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Generation of Total Suspended Particulate (TSP) in Ambient Air from Four Soil Types in Indonesia

A.S. Yuwono[1]*, B. Mulyanto[2], M. Fauzan[1], F. Mulyani[1], C.R. Munthe[1]

*[1]*Dept. of Civil and Environmental Engineering, Bogor Agricultural University (IPB)*
PO Box 220 Bogor. 16002, Bogor, Indonesia.
Email: arief.sabdo.yuwono66@gmail.com
[2]Dept. of Soil Science and Land Resources,
Bogor Agricultural University (IPB), Indonesia

Abstract

Total Suspended Particulate (TSP) is important parameter contributing air quality deterioration. Generation of TSP from soil surface into the ambient air is allegedly affected by a number of factors associated with soil moisture content, the blowing wind, as well as vegetation covering the soil surface. Availability of TSP generation quantity expressed in a simple way would be a very useful for air quality change assessment. The research objectives were analysing the correlation between TSP generation from soil versus wind speed, soil moisture content, and vegetation cover as well as determining emission factors of the TSP from the soil under concern. Soil types used were Red Yellow Podzolic (RYP), Complex Red-Yellow Podzolic, Latosol, and Litosol (CPL), Regosol (REG), and Complex Red-Yellow Mediteran and Grumusol (CMG). The materials and instruments used during the experiment were High Volume Air Sampler [Staplex TF-IA], filter paper [Whatmann #41], experiment tunnel [L = 760 cm; W = 76 cm; H = 240 cm), air velocity meter (Velocicalc 8357-TSI], digital soil moisture tester [OGA Model TA-5], blower [Hercules; Ø = 24”; 220 V; 50 Hz; 170 W], universal oven [UNB 400], analytical balance [OHAUS; Adventurer Pro], Petri dish [Ø = 80 mm], distillate water, and soil samples [RYP, CPL, REG, and CMG]. Research was carried out in an experiment tunnel located in Bogor Municipality, West Java Province of Indonesia to avoid other environmental factors than vegetation cover, wind speed, and soil moisture content affecting the TSP generation from the soil. Results of the experiment showed that wind speed correlated positively with the generated TSP, whereas soil moisture content and vegetation covers correlated negatively with the TSP generation. The generated TSP from RYP, CPL, REG, and CMG covering the area were 26 μg/Nm^3, 74 μg/Nm^3, 84 μg/Nm^3, and 108 μg/Nm^3, respectively, far under the national threshold limits of 230 μg/Nm^3. The emission factors of the TSP generation as affected by soil moisture content, wind speed, and vegetation cover have been developed and ready for implementation.

Keywords: ambient air, soil moisture content, total suspended particulate, wind speed, vegetation cover

Introduction

Total Suspended Particulate (TSP) is a complex mixture of solid particles, liquid, or both in the air and contains inorganic and organic substances [1]. The diameter of TSP is less than 100 µm (SNI 19-7119.3-2005), whereas according to EPA the size range is 0.1-30 µm.

According to Liu et al. [2] TSP is part of particulate matter (PM) with diverse sources and is composed of combinations of inorganic ions, trace elements, elemental carbons (black soot), crustal materials, organic compounds, and biological matters [3]. Based on the research done by Kong et al. [4], major chemical components for TSP source soil dust from Dongying are crustal elements 45.4-48.5%, ions ±2%, and organic carbon ±2%. Chemical components that were absorbed onto the surface of the recipients could hurt human and environment [5; 6]. For example, organic carbons or polycyclic aromatic hydrocarbons (PAHs) and most trace elements are potential carcinogens (IPCC, 2007) [7]; black carbon warms the atmosphere, whereas sulphate and most organic compounds lead to climate cooling.

PM can also degrade visibility [2] and change radiation budget by absorbing or scattering solar radiation [8; 9; 10; 11]. In China, visibility condition has become an important issue for both the society and the scientific community. Decreased visibility has an effect significantly associated with elevated death rates in Shanghai [12]. It also reduces crop yields by decreasing photosynthetic radiation and affect regional climate by changing the radioactive properties of the atmosphere [9]. Lower visibility occurred mainly in the urban areas of Beijing, where the number of haze days showed an increasing trend [13]. Visibility was also affected by different chemical components and demonstrated the obvious seasonal pattern. In summer, high TSP and PM_{10} concentrations contributed significantly to low visibility. In autumn, however, high concentrations of TSP, PM_{10}, $PM_{2.5}$, SO_4^{2-},NO_3^-, NH_4^+, K^+, $HCOO^-$,OC, EC, Mg^{2+}, Na^+, in PM_{10}, and SO_4^{2-}, NH_4^+, NO_3^-,CL^-, EC in $PM_{2.5}$ showed stronger effects on visibility. High humidity and low temperatures contribute to low visibility in winter and autumn, whilst in spring, low temperature easily leads to low visibility [2].

