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Research Article
Post Nickel Mining Soil Characteristics and its Potential for Development of Non-Timber Producing Plants

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Abstract

Background and Objective: Soil of post nickel mining open-pit has suffered damage both physical and chemical. This study was aimed to study characteristics of post-mining land, which has been reclaimed and to evaluate its suitability for the development of non-timber crops. **Materials and Methods:** The soil survey was performed in the nickel reclamation area of PT Vale Indonesian Tbk. in Sorowako, Indonesia. As many as 8 soil profiles were excavated at each randomly selected stratified point at a scale of 1: 50,000. The qualitative method of determining land suitability classes uses the simple limiting factor approaches according to the FAO. **Results:** These findings showed that the soil permeability, soil cation exchange capacity, base saturation, P_2O_5 (Bray) content, was rather slow to moderate, soil reaction was acidic and slightly acidic, C-organic was very low to low, total N was very low to low and high of exchangeable Fe. Microscopic observations show primary minerals that are still present in the soil, namely; olivine, pyroxene, biotite and plagioclase, quartz and secondary minerals such as clay minerals (illite, kaolinite chlorite) and opaque. **Conclusion:** The soil characteristic of the study area still has poor fertility after reclamation. The study area is classified as moderately suitable (S_2) and marginally suitable (S_3) for non-timber crops. The main limiting factors are nutrient retention (nr), nutrient availability (na), soil depth (rc), slope (eh) and water availability (wa).

Key words: Post nickel mining, land suitability, ultramafic, reclamation, non-timber, crop requirement, Sorowako

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Mining activities, especially open pit ones, include activities of excavating the soil to a depth of tens of meters to obtain the desired mineral materials. It will cause mixing of overburden rock materials with topsoil resulting in a stretch of soil that has very low organic matter content, water retention and very low nutrients. Moreover, the content of the toxic elements is high and not structured[1]. According to Widiatmaka *et al.*[2] in the post nickel mining area the soil surface horizon is dominated by overburden which is not soil but the unstructured parent rock and high silt and clay content (>40%), base cations are dominated by Mg, whereas Ca, Na and K are relatively low. With the absence of reclamation efforts, the continued impact of mining activities is soil erosion, water and air pollution, soil poisoning, loss of potential biological resources and loss of economic potential[3]. The nickel mine of PT Vale Indonesia Tbk is located in Sorowako, South Sulawesi, Indonesia, in an area of land which is formed by the dominant parent material of serpentine (ultramafic). According to Kruckeberg[4]; Kidd et al.[5], serpentine soils formed from the weathering of ultramafic rocks that have low silica (SiO_2) content (<45%) and are rich in ferromagnesian minerals, high Mg and Fe concentrations, low Ca: Mg ratios and high metal-content metals such as Co, Cr and Ni. This characteristic is a major cause of poisoning in soils formed dominantly from serpentine[6], where Ni concentrations vary from 7 to 500 mg g^{-1}, but in ultramafic soils Ni concentrations[7] range from 700 to 8000 mg kg^{-1}. Serpentine soil is also poor in macronutrient content, namely nitrogen (N), potassium (K) and phosphorus (P), organic matter content and low water-holding capacity[7]. These properties cause serpentine soil to become a poor growing environment for normal plant growth.

Reclamation activities are essential to restore the condition of the land or at least close to the condition before the mining activities. Reclaimed ex-mining land is generally characterized by soil fertility and low organic matter content, soil compaction problems, massive soil structure, shallow roots, low water retention and high soil acidity[1]. Meaning that despite the reclamation efforts, the quality of the land in the former mining areas is still relatively low for plant growth compared to before mining.

The trend of improving soil quality on ex-mining land is an important indicator indicating the successful reclamation efforts. Quantification of the impact of post-mining reclamation on soil quality can be performed by calculating the soil quality index. With this knowledge, changes in soil quality (positive or negative) as a result of reclamation efforts can be easily measured and their progress can be compared between one location and another. Key indicators in determining the quality index of ex-mining land soils such as soil organic matter content, soil reaction, soil bulk density, soil moisture and soil respiration are suggested in every evaluation of soil quality[8]. Soil, climate and environmental biophysical

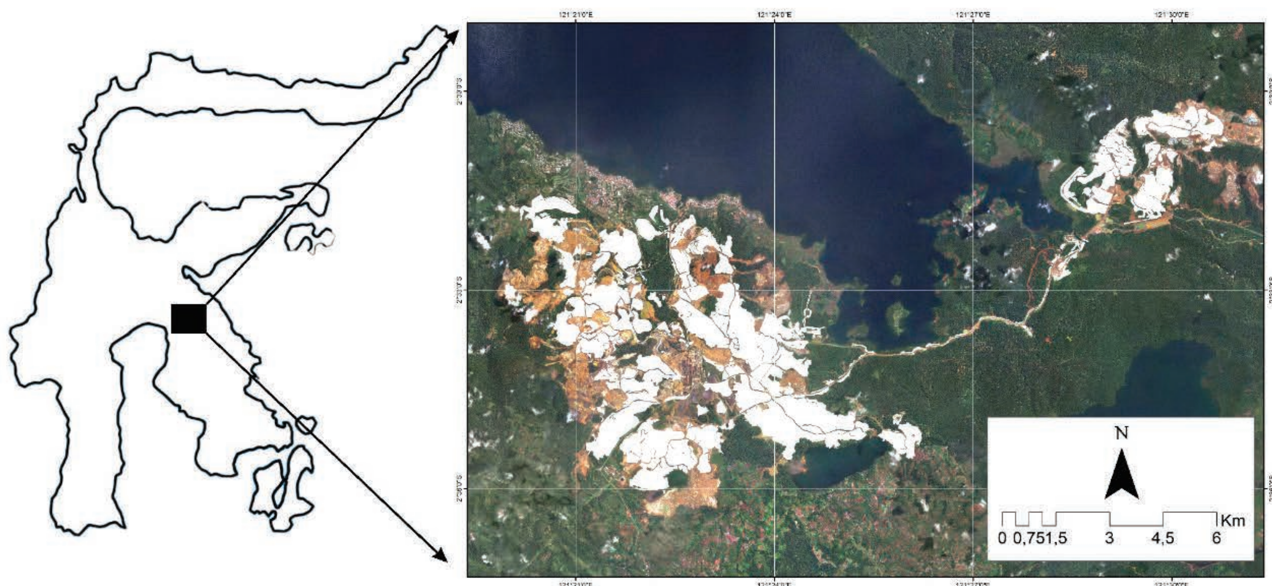

Fig. 1: Map of study area (PT vale Indonesia tbk reclamation area, white area)
Source: Analysis by using Geographical Information System

