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Identification of Soil Damage Due to Biomass Production in Bekasi Regency, Indonesia

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ABSTRACT

The primary objective of this study was to determine the current condition, areas, and potential of soil degradation due to biomass production in Bekasi Regency. This study used a survey-based methodology that involved direct field observation and collection of soil samples from specified agricultural and forestry areas based on work maps. The laboratory analysis was conducted on the collected soil samples. The initial phase of soil damage determination involved an evaluation of the current soil condition. Soil condition maps were created utilizing data derived from the determination of key soil parameters based on the standard of soil damage criteria. The result of the analysis indicated that the degree of soil damage in Bekasi Regency due to biomass production varied from slight to moderate. The primary limiting factors were identified as soil permeability (p), redox potential (r), total porosity (v), electrical conductivity (e), bulk density (d), and pH level (a). The limiting factors were predominantly influenced by the constraints associated with the physical characteristics of the soil. The phenomenon is commonly associated with the high level of land exploitation, characterized by the use of chemical inputs, resulting in soil compaction. The process of compaction has a substantial impact on soil properties, including permeability, porosity, redox potential, bulk density, and electrical conductivity.

***Keywords**: biomass, limit factor, soil damage, soil characteristic, soil compaction*

ABSTRAK

Penelitian ini bertujuan utama untuk menentukan kondisi terkini, luasan, serta potensi kerusakan tanah yang disebabkan oleh produksi biomassa di Kabupaten Bekasi. Metode yang digunakan dalam penelitian ini adalah berbasis survei dengan melakukan pengamatan langsung di lapangan dan pengumpulan sampel tanah dari lahan-lahan pertanian dan kehutanan yang ditentukan berdasarkan peta kerja. Analisis laboratorium dilakukan terhadap sampel tanah yang telah diambil untuk mengevaluasi sifat-sifat kimia, fisika, dan biologisnya. Tahap awal penentuan kerusakan tanah dilakukan melalui evaluasi kondisi tanah saat ini. Peta kondisi tanah disusun berdasarkan data yang diperoleh melalui analisis parameter tanah utama yang diidentifikasi sesuai dengan kriteria standar kerusakan tanah. Hasil analisa menunjukkan adanya variasi tingkat kerusakan tanah di Kabupaten Bekasi akibat produksi biomassa, mulai dari tingkat ringan hingga sedang. Beberapa faktor pembatas utama telah diidentifikasi, antara lain permeabilitas tanah (p), potensi redoks (r), porositas total (v), konduktivitas listrik (e), berat isi (d), dan tingkat pH (a). Faktor pembatas utama disebabkan oleh hambatan yang terkait dengan sifat-sifat fisik tanah. Dalam konteks umum, fenomena ini biasanya terkait dengan tingkat eksploitasi lahan yang tinggi, yang dicirikan oleh pemanfaatan input kimia yang berlebihan, yang berdampak pada pemadatan tanah. Proses pemadatan ini berpengaruh secara nyata terhadap karakteristik tanah, seperti permeabilitas, porositas, potensi redoks, berat jenis, dan konduktivitas listrik.

Kata kunci: biomassa, faktor pembatas, karakteristik tanah, kerusakan tanah, pemadatan tanah

INTRODUCTION

The soil functions as a primary producer of biomass essential for human life and contributes significantly to water resource conservation and overall environmental preservation. The process of biomass production involves the utilization of land resources to generate biomass. Biomass is the organic matter derived from plants including flowers, seeds, fruit, leaves, twigs, stems, and roots, resulting from agriculture, plantation, and forestry.

In practice, commercial biomass production necessitates optimizing productivity through utilizing multiple chemical inputs, including chemical fertilizers, pesticides, and improper management and processing systems. This phenomenon has the potential to cause significant soil damage, surpassing the threshold for allowable damage. The introduction of these pollutants into the soil can result in significant soil damage, ultimately rendering it unsustainable for various life-sustaining activities.

Soil damage due to biomass production necessitates effective control measures to ensure the conservation of soil condition and the maintenance of its quality. The regulation framework governing soil damage is controlled by the Republic of Indonesia Government Regulation No.150 year of 2000 concerning Soil Damage controlling for Biomass Production.

