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Soil physical health index in various land use of Keduang Sub-watershed, Central Java, Indonesia

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Abstract The results showed Keduang Sub-watershed is found to be four land uses, namely paddy fields (48.80%), dry fields (21.05%), plantations (22.92%), and forest (7.24%). Rice fields dominated the land use of the Keduang Sub-watershed. The Keduang Sub-watershed had low to very low soil physical health. SPHI is influenced by land use, where forests was the highest average (31.789) SPHI, while rice fields were the lowest (20.867) SPHI. In addition, the high and low SPHI are also determined by the physical condition of the soil in the Keduang Sub-watershed, namely the values for BD, porosity, and CMB. Soil management formulated for agricultural land in the Keduang Sub-watershed is involved in applying agroforestry, adding organic matter, and increasing the number of cover crops.

Keywords : Bulk density, Land management, Soil health factor, Soil health in forest

Introduction

Land use plays an essential role in the cycle of nutrients and carbon (Kim, 2016). The types of land use and management have an impact on the loss of natural ecosystems, decreased soil and water quality, and loss of biodiversity (Yee *et al.*, 2020). Conventional, semi-organic, and organic farming systems can affect soil quality index. Romadhon *et al.* (2024) explain that conventional agricultural systems have the lowest soil quality index (0.28) compared to organic systems (0.36). Research by Muttaqin *et al.* (2021) explains that in 2020, there will be an increase in the use of paddy fields (1.3%) and dry fields (3.8%). Intensive changes in land use can cause erosion, resulting in soil degradation (Li *et al.*, 2014). Soil degradation can also be caused by intensive cultivation of agricultural land (Gibbs *et al.*, 2015). Soil degradation can cause loss of availability of nutrients and water (Alemu *et al.*, 2022), organic matter, decreased soil cation exchange (Cahyani *et al.*, 2024), root penetration, and microbial activity (Rabot *et al.*, 2018). Research by Santos *et al.* (2021) states that land conversion from natural vegetation to agriculture causes the degradation of soil physical properties

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such as soil texture (Widhiyastuti *et al*., 2023), compaction, porosity, water retention, and aggregate stability.

The Keduang Sub-watershed is the widest in Wonogiri Regency, with an area of 39,582 ha. The Keduang sub-watershed has plantation area types of annual plants such as teak (*Tectona grandis*), sengon (*Albizia falcataria*), and pine (*Pinus merkussi*). The forest area is located on steep slopes. It is dominated by agroforestry in the form of annual and seasonal crops such as turmeric (*Curcuma longa*), peanuts (*Arachis hypogaea*), ginger (*Zingiber officinale*), and corn (*Zea mays*). Research by Yuliantoro *et al*. (2021) explained that there are seven types of vegetation in the Keduang watershed, including *Tectona grandis*, *Albizia falcataria*, mahogany (*Swietenia mahagonia*), johar (*Cassia siamea*), *Pinus merkussi*, sonokeling (*Dalbergia latifolia*) and white teak (*Gmelina arborea*). The forest area in the Keduang Sub-watershed represents only 7.24% of the total area, with rice fields and moors being the predominant features of the studied region.

Land use change in the Keduang Sub-watershed with rather steep contours increases the soil degradation potential (Istiqomah *et al*., 2023). The Keduang watershed is one of the largest contributors to sedimentation in the Gajah Mungkur reservoir due to its high soil erosion value, and landscape characteristics are dominated by agricultural land in hilly areas (Indrawati *et al*., 2022). Gajah Mungkur Reservoir has an area of 8,800 ha, the sixth largest reservoir in Indonesia (Utomo *et al*., 2010; Nissa and Suadi, 2022). Research by Muttaqin *et al*. (2021) showed that the erosion value in the Keduang watershed will reach 363.38 $m^3.s^{-1}$ in 2020. The research of Ari Murdhianti *et al*. (2021) confirms that the Keduang watershed has an erosion value of 49.313 $tons.ha^{-1}.year^{-1}$ with a sedimentation volume of 11,788 $m^3.year^{-1}$. The erosion problem in the Keduang Sub-watershed causes soil degradation in several agricultural land uses, resulting in decreased soil physical health.

