Spatial Identification of Black Soils in Indonesia

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Abstract. Black soils are dark in color, having soil organic carbon, high base saturation and generally good in soil structure. Having relatively higher soil organic carbon, which is declining due to intensive cultivation, therefore, the conservation and wise use of these soils are of great important. This study aimed to identify spatial distribution of black soils in Indonesia. We used available national soil maps as reference. The identification was derived from the following: (i) collated available, published soil maps, (ii) studied map legends and identified mapping unit, (iii) plotted mapping unit, (iv) calculated the coverage based on proportion of Mollisols in given map units, and (v) did spatial cross tabulation with slope map and parent material map. Results show that black soils cover 6.3 Mha and are categorized into 9 soil great groups (Hapludolls, Haplustolls, Endoaquolls, Argiudolls, Argiustolls, Rendolls, Calciustolls, Haprendolls, and Epiaquolls). We argue this has potential to be used as general guide for implementing conservation techniques.

Keywords: Soil Structure; Mollisols; Soil Great Groups; Conservation Techniques

1. Introduction

Black soils, according International Network on Black Soils (INBS) criteria, are soils that are black in color, have high soil organic carbon (SOC) content, high base saturation, and good in soil structure[1]. INBS endorse the use of soil classification as the estimate of black soils distribution in the member countries including Indonesia. Black soils are of Mollisols according to Soil Taxonomy [2] or Phaeozem and Kartazem according to World Resource Base for Soil Research [3], or Mollisols according to Indonesian Soil Classification [4]. Indonesian soil maps have made use Soil Taxonomy, hence Mollisols can be used as proximate for black soils and for identifying distribution countrywide.

Intensive systematic soil mapping program results in semi detailed soil maps. At present, all regencies and municipalities are characterized by the semi detailed soil maps, at the scale of 1:50,000. This soil map is presented in term of soil atlas describing soil mapping units as listed in the legend. The soil atlas can be found in public repository such as the library or Indonesian Center for Agricultural Land Resource Research and Development (ICALRD). This map also provides rich information about soil, hence can be used as source of soil information including black soil studies.

Subagyo reported that Mollisols covers 9.9 Mha[5], based on the Indonesian Exploratory Soil Map of 1:1,000,000 scale[6]. Hikmatullah and Suryani reported that Mollisols in Sulawesi were about 1,162,483 ha[7], meanwhile Sunyoto found 11,328 ha Mollisols in East Sumba[8]. Thus, there is a very rough estimate of black soils based on literature. Therefore, amore detailed and finer map and information may be required due to some generality in coarser scale.

Black soils are productive soils for food security and farmer prosperity in America, Brazil, Argentina, Russia, and China, including Indonesia [9]. Due to high organic soil matter, their
conservation and sustainable use are crucial for supporting food security and nutrients, as well as mitigating climate change. While these soils are mostly classified as Mollisols, there is limited information regarding their distribution, characteristics, and use in Indonesia.

Black soils is of great importance in climate change. High content of SOC is held in these productive soils. Intensive tillage can destroy soil structure and expose more carbon for microorganism leading to the decrease of carbon content. Moreover, this carbon will emit to the atmosphere through greenhouse gas emission. Protection of black soils means preventing the loss of soil organic carbon and a positive impact to climate change.

The aim of this study was to identify spatial distribution of black soils in Indonesia based on soil survey data. This information is of great importance as black soil stores high organic carbon naturally and in several places as centre for crop and fiber production due to its high productivity. In the context of climate change and food security, maintenance and wise use of this soil is important, hence information should be comprehensive. This study provides baseline information from which further in depth study can be done.

2. Materials and Methods

2.1. Dataset

Dataset used in this study were Soil Map Atlases that available in the public library of ICALRD in Bogor (Indonesia). These atlases were the result of systematic soil survey of 1:50.000 by ICALRD. The atlas contains soil map, map legend, and its explanation. Soil map is composed of mapping units’ number and described in the map legend.

The soil legend describes mapping units where each mapping unit composed of soil unit, landform type, slope, and parent material. One mapping unit may be consisted of one, two or three soil unit. The soil unit is described using the Soil Taxonomy up to great group for reconnaissance soil map and subgroup for semi detailed soil map.

