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Relationship Between NDVI and the Microbial Content of Soil in Detecting Fertility Level at Semarang Regency, Jawa Tengah, Indonesia

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ABSTRACT

Global warming is the most significant environmental issue that causes the utmost concern for researchers and scientists. Furthermore, impacts recorded include the potential for drought and the reduction of soil ability to support biomass production, subsequently posing a significant threat to agriculture. Moreover, vegetation density is known to support microorganism activities actively, and its analysis requires remote sensing techniques, involving normalized differential vegetation index (NDVI) and soil adjustment vegetation index (SAVI), associated with microbial content in the soil. Besides, the level recorded is assumed to have a strong correlation with soil fertility, which is a prerequisite for the development of vegetation cover. Hence, most of the research was conducted in fertile lands situated in the Ungaran, Merbabu, and Telomoyo volcanic areas. The results show the absence of a positive correlation between soil fertility and the number of microorganism's present, although the association with vegetation cover is relatively low.

INTRODUCTION

Land use is always changing and increasing (Lal & Kumar 2017, Rizk & Rashed 2015), both for settlements and industry, which triggers a reduction in the rate of vegetation cover (Islam et al. 2018). Furthermore, the increase of deforestation practices poses various threats (both long and short term), which consequently becomes global issues (Nanzad et al. 2019, Islam et al. 2018, Gillespie et al. 2018). The other effects of deforestation practices lead to the potential occurrence of drought (Rudiarto 2018), flooding (Dewi 2016), rising temperatures, and declining soil fertility in the future (Nugraha 2017).

The reduction in soil fertility as a global issue (Chauhan et al. 2017), characterized by a decrease in biomass resulting from leaf litter (Ning et al. 2019). This further triggers difficulty in improving plant growth, as it affects critical soil. Besides, the effect is profoundly felt in Java Island, due to the increase in surface temperature and its extreme differences between day and night.

Detecting land use through remote sensing methods has already developed (Myint et al. 2011, Coulter et al. 2016, Town et al. 2018), and the ability of geographic information system (GIS) is very efficient in calculating the extent of objects on the earth surface (Rizk & Rashed 2015, Rimal et al. 2018, Lu & Wu 2019). Also, the capacity to detect objects and plant health is enhanced based on satellite imagery data (Arrogante-funes et al. 2018), as their visual analysis is often accurately calculated by pixel area (Bhaskaran et al. 2010). Meanwhile, the study requires the comparison of field data with information obtained from satellite imagery.

GIS can perform calculations on a regional scale, and broader (Iryanthony et al. 2019), and the results obtained are usually a combination of the classification. Besides, the vegetation index method is used to detect the level of plant density, and also to calculate the level of soil fertility in the presence of vegetation cover. Hence, GIS is efficient as software for calculating the area, which is generated from Landsat satellite data (Town et al. 2018, Iryanthony et al. 2019).

NDVI (normalized differential vegetation index) is an index used to identify the level of vegetation density from satellite (Filgueiras et al. 2019). Furthermore, it plays an essential role in determining the extent of thickness on a broad scale (Yangchengsi et al. 2019), by utilizing the red band that is sensitive to leaves, and the near-infrared (NIR) band known to be sensitive to leaf chlorophyll (Nanzad et al. 2019, Seo et al. 2019). Furthermore, most studies use NDVI for the detection of plant health, although some apply it for density. Conversely, the SAVI (soil adjustment vegetation index) method has also been used as a soil fertility detector (Huete 1988).

NDVI is very sensitive to areas without vegetation cover, thus necessitating SAVI in soil detection (Ren et al. 2018). However, its products are responsive to variations in soil colour, moisture, and saturation effects of high-density areas, depending on the regional character. Therefore, it demands efforts towards its improvement (Huete 1988), attained by developing an index, which reduces the dominance of red and NIR bands, through the vegetation canopy. Furthermore, the index is a transformation technique used to minimize the effect of brightness from these spectral wavelengths.

Soil organisms are found near the roots of plants (0-40 cm), especially during weathering, and most of them belong to a critical group of plants (flora) and animals (fauna). Besides, the microorganisms are difficult to be seen with the bare eye. Also, those organisms have thus been widely developed in the area of agriculture. Previous studies were closely related to soil fertility and plant growth, including phosphate solvent microbes (MPP). Furthermore, the types of microbes used include microbial symbiosis with Azolla plants, fastening with the N_2 atmosphere on both free-living and symbiotic species, mycorrhizal, and cellulose microbes.