The definition of soil health, according to Hatten and Liles (2019), is the ability of the soil to maintain ecosystems and support the maximum growth and development of living things. Soil physical health is the ability of the soil to impact the movement of water and nutrients, soil temperature, porosity, and root growth (Blanco-Canqui and Benjamin, 2015; Sainju *et al*., 2022). The management of soil physical health in the Keduang watershed focuses on agroforestry management to maximize biodiversity and land cover. Improving the health of soil physics can be done by managing drainage in the sub-watershed, which aims to minimize soil erosion and support agricultural production (Strock, 2018). Determining the physical health value of soil refers to the research of Riwandi and Handajaningsih (2011) using the scoring and weighting methods.

The advantages of the scoring and weighting method are that it is easy and has a reasonably high accuracy. The research method of Riwandi and Handajaningsih (2011), which is used as a reference, is updated by looking at aspects of physics and developed using spatial analysis methods. The data used in the spatial analysis are land characteristic data in thematic maps of rainfall, slope, soil type, land use, and soil physical health index parameters. Spatial analysis based on Geographic Information Systems (GIS) aims to map the distribution of soil physical health indices, especially on agricultural land in the Keduang Sub-watershed. The novelty of this study is to examine the soil physical health index in various land uses in the Keduang Sub-Watershed. The aim was to identify and map the physical health of the soil in the Keduang sub-watershed and provide recommendations on land that is indicated to be unhealthy.

Material and method

Research area description

The research was conducted in the Keduang Sub-watershed, Central Java, from December 2022 to January 2023. The Keduang Sub-watershed is between 7°42'29" – 7°55'39" S and 111°11'01" – 111°24'54" E (Muttaqin *et al*., 2021). The Keduang Sub-watershed is located in two regencies, namely Wonogiri and Karanganyar districts, with an area of 39,582 ha. The research area of the Keduang Sub-watershed is shown in Table 1. The research area has an altitude between 150 and 2,000 m above sea level, with slopes ranging from 1% to >45%. The research area has inceptisols, alfisols, entisols, and andisols soil types. Land use in the Keduang sub-watershed includes paddy fields, dry fields, plantations, and forests.

Table 1. The research area of the Keduang Sub-watershed

No	Subdistrict	Regency	Area (ha)
1	Girimarto	Wonogiri	4,461
2	Jatipurno	Wonogiri	5,574
3	Ngadirojo	Wonogiri	3,672
4	Nguntoronadi	Wonogiri	1,299
5	Slogohimo	Wonogiri	6,211
6	Sidoharjo	Wonogiri	5,052
7	Jatiroto	Wonogiri	7,262
8	Jatisrono	Wonogiri	5,432
9	Jatiyoso	Karanganyar	694

Source : (Sutrisno *et al*., 2012)

Determination of sample points

The research was descriptive explorative research through observation and sampling in the yield. Using the ArcGIS application, sampling points based on land mapping unit (LMU) were composed of thematic map sources. Map of the source of diversity in the form of rainfall was obtained from the Bengawan Solo River Basin Center (BBWS) in 2022, land use maps were obtained from the website Indonesia Geospatial Portal, slope maps were obtained from the National Digital Elevation Model (DEMNAS) and soil type maps were obtained from Agricultural Land Resources Research and Development (BBSDLP) in 2018. The overlapping results used 22 LMUs as sampling points, with each LMU being replicated for 3 points determined purposively and resulting in 66 sample points (Figure 1).

