The evaluate soil quality of mangrove forest in Merauke, Papua

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Abstract. Mangroves are very important to reduce climate change impact since they have been the indispensible portion of the environment serving different functions such as coastline assurance, obstructing salt water interruption, aquaculture, fodder for post, kindling, charcoal generation and moderating botanical and faunal species. Knowledge of soil quality is important for appropriate decision making regarding sustainable land use systems mangrove forest. Soil quality management helps to maintain biological productivity; air and water quality; and human habitation and health. The objective was to evaluate and identify an effective SQ indicator dataset from different mangrove forest types in the Payum beach Merauke area, the soil quality index are computed for basic of framework soil management system. The study was carried out from November 2019 to May 2020. This research use descriptive exploratory research method through field survey. Precise inspecting with three transect each measuring 5 m² were built up in both plots. The total of 9 soil samples consisting of 3 transect type were collected from layer surface 0 to 15 cm, for evaluated quantify soil nutrient reserve and soil quality index (SQI). Soil samples were the analyzed for physical, chemical and biology indicators were used standard laboratory method. The results showed that for mangrove forest has the lowest to medium soil quality index (0.33-0.38) so natural forest has the medium soil quality index (0.39). Soil organic carbon and available phosphorus play major roles in making significant differences in the SQI among the different mangrove forest.

1. Introduction
Merauke Regency is in the eastern region of Indonesia which has potential resources abundant nature. One of the existing potentials is mangrove forest. The capacities of mangroves incorporate coastline security, aquaculture, kindling source, charcoal production and the preservation of flower and faunal species. Walters [1] stated that the term of Mangrove is portray a gather of floristically asso- rted trees and shrubs which characterise the intertidal vegetation of numerous tropical and subtropical areas.

Physio-chemical characteristics of soils vary in space and time because of variations in topography, climate, weathering processes, vegetation cover, microbial activities, and other biotic and abiotic factors [2]. Soil fertility depletion is important process in land degradation and a major constraint to improve food security in developing countries [3].

Soil quality is the ability of a soil to function within an ecosystem boundary to sustain biological productivity, maintain air and water quality, and support human habitation and health [4]. Soil quality has two parts the intrinsic part covering the inherent capacity of the soil for crop growth, and the dynamic part influenced by the soil user [5]. Dynamic soil quality is the result of human use and management
[6]. According Krishna et al. [7] the soil quality depends on the soil nutrient pools and reserves, which are modulated by land use and a number of other management factors. The process degradation of soil quality has posed a threat to agricultural productivity, economic growth, and healthy environment on a global scale [8] caused by improper land use and soil management, erratic and erosive rainfall, steep terrain, deforestation, and overgrazing. In Indonesia, use of chemical fertilizers and pesticides has been the primary cause of soil degradation, an additionally, socio-economic and political issues such as land tenure, capital, and infrastructure hasten the degradation [9]. Mismanagement of soil can cause harmful changes in soil function, there is need for tools and methods to assess and monitor soil quality [10].

These relationships between soil indicator and soil function are necessary to determine if changes in a soil indicator represent improvement or degradation of a soil function and to determine if differences in the value of an indicator between treatments or over time are meaningful. One effective tool to relate soil indicator measures to soil function is the soil management assessment framework (SMAF) [11], which is an additive, non-linear indexing tool for assessing soil function using scoring curves [12]. The scoring curves in the SMAF require soil indicator data along with crop and soil information.

The value of soil quality indicators will determine the soil's ability to fulfill its functions [13]. Soil quality index (SQI) are tools for adaptive soil resource management [14]. SQI depends on (1) choosing soil characteristic indicator that appropriate with set data minimum, (2) changing the indicator to score, (3) joining the score into soil quality index [15]. SQI can use to choose the tree which appropriates to land reclamation [16].

2. Materials and Methods

2.1 Study site and soil sample determination

This study was conducted in laboratory and field. Field study was conducted in the Payum beach Merauke District, Papua. The study site was located in tropical region (137°-141° E and 6°00’-9°00’ S). The mangrove woodland in the Payum beach is primarily dominant by the Avicennia, Aegiceras, Acanthus, Bruguiera, Acanthus, Rhizophora and Sonneratia species. It has monsoon climate zone with temperature 25°-29°C. The average of annual precipitation is approximately 1,513 mm. The slope ranges between 0-45%. The analysis of soil physical, soil chemical and soil biological properties were conducted on Laboratory of Soil Biology and Biotechnology, Central Laboratory of Mathematics and Sciences in Sebelas Maret University, Surakarta and the Faculty of Agriculture in Musamus University, Merauke. The study was carried out from November 2019 to May 2020. The soil samples were taken purposively (purposive sampling) in different area and soil type. Plots of 5 x 5 m quadrants were established for three (3) transect both mangrove stands. Hence, the total sampling zone for each square was 0.05 ha. Soil tests were collected at 0-15 cm.