2.2. Working steps

Figure 1 show flow chart in creating black soil map. Based on Exploratory soil map at 1:1.000.000 scale, Subagyo identified provinces having Mollisols[5]. Using this information, we collect soil atlas at scale of 1:50.000. For each soil atlas, we identify and clip mapping unit having Mollisols based on information on map legend. The soil order of Mollisols becomes proximate of black soils as suggested by International Network on Black Soils. Yet, in the used soil atlas, soil type is classified up to subgroup level of Soil Taxonomy System.

Then, we identify the proportion of soil type in a given soil mapping unit (SMU). For this, we inspect map legend, where a SMU may have 1 to 3 soil type or more. The soil proportion may predominant (P) if the soil type covers more than 75% of SMU, dominant (D) if soil type covers 50-75% of SMU, fair (F) if soil type covers 25-50 % of SMU, minor (M) if soil type covers 10-25% of SMU, or trace (T) if soil type covers less than 10% of SMU. Meanwhile, map legend also provides the coverage of SMU in hectare. By using median value of the percentage class of the soil type proportion, the coverage of each soil type in the SMU can be estimated. If more than one soil type of Mollisols in a given SMU, then the coverage of Mollisols are the sum of the coverage of each soil type. Thus, each SMU has the coverage of black soils.

SMUs have Mollisols become SMU of black soil. By plotting these SMUs, a map of black soils can be drawn. For map legend, we assigned the SMU as predominant (P) if SMU has the coverage of black soils of 75% or more, dominant (D) if SMU has the coverage of black soils 50-75%, and fair (F) if SMU has the coverage of black soils less than 50 %.
Figure 1. Flowchart for creating black soil map based on available soil maps

3. Results and Discussion

3.1. Spatial Distribution
Figure 1 shows nationwide distribution of black soils, with main reference to Mollisols. Black soils covers about 6.3 Mha and are found mainly in northern Sumatera, eastern Java & Madura, Lesser Sunda Islands, Sulawesi, Moluccas Island, and Papua. This figure is lower than previous study by Subagyo who estimated the coverage of Mollisols about 9.9 Mha[5]. Subagyo used Explanatory Soil Map at the scale of 1:1,000,000 [6] meanwhile this study used semi-detailed soil map of 1:50,000 scale as the input. Thus, this study exercised finer, more detailed scale information and so provided better estimate of the spatial distribution and coverage of black soils.
Administratively, black soils only cover 14 provinces of 32 provinces in Indonesia (Table 1). The soil is extensively found in Sulawesi Tengah Province covering 2.8 Mha, followed by Nusa Tenggara Timur (NTT) Province about 0.8 Mha, Sulawesi Selatan Province about 0.58 Mha, Sulawesi Tenggara Province about 0.53 Mha, and Maluku Province 0.38 Mha.

Topographically, the black soils of the area having slope <8% are about 2.6 M ha or 42.6% of total coverage of black soils (Table 1). This data indicates that this soil is prone intensive agriculture and nutrient mining. In this area, this soil is used for various crop production such as rice in Minahasa Selatan (Sulawesi Utara) and Jawa Timur; maize in Gorontalo, NTT, NTB, Sulawesi Tengah; sugarcane in Boalemo (Gorontalo), Aceh, and Jawa Timur; vegetables in Sulawesi Tengah and Sulawesi Utara; cocoa in Sulawesi Tengah. Tora, yam sweet potato, and cassava are also found in mostly black soil areas. Although intensive, farmers usually use no or less input leading to nutrient imbalance and soil carbon removal and shallowing soil due to erosion when soil tillage time.

Meanwhile, about 64% of black soils is on areas having slope of 8% or more or in hilly and mountainous areas (Table 1), cause the soil prone to erosion. Low annual rainfall but high intensity in short time makes soil erosion severe. In hilly and mountainous area, black soils are prone to geological soil erosion and can be accelerate if soil conservation measure is not implemented properly leading to more severe erosion. Soil erosion may remove very fertile, high organic carbon, top soils and at the same time threaten the occurrence of the black soils in the respective region.