Soil damage due to biomass production in Indonesia has emerged as a critical issue, which has been further compounded by the adoption of contemporary agricultural practices since the 1970s. The conversion of lowland forests into oil palm and rubber plantations has resulted in alterations in soil nitrogen-cycling processes, with implications for soil fertility and quality (Prasetyo ., 2022; Allen ., 2015). Runoff water has been determined to be a substantial factor in soil damage, impacting soil fertility and agricultural productivity (Hikmah, 2019). A spatial analysis of degraded lands in Indonesia has indicated a restricted capacity for agricultural productivity and carbon sequestration, thereby underscoring the adverse effects on soil fertility and biomass yield (Jaung ., 2018).

Soil erosion has been recognized as a serious soil damage problem in Indonesia, especially within watershed areas, where high erosion rates have been reported in all watershed regions in Indonesia (Susanti *et al*., 2019; Harliando *et al*., 2022; Rofita *et al*., 2021). The impact of soil erosion on biomass production is apparent, as the water scarcity caused by soil erosion induces drought stress, ultimately leading to decreased plant biomass production (Rashid *et al*., 2021). Furthermore, research has demonstrated that soil damage caused by environmental factors such as excessive heat, cold, and imbalanced soil moisture can lead to a reduction in the activity of soil biomass, thereby compounding the issue (Cantwell *et al*., 1989).

In Indonesia, efforts to mitigate soil damage have entailed the utilization of coal ash on previously mined land to mitigate erosion, as well as the refinement of the RUSLE CP factor for the modeling of soil erosion in tropical watersheds (Matsumoto *et al*., 2016; Harliando *et al*., 2022). Prior research has investigated the remediation impact of biomass amendment on the physical-chemical characteristics and sustainable utilization of sandy soil, suggesting potential approaches for increasing soil degradation and enhancing soil fertility for biomass cultivation (Ren *et al*., 2021).

The primary objective of this study is to determine the current condition, areas, and potential of soil degradation due to biomass production in Bekasi Regency.

MATERIALS AND METHODS

The data utilized in this study encompasses a variety of materials, such as topographic maps, satellite images, land use maps, soil maps, climatic maps, maps of soil damage potential, and maps detailing the status of soil degradation. At this step, the map representing of the 23 districts have been compiled that encompass the entirety of Bekasi Regency.

This study is a survey-based methodology that involves direct field observation and collection of soil samples from specified agricultural and forestry areas based on work maps. The laboratory analysis was conducted on the collected soil.

The primary objective of the preparatory phase involves the creation of a baseline soil condition map and the identification of areas with soils that may be susceptible to potential vulnerabilities. The first phase in the creation of the Baseline Condition Map entails the identification of suitable operational zones by integrating data with the Regional Spatial Planning Map. The compilation of the Baseline Condition Map involves multiple sequential steps, including the filtering of relevant work areas, scoring the potential for land damage on thematic maps, overlaying pertinent thematic maps, and determining the potential for soil damage.

The mapping of soil status facilitates the identification of limiting factors that affect soil fertility within a specific location, allowing the implementation of targeted soil management strategies that address these recognized constraints. Soil fertility evaluation is often conducted using soil analysis or soil testing methodologies. This study employed five soil fertility parameters, including Cation Exchange Capacity (CEC), Base Saturation (BS), Organic Carbon content, and levels of Phosphorus (P) and Potassium (K) in the soil, following the technical guidelines for soil fertility evaluation (Soil Research Center, 1995), to assess soil fertility status.

The research methodology aligns with the guidelines stipulated in Government Regulation Number 150 year of 2000, which pertains to the control of soil damage for biomass production, as well as the Ministerial Decree of the State Ministry of Environment Number 07 year of 2006, which delineates the standard criteria for measuring soil damage in biomass production.

RESULT AND DISCUSSION

Soil Damage Potential

The evaluation of soil damage commences with an assessment of the current soil conditions. The compilation of the soil condition map is derived from the analysis of characteristic parameters established in the standard criteria for assessing soil damage. The legend of the map contains a spectrum of numerical values representing the scores of various parameters such as soil type, slope gradient, annual rainfall, and land use. Table 1 presents the results of the analysis of the potential for soil damage in the various districts of the Bekasi Regency.