Particles in the air can move as far as thousands of kilometres caused by the wind at high speed on the soil surface [14; 15], mechanical turbulence and frontal lifting [16]. Research shows a strong dust storm that happened in the Gobi desert caused displacement of dust and sand into East Asia, Korea and Japan [17]. Gobi is the driest area on Earth which has soil with poor characteristics of nutrient elements and contains a lot of gravels [17].

Soil erosion by wind (deflation) causes soil particles experience saltation and suspension. Approximately 50-75% of soil erosion by wind was caused by saltation that removes the layer of topsoil [18]. The saltation and suspension effect of each soil type was affected by soil texture that indicates the erodibility of soil [18; 19]. Other effects that contribute to these processes are soil surface roughness that causes a lot of air goes into soil layers [18] and local climatology like a low rain intensity, low humidity, high temperature and high wind speeds [18; 20]. These have an impact on air quality changes significantly [21; 22].

The negative impacts of TSP need to be understood and reduced, as it is important to know the source and the affecting parameters. Several studies have been conducted concerning TSP generation using several types of soil in Java. The results showed that TSP generation from Andisol, Ultisol, and Oxisol soils were positively correlated with wind speed and negatively correlated with soil moisture content [23; 24]. There is, however, very little study was performed on other types of soils. This research, therefore, was carried out on the TSP generation and its correlation with the affecting factors on other soil types i.e. Red-Yellow Podzolic (RPY); Complex Red-Yellow Podzolic, Latosol, and Litosol (CPL); Regosol (REG) and Complex Red-Yellow Mediteran and Grumusol (CMG). The results obtained can be used to complete the emission factors for TSP generation on most of soil types in Java Island, Indonesia. The compiled emission factors subsequently become important basis for a quantitative environmental impact assessment, especially on anthropogenic air quality deterioration in Java Island. The limitation of Java Island is based on the fact that Java is well known as both the most densely populated island and the most important island in Indonesia, yet the basic information on emission factors is not available.

The objectives of this study were (1) analysing the correlation between TSP generation versus wind speed, soil moisture content, and vegetation cover from the RYP, CPL, REG, and CMG soil; (2) measuring TSP generation as affected by wind speed, soil moisture content, and vegetation cover; (3) determining emission factors of the TSP from the RYP, CPL, REG, and CMG soils.

Material and Methods

The materials and instruments used during the experiment were a High Volume Air Sampler [HVAS, Staplex-USA Model TFIA-2], filter paper [1.6 µm, Whatmann #1820-110], tunnel [7.8 m length, 0.76 m width, and 2.4 m height], air velocity meter [VELOCICALC 8357-TSI], digital soil moisture tester [OGA Model TA-5], blower [Hercules; Ø = 24”; 220V; 50 Hz; 170 W], universal oven [UNB 400], timer, analytical balance [OHAUS; Adventurer Pro], Petri dish [Ø = 80 mm], distillate water, and soil samples [RYP, CPL, REG, and CMG].

Research was carried out by developing a model that describes the relationship or correlation between vegetation cover, wind speed, and soil moisture content with TSP generation. The study was conducted in an experiment tunnel. The tests were conducted with the same method as the previous study performed by Yuwono et al. [24] and Rochimawati et al. [23], using gravimetric method and one hour time elapse measurement. TSP concentration measurement scheme is presented in Fig.1.