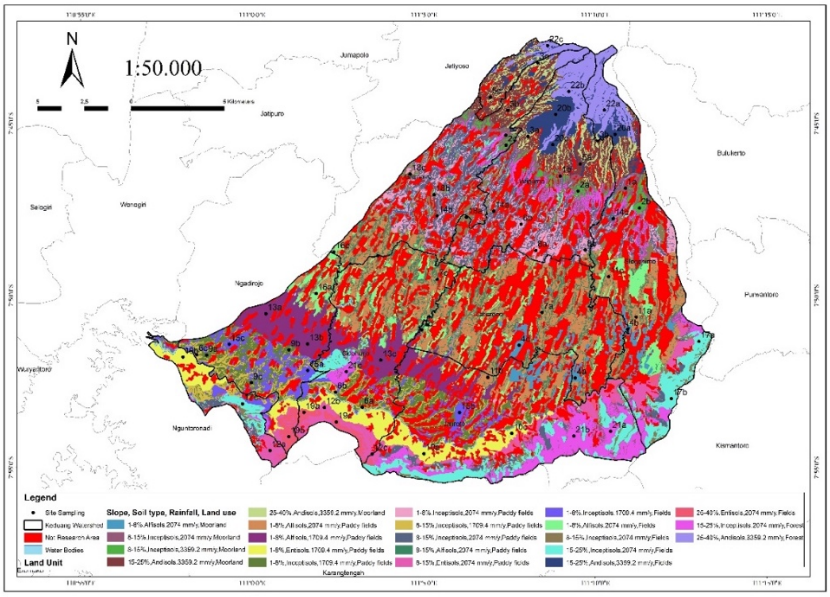

Figure 1. Land map units and sampling points in the research area

Assessment of soil physical health index

The assessment was determined through Principal Component Analysis (PCA) to obtain the MDS used to determine the soil's physical health (Zeraatpisheh *et al.,* 2020). The PC value used has an eigenvalue ≥1. Indicators with values and correlates on each PC are considered the best indicators (Maleki *et al*., 2022). The data selected as the MDS is then determined through scoring based on research of Riwandi and Handajaningsih (2011), and modifications are based on the conditions of the Keduang sub-watershed. The Soil physical health indicator scores are presented in Table 2.

The indicators selected as the MDS are used to calculate the weight index (Wi) by calculating the proportion divided by the cumulative. The indicators selected as the MDS are given a score (Si) (Zeraatpisheh *et al*., 2020). The formula for calculating the soil physical health index in equation 1 below :

(SPHI) (%) $\sum_{i}^{n} 1 = Wi \times Si^{n}$ x 100 (Puspitasari, 2018) …………. (1)

SPHI is Soil Physical Health Index; Wi is the Weighting index; Si is the Scoring index; n is the total sample of Soil Physical Health indicators. The data that has been calculated is then classified into five classes namely very low (0 – 20%), low (20 – 40%), moderate (40 – 60%), high (60 – 80%) and very high (80 – 100 %) (Moebius-Clune *et al*., 2017).

Table 2. Scoring of soil physical health indicators

Indicators	Limiting factor and relative score				
	5 (Very High)	4 (High)	3 (Intermediate)	2 (Low)	1 (Very Low)
Soil Texture (1)	L	SiC, CL, SiCL, SiL,	SCL, SL, SC	LS, Si	S, C
Soil Structure	Granular	Blocky	Prismatic	Columnar	Platy
Penetration ($kg.cm^{-2}$) (1)	<1	1 – 1.1	1.2 – 1.3	>1.4 - >1.5	>1.5
Soil Humidity (%) (1)	25 - 50	50 – 62.5	62.5 – 75	<25	>75
Water Content (%)	30 – 19	18 – 9	8 – 4	3 – 1	31 - 40
Soil Colour (1)	Black	Brown	Green	Yellow	Red
Soil Aggregates	>80	80 - 65	65 - 50	50 - 40	<40
Slope (%) (1)	Flat	Sloping	Rather steep	Steep	Very steep
Effective Depth (cm) (1)	>150	150 - 90	90 - 60	60 - 30	<30
Porosity (%)	50 - 59	49 - 40	39 - 35 dan 60 - 64	34 - 30 dan 65 - 69	<30 dan >70
Particle Density ($gr.cm^{-3}$) (3)	>1.5	1.5 – 1.4	1.4 – 1.3	1.3 – 1.2	1.2 – 1.0
Permeability ($cm.hour^{-1}$) (3)	4 – 4.8	2.9 – 3.9 dan 4.9 – 5.8	1.8 – 2.8 dan 5.9 – 6.8	0.7 – 1.7 dan 7 – 8	<0.7 dam >8.0
Soil Compaction (1)	Freely root penetration	Loosely soil	Firm, Restricted Root	Hard, compact	Hard, compact, bad root penetration
Electrical Conductivity (2)	<1	1-2	2 – 3	3-4	>4
Bulk Density (3)	<1.3	1.3 – 1.4	1.4 – 1.5	1.5 – 1.6	>1.6
C Mikrobial Biomass	>25	25 - 20	20 - 10	10 - 5	<5

Source : (1)(Riwandi and Handajaningsih 2011; Puspitasari 2018), (2)(Balittanah 2005), (3)(Minister of Environment 2006) and adapted to the conditions of the research environment

Notes : L : Loam, SiC : Silty Clay, CL : Clay Loam, SiCL : Silty Clay Loam, SiL : Silty Loam, SCL : Sandy Clay Loam, SL : Sandy Loam, SC : Sandy Clay, LS : Loamy Sand, Si : Silt, C : Clay, S : Sand

SPHI mapping determines the distribution of soil physical health in various land uses in the Keduang Sub-watershed (Zeraatpisheh *et al*., 2020). The SPHI mapping is based on the class that has been obtained from the calculation of each LMU. The mapping results will be interpreted as figures that aim to plan and manage agricultural land.

