Developing and Testing Soil Correlation Matrix to Assess the Spatial Variation of Soil Resource in Indonesia

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Abstract. Soil survey and mapping in Indonesia uses 3 different soil classification systems simultaneously. These systems are the Soil Taxonomy of the United States Department of Agriculture (ST), World Reference Base (WRB) of the Food and Agriculture Organization, and Indonesian Soil Classification (ISC). The remaining challenge is to harmonize and interpret soil information among these systems. This study aimed to develop a correlation matrix to correlate soil names and to test it in Sukabumi Regency, West Java. The matrix was developed based on the peculiar soil properties which differentiate one soil class from another. Based on the results, in Indonesia, there are 10 soil orders dominant from 12 soil orders of ST System, 17 RSGs from 32 RSGs in WRB system (2015), and 16 soil types of ISC System (2016). Testing in Sukabumi showed a good example of using the correlation matrix to develop a WRB based soil type map. The correlation matrix was found helpful in developing the WRB soil map in a regional scale.

Keywords: World Reference Base; ISC System; RSGs; ISC

1. Introduction
Soil surveys, mapping, and classification in Indonesia are carried out dynamically with the developing standards and methods in the world. Like Canada, the Netherlands, China, and Japan [1], [2], Indonesia developed a specific soil classification system that is easily understood by local soil experts [3], while still following the soil classification based on the Soil Taxonomy classification system developed by USDA [4], [5] and FAO soil classification [5] to facilitate communication with fellow world soil experts.

FAO soil classification was developed into the World Reference Base (WRB) and is used by many countries because it still accommodates a unique classification system for each country [7]. Then, the WRB system is used by soil experts from various countries who are members of The Global Soil Partnership (GSP) to promote soil as a Global Agenda and promote Sustainable Soil Management (SSM) to ensure soil health and productivity in serving the ecosystem. One of the GSP agendas is to develop a global soil map for world food security and mitigate global climate change [8].

Currently, Indonesia has completed soil mapping for the entire region at various levels of scale. Soil mapping at a scale of 1: 1,000,000 has been carried out for national strategic planning with a soil classification system based on Soil Taxonomy up to Great Group level. Then, soil map with a scale of 1: 250,000 for provincial strategic planning based on Soil Taxonomy to the Sub-Group level. The maps developed were not understood by soil practitioners who only studied the Indonesian Soil Classification (ISC) system. Thus, the purpose of soil maps for national and provincial strategic planning is not effective.
Furthermore, soil map with a scale of 1: 50,000 for regency level operational planning. At this level, soil classification uses Soil Taxonomy, FAO soil classification, and Indonesian Soil Classification (ISC) so that users can better understand soil information. The 3 maps with different scales have different levels of detailed information and the fineness of the polygon boundaries. All maps are based on vector data namely polygons with map legends.

There are 2 remaining issues on the 3 scales map with 3 classification systems. First, each classification system develops dynamically so that there are always changes and additions to soil classification in every decade [3]. This has an impact on irrelevant soil classification [7]. Second, the soil classification is still considered as tacit knowledge by surveyors, mappers, and soil experts [9].

The user can only interpret the classification system from the map legend. Several conversion keys have been developed to relate soil classifications based on certain classifications with other soil classifications [10], [11]. This conversion can be a reference for the conversion of soil classification according to the Taxonomic System to the WRB System for soils in Indonesia. Buurman developed a correlation between FAO classification and The Puslitan classification in 1983. While Subardja developed a key conversion between the Indonesian Soil Classification (ISC) and the Taxonomy System in 2015.

Recently, the FAO team has also developed the conversion from the Soil Taxonomy System to the WRB system which is the reference for many countries. Some countries such as Iran have also attempted to develop references to correlate the two international systems with their respective classification systems [12], [13]. However, the correlation matrix developed by FAO is still general and only covers soils in sub-tropical or developed countries that apply the WRB classification system.

The correlation matrix does not yet accommodate soils in tropical regions, such as in Indonesia, which thrive in high rainfall so that the soil weathering rate is very high. The purposes of this study were to 1) develop a correlation matrix of 3 soil classifications in the tropics, and 2) test the correlation matrix to develop a map of WRB soil types in Sukabumi Regency.