Illustration of tunnels used to measure TSP is presented in Fig. 2. TSP generation obtained by using Equation (1), (2) and (3) based on Indonesian national standard namely SNI 19-7119.3-2005.

$$Q_s = Q_0 \times \left[\frac{T_s \times P_0}{T_0 \times P_s}\right]^{\frac{1}{2}} \quad (1)$$

$$V = \frac{Q_{S_1} + Q_{S_2}}{2} \text{ x } T \quad (2)$$

$$C = \frac{(W_2 - W_1) \text{ x } 10^6}{V} \quad (3)$$

Where:

Q_s : Corrected flow rate (m^3/minute)
Q_0 : Flow rate on test (m^3/minute)
T_s : Standard temperature (298 K)
T_0 : Absolute temperature (Temperature on test, °C + 273)
P_s : Standard barometric pressure (760 mmHg)
P_0 : Barometric pressure on test (mmHg)
V : The volume air on test (m^3)
Q_{S_1} : Flow rate of the 1st (m^3/minute)
Q_{S_2} : Flow rate 2nd (m^3/minute)
T : Measurement time elapsed (minute)
C : TSP concentration (µg/Nm^3)
W_1 : Initial weight of filter paper (gram)
W_2 : Final weight of filter paper (gram)
10^6 : Conversion factor from gram to µg.