The analysis was predicated upon the weighting values ascribed to individual land and environmental criteria within a given region, following the prescribed methodology for assessing soil damage as per the Ministerial Decree of Environment number 7 of 2006.

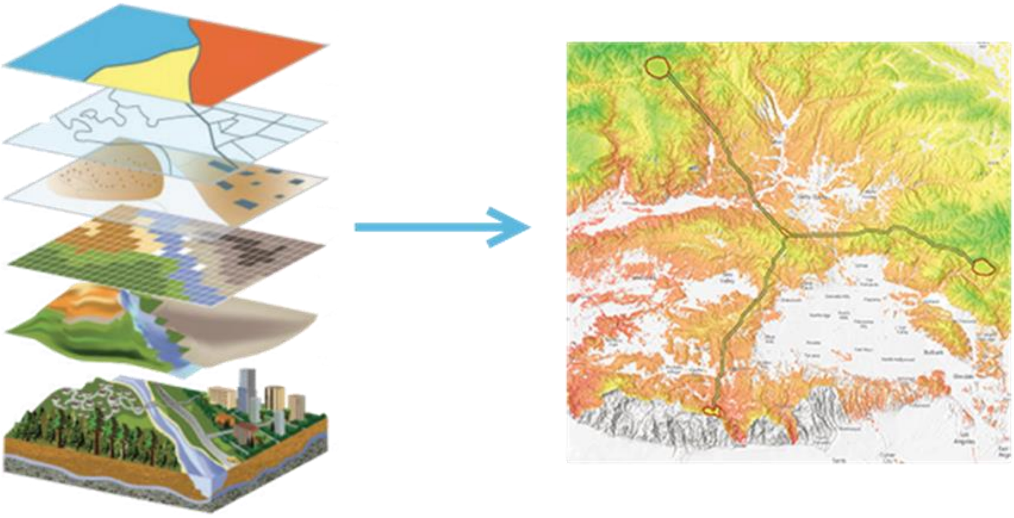

Figure 1. An example of a map overlaying process

Table 1. Recapitulation of potential soil damage in effective land areas

Symbol	Potential Soil Damage	Area	
		Ha	%
PR I	Very Low	25,213.63	36.58
PR II	Low	38,421.87	55.75
PR III	Moderate	5,283.13	7.67
Total Area		68,918.63	100.0 0

Source: Result of analysis

The analysis of the data in Table 1 suggests that the potential for soil damage in the Bekasi Regency varies based on factors such as soil types, land slope conditions, rainfall intensity and distribution, and land use types, ranging from very low to moderate. Numerous factors influence the potential degradation of soil in the context of biomass production, encompassing a range of agricultural, environmental, and management-related dimensions. The existing literature offers valuable insights into the multitude of factors that contribute to soil degradation, including but not limited to the depletion of organic matter, application of herbicides, practices related to land use and agriculture management, soil compaction, and damage caused by machinery.

Gollany *et al*. (2015) have identified biomass production systems as having a noteworthy impact on the removal of organic matter, leading to implications for soil organic matter, carbon, and nutrient storage. These effects can ultimately influence long-term soil productivity and have off-site impacts. The persistence of herbicides like glyphosate in soil and their potential migration to ground and surface waters are influenced by soil composition and precipitation, emphasizing the significance of herbicide application in soil degradation (Borggaard & Gimsing, 2007).

The issue of soil degradation, stemming from various factors including excessive tillage, improper crop rotations, deforestation, and urban sprawl, has been acknowledged as a worldwide concern leading to detrimental impacts on soil quality and productivity (Karlen & Rice, 2015). Additionally, it has been recognized that intensive agricultural management and soil pollution act as persistent contributors to the detriment of agricultural production sustainability, highlighting the significant impact of agricultural practices on soil quality (Meli *et al*., 2006).