Data analysis

Analysis of variance (ANOVA) was used to determine the effect of land use on soil physical health index. The significant data continued with Duncan's Multiple Range Test (DMRT) to determine the significant effect of parameters. Meanwhile, correlation analysis was used to determine the relationship between land use and the physical health of the soil in the Keduang watershed.

Result

Soil characteristics

Soil characteristics PC analysis explained that the first six PCs had an eigenvalue of more than (≥)1 (Table 3). The first six PCs explained that there was a 74.6% variance in the original data. The variables in PC 1 are adequate depth, humidity, BD, and CMB. PC 2 has two variables, namely soil density and penetration. PC 3 has two variables, namely PD and porosity. PC 4 has one variable, aggregate stability, PC 5 has variable electrical conductivity, and PC 6 has variable structure and soil texture.

Table 3. Principal Component Analysis (PCA) results

Eigenvalue	4.568	2.1191	1.6588	1.4194	1.1431	1.0284
Proportion	0.286	0.132	0.104	0.089	0.071	0.064
Cumulative	0.286	0.418	0.522	0.61	0.682	0.746
Eigenvectors						
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Soil Colour	-0.003	0.366	-0.017	-0.011	0.118	-0.641
Soil Structure	0.182	-0.349	0.036	-0.106	-0.226	**0.392***
Soil Compaction	-0.225	**-0.487***	0.014	0.041	0.027	-0.217
Slope	-0.275	0.222	-0.302	0.02	-0.214	-0.065
Soil Texture	0.049	-0.323	0.264	-0.315	0.313	**-0.328***
Penetration	0.336	**0.387***	0.063	0.02	0.049	0.127
Effective Depth	**0.422***	0.036	-0.035	-0.013	-0.03	0.054
Soil Humidity	**-0.429***	-0.053	-0.079	-0.01	0.103	0.03
Soil Aggregates	-0.063	-0.093	-0.194	**0.601***	0.136	-0.073
PD	0.087	-0.038	**-0.686***	-0.149	0.196	0.109
BD	**-0.324***	0.176	-0.085	-0.209	-0.058	0.3
Porosity	0.31	-0.139	**-0.483***	0.031	0.195	-0.132
Water Content	0.016	-0.246	-0.232	-0.082	-0.693	-0.311
Permeability	0.03	-0.145	0.105	**0.651***	0.032	0.089
EC	-0.293	-0.088	-0.114	-0.108	**0.394***	0.167
CMB	**0.251***	-0.224	-0.012	-0.13	0.207	-0.008

Remarks: PD: Particle density, BD: Bulk density, EC: Electrical conductivity, CMB: Carbon microbial biomass *: PC value of selected indicator

Distribution of Soil Physical Health Index in the Keduang Sub-watershed

This sub-chapter describes the classification of soil physical health indices for each LMU, parameters affecting soil physical health, and the average SPHI for several agricultural land uses in the Keduang watershed.

Table 5 shows LMU 13 has the lowest SPHI score of 18.4%, which is due to BD (1.73 g.cm^{-3}), porosity (22.26%), and texture (clay), with each score 1, unhealthy category. While LMU 21 and 22 had the highest SPHI score of 32.9% with BD values of 1.17 g.cm^{-3}, porosity of 49.119%, and EC of 2.28 dS.m^{-3}, CMB of 5.81 mg C.kg^{-1} and aggregate stability of 81.08. The BD value at LMU 22 is 1.17 g.cm^{-3} with a soil health score of 5, while the lowest BD score is 1 with a value of 1.73 g.cm^{-3} at LMU 13. The highest porosity value is at LMU 22, 49.119%, while the lowest is at LMU 14, 14.878%. The lowest EC value is at LMU 17, 1.368 dS.m-3, while the highest is at LMU 11, 5.242 dS.m^{-3}. The highest CMB value is found in LMU 22, which is 5,815 mg C.kg$^{-1,}$ and the lowest is in LMU 7, which is 1,365 mg C.kg^{-1}. The index of soil physical health in the Keduang Sub-watershed can be seen in Table 5.