2. Materials and Method

2.1. Dataset
The 1: 50,000 scale soil map in all regencies throughout Indonesia informs soil classification and other soil properties based on USDA soil taxonomy, WRB, and Indonesian Soil Classification (ISC).

2.2 Location
The study location covered the entire territory of Indonesia from Sabang-Merauke which represents soil in tropical areas with tropical rainforest sub-climate (Af), savanna sub-climate (Aw), and tropical monsoon sub-climate (Am). While the correlation matrix test was conducted in Sukabumi Regency, West Java.

![Figure 1. Study area in Indonesia that represent tropical area and verification in Sukabumi Regency](image-url)
2.3. Workflow

![Figure 2. Workflow of developing key control and field verification](image)

The workflow was divided into 3 main stages namely 1) preparing the dataset including collecting soil maps and data, standardizing, harmonizing, and developing a geodatabase; 2) testing in the selected area by determining the selected area, determining the dominant soil, developing the conversion key, developing WRB soil type; and 3) planning for observation, soil observation, and classification evaluation.

2.4 Taxo transfer rule

The three land classification systems have different hierarchical levels. Soil Taxonomy has 6 hierarchical levels with the highest hierarchy at the order level followed by sub-orders, great groups, subgroups, families, and series. In the world, there are 12 soil orders with different temperature regimes, moisture regimes, parent materials, and diagnostic horizons.

Meanwhile, the WRB classification system has 2 hierarchical levels, namely Reference Soil Groups (RSGs) as the highest level and principal and supplementary qualifiers. Currently, there are 32 (RSGs) types of soil in the world. Then, the Indonesian Soil Classification (ISC) has 2 hierarchical levels, namely soil type at the first level and the next level. In Indonesia, according to the Indonesian Soil Classification (ISC) System, there are 20 soil types.

![Figure 3. Workflow to determine system classification for central of taxo transfer](image)

2.5. Determination of soil type in Indonesia in the central of taxo transfer

After obtaining the central of taxo transfer, the top hierarchy in the selected classification system was evaluated using the “if-then” rule with several factors such as the temperature regime, moisture regime, parent material, and the diagnostic horizon as in the figure below:
3. Results and Discussion

3.1 Correlation matrix for Indonesia

Based on the central of tax transfer which is processed with the "if-then" rule which considers the environment in tropical regions, Indonesia has 10 order soils out of 12 order soils in the Soil Taxonomy. Two soil orders based on parent material as a differentiating factor, namely Histosols and Andisols and 9 other soil orders based on characteristics and horizons namely Oxisols, Alfisols, Ultisols, Vertisols, Spodosols, Mollisols, Inceptisols, and Entisols.

Table 1. Correlation matrix for three top hierarchy of soil classification: Soil Taxonomy (USDA), WRB, and Indonesian Classification.

| No | US Soil Taxonomy (2014) | Horizon and Characteristic Diagnostic (US Soil Taxonomy) | WRB (2015) | Comment | Nasional 2016 |
|----|-------------------------|--------------------------------------------------------|------------|---------|---------------|
| 1  | Histisols               | Histic Epipedon                                        | Histosols  | Clear   | Organosol     |
| 2  | Spodosols               | Spodic Horizon                                         | Podzol     | Clear   | Podsol        |
| 3  | Andisols                | Andic Soil Properties                                  | Andosols   | Clear   | Andosol       |
| 4  | Vertisols               | Vertic Soil Properties                                 | Vertisols  | Clear   | Grumusol      |
| 5  | Oxisols                 | Oxic Horizon                                           | Ferralsols | Clear   | Oksisol       |
|    |                         |                                                        | Acrisols   | Ultsils with low activity clay | Podsolik |
| 6  | Ultisols                | Argillic Horizon and low base saturation               | Alisols    | Ultsils with high activity clay | Mediteran/Nitosol/P lanosol |
| 7  | Mollisols               | Mollie Epipedon                                        | Phaeozems  | Ultsils with low activity clay | Molisol |
| 8  | Alfisols                | Argillic Horizon and high base saturation              | Lixisols   | Alfsils with high activity clay | Kambisol/Latosol |
| 9  | Inceptisols             | Cambic Horizon                                         | Cambisols  | Clear   | Kambisol/Latosol |
|    |                         |                                                        | Gleysols   | Inceptisols with aquic condition | Gleisol |
|    |                         |                                                        | Arenosols  | Psamments Soils of coarse texture | Regosol |
| 10 | Entisols                | No Diagnostic Horizon                                  | Fluvisols  | Recent alluvial soils (Fluvaint and Fluvaquents) | Aluvial |
|    |                         |                                                        | Leptosols  | Lithic Sub Group | Litosol |
Next, the differentiating factors for the 10 soil orders were correlated in a matrix as in table 1. Based on this matrix, Indonesia has 16 Soil References based on the WRB system of 32 Soil References in the world. The four soil orders of Soil Taxonomy can be easily matched, namely Histosols, Spodosols, Andisols, and Vertisols. The four of them have characteristic factors, namely Histic epipedon, Spodic horizon, Andik, and Vertic which are also characteristic for Histosols, Podzols, Andosols, and Vertisols in WRB.