data which are influential to plant growth need to be identified and characterized through soil surveys and evaluation of land resources. The data produced is then interpreted for specific use[8,9]. Land evaluation is an approach to assess the potential of land resources that provides information and alternative land uses that are appropriate and optimal[9,10].

This study was aimed to study the terrain, physical, chemical and mineral characteristics of nickel post-mining land and to evaluate its suitability for the development of non-timber crops.

Materials and methods study area: This research was conducted in the reclamation area of PT Vale Indonesia Tbk. in Nuha Subdistrict, East Luwu Regency, South Sulawesi, Indonesia, which covers an area of around 3000 ha (Fig. 1) located at 121°8'39.01" BT-121°43'27.10" BT and 2°27'23.90" LS-2°49'14.60"LS. The study was carried out from July to December 2019.

Soil analysis: Representative profile points are determined based on the results of the basic map overlay. These maps are block maps according to planting/reclamation years, slope maps, soil types and geological maps, each on a scale of 1: 50,000. The soil survey was conducted by a random stratified method, as many as 8 sampling points were randomly assigned including reclamation areas. In each soil profile, up to 3 soil samples were collected from each layer/horizon. Measurable parameters for non-timber plant development potential in reclamation areas include soil texture (3 fractions), pH H_20, Ca-dd, Mg-dd, K-dd, Na-dd, cation exchange capacity (CEC), Organic carbon, base saturation (BS).

MATERIALS AND METHODS

To support the analysis of post nickel mining soil quality, soil mineralogical analysis was carried out using the XRD method to determine the type of clay mineral fraction and the polarization microscopy method for determining the type of mineral sand fraction.

The method of soil physical and chemical properties measurement refers to Schulte *et al.*[11] and Landon[12]. Interpretation of results was based on the criteria of the Landon[12] and FAO[13]. Soil texture was determined by the hydrometer method[14], C-organic by previous method[15]. Soil reaction[16] (pH) is determined by a pH meter using the ratio of soil: water (1: 2.5). The cation exchange capacity (CEC) and the number of exchangeable alkalis are determined by the 1 N NH_4OAc extraction method (pH 7.0)[16]. Measurement of total N levels using the Kjeldahl method, P_2O_5 levels with the Bray method, the exchangeable Fe content with the DTPA method and exchangeable Al with the 1 N KCl extraction method.

X-ray Diffraction (XRD) analysis was performed to analyze the clay fraction. The clay fraction derived from texture analysis. XRD method analysis was recording and visualizing X-ray reflections from crystal lattices in a graphical form that were analyzed or identified based on standard mineral characteristics of research results published by Peterson and Swaffield[17]. Sand fraction analysis used sand fraction material derived from the results of texture analysis.

The potential of post nickel mining soil for non-timber plant development is determined based on the results of matching the land suitability criteria of several target plants with characteristics of post nickel mining soil. The land suitability criteria of the target plants (breadfruit, rambutan, mango, nutmeg, mangosteen, durian) were based on the criteria of Sys *et al.*[18]. The land evaluation method was the simple limitation method[10,19]. Land suitability class reflected degrees of suitability. The class of suitability consists of; S_1 = highly suitable; S_2 = moderately suitable; S_3 = marginally suitable, N_1 = currently not suitable and N_2 = not suitable permanently.

RESULTS AND DISCUSSION

Terrain characteristics of the study area: The study area is dominated by slopes of: 15-25% (29%), 8-15% (28%), 25-45% (23%) and the remaining slopes are 3-8% (13%) (Fig. 2). The dominant parent material of the ultramafic complex is 92% and the rest (8%) is classified as lake sediment (Fig. 3). Based on the soil taxonomy classification[19], soil types are dominated by the Oxisols order (79%) and the remaining 21% are classified as Inceptisols (Fig. 4). Soil drainage at all points is relatively good and the percentage of rock at the surface is <5%.

The climate in the study area belongs to type A climate (according to Schmidt-Ferguson), annual average air temperature is 26.8°C, relative humidity is 82.6%. The average annual rainfall over a period of 30 years (1989-2018) was 3,076 mm/year (Fig. 5).

Soil physical characteristics: Analysis of the physical characteristics of the 8 representative soil profiles showed that the soil bulk density contents varied considerably, ranging from 1.00-1.37 g cm^{-3}. In addition, soil permeability which shows the soil's ability to pass water infiltration at a certain

