosphorus (Daniel et al., 1987 in Marjenah, 2007). In contrast, C-organic content, organic matter, and C/N ratios were recorded lower in fire-swept soils, in line with vegetation loss and burning of organic matter that had a thermal decomposition threshold of around 100°C (De Bano et al., 1998). This decrease in carbon stocks is an important note because, in contrast to macronutrients that can be re-accumulated through a succession of vegetation in a few years, the recovery of soil organic matter reserves generally takes much longer.

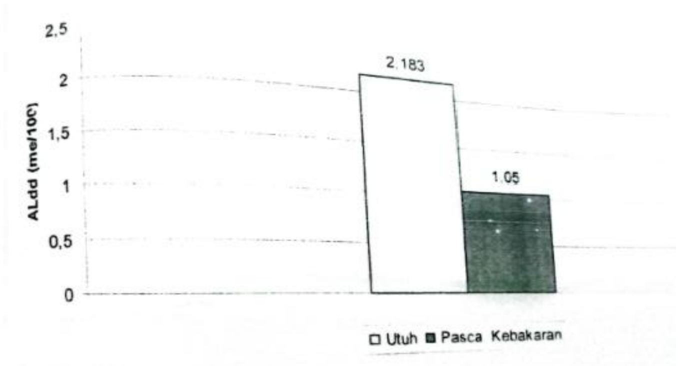

Figure 14. Analisis Aldd.

The content of interchangeable aluminum (Aldd) was recorded higher in intact forest soil than in fire-damaged soils Figure 14. This pattern is consistent with soil pH in each condition: burning releases alkalinations from ash, especially Ca, Mg, and K, which raise soil pH, and such pH increases the solubility of Al^{3+} in soil solution, so that measured Al becomes lower in fire-extinguished soils (Rosmarkam & Yuwono, 2002). The cation exchange capacity (KTK) in fire-affected soils was recorded higher than in intact forests, although both were relatively low Figure 15, thought to be related to post-fire pH increases in pH-dependent loads in organic colloids and clays (Hakim et al., 1986). In line with the above mechanism, the pH of the fire-damaged soil was recorded to be more neutral than that of the whole forest Figure 16, as a direct consequence of the release of alkaline from burning (Syumanda, 2007; Pyne et al., 1996).

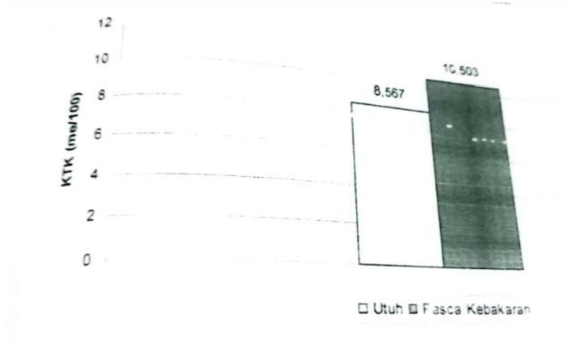

Figure 15. KTK Analysis

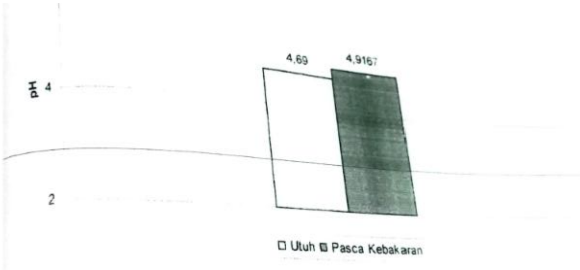

Figure 16. pH analysis.

Biological Properties of Soil

The number of soil microorganisms in intact forests was recorded higher than in fire-savvy forests Figure 17, in line with the direct effects of burning heat that killed some microorganism populations and reduced the reserves of microbial foodstuffs in the soil (Pyne et al., 1996). These effects are generally temporary, with microorganism populations expected to recover gradually in the post-fire years as vegetation returns and new organic matter accumulates. However, without longitudinal observation data at the same location, the recovery rate in this study is still an estimate based on general patterns in the literature, not direct measurement results.