Meanwhile, some forms of microorganisms have been developed for the improvement of lands polluted. Within the soil, bacteria have been identified as the most abundant group, which, together with others, play an essential role in the decomposition of organic matter, synthesis of acid or certain organic compounds, and N mineralization.

This study, therefore, aims to determine the ability and correlation of NDVI and SAVI results in detecting soil fertility at the uphold areas of Semarang Regency. This detection was conducted through the analysis of microbial content as an indicator, and the types of microbes evaluated include bacteria, actinomycetes, fungi, microalgae, protozoa, nematodes, and worms. Besides, they were cumulatively measured in terms of total microbes (CFU/gram).

MATERIALS AND METHODS

Study Area

The study was conducted in all districts of Semarang Regency. For additional information, Semarang Regency has an altitude between 300-2500 m. This location is a stretch of Ungaran and Telomoyo Volcano, as well as a portion of Merbabu Volcano. Topographically, the regency is very diverse that possesses protected forests on each volcano, and some areas are always green. Also, the central part consists of the Rawa Pening Lake area, which comprises mostly of organic soil, composed of organic material. Therefore, the slope mainly entails vegetable and protected forest land, while Ungaran and Merbabu Volcano were adopted in other uses such as tea plantation. Furthermore, a small portion of coffee plants was also identified, although it is not a leading commodity in the region. The research area is shown in Fig. 1.

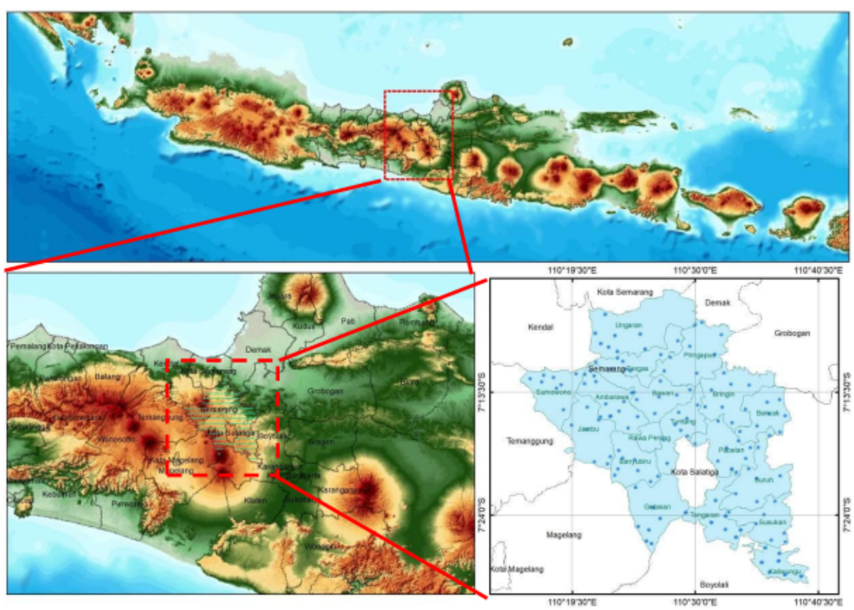

Fig. 1: Location and distribution of research samples in Semarang Regency symbolized by small dots.

Microbial Test

Microbial content tests were conducted on the soil samples obtained from the location (Fig. 1) for subsequent laboratory analysis. Meanwhile, the number of microbes was identified as the total population in the soil. The identification was measured by using a colony counter. Generally, the usual amount is about 107 CFU/g of soil or 107 colony-forming unit of microbes in 1 g of soil, and the degradation is said to have occurred at the value of <102 CFU/g of soil, both for dry land and wetlands. Besides, the measurement was performed using the plating technique, as stipulated in Government Regulation Number 150 of 2000, concerned with the Control of Soil Damage for Biomass Production. Therefore, the number recorded is a strong determinant of fertility, through the recognition of abundant microbes.