2.2 Materials and tools

The materials and tools were used in the field analysis consist of soil auger, clinometer, pH stick, distilled water, and other chemicals for soil judgement. The materials consist of disturbed and undisturbed soil from 0 -15 cm depth. Samples were taken from four different points and mixed.

2.3 Laboratory and data analysis

The soil samples were taken purposively in different area and magrove type. Plots of 5 x 5 m quadrants were established for three (3) transect both mangrove stands. Soil tests were collected at 0-15 cm. Soil bulk density (BD), soil aggregated stability (SAS), soil porosity (SP). Soil pH was determined in 1:2.5 soil-water suspension and measured using a pH-meter, Cation Exchange Capacity (CEC), organic carbon (OC), available-N (Av-N), Available-P (Av-P), Available-K (Av-K), electrical conductivity (EC), particulate organic matter (POM), and soil respiration (qCO₂). The results of data were analyzed by Pearson Correlation and Principal Component Analysis (PCA). Soil quality was assessed by SQI (scoring of selected variables). The scores are between the interval of 0.1–1.0. The high score indicates
that the soil has high quality. SQI formula was based on Susan et al. [12] and Qi et al. [17] with modification as follows:

\[ SQi = \frac{\sum W_i \times S_i}{n} \]  

(1)

where: \( W_i \) is the assigned weight of each indicator, which is gained from a selected PC, \( S_i \) is the score of the indicator, and \( n \) is the number of variables in the refined minimum data set (MDS). SQI classification was based on Cantu et al. [18] to determine soil quality status.

3. Result and discussion

3.1 Effects of mangroves types on soil quality parameters

The revealed that soil parameters like soil pH, soil moisture, bulk density, total nitrogen, available phosphorus, and soil organic carbon were significantly different among the different mangroves types (Table 1). Soil indicators consist of physical, chemical and biological properties of soil, used to assess and evaluate of soil quality [19].

Table 1. Means of soil properties at different mangrove field locations in Merauke district, Papua

| Transec | Av-N (ppm) | Av-P (ppm) | Av-K (ppm) | pH  | BD (g.cm\(^{-3}\)) | POM (%) | OC (%) | SP (%) | SAS (cmol.kg\(^{-1}\)) | EC (dS.m\(^{-1}\)) | SR (mg.CO\(_{2}\).cm\(^{2}\).hr\(^{-1}\)) | CEC (cmol.kg\(^{-1}\)) |
|---------|------------|------------|------------|-----|---------------------|---------|--------|-------|-------------------------|----------------|------------------------|------------------|
| 1       | 0.29       | 17         | 9.1        | 5.8 | 1.33                | 21.7    | 1.51   | 36.89 | 50                      | 0.51            | 0.62                   | 16.64            |
| 2       | 0.38       | 13.8       | 5.6        | 5.82| 1.33                | 20.9    | 1.43   | 40.5  | 42                      | 0.19            | 0.47                   | 15.64            |
| 3       | 0.31       | 18.87      | 6.8        | 4.973| 1.22                | 27.4    | 1.34   | 36.33 | 53.3                    | 0.19            | 0.57                   | 13.97            |
| 4       | 0.64       | 11.4       | 8.6        | 5.5 | 1.15                | 26.6    | 2.9    | 51    | 49                      | 0.09            | 0.67                   | 22.45            |

The result indicated that bulk density (BD) soil common to all mangrove types was found to be significantly higher in mangrove, followed by natural forest (transec 4), BD in transec 1-4 were lower than 1.5 [g.cm\(^{-3}\)], it is categorized as an optimal value. Low BD indicates as good condition, it means that soil has good soil pore, root penetration, water and air circulation and soil aggregates [20]. According to Wander et al. [21], the optimum of SP ranges between 40-60% in natural forest, and between 30-40% in mangrove forest. Based on the Indonesian Agency for Agricultural Research and Development [22] SAS in all transec was slightly solid (42-53%).

The soil was found to be acidic in all the mangrove types (pH < 7). So, to the active rain, the basic cations are leached away, making the soil acidic [23]. On the other hand, the acidic soil in mangrove forest may be due the acids released for the decomposition of organic matter from the vegetation of mangrove forest [24]. Based on the Indonesian Soil Research Institute [24] soil pH was acid (<5.3); OC was moderate (2-3%); Av-N was high in natural forest (4), moderate in mangrove forest; CEC was range between of 13-23 cmol.kg\(^{-1}\) in all locations and considered as low; EC was very low in all locations (<0.1 dS.m\(^{-1}\)); and Av-K was low in all transec (< 10 ppm). According to Wander et al. [21] Av-P in all locations were high (>15 ppm), soil respiration was also high (>0.132 mgCO\(_{2}\).gr\(^{-1}\)). High soil respiration rate indicates that biological activities occur at higher and faster than the decomposition of organic matters [25] and it is able to supply of plant nutrients. It can be maintained by organic and mineral fertilizer with 10 t.ha\(^{-1}\) of manure or with equivalent amount of mineral fertilizers for long time period [26].