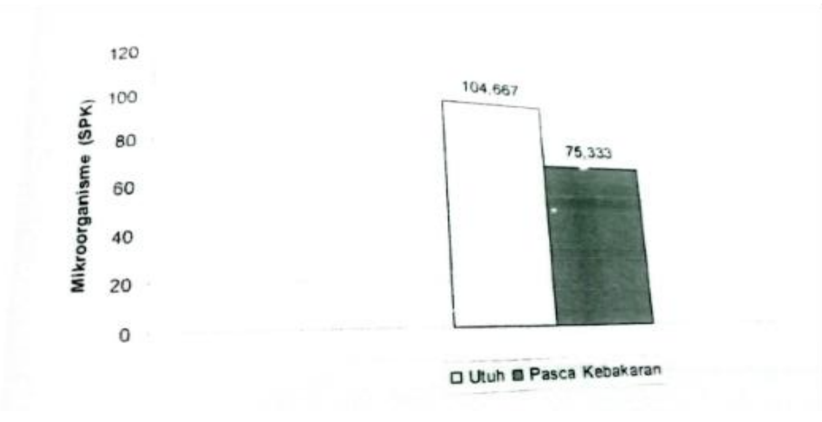

Figure. 17 Microorganism Analysis

The Impact of Fire on Erosion

Erosion estimation using the USLE method shows that the potential for erosion in the area of the fire excerpt is much higher than the whole forest seen in Figure 18, with values of 189.177 and 0.4509 tons/ha/year respectively based on the calculation results in this manuscript (this value needs to be reconfirmed to the original calculation appendix considering that a difference of about ten times compared to the results of the recalculation of the formula and inputs listed). This difference in erosion potential is mainly driven by the loss of vegetation cover, which is reflected in the increase in factor C from 0.005 to 1, much more dominant proportionally than the difference in slope between the two plots as reflected in the increase in the LS factor from 1.4 to 3.1.

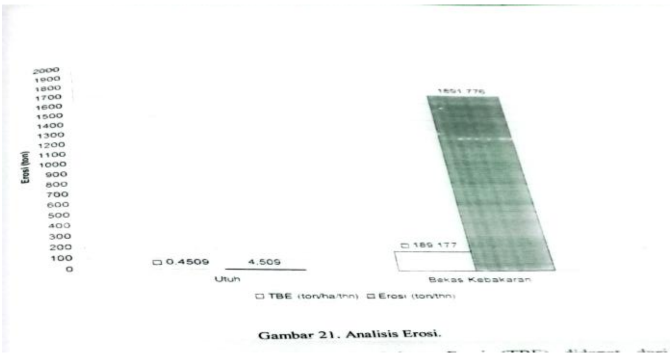

Figure 18. Erosion Analysis

Thus, the high potential for erosion in the area of the fire excerpt is most appropriately attributed to the combination of the loss of cover vegetation as the dominant factor, with the steeper slope conditions on the plot as an additional contributing factor, rather than as a single consequence of the fire event itself. Referring to the tolerable erosion threshold of 12.5 tons/ha/year (Hudson, 1976 in Sarief, 1985), the conditions in the area of the fire excerpt far exceeded this threshold, while intact forests were still within safe limits. These findings are consistent with the risk of loss of fertile soil layers and decreased water-holding capacity of the soil in the burned areas (Arsyad, 1989), and indicate the need for immediate soil conservation measures in post-fire areas to prevent further land degradation.

CONCLUSIONS

Forest fires have a diverse impact on the soil properties in the study area. In physical properties, fire increases soil porosity, moisture content, and permeability, but decreases the density of shale and particle density due to the loss of soil particle binding organic matter. In chemical properties, fire increases N, P, K, and KTK levels and raises soil pH to a more neutral direction, but this increase is short-term because it relies on the nutrient supply from ash, while the C-organic content and organic matter that determine long-term structural fertility decreases. In biological traits, the total number of soil microorganisms decreased post-fire, although the study did not measure other aspects of soil biology such as species diversity or enzymatic activity. Fires also increase the potential for soil erosion markedly, although this increase may also be influenced by the difference in slopes between the two areas being compared, so it cannot be attributed solely to the loss of vegetation due to fires.

Further research is recommended to replicate this comparative design at multiple independent fire sites with equivalent slope conditions, so that the impact of fire on soil properties can be more clearly separated from topographic influences. Time recording since the fire incident is also suggested to be included in the design of the next study, given that the restoration of the physical, chemical, and biological properties of the soil is known to change over post-fire time. In addition, longitudinal monitoring at the same location will provide a more accurate picture of the rate of soil recovery compared to the one-time portrait approach used in this study. Further studies on the economic impact of forest fires and spatial mapping of burned areas in South Konawe Regency also remain relevant to be developed as a complement to the biophysical information that has been obtained from this study.

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