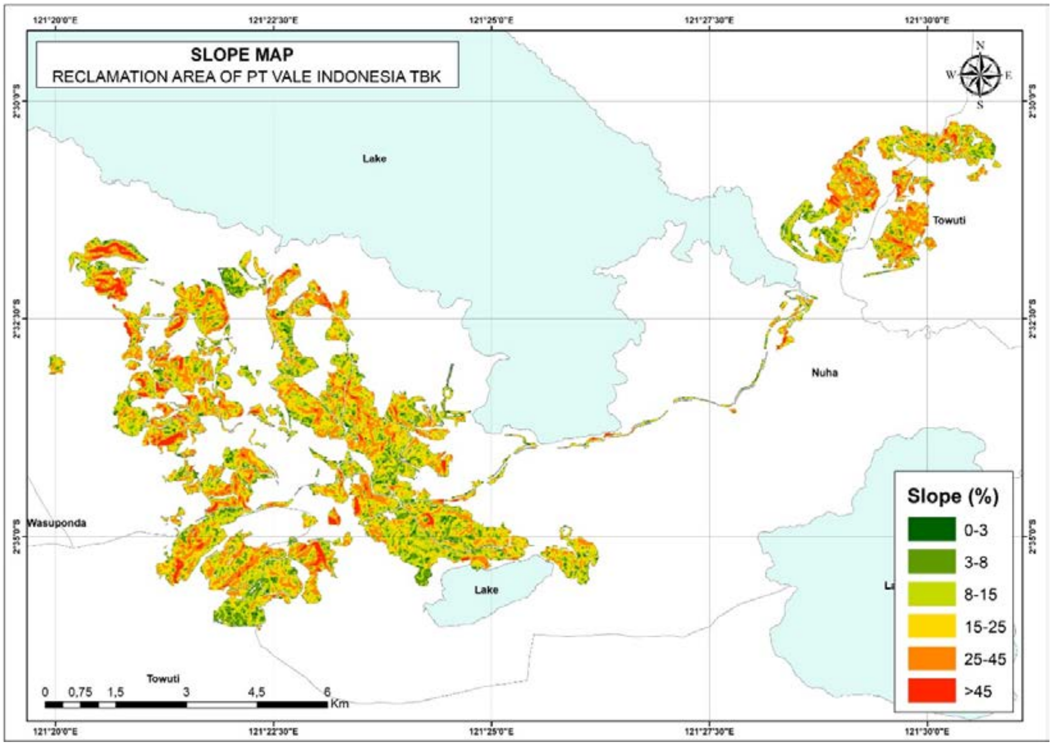

Fig. 2: Map of the slopes in the study area
Source: Analysis by using geographical information system

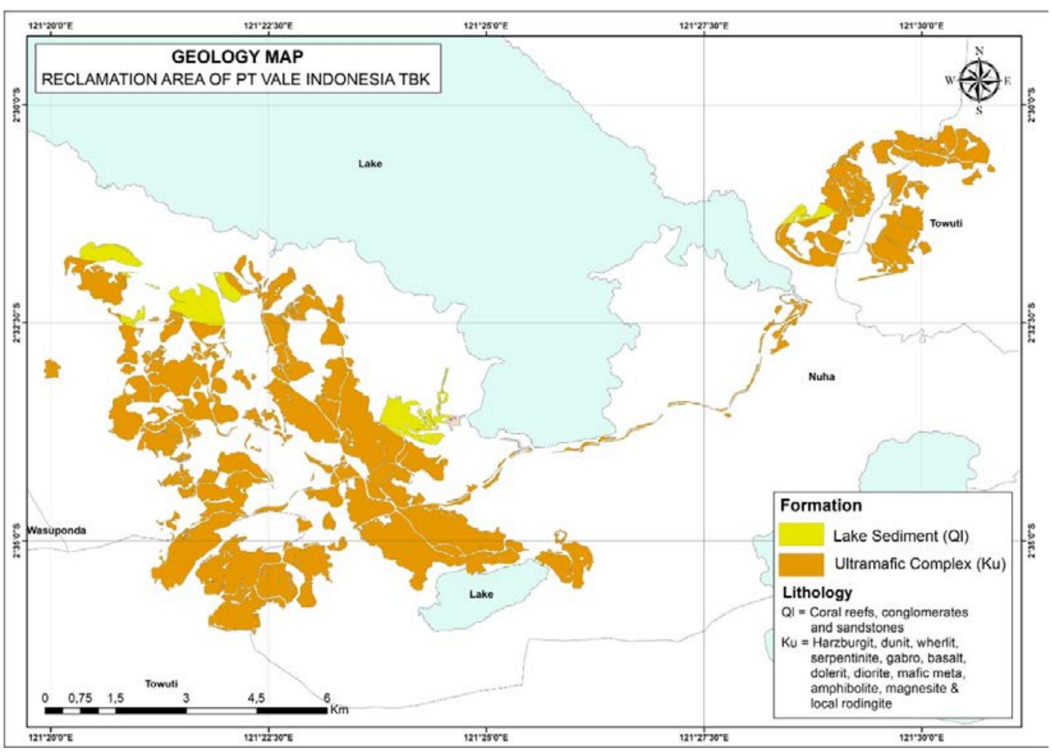

Fig. 3: Geological map of the study area
Source: Analysis by using geographical information system