Table 1. The Distribution of Black Soils based on Slope

| Province Name            | <3%       | 3-8%      | 8-15%     | 15-25%    | 25-40%    | >40%     | Total        |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|--------------|
| (………………………………………Ha………………………..) | Ha        | %         |           |           |           |           |              |
| 1. Sulawesi Tengah       | 916,486   | 527,445   | 330,592   | 361,514   | 175,496   | 567,474  | 2,879,006   | 45.6        |
| 2. NTT                   | 84,597    | 68,470    | 99,621    | 171,307   | 242,555   | 213,260  | 879,810     | 13.9        |
| 3. Sulawesi Selatan      | 307,240   | 71,219    | 68,744    | 63,743    | 46,827    | 31,343   | 589,116     | 9.3         |
| 4. Sulawesi Tenggara     | 124,242   | 157,330   | 105,072   | 65,913    | 829       | 81,756   | 535,142     | 8.5         |
| 5. Maluku                | 177,311   | 138,946   | 10,955    | 52,494    | 6,576     | 386,282  | 257,635     | 4.1         |
| 6. Papua                 | 245       | 196       | 12,911    | 17,153    | 34,348    | 192,782  | 257,635     | 4.1         |
| 7. Maluku Utara          | 13,440    | 27,349    | 39,878    | 64,980    | 36,854    | 60,567   | 243,060     | 3.9         |
| 8. Sulawesi Utara        | 9,075     | 3,158     | 20,094    | 66,938    | 33,925    | 56,396   | 189,585     | 3.0         |
| 9. Aceh                  | 3,634     | 25        | 4,633     | 17,776    | 35,465    | 26,803   | 88,337      | 1.4         |
| 10. NTB                  | 4,781     | 13,917    | 13,594    | 8,680     | 30,687    | 71,659   | 243,060     | 3.9         |
| 11. Jawa Timur           | 358       | 13,320    | 4,985     | 22,875    | 26,135    | 731      | 68,404      | 1.1         |
| 12. Gorontalo            | 2,018     | 3,422     | 11,142    | 43,815    | 6,241     | 663      | 67,302      | 1.1         |
| 13. Jawa Tengah          | 7,732     | 13,062    | 5,529     | 8,852     | 1,351     | 42       | 36,568      | 0.6         |
| 14. Sulawesi Barat       | 390       | 20,013    | 20,403    | 34,348    | 6,241     | 3063     | 20,403      | 0.3         |
| Total                    | 1,651,160 | 1,037,860 | 728,140   | 986,052   | 677,281   | 1,231,817| 6,312,309   | 100.0       |
| (%)                      | 26.2      | 16.4      | 11.5      | 15.6      | 10.7      | 19.5     | 100.0       |

3.2. The variability of black soils

Table 2 list 32 soil subgroup of 9 great groups of Mollisols as black soils in Indonesia. Subagyo et al. (2000) found 6 great groups of Mollisols, namely Hapluudolls, Haplustolls, Endoaquolls, Argiudolls, Argiustolls, and Rendolls. Not only does, this study confirms these results additionally found 3 new great groups namely Calciustolls, Haprendolls, and Epiaquolls. Variation in subgroup level is due to difference in the prefix reflecting specific pedogenic process.
These 11 prefix subgroups include: Pachic, Lithic, Typic, Oxyaquic, Vertic, Fluvaquentic, Andic, Aquic, Fluventic, Inceptic, and Mollic. Based on the occurrence in each regional, the most common subgroups are Typic Hapludolls, Lithic Hapludolls, Lithic Haprendolls. This data suggests that black soils in Indonesia have different soil properties that subsequently required specific soil and land management technologies.

**Table 2. List of types of soil subgroup of black soils**

| Soil Subgroup                  | Province Number* |
|--------------------------------|------------------|
| 1. Pachic Argiudolls           | ✔                |
| 2. Typic Argiudolls            | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 3. Lithic Argiudolls           | ✔                |
| 4. Oxyaquic Argiudolls         | ✔                |
| 5. Vertic Argiudolls           | ✔                |
| 6. Typic Argiustolls           | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 7. Pachic Argiustolls          | ✔                |
| 8. Lithic Argiustolls          | ✔                |
| 9. Vertic Argiustolls          | ✔                |
| 10. Typic Calciustolls         | ✔                |
| 11. Typic Endoaquolls          | ✔                |
| 12. Vertic Endoaquolls         | ✔                |
| 13. Fluvaquentic Endoaquolls   | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 14. Typic Epiaquolls           | ✔                |
| 15. Typic Hapludolls           | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 16. Lithic Hapludolls          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 17. Pachic Hapludolls          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 18. Andic Hapludolls           | ✔ ✔ ✔              |
| 19. Aquic Hapludolls           | ✔ ✔ ✔              |
| 20. Oxyaquic Hapludolls        | ✔ ✔ ✔              |
| 21. Fluventic Hapludolls       | ✔ ✔ ✔              |
| 22. Inceptic Hapludolls        | ✔ ✔ ✔              |
| 23. Mollic Hapludolls          | ✔ ✔ ✔              |
| 24. Lithic Haplustolls         | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 25. Typic Haplustolls          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 26. Vertic Haplustolls         | ✔ ✔ ✔              |
| 27. Andic Haplustolls          | ✔ ✔ ✔              |
| 28. Fluventic Haplustolls      | ✔ ✔ ✔              |
| 29. Pachic Haplustolls         | ✔ ✔ ✔              |
| 30. Lithic Haprendolls         | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 31. Typic Haprendolls          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ |
| 32. Lithic Rendolls            | ✔ ✔ ✔              |
| **Total Subgroup**             | 9 19 7 5 6 5 4 8 4 5 10 4 10 2 |
3.3. Black soils and lithology association