3.2 SQI of mangroves forest

The selected indicators from available data sets for calculating the SQI were analyzed by Pearson Correlation Analysis to determine the relationship among variables [27]. The result shows that there were correlations among variables are of soil (Table 2). pH–Av-P (0.63), OC–Av-P (-0.64), EC–Av-P (0.74) and CEC (0.76). Negative correlation indicates that the indicators negatively affect each other. Positive correlation indicates that the indicators are correlating in a line. Soil pH was between 4.9-5.8 lower than the minimum range of optimum pH for the availability of P, it leads to a positive correlation
between pH and Av-P [28]. Liming and other activity to increase soil pH has positive influence on soil Av-P [29]. And CEC has positive correlation [30]. Positive correlations between Av-P and EC are generally present in sodic soils due to the presence of sodium carbonate that is form soluble sodium phosphates and improves the status of dissolved P [31].

The assessment of SQI uses minimum data set (MDS) [32], that is potentially selected by the chosen indicators from the kind of soil quality indicators such as soil physical, chemical and biological properties. The determination of MDS uses Principal Component Analysis [32]. The different of the research is a linear scoring method based on the highest score in soil function [32]. Liebig et al. [33] noted that pH indicator can be high up to limit level (pH 6.5), after that the score can be low up to limit level. PCA can generate data in PC (principal component) or a major component. The value was taken as weighting index (Wi). PCs which eligible as data set were PC1 to PC5 (eigen values ≥1), and it represented 89.3% of the data variability.

| Principal component                  | PC1     | PC2     | PC3     | PC4     | PC5     |
|--------------------------------------|---------|---------|---------|---------|---------|
| Eigenvalue                           | 3.3014  | 2.9562  | 2.0980  | 1.5202  | 1.162   |
| Proportion                           | 0.275   | 0.246   | 0.175   | 0.127   | 0.097   |
| Cumulative                           | 0.275   | 0.521   | 0.696   | 0.823   | 0.920   |
| Available –N                         | 0.101   | -0.289  | -0.216  | 0.339   | 0.586   |
| Available –P                         | 0.085   | 0.219   | -0.121  | 0.558   | -0.397  |
| Available-K                          | 0.220   | -0.214  | 0.351   | 0.416   | 0.001   |
| pH                                   | -0.375  | -0.150  | 0.103   | 0.460   | 0.280   |
| Bulk Density                         | -0.440  | 0.126   | 0.193   | 0.283   | -0.197  |
| Particulate organic matter           | 0.502   | 0.019   | -0.208  | 0.151   | 0.017   |
| Organic carbon                       | 0.056   | -0.526  | -0.044  | -0.176  | -0.095  |
| Soil porosity                        | -0.171  | -0.357  | -0.367  | -0.019  | -0.381  |
| Soil aggregate stability             | 0.513   | 0.042   | 0.158   | 0.041   | 0.039   |
| Electrical conductivity              | -0.062  | 0.028   | 0.617   | -0.211  | 0.202   |
| Soil respiration                     | 0.201   | -0.263  | 0.423   | 0.085   | -0.430  |
| Cation exchange capacity             | -0.089  | -0.555  | 0.058   | -0.042  | -0.031  |

* the boldface is eigen values for correspond to the PCs examined the index.
* the underlined- boldface is factors correspond to the parameters included in the index.

Based on the PCA chooses and arranges all the main indicators that influence the soil quality index the most into a smaller number of indicators. The result of PCA shows that the influence of each indicator towards the soil quality index can be seen in Table 3. In the PC1 shows a proportion of 0.275, meaning that the indicator located on PC1 has an effect of 27.5%. In the PC1 has 2 indicators namely POM, and SAS. Each indicator in PC1 has an influence percentage of 13.75% on the value of soil quality. In the PC2 has a proportion of 0.246 which means that the indicator located on PC2 has 24.6 % influence on the SQI. The indicator on PC2 is soil OC and CEC so the influence value on the SQI is 12.3%. In the PC3 shows a proportion of 0.175, meaning that the indicator located on PC 3 has an effect of 17.5%. In the PC3 has 2 indicators namely EC and SR. Each indicator in PC3 has an influence percentage of 8.75% on the value of soil quality. In the PC4 shows a proportion of 0.127, meaning that the indicator located on PC4 has an effect of 12.7 %. In the PC 4 has 3 indicators namely available-P, available-K and pH. Each indicator in PC 5 has an influence percentage of 4.25% on the value of soil quality. In the PC 5 shows a proportion of 0.097, meaning that the indicator located on PC 5 has an effect of 9.7%. In the PC 5 has 1 indicator namely available –N, so the indicators in PC5 has an influence percentage of 9.7% on the value of soil quality.
Eight variables above have a high sensitivity toward soil quality in research location. Choosing indicator was based on the correlation of weighting factor index [32], as a MDS for various kind of soil system. Soil quality indicator is a process and sensitively soil character toward the changes of soil function [17]. SQI is the result of weighting factor with MDS. There are several interrelated and influential indicators on soil quality at the research site. Each indicator has a different index weight value presented in the form of a loading plot in Figure 1.