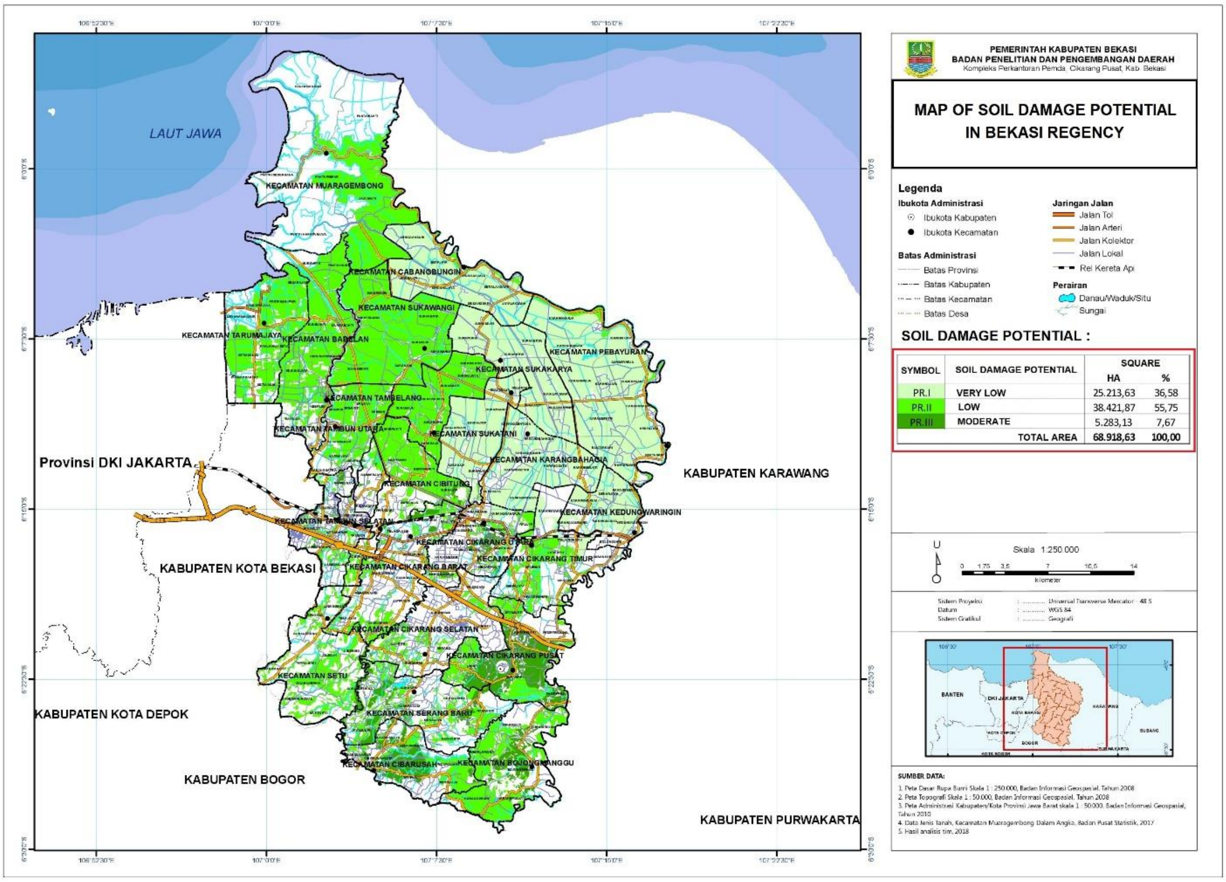

Figure 2. Map of soil damage potential in Bekasi Regency (Source: Result of Analysis)

The expansion and intensification of agriculture in sub-Saharan Africa have been identified as the predominant factors contributing to soil degradation, indicative of the impact of land use practices on soil quality (Tully *et al*., 2015). Furthermore, the process of logging, especially when involving heavy ground-based machinery, has been linked to significant and enduring harm to forest soil systems, resulting in adverse impacts on forest productivity and ecosystem function (Picchio *et al*., 2020).