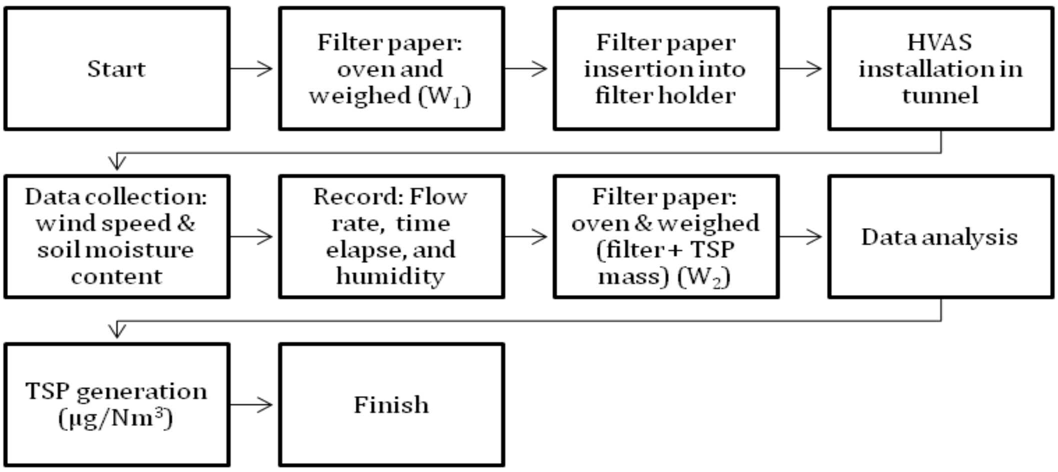

Figure 1: Flowchart of the research procedure

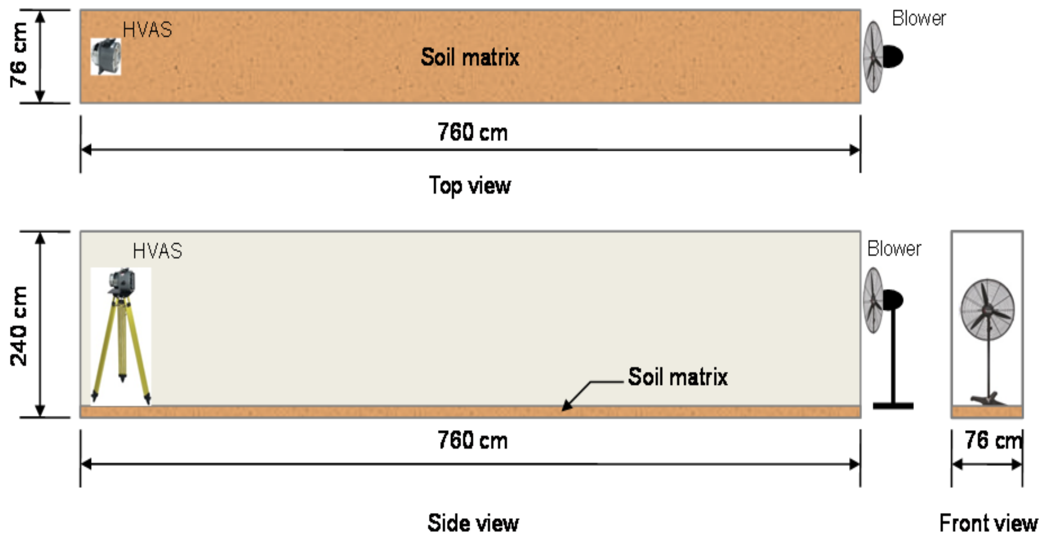

Figure 2: Experimental set up of the research

Results and discussion

The TSP generation on four types of soil is different at the same wind speed, soil moisture content, and vegetation cover. This is caused by the difference in physical and chemical properties of the four types of soils. The texture of the soil (Table 1) can also causes TSP generation to be different. Soil texture is associated with the distribution of the soil particle sizes on any type of soil. Soil texture is an important factor for erodibility of soil because it affects the consistency of cohesion and mobility of soil particle [25]. In addition, another factor that caused different TSP generation on different soil types allegedly is the C-Organic content that affects the stability of soil particle. TSP generation from the four types of soil is presented in Fig. 3.

Table 1: Soil texture analysis

Fraction	Soil type			
	RYP	CPL	REG	CMG
Clay (< 0.002 mm), %	5	5	5	1
Silt (0.002-0.05 mm), %	74	39	32	59
Sand (0.05-2.0 mm), %	21	56	63	40
Description	Silt loam	Sandy loam	Sandy loam	Silt loam

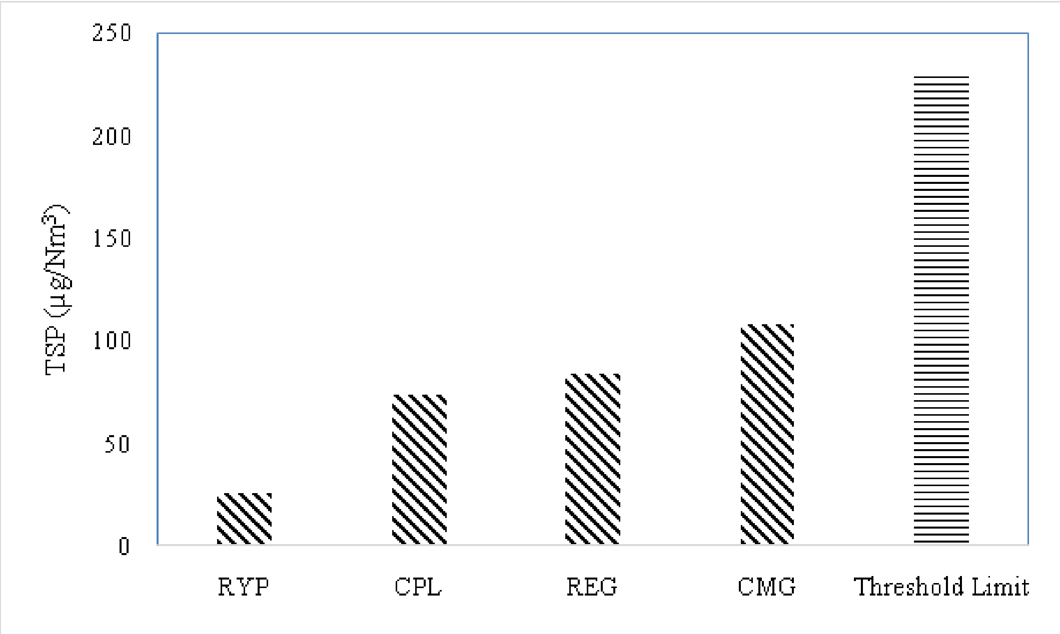

Figure 3: TSP generation from RYP, CPL, REG, CMG soil

TSP generation on CMG was higher than that of other soil types. Total silt and sand fraction on CMG soil is also high (Table 1) so that the soil will be more easily eroded if it has higher dust content [26]. The other contributing factors according to Bacon et al. [27] are C-organic soil content, salinity, and carbonate content ($CaCO_3$).

Protection on the particulate generation is a factor associated with vegetation cover. Increased coverage of vegetation cover is effective for reducing dust (particulate matter) produced by the soil surface [28; 23]. Areas with low rainfall and low vegetation cover produce a high dust generation. However, this is influenced by the spatial and temporal aspects of dust emissions as well as the availability of land and local wind data [29]. The correlation between TSP generation and vegetation cover is presented in Fig. 4.