Soil samples were taken with guidance from the land damage map (Fig. 5A) obtained from the Ministry of Environment and Forestry, and the microbial content was used as one of the parameters for determining the richness of biomass. Furthermore, all microbial samples were obtained from areas with high critical levels, and the parameter for criticality was divided into five levels of damage. This study, therefore, produces a sample distribution data that is proportional in terms of damage level and random vegetation, to produce heterogeneously distributed values. Moreover, up to 130 samples spread throughout the Semarang Regency were collected, representing the 19 sub-districts (details are seen in Figs. 1 and 5).

Satellite Imagery Data

Landsat 8 OLI was utilized with a spatial resolution of 30 m, and cloud cover <10%. This satellite imagery was taken in the dry season to obtain minimal or cloud-free weather conditions. Furthermore, the obtained satellite imagery is the best representation of growth and vegetation variables, with the visible red band 4 (630-680 nm) and the NIR band 5 (845-885 nm) also widely utilized (Trihatmoko 2020). Besides, each is used to construct the NDVI and SAVI models, while the satellite imagery data was obtained from USGS.

The research also utilized Sentinel 2A as open access data, which is similar to Landsat imagery for its characteristics and metadata. Therefore, all data used were sourced from ESA and USGS, while image processing involved the use of a Semi-Automatic Classification Tool (SCP) extension in QGIS 3.4 vector software. Besides, some devices were combined extensions, and are thus adopted for processing, through SCP. It is possible to directly download Satellite imagery data through software, as they allow outputs in both radiometric and atmospheric correction process.

IDW model

The IDW (inverse distance weighted) method is a GIS model interpolation technique that is used to connect multiple data points values (Wong 2017), and also being linked to interpolation. Besides, the ability to numerically display information tends to enhance the ease of analysing the distribution (Lima et al. 2003). This model demands that the data is also linked, which subsequently creates contours (Mei & Tian 2016), and the IDW is known to possess excellent flexibility, in several applications (Buchori et al. 2017). These unique capabilities make the interpolation method appear more natural in the connection of one point to another. The equation as follows:

$$P_i = \frac{\sum_{j=1}^{G} P_j/D_{ij}^n}{\sum_{j=1}^{G} 1/D_{ij}^n} \quad \ldots(1)$$

Pi is the height value at the location i; Pj is the height value at the sampled location j; Dij is the distance from i to j; G is the number of sampled areas, and n is the inverse-distance weighting power.

IV (INDEX OF VEGETASI)

Vegetation index in remote sensing plays a vital role in detecting the presence and cover of vegetation. Thus, NDVI derived from satellites serve as an essential index in the study of climate change, right from the early 1980s (Gholamnia et al. 2019). This technique is well-known to play a crucial role in land cover detection (Yangchengsi et al. 2019). The equation as follows:

$$NDVI = \frac{(Band\ 5 - band\ 4)}{(Band\ 5 + band\ 4)} \quad \ldots(2)$$

This modelling combines NDVI with SAVI with soil conditions, as the latter is beneficial concerning the field parameters used, and the microbial content. Furthermore, the microorganism load is used as an indication for the level of fertility, marked by a high positive NDVI vegetation cover, and a good SAVI value. Hence, it is expected that there is a linear relationship between each IV and surface vegetation conditions, using the equation as follows:

$$SAVI = \left[\frac{(Band\ 5 - band\ 4)}{(Band\ 5 + band\ 4 + L)}\right] x\ 1 + L \quad \ldots(3)$$

The NIR band fills band 5 in the Landsat 8 OLI, and band 4 is red. Meanwhile, the NIR in the 2MSI sentinel image resides in band 6, and the red was in band 4.

RESULTS AND DISCUSSION

NDVI describes the greenness level of a plant. This index is a mathematical combination of the red and NIR band, which has been used for a long time as an indicator to identify and characterize the condition of vegetation. Furthermore, the calculations are based on the principle stipulating that green plants grow more effectively by absorbing radiation in the visible light spectrum region (PAR or Photosynthetically Active Radiation), and also because they strongly reflect radiation from the NIR region. Besides, the concept of spectral patterns tends to use only the red band image on the mathematical algorithm. These spectral reflections are specifically ratios reproduced from the incoming radiation on each band. Hence they assume values between 0.0 and 1.0. By design, NDVI varies between -1.0 and +1.0., known to be functional, although not linear, and also equivalent to a simple infrared/red ratio (NIR/VIS). However, it possesses the advantage of being generally limited to the possible linearity of functional relationship with the nature of the vegetation (for example, it is characterized by the presence of biomass). Furthermore, simple ratios (different from NDVI) are always positive, with the tendency of possessing practical advantages. However, they also possess an unlimited mathematical range (0 to infinity), which is a comparable practical disadvantage.