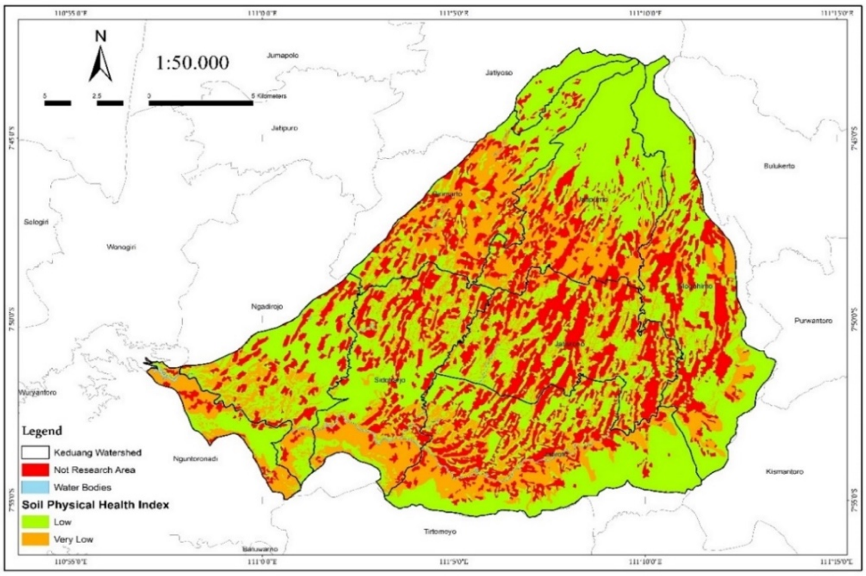

Figure 2. Soil Physical Health Map

The mapping of soil physical health in the Keduang sub-watershed can be seen in Figure 2. This study obtained two soil physical health index classifications: low and very low. The soil has a very low physical health index of 9,151 ha (31.29%), and the low classification has an area of 20,091 ha (68.71% of the study area). The areas are not included in the study which have an area of 10,761 ha, namely residential areas and water bodies. Figure 2 provides information on Jatiyoso District, which has an unhealthy distribution of soil physical health and an unhealthy classification of 100%. In comparison, Nguntoronadi District has an area with an unhealthy classification of 515 ha (47.25%) of the study area in Nguntoronadi District. Other sub-districts such as Girimarto, Slogohimo, Sidoharjo, Jatipurno, Jatisrono, Jatiroto, and Ngadirojo have unhealthy classifications above 50% of the total area of the study in each sub-district.

Table 4. Correlation Analysis Between Indicators and Soil Physical Health Index

	17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-0.094															
2	**.398****	**-.314***														
3	0.020	-0.150	0.085													
4	**-.556****	0.141	**-.347****	-0.003												
5	.335**	-0.085	0.122	0.200	**-.341****											
6	**.249***	0.211	0.042	**-.749****	**-.308***	-0.157										
7	.701**	-0.007	**.340****	**-.464****	**-.474****	0.096	**.668****									
8	**-.724****	-0.034	**-.324****	**.445****	**.474****	-0.047	**-.672****	**-.861****								
9	0.181	-0.040	-0.070	0.153	0.079	-0.102	-0.105	-0.110	0.180							
10	0.090	-0.009	0.067	-0.067	0.058	-0.115	0.045	0.217	-0.035	0.071						
11	**-.772****	0.037	**-.244***	0.109	**.394****	-0.179	-.299*	**-.516****	**.644****	-0.049	0.141					
12	**.623****	-0.035	0.209	-0.170	-0.233	0.031	**.277***	**.557****	**-.500****	0.091	**.681****	**-.618****				
13	0.184	-0.102	0.177	0.209	0.123	0.026	-0.212	0.059	-0.049	-0.006	0.117	-0.059	0.134			
14	0.201	-0.100	0.033	0.121	-0.116	-0.120	-0.050	0.064	-0.057	**.292***	-0.134	-0.183	0.011	-0.043		
15	**-.502****	-0.079	-0.155	**.324****	**.358****	0.053	**-.443****	**-.499****	**.570****	0.051	0.052	**.356****	-0.232	-0.183	-0.066	
16	**.502****	-0.100	**.269***	-0.002	**-.352****	0.196	0.230	**.384****	**-.402****	-0.150	0.157	**-.354****	**.391****	0.021	0.066	-0.221