The research conducted by Bawa *et al*. (2019) demonstrates that soil amendments can alleviate the detrimental impacts of soil compaction on root biomass yield. This highlights the potential of management practices to mitigate soil damage. Moreover, Dudáková *et al*. (2020) emphasized the importance of considering the effects of logging operations on soil integrity by highlighting the impact of machinery-induced damage on forest soils.

The literature also examines the influence of soil moisture regimes on plant biomass production, with flooding recognized as exerting a substantial adverse effect on above-ground biomass production (Pezeshki *et al*., 1998) Additionally, the identification of easily degradable carbon as a marker of microbial hotspots and soil degradation highlights the significance of soil carbon dynamics in the processes of soil quality and degradation (Wolińska *et al*., 2018)

Soil Damage Status

Data presented in Table 2, indicated that soil damage due to biomass production in Bekasi Regency varies from slight to moderate. The predominant contributing factors include soil permeability (p), redox potential (r), total porosity (v), electrical conductivity (e), bulk density (d), and pH level (a). The limiting factors are primarily influenced by physical soil property constraints, often linked to the intensity of land utilization with chemical inputs, leading to soil compaction as a result. The process of compaction has a considerable influence on the soil's attributes including permeability, porosity, redox potential, bulk density, and electrical conductivity.

The permeability of soil (p) plays a crucial role in determining the vertical distribution of specific organisms within the soil, as demonstrated by Min *et al*. (2011). Moreover, it has an impact on the transportation and dispersion of gases, as well as the facilitation of soil penetration by developing roots (Aikins & Afuakwa, 2012). The correlation between soil water content and bulk soil electrical conductivity has been ascertained, demonstrating the interaction between water content and electrical conductivity (Sheets & Hendrickx, 1995).

The relationship between redox potential (r) and electrical conductivity (e) is interdependent, as the latter is affected by the moisture level within the soil (Escuer & Vabrit, 2017). Zuo *et al.* (2023) have recognized the pH level as a primary determinant influencing the composition of microbial communities within the soil, while Li and Xing (2010) have identified it as a constraint on crop yield, particularly in acidic soils, because of its detrimental effects on both root and aerial plant structures.

Table 2. Soil Damage Status Due to Biomass Production in Bekasi Regency

Symbol	Soil Damage Status	Limiting Factors	Area	
			Ha	%
R.I - p,r	lightly damaged	soil permeability, redox potential	2,213.31	2%
R.I - v,p,r	lightly damaged	total porosity, soil permeability, redox potential	33,654.35	26%
R.I - p,e,r	lightly damaged	soil permeability, electrical conductivity, redox potential	29.77	0%
R.II - p,e,r	moderately damaged	soil permeability, electrical conductivity, redox potential	11,795.98	9%
R.II - v,p,e	moderately damaged	total porosity, soil permeability, electrical conductivity	3,751.47	3%
R.II - v,e,r	moderately damaged	total porosity, electrical conductivity, redox potential	10,044.65	8%
R.I - d,p	lightly damaged	bulk density, soil permeability	3,230.30	3%
R.I - d,p,a	lightly damaged	bulk density, soil permeability, pH	2,150.27	2%
R.I-d,p,v	lightly damaged	bulk density, soil permeability, total porosity	1,671.92	1%
NEA	Non-Effective Area		59,044.80	46%
		Total Area	127,586.82	100%