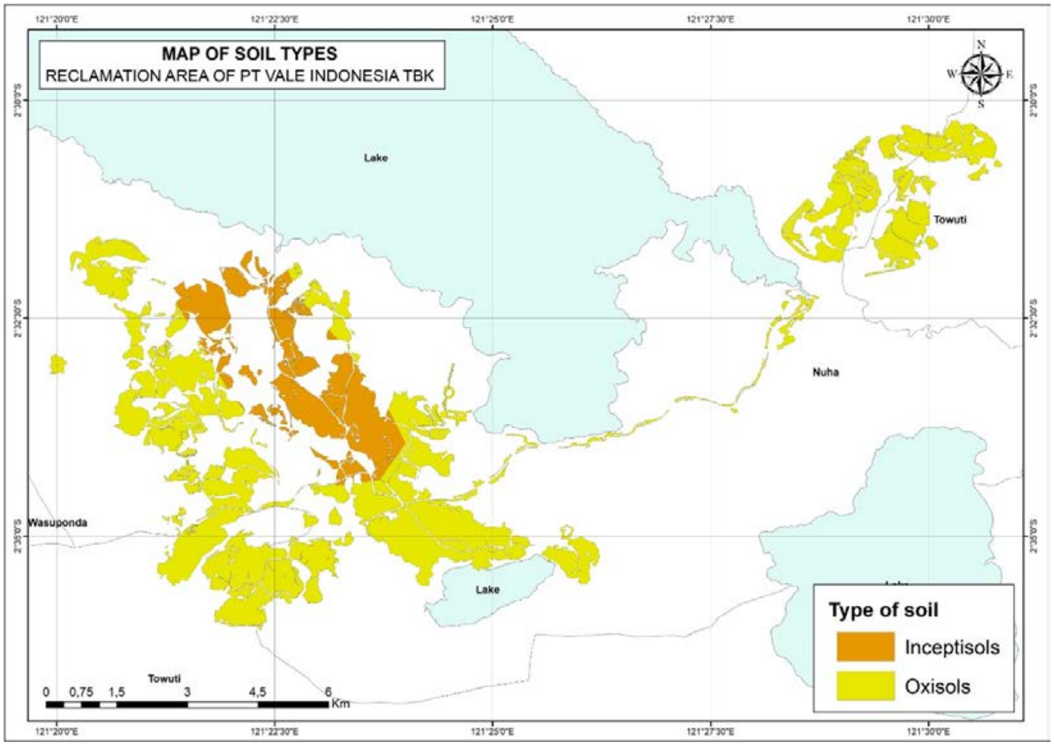

Fig. 4: Map of soil types in the study area
Source: Analysis by using Geographical Information System

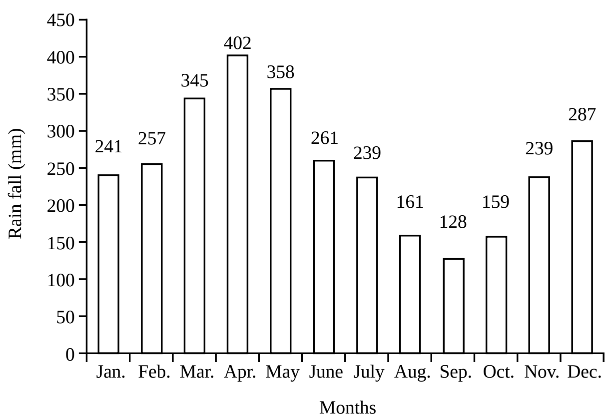

Fig. 5: Average 30-year rainfall (1989-2018) of the concession area of PT. Vale Indonesia Tbk

time unit (cm hour^{-1}) is quite slow to moderate[11]. Soil moisture content ranges from 3.5 to 12.2 g g^{-1}, which means that the ability of the soil is relatively low in holding water[19, 20]. The soil texture varies, namely clay loam, silty loam, silty clay loam, silty clay and clay. Mining activities caused the soil solum to become shallow and without topsoil. The dredging process resulted in soil aggregates became unstable.

Soil chemical characteristics: Analysis of soil chemical showed that in general, the soil fertility is low. It was indicated by chemical properties of soil fertility such as soil reaction (pH) in the range of 5-6 (acidic and slightly acidic), C-organic <2% (very low-low), total N value <2% classified very low-low, P_2O_5 (Bray) <10 ppm P which is classified as low-moderate), the exchange capacity of the soil cation is dominated by values <16 cmol kg^{-1} (low-moderate), base saturation is dominated by values <60% which are classified as low-moderate and exchangeable Fe content and exchangeable Al were both high. As an essential element needed by plants, iron has many important roles in the process of plant metabolism[21]. The metabolic process includes photosynthesis, respiration, the main constituent of cell proteins[22] is also responsible for the quality and quantity of plant yields[23]. However, iron will be toxic when it accumulates large amounts in plant tissue[24]. Plants with high iron content are characterized by stunted growth, rusty leaf spot, leaf edge stained and a poor root system. In some cases, it is responsible for crop death and yield decrease by up to 100%, depending on cultivar tolerance, resistance to stress and plant management in practice[25]. The high solubility of Al and Fe absorbs phosphate so that the availability of P for plants is low. This condition