Notes : *: significant (P= 0.05 – 0.01). **: significant (P <0.01), 1: soil color, 2: soil structure, 3: soil compaction, 4: slope, 5: soil texture, 6: penetration, 7: effective depth, 8: soil humidity, 9: soil aggregates, 10: PD, 11: BD, 12: Porosity, 13: water content, 14: Permeability, 15: EC,16: CMB, 17: SPHI.

Table 5. The SPHI on each LMU

MDS	Pro	Cum	Wi									Paddy fields							Plantation					Forest	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
ED	0.286	0.746	0.096	4	4	4	5	4	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5
SH	0.286	0.746	0.096	3	3	3	3	4	1	1	1	1	1	1	1	1	1	4	4	4	5	4	3	5	5
BD	0.286	0.746	0.096	2	3	3	1	1	1	2	1	1	1	2	5	1	2	5	3	4	4	4	4	5	5
CMB	0.286	0.746	0.096	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
SC	0.132	0.746	0.088	3	3	3	2	2	4	4	4	3	4	4	3	4	5	3	2	4	3	4	4	4	4
Pen	0.132	0.746	0.088	5	5	5	3	4	5	5	5	5	5	5	5	5	5	3	3	5	2	5	5	5	5
PD	0.104	0.746	0.070	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Por	0.104	0.746	0.070	1	2	1	1	1	1	2	1	1	1	2	2	1	1	4	2	2	2	4	4	4	4
SA	0.089	0.746	0.060	2	4	3	3	3	5	5	5	1	5	4	4	3	4	4	3	4	4	2	4	5	5
Perm	0.089	0.746	0.060	3	4	3	4	3	4	4	5	4	4	2	3	2	5	4	4	4	4	4	4	5	5
EC	0.071	0.746	0.095	2	2	3	2	3	1	2	2	2	1	1	3	2	1	3	3	4	3	2	2	3	3
SS	0.064	0.746	0.043	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
ST	0.064	0.746	0.043	1	1	1	4	1	4	1	1	4	1	1	4	1	4	1	1	4	1	4	4	4	4
	SPHI			21.4	24.1	23.4	21.3	21.3	20.5	21.5	20.7	18.7	19.5	19.4	23.9	18.4	21.9	27.5	23.8	29.4	25.7	28.1	29.0	32.9	32.9
	SPHI average					22.3						20.5							27.3					32.9	
	Score					2						2							2					2	
	Class														Low										

Notes: MDS: Minimum Data Set, Pro: Proportion, Cum: Cumulative, Wi: weighting index, ED: effective depth, SH: soil humidity, BD: bulk density, CMB: C microbial biomass, SC: soil compaction, Pen: penetration, PD: particle density; Por: Porosity, SA: soil aggregates, Perm: Permeability, EC: electrical conductivity, SS: soil structure, ST: soil texture.

Effect of Land Use on SPHI

The Keduang Sub-watershed has four land uses as paddy fields, dry fields, plantations, and forests. The area of each land use is forest 2,122 ha (7.24%), plantations 6.714 ha (22.92%), dry fields 6,166 ha (21.05%), and rice fields 14,296 ha (48.80%). The results indicated that land use significantly affected the soil physical health index ($P < 0.05$).

Table 6. The average value of soil physical health index under different types of land use

Land Use Types	SPHI
Forest	31.789^{a}
Plantation	26.333^{b}
Moorland	22.707^{c}
Paddy fields	20.867^{d}

Remark: Different notations show a significant level (p <0.01)