Source: Result of analysis

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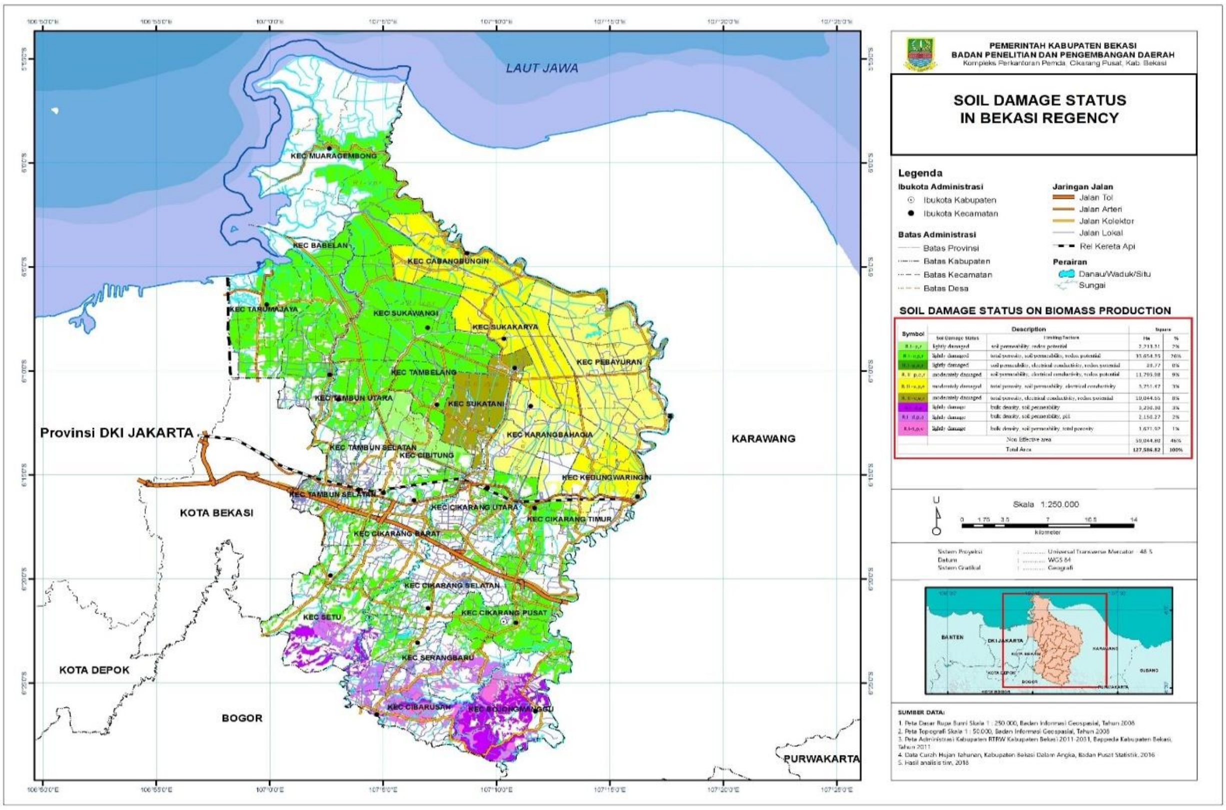

Figure 3. Map of soil damage status in Bekasi Regency (Source: Result of analysis)

Soil porosity, as represented by total porosity (v), is subject to the influence of a variety of factors including tillage practices, organic matter content, soil structure, and cultivation methods, all of which have a combined impact on soil porosity (Darma & Fahrunsyah, 2022; Tang-yuan *et al*., 2009). Moreover, there exists an inverse relationship between the bulk density (d) of the soil and its total porosity, as fluctuations in bulk density have the potential to cause changes in the overall soil porosity (Yu *et al*., 2018).

The interaction of these factors has a substantial impact on the state of soil damage. The soil water content, pH level, and electrical conductivity have been identified as influential factors shaping soil microbial communities and impacting crop production. Furthermore, it is essential to consider soil porosity and bulk density to comprehend the physical characteristics of soil and their influence on soil degradation

CONCLUSION

The study resulted in several conclusions based on the data analysis. Firstly, the status of soil damage in the study area was found to be a lightly damage level, with specific limiting factors identified at each location. Secondly, the dominant limiting factors for the status of land degradation in the study area were found to be soil permeability (p), redox potential (r), total porosity (v), electrical conductivity (e), bulk density (d), and pH level (a).

The observed effects are probably attributable to the influence of wet rice cultivation practices, including flooding, mudding, and mechanical actions such as plowing, leading to the development of an artificial clay layer, which in turn impacts the soil's low porosity, soil permeability, and redox potential. An alternative explanation may be attributed to soil compaction resulting from the application of chemical fertilizers and pesticides.

Chemical compounds introduce residues that can detrimentally impact the physical properties of soil through the aggregation of soil particles, thereby compromising soil pore space closure and subsequently influencing other soil characteristics including bulk density, electrical conductivity, and pH.

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