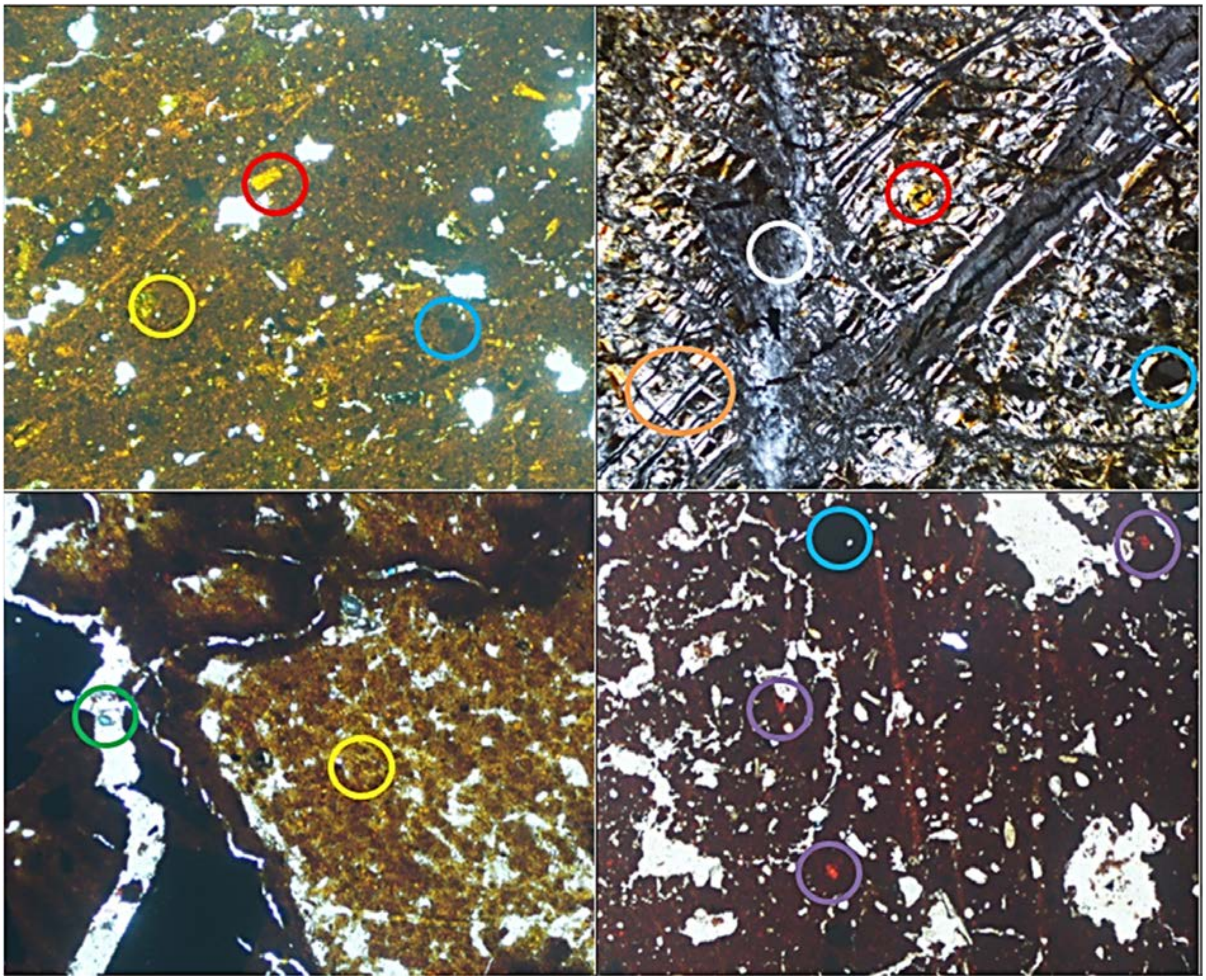

Fig. 6: Appearance of Olivine mineral (yellow circle), pyroxene (red circle), biotite (purple circle), plagioclase (green circle), opaque (blue circle), serpentine (orange circle) and quartz (white circle)

could inhibit and even stop root growth[26]. Soil reaction (pH) varies which tends to be acidic and could result in the possibility of poisoning by certain elements such as Al and Fe. Soil reaction or soil pH is one of the important chemical properties of plant growth, which affects the availability of macro and micronutrients. This is due to the mechanism of ion exchange in soil colloids and soil solutions which is affected by the degree of soil acidity. The Ca: Mg ratio of the soil showed a value of <1, the Mg content was higher than Ca which results in an imbalanced nutrients condition in the soil[27]. Data on physical characteristics, soil chemistry and study area terrain are presented in Table 1.

Soil mineral characteristics: Microscopic observations show primary minerals present in the soil, namely: olivine, pyroxene, biotite and plagioclase; resistant minerals such as quartz; and secondary minerals such as clay mineral and opaque minerals (Fig. 6). In general, the dominant minerals are constituents of ultramafic igneous rocks such as olivine, pyroxene and biotite. The dominance of olivine indicates the location of the study belongs to the peridotite mineral. This mineral is often found in landscapes which is formed by the weathering of ultramafic igneous rock. Based on the presence of primary minerals, the soil at the research location is classified into the soil that develops from the results of transformation and translocation processes[28]. The transfer process that occurs in the tertiary residual zone is deposited through a geomorphological process (transfer place) to the depositional zone in the quarter. This is evidenced by the discovery of ultramafic igneous rock, constituent minerals such as olivine in large quantities on the surface horizon (Fig. 7a-b).

In general, illite, chlorite and kaolinite minerals can all be found at almost all sampled points. These minerals were a transformation from the primary mineral that existed before.

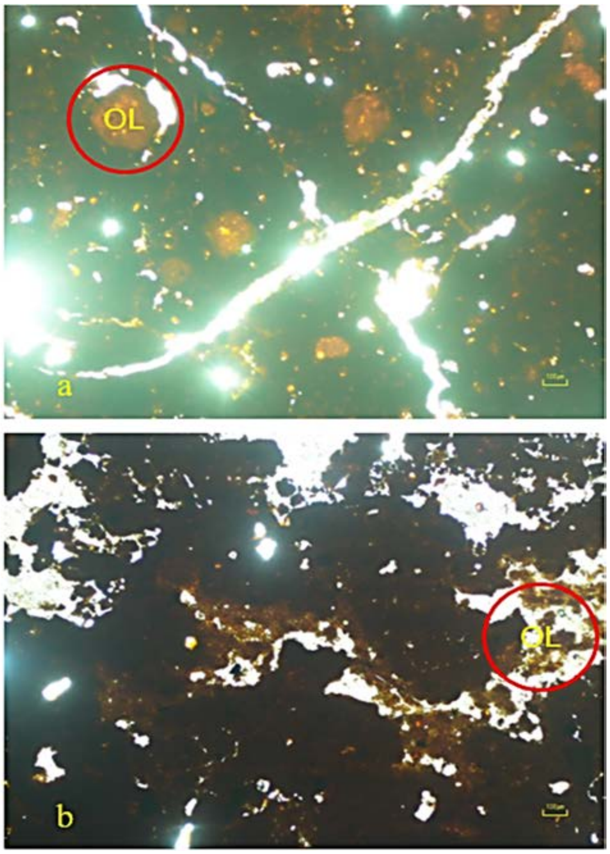

Fig. 7a-b: Olivine minerals found in the study area

Chlorite is an altered mineral of the mineral pyroxene and biotite; ill it is a mineral alteration from muscovite and biotite; while kaolinite is an altered mineral from feldspar minerals such as plagioclase[29,30]. Primary minerals such as muscovite were not found in the representative pedon observed through a polarizing microscope, but the secondary minerals were mostly found with high intensity. Similarly, plagioclase minerals were found with a very low level of distribution, but the secondary mineral can be found in almost all observation points. This indicates that the mineral has undergone a weathering process which further becomes a secondary mineral.

Land suitability of reclamation area for non-timber plants: Land suitability analysis of the research area is moderately suitable (S_2) and marginally suitable (S_3). The heaviest limiting factor (S_3) is the average rainfall (wa)> 3,000 mm per year in the entire study area, then the slope (15-25%) which are specifically limiting for mangosteen and mango. However, for breadfruit plants, rambutan, durian and nutmeg, these are moderately suitable (S_2). The other major limiting factors are nutrient content (nr) and low nutrient availability (na). Cation exchange capacity, Carbon organic, relatively low base saturation, pH H_2O acidic-rather acidic. The results of the land suitability analysis of 6 (six) types of non-timber plants are completely shown in Table 2.