The description range of NDVI values is -1 to 1, where the negatives (values close to -1) tend to correspond with water. Furthermore, values that approach zero (-0.1 to 0.1) generally relate to barren areas of rock, sand, or snow. At the same time, the positive and low records represent shrubs and grasslands (about 0.2 to 0.4), and higher values indicate tropical and moderate rainforests (values close to 1). Moreover, details on positive values (0 = non-living things, including roads, buildings, soil or dead plants, 0 - 0.33 = unhealthy plants, 0.33 - 0.66 = healthy plants, > 0.66 = very healthy plants.

NDVI results from the Sentinel 2A and Landsat 8 OLI satellite imagery in 2019, recorded in the dry season, showed a more accurate distribution of areas with dense vegetation. Besides, the weather condition during the time allowed all mostly forested regions to remain denser in contrast with other less vegetated plains. Unlike the rainy season, most areas tend to look green, since Indonesia enters the agricultural growth period. Therefore, being a protected area as a national park, Semarang Regency is observed to possess a higher thickness value.

The location of Ungaran, Bergas, and Sumowono are on the slopes of Ungaran Volcano, which contains some forests protected under the supervision of the Ministry of Environment and Forestry. These include Jambu, with the steep morphological condition that is impossible for settlements. Thus, most of the area is a stretch of vegetation in Telomoyo Volcano. Furthermore, Getasan is the slope area of Merbabu Volcano, included in the administration of Semarang and some of Boyolali Regency area.

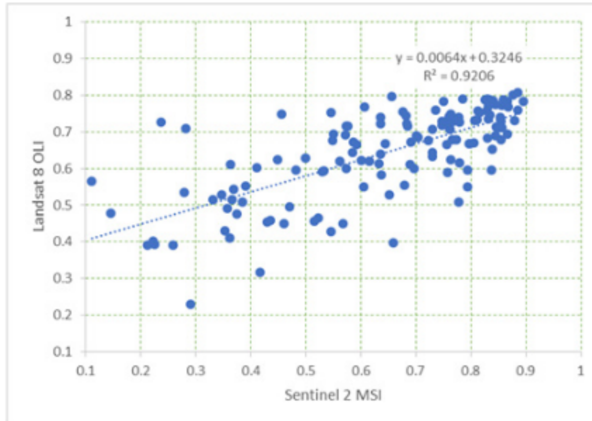

Fig. 2: Regression values of NDVI Sentinel and Landsat imagery.

The vegetation density evaluation capacity of Landsat and Sentinel data was similar, although the latter possesses a higher resolution (10 m). Moreover, Landsat is highly necessary while discussing long-term multi-temporal analysis. Besides, NDVI OLI data regression results showed a data distribution by the determination coefficient (R^2) at about 0.92 (Fig. 2). This value means that the data distribution of the two variables is mostly inline, and it means that they have a reasonable correlation of up to 92%. This correlation result was consistent with the theory of Zhang et al. (2018), where the association in atmospheric regression reached R^2=0.90. This result, therefore, shows close consistency and similarity between the value of Landsat and Sentinel (Fig. 3).

SAVI was used to correct NDVI for the effect of soil brightness in areas where the vegetative cover was low (Fig. 4). Therefore, the SAVI derived from Landsat Surface Reflectance was calculated as the ratio between R and NIR values, using a soil brightness correction factor (L) defined as 0.5 to accommodate most cover types. Besides, SAVI is similar to NDVI, although its user preference is in areas of low vegetative cover (<40%). However, the reflectance attained on instances where large amounts of surface earth were exposed tends to affect NDVI values (which changes up to 20%). Also, "L" is the correction factor that ranges from 0 for very high to 1 for shallow vegetation cover, and a value of 0.5 is usually used for medium. Meanwhile, SAVI tends to possess a similar equation as NDVI when "L" is equal to zero. However, the adjustment factor was identified through trial and error, and when the vegetation index was identical for both dark and light soils.