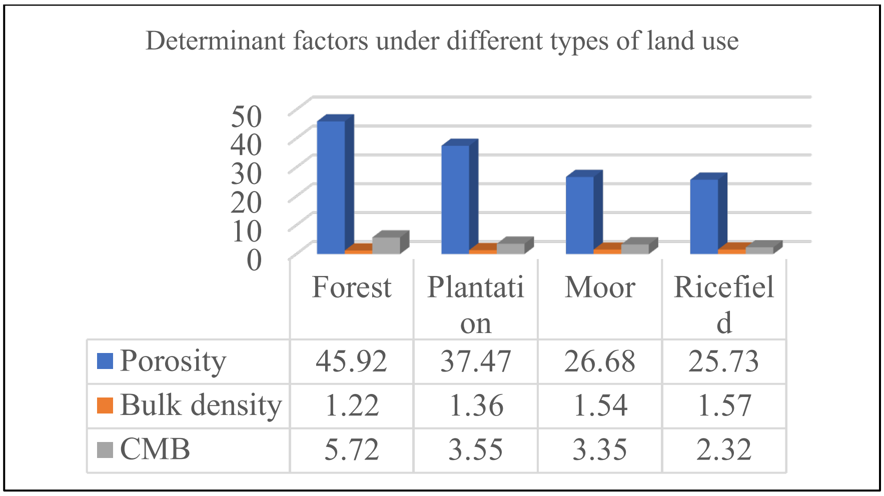

Figure 3. The average value of determining factors in various land use

Discussion

Result revealed that the proportion value on each PC can represent the value of soil physical health index data. PC 1 has a proportion value of 28.6%, PC 2 is 13.2%, PC 3 is 10.4%, PC 4 is 8.9%, PC 5 is 7.1% and PC 6 is 6.4% for each indicator selected on each PC. Table 4 shows that SPHI negatively correlates with BD ($r = -0.772$, p-value = 0.000, $N = 66$), meaning areas with high BD have a low soil health index. BD is an essential indicator in soil physics because it describes the volume of voids between particles closely correlating with porosity (Mujiyo *et al.*, 2022). The unhealthy BD value category is > 1.6 $g.cm^{-3}$ because the higher the soil density refers to the relative amount of pore space, the higher the BD value (Rayne and Aula, 2020).

The results of the correlation analysis between BD values and porosity have a negative correlation (r = -0.618, p-value = 0.000, N = 66), which means that the higher the BD value, the lower the porosity value (Table 4). The data also explains that soil porosity has a positive relationship to CMB. CMB is soil carbon that can be used to determine soil biological activity (Suswatiningsih and Anshori, 2023), which is affected by soil organic carbon, water retention, and soil pH (Weralupitiya *et al*., 2022). It is in line with the research of Zeraatpisheh *et al.* (2020), which states that high soil organic carbon values can reduce BD. The Table shows that the correlation of soil moisture with SPHI and CMB has a negative correlation (r = -0.724, p-value = 0.000, N = 66) and (r = -0.402, p-value = 0.001, N = 66)). This condition explains that flooded soil will reduce the microbes in the soil, which will decrease the soil's physical health (Romadhon *et al.,* 2023). Shah *et al*. (2021) stated that inundation on agricultural land for the first week can reduce microbial activity. Still, on days 10 to 15, microbial activity is the same as non-flooded soil. The availability of organic matter influences microbial stability in agricultural soil, the stability of soil aggregates, and the amount of carbon input (Griffiths and Philippot, 2013).

The average distribution of the soil physical health index for each land use and showed that paddy field use had a lower health index than dry fields, plantations, and forests. Rahayu *et al*. (2024) explained, soil quality or soil heatlh can be affected by soil properties, environmental conditions, vegetations, land management and land use. Paddy fields were the lowest soil physical health index because there were two rice planting periods in one year, which can increase soil degradation due to increased BD values (Mujiyo *et al*., 2021). This study used the moorland to plant cassava, turmeric, and corn. According to Li *et al*. (2019), agricultural land has a higher BD value than other land uses due to a long-term processing system. The research results on farmers and rice field owners show that, on average, farmers plant rice twice a year, using primarily inorganic fertilizers and pesticides to prevent pest attacks. Supriyadi *et al*. (2021) confirmed that the soil quality index score in organic rice fields was higher (2.3) compared to semi-organic rice fields (2.2) and conventional rice fields (1.7). Research by Supriyadi *et al*. (2020) showed that the organic C content in rice fields (2.4%) was higher than in conventional rice fields (1.8%), and there is an increase of 0.6% in organic fields. Srivastav (2020) and Huang and Jin (2008) explained that excessive use of chemical fertilizers can increase soil and water pollution, lower pH, and increase heavy metal content. Groundwater contamination occurs due to a mixture of chemicals that cause eutrophication, thus affecting the health of living things (Khan *et al*., 2018). Using chemical fertilizers can reduce organic matter content, increase soil BD, and reduce the stability of soil aggregates (Bhatt *et al*., 2019). In contrast to forests, dominated by annual crops and cover crops such as grasses and rhizomes, the BD value is lower than that of paddy fields. The decrease in soil BD can be caused by the organic matter content derived from plant residues (Molla *et al*., 2022).