The study area is moderately suitable (S_2) for rambutan (*Nephelium lappaceum*) as this plant is able to grow optimally on soils with a pH of 5.0-6.0, sufficient organic matter content and no inundation (good drainage) with rainfall of 1,000-4,000 mm and evenly distributed throughout the year[18]. The main limiting factors encountered were soil depth (<100 cm), low nutrient availability (total N, P_2O_5) and slope of 15-25% at some points.

Nutmeg (*Myristica fragrans*) has the potential to be developed in the research area. The suitability analysis showed that nutmeg is moderately suitable (S_2) with a limiting factor in low nutrient availability. Nutmeg requires a hot tropical climate with high rainfall, without any apparent dry period. Good rainfall for nutmeg growth is 2,000-3,500 mm per year[31,32].

Mango (*Mangifera indica*) is marginally suitable (S_3) to be developed in the research area. One of the heaviest inhibiting factors is the average annual rainfall, which is quite high (3.076 mm). Too much rain will cause a yield decrease for mango due to the rain occurs during the flowering period will result in flower falls. Optimal rainfall for mangoes is around 1,250-1,750 mm per year[19]. Soil texture suitable for mangoes is classified as clay, with a soil pH of 5.5-7.8.

Durian (*Durio zibethinus*) is moderately suitable (S_2) for the study area. Durian generally requires sufficient water availability and they grow well in areas with rainfall of 2,000-3,000 mm per year, with the optimal temperature of 25-28×C. Nevertheless, durian can also be planted in lowlands with the requirement of evenly distributed rainfall throughout the year. Durian grows well on clay, silty and loamy soils, soils with a depth of >75 cm, good drainage yet tolerant to somewhat inhibit and soil[18] with a pH of 5.5-7.8.

The land suitability analysis revealed that breadfruit (*Artocarpus altilis*) were moderately suitable (S_2) for the study area. Breadfruit is highly adaptive to the environment, especially to salinity and physiographic conditions due to shallow water. Breadfruit can grow well and support the diversification of food, i.e. potential for non-rice food reserves[18]. This plant can also grow well in hot areas with an average temperature of around 22-28^{o}C which has a wet climate with annual rainfall of 1,000-4,000 mm[18].

Mangosteen (*Garcinia mangostana*) can grow optimally insufficient soil organic matter (>1.2%), soil pH of 5.0-6.0. Rainfall of 1,250-2,000 mm is evenly distributed throughout the year, temperature of 22-32°C with humidity[18] of 80%.

Table 1: Terrain and Soil physical and chemical Characteristics of the study area

Land unit	Soil texture	BD (g cm^{-3})	SP (cm h^{-1})	WC (g g^{-1})	Slope (%)	SD (cm)	Drainage	pH H_2O	C-org (%)	N total (%)	P_2O_5 (ppm)	CEC (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	BS (%)	K_2O (mg/100 g)	Fe (ppm)	Al (cmol kg^{-1})
T_1L_1	Silty loam	1.37	1.00	3.7	3-8	110	Good	5.84	1.50	0.14	7.54	9.71	2.55	4.13	44	19.63	63.21	1.11
T_1L_2	Silty loam	1.29	2.00	3.5			Good	5.85	1.40	0.11	4.68	10.74	2.82	3.70	47	12.14	45.85	2.29
T_2L_1	Clay loam	1.21	5.25	5.3	3-8	80	Good	6.10	1.23	0.12	10.85	15.91	3.48	4.36	52	21.15	25.36	0.77
T_2L_2	Silty clay	1.25	4.67	6.4			Good	5.82	1.05	0.11	9.53	9.35	1.94	3.48	61	20.45	36.65	0.99
T_3L_1	Clay loam	1.04	4.49	10.4	15-25	80	Good	5.78	1.41	0.13	6.78	12.21	3.22	4.77	69	24.63	54.21	0.55
T_3L_2	Silty clay loam	1.00	4.00	9.2			Good	5.83	1.46	0.13	5.54	13.27	3.31	4.53	62	25.32	36.65	1.23
T_3L_3	Clay loam	1.08	3.98	9.3			Good	5.83	0.68	0.09	5.38	16.02	2.34	4.72	47	20.14	52.32	1.41
T_4L_1	Clay loam	1.25	3.44	7.5	8-15	100	Good	5.98	0.71	0.08	10.68	11.87	2.73	3.06	53	19.63	25.21	0.33
T_4L_2	Clay loam	1.15	3.00	3.7			Good	6.04	0.85	0.07	11.58	13.49	2.12	3.18	43	20.14	32.25	0.51
T_5L_1	Clay loam	1.28	1.59	4.2	0-3	80	Good	5.67	1.63	0.11	9.37	15.53	2.67	4.07	47	16.32	32.25	1.26
T_5L_2	Clay	1.30	1.25	5.3			Good	5.76	1.45	0.08	8.02	20.81	2.18	3.40	30	20.14	26.21	1.65
T_6L_1	Clay loam	1.20	4.62	4.2	3-8	75	Good	6.07	1.12	0.11	10.36	15.30	2.98	3.71	48	19.63	52.32	1.17
T_6L_2	Silty clay	1.28	3.78	3.9			Good	6.00	1.10	0.11	6.73	16.06	2.73	3.75	43	15.63	36.25	0.97
T_7L_1	Clay loam	1.22	8.57	3.8	8-15	75	Good	5.75	1.35	0.13	11.57	12.89	1.56	2.26	35	21.14	42.63	0.33
T_7L_2	Silty loam	1.25	7.50	4.2			Good	6.02	1.34	0.13	9.53	11.53	2.11	3.41	53	20.51	28.63	0.57
T_8L_1	Silty clay loam	1.05	10.25	2.6	8-15	110	Good	5.62	1.03	0.08	7.46	18.32	2.00	3.15	31	20.14	23.25	0.57
T_8L_2	Clay loam	1.23	5.23	3.4			Good	5.72	1.11	0.06	11.57	15.57	1.57	3.12	33	16.32	20.14	0.55