Table 3 list parent material and its occurrence in provinces associated with black soils. Limestone is main parent material from which black soils develop, found in all provinces. Mella and Mermut concluded that Mollisols have developed mainly from the weathering of limestone in West Timor, NTT Province[10]. Coral limestone is second larger area and extensively found in Sulawesi Tengah, Sulawesi Tenggara, Sulawesi Utara and Gorontalo Province.

| Parent Material                  | Province Number* | Coverage |
|----------------------------------|------------------|----------|
| 1. Limestone                     | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 2,948,973 |
| 2. Coral limestone               | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 1,480,865 |
| 3. Intermediate volcanic rock    | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 637,331  |
| 4. Limestone and Marl            | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 285,137  |
| 5. Calcarenite                   | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 114,498  |
| 6. Limestone and Marble          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 82,398   |
| 7. Marly limestone               | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 70,563   |
| 8. Marl                          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 57,221   |
| 9. Shale and Calciulfite         | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 48,961   |
| 10. Limestone and sandstone      | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 43,713   |
| 11. Calcareous sandstone         | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 42,717   |
| 12. Granite                      | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 36,991   |
| 13. Calcareous claystone         | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 26,050   |
| 14. Basaltic volcanic rocks      | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 17,641   |
| 15. Shale and sandstone          | ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ ✔ | 18,499   |

*See Table 1 for code number and province name

Black soils also developed from calcarenite especially in NTT. Meanwhile, black soils developed from marl are found mainly in Maluku Province then Jawa Timur, Aceh, NTT, and Jawa Tengah. The combination of limestone and marl is parent material for black soils mainly in Maluku, Sulawesi Tengah, and spot area of Jawa Timur and Sulawesi Utara. Marl limestone is only found in NTT from which black soils develop. Further, limestone and marble are also parent material for black soils in Sulawesi Tenggara. Limestone in combination with claystone, sandstone, coral, and tuff are found as parent materials of black soils in NTT.

Black soils also developed from intermediary volcanic rock (andesite, dasite, basaltic andesite), as found in NTT, Sulawesi Utara, Maluku Utara, NTB, Sulawesi Selatan, Sulawesi Tengah, and Jawa Timur. The volcanic rocks are mostly in the form of tuff, lava and breccia. Calcareous sandstone is another parent material that distributes extensively in Aceh, Jawa Tengah, Sulawesi Selatan, Jawa Timur, Maluku Utara, Maluku, and Papua. Meanwhile, calcareous claystone is parent material for BS mainly in NTT, and also found in Jawa Tengah and Papua.

3.4. Factors controlling black soil distribution

Our data suggest that the occurrence of blacksoils associates with specific parent material and climatic condition. Dames (1955) also concluded that black soil originate from: (i) limestone and marly
limestone, (ii) marls, calcareous shales and loamstones, or calcareous sandstone and claystone, (iii) intermediate to basaltic tuff sediments, (iv) recent intermediate to basaltic volcanic deposit (lahar, river deposit), and (v) recent alluvium (alluvial plains), mainly fine marly and volcanic deposit. Thus, the presence of certain parent material can be an indication for the possibility of the occurrence of black soils.

By comparing black soil distribution with Indonesian agro climate map[11–15], black soils associate with area having drier, semiarid climate, such as NTT and BTB. Dry climate is characterized by wet month less than 3 month, and dry month more than 4 or even more. Wet month is month having monthly rainfall 200 cm or more, whereas dry month is month having monthly rainfall less than 100 mm. Dames also found that black soils can be found in area were extremely climate[16]. In this area, mean annual rainfall about 1000 mm or less and dry period 6 months or more. Thus dry climate can be used as spatial indicator for black soil in Indonesia.