**Figure 1.** Loading plot of loading plot main indicator contribution as a way to measure the value of soil quality

The main indicator contribution as a way to measure the value of soil quality (Figure 1), POM, SAS, pH, BD, CEC, OC and SR had higher soil quality index value compare with another. It caused by the highest weighting factor and indicator scoring. The value of the selected indicators on the PC is multiplied by the scoring of each selected indicator to determine the value of soil quality at each location (Table 3).

The results indicate that soil on the natural forest (NF) has higher SQI (0.39) than the other of soil on mangroves forest (0.34-0.38). On the other hand, the results indicate that long term mangroves forest utilization may decrease soil quality. Subagyono et al. [34] stated that the puddling has potential to increase soil bulk density and run-off, and decrease soil quality. It requires an effort to prevent soil quality degradation e.g. changing of cultivation method, improving the status of selected MDS through adding of organic matters. Soil organic matter has reported as the most critical indicator of soil quality and agronomic sustainability due to its impact on other physical, chemical and biological indicators of soil quality [35]. The repairing process of soil organic material and nutrient cycling is very important for the land reclamation after the ecosystem disturbed. Soil organic carbon is the right parameter to evaluate the soil quality in reclamation area after the mining process. Organic carbon was being the soil quality indicator that easy to check every time [16]. Organic carbon is a discriminatory soil quality indicator which can be used to check the soil degradation caused by soil erosion. SOC can be used as a dominant indicator, deep 0-10 cm, in scoring the soil quality of various kind area and cultivation, besides that soil organic C was classified as an important indicator to check the soil quality in agroecosystem. SOC has a positive correlation with cation exchange capacity (CEC), total N and available P. The
determination of organic material will be caused the cation exchange capacity value become higher. Organic material has a function as a plant nutrition especially nitrogen and phosphate.

**Table 3. Soil quality class of each study location in mangroves forest Merauke district, Papua Indonesia**

|     | Wi   | Si   | Natural Forest | TRANSEC3 | TRANSEC2 | TRANSEC1 |
|-----|------|------|----------------|----------|----------|----------|
| POM | 0.50 | 0.75 | 0.38           | 0.75     | 0.38     | 0.75     | 0.38     |
| SAS | 0.51 | 0.50 | 0.26           | 0.50     | 0.26     | 0.50     | 0.26     |
| OC  | 0.53 | 0.75 | 0.39           | 0.75     | 0.39     | 0.75     | 0.39     |
| CEC | 0.56 | 1.00 | 0.56           | 0.50     | 0.28     | 1.00     | 0.56     |
| EC  | 0.62 | 0.75 | 0.46           | 0.75     | 0.46     | 0.75     | 0.46     |
| SR  | 0.42 | 1.00 | 0.42           | 0.50     | 0.21     | 0.50     | 0.21     |
| Av-P| 0.56 | 0.75 | 0.42           | 0.75     | 0.42     | 0.75     | 0.42     |
| Av-K| 0.42 | 0.75 | 0.31           | 0.75     | 0.31     | 0.75     | 0.31     |
| pH  | 0.46 | 0.50 | 0.23           | 0.50     | 0.23     | 0.50     | 0.23     |
| Av-N| 0.59 | 0.75 | 0.44           | 0.75     | 0.44     | 0.75     | 0.44     |
|     | 3.87 | 3.38 | 3.66           | 0.35     | 3.76     |          |
| SQI(b) | 0.39 | 0.34 | 0.37           | 0.38     |          |          |
| Scale* | M    | L    | M              | M        |          |          |
| Class# | 3    | 4    | 3              | 3        |          |          |

* nMDS= number of selected minimum data set, Wi = the assigned weight of each indicator, Si = the indicator score, M= moderate, and L = low

4. Conclusion

Soil quality index (SQI) in natural forest soil (0.39) is higher than mangroves forest (0.34). The higher index value shown that the good soil quality and well soil function and had ecologically sustainable. To maintain and sustain the productivity of mangroves forest, the conservation effort is required.

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