CEC: Cation exchange capacity, BS: Base saturation, BD: Bulk density, SD: Soil depth, WC: Water content

Table 2: Land suitability classes of non-timber crops in the study area

Land unit	*Nephelium lappaceum* (Rambutan)	*Durio zibethinus* (Durian)	*Artocarpus altilis* (Breadfruit)	*Myristica fragrans* (Nutmeg)	Garcinia mangostana (Mangosteen)	*Mangifera indica* (Mango)
T_1	S_2na, nr, wa	S_2na, nr, wa	S_2na, nr, wa	S_2na, nr, wa	S_2wa	S_3wa
T_2	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_3wa	S_3wa
T_3	S_3eh	S_3eh	S_3eh	S_3eh	S_3eh, wa	S_3eh, wa
T_4	S_2nr, na, wa	S_2nr, na, wa	S_2nr, na, wa	S_2nr, na, wa	S_3wa	S_3wa
T_5	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_3eh, wa	S_3eh, wa
T_6	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_2rc, nr, na, wa	S_3eh, wa	S_3eh, wa
T_7	S_2rc, nr, na, eh, wa	S_2rc, nr, na, eh, wa	S_2rc, nr, na, eh, wa	S_2rc, nr, na, eh, wa	S_3wa	S_3wa
T_8	S_2nr, na, eh, wa	S_2nr, na, eh, wa	S_2nr, na, eh, wa	S_2nr, na, eh, wa	S_3wa	S_3wa

S_3eh: Marginally suitable; limiting factor slope (eh), S_2rc, nr, na, eh, wa: Moderately suitable; limiting factors consist of: soil depth (rc), nutrient retention (nr), nutrient availability (na), slope (eh), precipitation (wa), S_2rc, nr, na, wa: Moderately suitable; limiting factors soil depth (rc), nutrient retention (nr), nutrient availability (na), precipitation (wa), S_2nr, na, eh, wa: Moderately suitable; limiting factors consist of: nutrient retention (nr), nutrient availability (na), slope (eh), precipitation (wa), S_2na, nr, wa: Moderately suitable; limiting factors consist of: nutrient availability (na), nutrient retention (nr), precipitation (wa), S_3wa: Marginally suitable; limiting factor precipitation (wa)

Mangosteen requires uninundated land with good drainage and groundwater depth of >75 cm. The results of the analysis of the suitability of the research land for the development of mangosteen are classified as marginally suitable (S_3) with a fairly high rainfall limiting factor.

Limiting factors of nutrient retention and nutrient availability can be overcome by liming and application of organic material such as compost which aims to improve soil fertility[33]. This has been done by PT Vale Indonesia Tbk. using organic compost. The addition of organic matter, such as the use of mulch from plant residues, green manure, manure and compost can increase soil nutrient content. When the pH is below 6.0, the soil needs the application of agricultural lime ($CaCO_3$). In ultramafic soils with low Ca:Mg ratios, it is better to avoid the use of dolomite ($CaMg\ (CO_3)_2$) to avoid nutrient imbalance in the soil. Low Ca:Mg ratios (<1) are not preferable for some plants[34]. The post-nickel mining soil in the study area that had been reclaimed had the potential or suitable for planting non-timber plants such as rambutan, durian, breadfruit, nutmeg, mango and mangosteen while continuing to take action to improve soil chemical and physical properties through the addition of organic material.

CONCLUSION

Evaluation of the physical, chemical and terrain characteristics of post nickel mining land at PT Vale Indonesia Tbk. showed land suitability classes of moderately suitable (S_2) and marginally suitable (S_3) for the development of non-timber crops such as durian, rambutan, breadfruit, nutmeg, mangosteen and mango. The main limiting factors for all plants are the chemical characteristics of the soil (CEC, BS, N, P_2O_5), fairly high rainfall (specifically limiting for mangosteen and mango) and rather shallow soil depth (<100 cm). The low water holding capacity and high iron (Fe) content can be serious inhibitors to plant growth and production. Microscopic observations showed that the dominant minerals found are ultramafic igneous rocks such as olivine, pyroxene and biotite. In addition, secondary minerals such as illite, chlorite and kaolinite were found which indicated that there was an ultimate weathering process in the soil, which means that the nutrient-carrying minerals have weathered.

SIGNIFICANCE STATEMENT

This study discovers the characteristics of post Nickel mining soil after land reclamation and its suitability for non-timber producing crops. The soil characteristics result in analysis showed the soil fertility which still low to moderate and classified as marginally to moderately suitable for non-timber crops. These findings might be used as a reference by other researchers to manage the post Nickel mining soil formed by ultramafic parent material for agriculture purposes.