Subsequently, at the lower level of the hierarchy, the characteristics became a reference. In other words, the differentiating factors at the suborder, and great group levels were matched with the principal qualifier and supplement qualifier for the WRB as shown in Table 2 below for Jawa Barat Province and Daerah Istimewa Jakarta Province.

**Table 2.** Correlation matrix for next level hierarchy of soil classification: Soil Taxonomy (USDA), WRB, and Indonesian Classification in Java Island.

| USDA SOIL TAXONOMY | WRB (2015) | ICS (2016) |
|--------------------|------------|------------|
| Endoaquepts        | Dystric Gleysols | Gleisol Distrik |
| Endoaquepts        | Thionic Gleysols | Gleisol Sulfurik |
| Endoaquepts        | Tidalic Gleysols | Gleisol Distrik |
| Epiaquepts         | Dystric Gleysols | Gleisol Distrik |
| Halaquepts         | Gleyic Solonchacks | Gleisol Sodik |
| Eutrudcpts         | Eutric Cambisols | Kambisol Eutrik |
| Dystrudepts        | Dystric Cambisols | Kambisol Distrik |
| Haplustepts        | Eutric Cambisols | Kambisol Eutrik |
| Hydreaquents       | Tidalic Gleysols | Aluvial Hidrik |
| Fluvaquequents     | Dystric Fluvic Gleysols | Aluvial Gleik |
| Endoaquents        | Tidalic Gleysols | Aluvial Gleik |
| Ustipsamments      | Tidalic Arenosols | Regosol Ustik |
| Udipsamments       | Dystric Arenosols | Regosol Distrik |
| Udipsamments       | Tidalic Arenosols | Regosol Distrik |
| Udorthents         | Dystric Regosols | Arenosol Kambik |
| Hapluderts         | Haplic Vertisols | Gramusol Kromik |
| Hapludands         | Dystric Andosols | Andosol Distrik |
| Epiaquands         | Dystric Gleysols | Andosol Gleik |
| Paleudults         | Haplic Acrisols | Nitosol Distrik |
| Kandidudults       | Haplic Acrisols | Podsolik Kandik |
| Hapludults         | Haplic Acrisols | Podsolik Haplik |
| Paleustults        | Haplic Acrisols | Nitosol Ustik |
| Haplustults        | Haplic Acrisols | Podsolik Ustik |
| Hapludafis         | Haplic Luvisols | Mediteran Haplik |
| Haplustalfis       | Rhodic Luvisols | Mediteran Rodik |

### 3.2. Limitation of matrix correlation

The use of the correlation matrix requires carefulness in the Ultisols or soils with an argillic horizon and low base saturation. Ultisols in the WRB system can be divided into Acrisols for Ultisols with low activity clay, Alisols for Ultisols with high activity clay, and Plinthosols for Ultisols with plinthite. Similarly, Alfisols can be divided into Lixisols for Alfisols with low activity clay and Luvisols for Alfisols with high activity clay.
Ultisols and Alfisols can be matched to Acrisols and Alisols and Lixisols and Luvisols. This will be more detailed if the soil map legend provides laboratory data, especially base saturation. The main differentiator of Ultisols and Alfisols in Soil Taxonomy is base saturation <35% for Ultisols and >35% for Alfisols in the control section with a depth of 1.8 m. Meanwhile, the differentiator for Arcisols and Alisols with Lixisols and Luvisols is effective base saturation <50% (Acrisols and Alisols) and effective base saturation >50% (Lixisols and Luvisols).