CMB in forests has the highest yield compared to paddy fields, moorland, and plantations (Picture 3). Forests are one of the best land uses that contribute to litter, the primary sources of carbon, nitrogen (Urbanová *et al*., 2015), phosphorus, and other soil minerals (Keiluweit *et al*., 2015). In the study of Zeng *et al*. (2017), plant litter significantly affected the soil carbon fraction. Strengthened by the research of Chalise *et al*. (2019), explaining that returning crop yields can reduce soil BD and that cover crops found in forests can increase soil organic carbon, thereby reducing soil BD (Dolan *et al*., 2006; Tormena *et al*., 2017). Priyadarshini *et al*. (2019) stated that forests converted into cultivation and agricultural land reduce C reserves above ground by ~50 $Mg.ha^{-1}$ and underground by ~20 $Mg.ha^{-1}$. The results of the correlation between CMB and BD had a negative correlation, which means that the higher the BD, the less porous the soil, microorganisms cannot develop properly, and vice versa. According to Herawati *et al*. (2024), mycorrhizal fungi prefer an environment with micro-aggregates, while bacteria prefer macro-aggregates. Forest soils in the Keduang Watershed have a texture of silty loam, loam, and clay loam which if there is additional litter, can reduce the value of bulk density (Moebius-Clune *et al.,* 2008).

Efforts that can be made to improve physical health in the Keduang watershed with low and very low classifications caused by high BD values and low porosity can be made by adding soil organic matter. According to Mujiyo *et al*. (2022), adding organic matter and minimizing tillage can reduce BD so that soil porosity increased. Sun *et al*. (2021) explained that adding organic matter, one of which is biochar, can increase soil fertility, nutrient retention, and microbial activity. Dissolved organic matter helps increase infiltration and absorption (Dewi *et al*., 2023). In addition, efforts can be made to improve soil health in paddy fields by using agroforestry systems (Dewi *et al*., 2022). Agroforestry is used to increase agricultural products, crops, livestock, and biodiversity (Borelli *et al*., 2017). Rodenburg *et al*. (2022) explains that an agroforestry system on paddy fields that is given additional fertilizer increases production by 38% compared to controls due to biomass transfer. Using cover crops on moorland, plantations (Sulaiman *et al*., 2023), and forests can decrease soil erosion and increase the physical health index of the soil (Solikhatun *et al*., 2020). Cover crops are essential in maintaining organic matter content and reducing soil erosion . Applying cover crops can increase pore size by 33% and minimize soil volume weight by up to 4%. (Haruna *et al*., 2020).

The conversion (Wahyuti *et al*., 2023) and use of intensive agricultural land around watersheds (DAS) decreased soil health through erosion and disrupts soil and water ecosystems. In our research, we examined the condition of soil health, especially in terms of physical characteristics, and found the factors that most determine the physical health of the soil so that we can form a management strategy that is right on target for maintaining soil health for agricultural land and the watershed environment. The results showed the distribution of soil physical health indexes in the Keduang watershed at low and very low indexes. It also found that the diversity of land use types affects soil physical health conditions, paddy fields were the lowest soil health, while forests were the highest soil health. In each land use, the health conditions of each soil physical indicator was significant differences. They are strongly related to the dynamics of soil health, which are now referred to as determining factors, including volume weight, porosity, and C microbial biomass. These determinants is supposed to be a key characteristic in forming strategies in land management efforts to improve the conditions of these determinants so that soil health is maintained. Efforts to improve the health of soil physics in the Keduang watershed can be carried out by applying organic matter, covering crops, and agroforestry systems to paddy fields. The benefits of this research are expected to provide data on the distribution of soil physical health on agricultural land use. It can improve and maintain soil physical health in the Keduang watershed. In addition, it can provide information regarding recommendations for efforts that can be given to locations with a low classification of soil physical health index to maintain sustainability in the future.

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