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REFERENCES

1. Khusrizal, Basyaruddin, B. Mulyanto and A. Rauf, 2012. Characteristics mineralogy of coastal North Aceh affected by tsunami. Bionatura-Jurnal Ilmu-ilmu Hayati dan Fisik., 14: 12-21.
2. Widiatmaka, W., S. Suwarno and N. Kusmaryandi, 2019. Soil pedology characteristics and revegetation of land nickel post mining: A case study of Pomalaa nickel mine, Southeast Sulawesi. J. Tanah. Lingk., 10.29244/jitl.12.2.1-10
3. Sheoran, V., A.S. Sheoran and P. Poonia, 2010. Soil reclamation of abandoned mine land by revegetation: A review. Int. J. Soil Sedim. Water, Vol. 3, No. 2.
4. Kruckeberg, A.R., 2004. Geology and Plant Life: The E ects of Landforms and Rock Types on Plants. University of Washington Press, Seattle, WA, USA, Pages: 304.
5. Kidd, P.S., A. Bani, E. Benizri, C. Gonnelli, C. Hazotte, *et al*., 2018. Developing sustainable agromining systems in agricultural ultramafic soils for Nickel recovery. Front. Environ. Sci., 10.3389/fenvs.2018.00044
6. Alves, A.R.A., E.F. Silva and L.A.B. Novo, 2019. Morais Ultramafic Complex: A Survey towards Nickel Phytomining. Resources, 10.3390/resources8030144
7. Sobczyk, M.K., J.A.C. Smith, A.J. Pollard and D.A. Filatov, 2016. Evolution of nickel hyperaccumulation and serpentine adaptation in the Alyssum serpyllifolium species complex. Heredity, 118: 31-41.
8. Hamdan andT. Rahman, 2015. Land suitability for horticultural (fruit) crops development in Mukomuko District, Bengkulu Province. International Seminar on Promoting Local Resources for Food and Health, : 259-264.
9. Sys, C., E. van Ranst and J. Debaveye, 1991. Land Evaluation. Part 1: Principles in Land Evaluation and Crop Production Calculations. General Administration for Development Cooperation, Brussels, Belgium.
10. Habibie, M.I., R. Noguchi, M. Shusuke and T. Ahamed, 2019. Land suitability analysis for maize production in Indonesia using satellite remote sensing and GIS-based multicriteria decision support system. GeoJ., 10.1007/s10708-019-10091-5

11. Schulte, E.E., J.B. Peters and P.R. Hodgson, 1987. Wisconsin procedures for soil testing, plant analysis and feed and forage analysis. No.6, Soil fertility series. College of Agriculture and Life Sciences, University of Wisconsin-Extension-Madison.
12. Landon, J.R., 1991. Booker Tropical Soil Manual. A Handbook of Soil Survey and Agricultural Land Evaluation in the Tropics and Sub-Tropics. 1st Edn., Longman, London, ISBN-13: 978-0582005570, Pages: 185.
13. Motsara, M.R. and R.N. Roy, 2008. Guide to Laboratory Establishment for Plant Nutrient Analysis. FAO, United Kingdom, Pages: 204.
14. Bouyoucos, G.J., 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. J., 43: 434-438.
15. Ganten, D., K. Ruckpaul, W. Birchmeier, J.T. Epplen and K. Genser *et al*., 2006. Standard Operating Procedure. Springer Berlin Heidelberg, Berlin, Heidelberg .
16. Soil Survey Staff, 2014. Kellogg soil survey laboratory methods manual. Soil Survey Investigations Report No. 42, Version 5.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.
17. Peterson, E. and R. Swaffield, 1987. Thermal analysis dalam. In: A Handbook of Determinative Methode in Clay Mineralogy. Wilson, M. J., Blacky and Son Ltd. New York, Pages: 308.
18. Sys, C., E. Van Ranst, E., J. Debaveye and F. Beernaert, 1991. Land evaluation Part III. Crop Requirements. Agricultural Publications No. 7. General Administration for Development Cooperation. Brussel-Belgium.
19. FAO., 1976. A Framework for Land Evaluation. 1st Edn., FAO., Rome, Italy.
20. Soil Survey Staff, 2014. Keys to Soil Taxonomy. 12th Edn., USDA-Natural Resources Conservation Service, Washington, DC., USA., Pages: 360.
21. Rout, G.R. and S. Sahoo, 2005. Role of iron in plant growth and metabolism. Rev. Agric. Sci., 3: 1-24.
22. Klute, A., 1986. Water Retention: Laboratory Methods. In: Methods of Soil Analysis, Part I: Physical and Mineralogical Methods, Klute, A. (Ed.). Agronomy Monograph No. 9, American Society of Agronomy, Madison, WI. USA., pp: 635-662.
23. Mehraban, P., A.A. Zadeh and H.R. Sadeghipour, 2008. Iron toxicity in rice (*Oryza sativa* L.), under different potassium nutrition. Asian J. Plant Sci., 7: 251-259.
24. Connolly, E.L. and M. Guerinot, 2002. Iron stress in plants. Genome Biol., Vol. 3. 10.1186/gb-2002-3-8-reviews1024
25. Sahrawat, K.L., 2005. Iron toxicity in wetland rice and the role of other nutrients. J. Plant Nutr., 27: 1471-1504.
26. Muhammad, N., G. Zvobgo and Z. Guo-ping, 2019. A review: The beneficial effects and possible mechanisms of aluminum on plant growth in acidic soil. J. Integr. Agri., 18: 1518-1528.
27. Brearley, F.Q., 2005. Nutrient limitation in a Malaysian ultramafic soil. J. Trop. For. Sci., 17: 596-609.
28. Sutanto, R., 2005. Fundamental of Soil Science. Percetakan Kanisius, Yogyakarta, Indonesia, Pages: 204.
29. Gifkins C, W. Herrmann and R. Large, 2005. Altered volcanic rocks – A guide to description and interpretation. Centre Ore. Dep. Res., Univ Tasmania.
30. Pirajno, F., 2009. Hydrothermal Processes and Mineral Systems. Springer, Australia.
31. Basir, A., S. Baja, C. Lopulisa and R. Neswati, 2018. Analysis of land characteristics (soil and climate) for nutmeg suitability evaluation (Myristica fragrans Houtt) in The Banda Naire Island of Central Maluku Districts. Int. J. Curr. Res. Biosci. Plant Biol., 5: 10-16.
32. Basir, A., R. Neswati, S. Baja and C. Lopulisa, 2018. Climate index for estimating nutmeg plant suitability under tropical rainforests in Maluku province, Indonesia. SSRG Int. J. Agric. Environ. Sci., 5: 23-30.
33. Sukaryorini, P. and M. Arifin, 2006. Mapping of land suitability for fruit plant commodities in Munjungan District, Trenggalek Regency. J. Pertanian MAPETA, 8: 151-154.
34. Proctor, J.and S.R.J. Woodell, 1975. The ecology of serpentine soils. Adv. Ecol. Res., 9: 255-366.