The survey-based on the location of soil damage shows different distributions from the density of vegetation on NDVI (Fig. 5). Thus, a high value was concentrated in the Tengaran, Susukan, and Kaliwungu areas, as well as on the

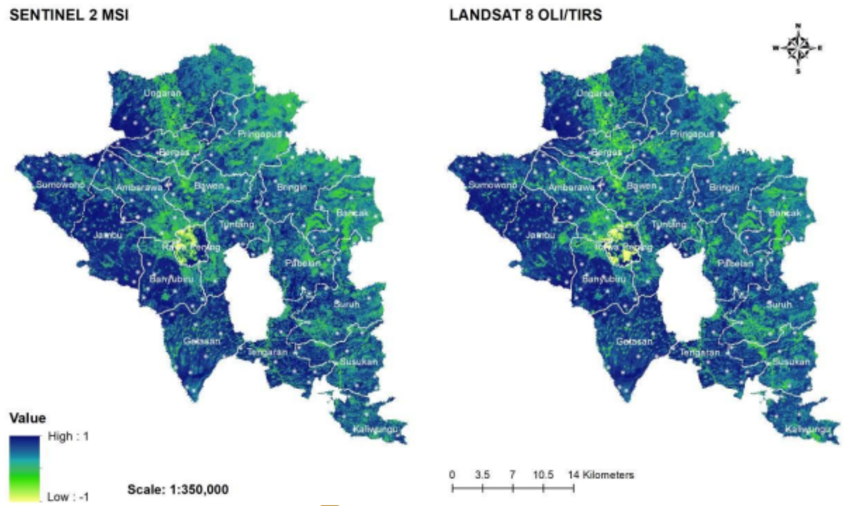

Fig. 3: NDVI results from satellite images of Sentinel 2A and Landsat 8 in 2019, recording in the dry season.

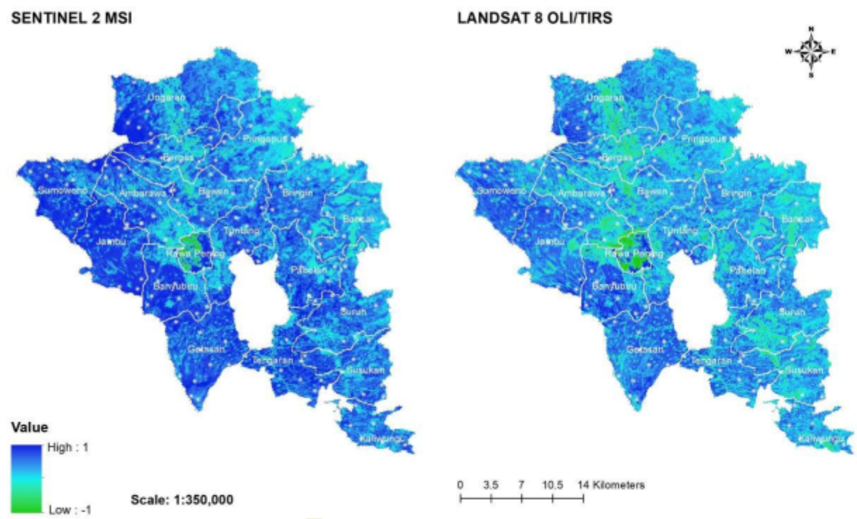

Fig. 4: The utilizing of SAVI of Sentinel 2A and Landsat 8 OLI in Semarang Regency.

Merbabu Volcano slope. This was mostly characterized by covers of paddy fields, and region with an adequate water source, with the possibility of harvest reaching three times in a year.

Testing the relationship between the number of microbes in the soil with the satellite imagery, with NDVI and SAVI values, showed a weak correlation. Thus, there was a limitation in its ability to identify objects at the surface. Meanwhile, the association between the NDVI Landsat 8 OLI and the number of microbes present in the soil was 0.09. This condition was similar to the relationship between SAVI Landsat 8 OLI and microbe quantity (0.03), although the outcome was better than the Sentinel value, which was only 0.01. Furthermore, the correlation is shown in Fig. 6.