There is a problem when matching WRB with the Indonesian Soil Classification (ISC) System because there is the same classification, but has different meanings like Regosols, so that adjustments are needed. At WRB, Regosols is “very weakly developed mineral soils in unconsolidated materials that do not have a mollic or umbric horizon, are not very thin or very rich in coarse fragments (Leptosols), not sandy (Arenosols), and not with fluvic materials (Fluvisols). Regosols are extensive in eroding lands and accumulation zones, particularly in arid and semi-arid areas and in mountainous terrain.” [7] Meanwhile, in the Indonesian Soil Classification (ISC), Regosols is "Soils with a coarse texture (sand, loamy sand), having an A horizon, umbric or histic, thickness > 25 cm." [3]

Likewise, Cambisols in WRB, when matched to the Indonesian Soil Classification (ISC) System, has 2 possibilities, namely Kambisol or Latosol depending on the parent material, the clay content in the soil and the uniformity of color. Latosols was developed from intermediate volcanic material and contains clay above 40% with a more homogeneous color. However, the presence of the correlation matrix makes it easy for users to match the three classification systems so that they are not mistaken at the highest hierarchical level.

3.3. WRB map of Sukabumi Regency

Implementation of soil map verification uses the dominant soil map approach on each soil map in Sukabumi Regency because on each soil map there is dominant soil, fair soil, and minor soil [14]. Based on the legend of the Sukabumi Regency soil map, the dominant soil based on the level of soil development consists of 5 soil orders, namely Entisols, Inceptisols, Andisols, Alfisols, and Ultisols.

The five soil orders are then divided into 14 subgroups. The Entisols soil order consists of Sulfic Endoaquents, Typic Udipsamments, Lithic Udorthents, and Typic Udorthents. Meanwhile, Inceptisols soil order consists of Typic Endoaquents, Fluventic Dystrudepts, Typic Dystrudepts, Typic Eutrudepts, Sulfic Endoaquents, and Andic Dystrudepts. The Andisols soil order consists of two subgroups, namely Typic Hapludands and Typic Udivitrands. The Alfisols soil order consists of Typic Hapludalfs and the Ultisols soil order consists of Typic Hapludults.

Sukabumi is an area dominated by volcanic parent material so that the soil is dominated by Typic Hapludands which contain andic material with the largest area. Sukabumi also has a wet climate with high rainfall so that it produces soil with further weathering or Typic Hapludults with the second most extensive area followed by Typic Dystrudepts. Figure 3 presents a map of the dominant soil based on the soil taxonomy system.
Based on the key tropical soil correlation matrix, the five soil orders were matched with 8 soil references namely Fluvisols, Gleysols, Arenosols, Regosols, Cambisols, Andosols, Acrisols, and Luvisols. They consist of 12 soil types namely Gleyic Fluvisols, Thionic Gleysols, Dystric Arenosols, Leptic Regosols, Fluvic Cambisols, Dystric Cambisols, Eutric Cambisols, Andic Cambisols, Dystric Andosols, Vitric Andosols, Chromic Luvisols, and Chromic Acrisols. In Sukabumi, Dystric Andosols have the largest area followed by Chromic Acrisols and Dystric Cambisols as shown in Figure 4.
4. Conclusion
The key control is in the form of a correlation matrix to understand the characteristics of soil in Indonesia, located in a tropical region with a unique environmental setting. There are 10 soil orders in Indonesia from 12 soil orders in the world based on Soil Taxonomy. There are 17 soil references from 32 soil references on the WRB system. In the Indonesian soil classification system, both are equivalent to 17 soil types.

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