3.5. Future direction

Our study resulted indicative map of black soils in Indonesia and its association with topography and parent material. The main challenges are how to reduce soil erosion (sloping land, erratic rainfall), improve nutrient mining/nutrient imbalance, manage shallow solum, manage soil moisture, and select crops adapted to high clay content and high pH levels. Based on current practice and to increase crop productivity, we need to formulate site-specific land management packages which integrate conservation measures and sustainable methods tailored to Agri-Pedo-Socio conditions, and scale up existing farming systems (conservation agriculture, crop-cattle integration, and land management measures). Finally, more research is needed for better information as a base for better management, as well as strengthened international networks and collaboration in black soil research, management, and conservation.

Simply put, black soils store carbon. The loss of its topsoil due to soil erosion means loss of soil carbon[17,18], and its established that soil carbon is important for soil fertility, climate change and environmental services of this soils. Hence, it is critical to conserve this soil to reduce soil loss and soil shallowing. Black soils in sloping area and plain area need soil and conservation measure by creating mound terrace, plant follow contour, and other technique. In sloping land, implementing agroforestry system and semi intensive agriculture is recommended. In plain area, conservation agriculture is recommended.

Black soils tend to be utilized intensively for agriculture with low input but as they are highly productive. Also, in sloping soil, unfortunately conservation measure is not implemented by most farmers in all areas. During several decades, black soil have lost about 50% of their antecedent organic carbon (C) pool due to soil erosion, degradation, and other unsuitable human activities. The SOC contents of black soil in Northeast China decreased from 52 to 24 g kg−1 (46%) after 150 years of cultivation management [9].

Therefore, monitoring of black soils is needed in the future to evaluate the status of this soil where monitoring should be conducted in every agroecosystem and immediately actions can be taken for managing erosion and avoid soil degradation. Site selection for monitoring purposes can be done by grouping and selecting soil types as in Table 3, the selecting land use type and slope class. This monitoring will result in database and soil status across soil type, land use, and topography.

Management practices including no tillage, manure and compost fertilization, crop straw returning, biochar amendment, windbreak tree, and mulching cultivation are the recommended technologies. The C restoration in black soil is a win-win strategy for ensuring the security of food and soil resources while effectively mitigating global climate change. Thus, more attention should be given to protective management and land use for its impacts on SOC dynamics and soil properties in black soil regions [9,19,20].

A possible limitation of this study is that the mapping approach and technique used in this study depend upon available soil input and supporting equipment for data processing. Mapping unit boundary of black soil follow mapping unit boundary of inputted map, hence more detailed map input is needed for creating reliable black soil map. Hence, the legend of black soil map put the information
of proportion of black soil in each mapping unit and so our black soil map can be used as initial indication of determining black soil types precisely within the boundary. Additional more soil observation and empirical data as input to the map will offer more accurate distribution of black soil. In addition, technology options are available such as digital soil mapping methods such as spatial disaggregation and logistic regression technique in combination with soil-landscape modelling will accelerate and make easy map detailing.

4. Conclusion
In conclusion, this study has identified spatial distribution of black soil in Indonesia using geospatial analysis technique on soil map of 1:50.000 scale, with Mollisols as reference. Used procedure can be an option to derive thematic maps from available soil map. Black soil covers about 6.3 Mha, found mainly in Sulawesi Tengah, NTT, Sulawesi Selatan, Sulawesi Tenggara, and Maluku Province. Indonesian black soil highly varies, where 9 great groups are identified including Hapludolls, Haplustolls, Endoaquolls, Argiudolls, Argiustolls, Rendolls, Calciustolls, Haprendolls, and Epiaquolls. These great group derived 32 soil subgroups, with special characters as indicate by prefix of Pachic, Lithic, Tropic, Oxyaquic, Vertic, Fluvaquentic, Andic, Aquic, Fluventic, Inceptic, and Molic. This soil is developing from 15 type of parent material including limestone, intermediate and basaltic volcanic rock, marl, calcareous sandstone and claystone, shale, marble, and calccarenite. This black soil is found in plain area with slope less than 8 % about 2.6 Mha or about 42% of total coverage of black soils. The rest is found and hilly and mountainous area. With such landscape setting, black soils can be use intensively for agriculture and also prone to soil erosion. Soil and conservation measure including conservation agriculture are required to reduce soil erosion and nutrient mining and nutrient imbalance. The implementation of these measures should be tailored of soil variation and site-specific condition. More in-depth study on mapping black soil variation can be used digital soil mapping methods such as spatial disaggregation and logistic regression techniques.

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