The ability of satellite imagery to identify soil fertility was shallow, as an insignificant relationship was established with the numbers of microbes. This identification capacity is a research gap in the development of soil fertility detection methods using satellite imagery data. Furthermore, weaknesses were observed in the use of SAVI and NDVI as parameters in the identification of soil surface vegetation objects. Also, another flaw in the satellite imagery-based analysis encompassed the difficulty in the ability of the imagery to penetrate the soil in areas with dense vegetation

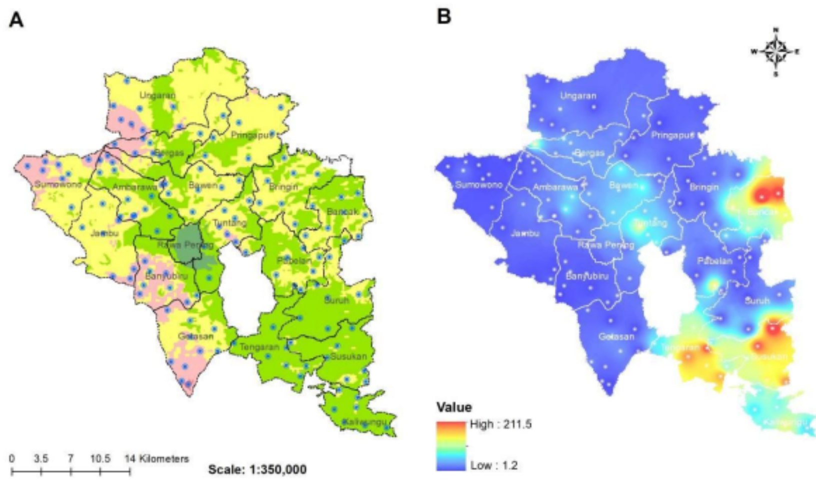

Fig. 5: Point sampling distribution based on land degradation maps issued by the Ministry of Environment and Forestry. B. IDW Interpolation of the amount of microbial content in the soil.

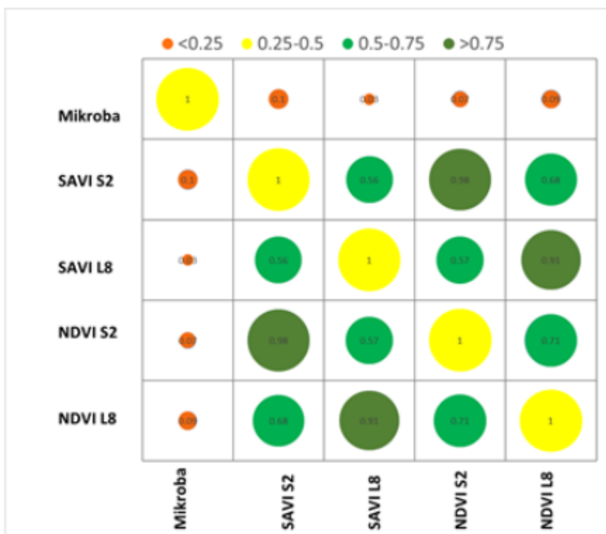

Fig. 6: Correlation matrix of the results of microbial surveys, SAVI Sentinel and Landsat, along with NDVI Sentinel and Landsat.

cover. Hence, there was still an insignificant relationship between the density recorded and the number of microbes. Furthermore, there are potentials to develop further methods for detecting soil fertility using satellite imagery.

CONCLUSION

There was a high similarity in the NDVI data obtained using Landsat 8 OLI and Sentinel 2A, due to the presence of sensors that move at almost the same wavelength. Moreover, Landsat satellite imagery tends to possess the same potential for resource observation with an equal number of sensors. At the same time, Sentinel has a resolution of 10 meters, in contrast with Landsat of 15 meters, with pan-sharpening band 8. Furthermore, between NDVI and SAVI, both satellites produced very similar results because the outline possesses the same function in earth observation. Therefore, the relationship between vegetation index and the number of microbes in the identification of soil fertility was observed to be relatively weak. Thus, the next step requires the testing of several indexes that possess closer relationships with the number of microbes, with the aid of satellite imagery, to identify fertility levels more accurately.

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