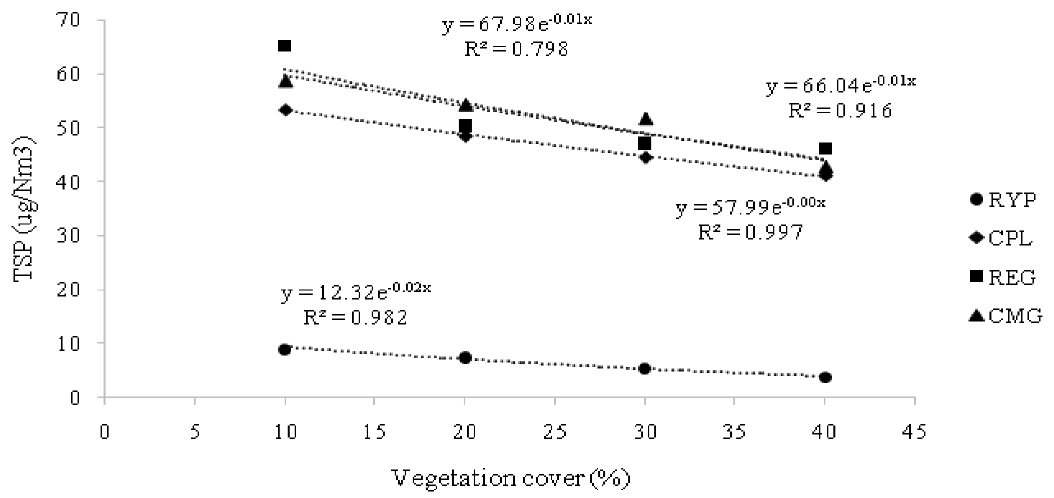

Figure 4: Correlation between TSP generation and vegetation cover on RYP, CPL, REG, and CMG soil.

Fig. 4 showed a high negative correlation between TSP generation and vegetation cover, indicated by a high value of R-Sq on the charts. Therefore, increasing percentage of vegetation cover can reduce the number of TSP generation. According to Bacon et al. [27], one potential factor that can significantly control the dust emission is protection of the soil from wind erosion (Aeolian) such as with addition of vegetation. Correlation between TSP generation versus wind speed and soil moisture content on RYP, CPL, REG and CMG soil are presented in Fig. 5, 6, 7, and 8.

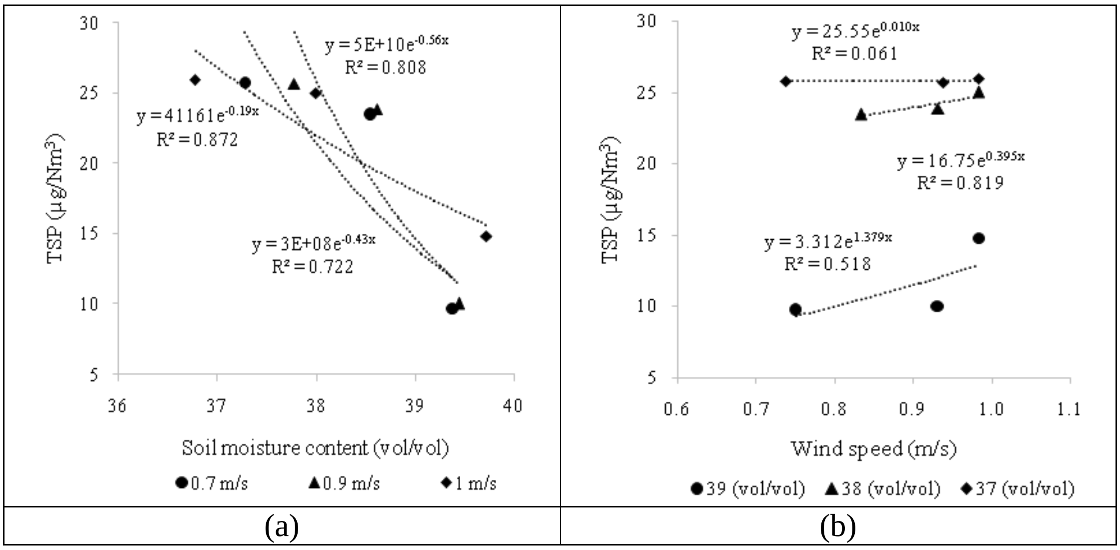

Figure 5: Correlation between TSP generations versus soil moisture content (vol/vol) (a) and wind speed (b) on RYP soil.

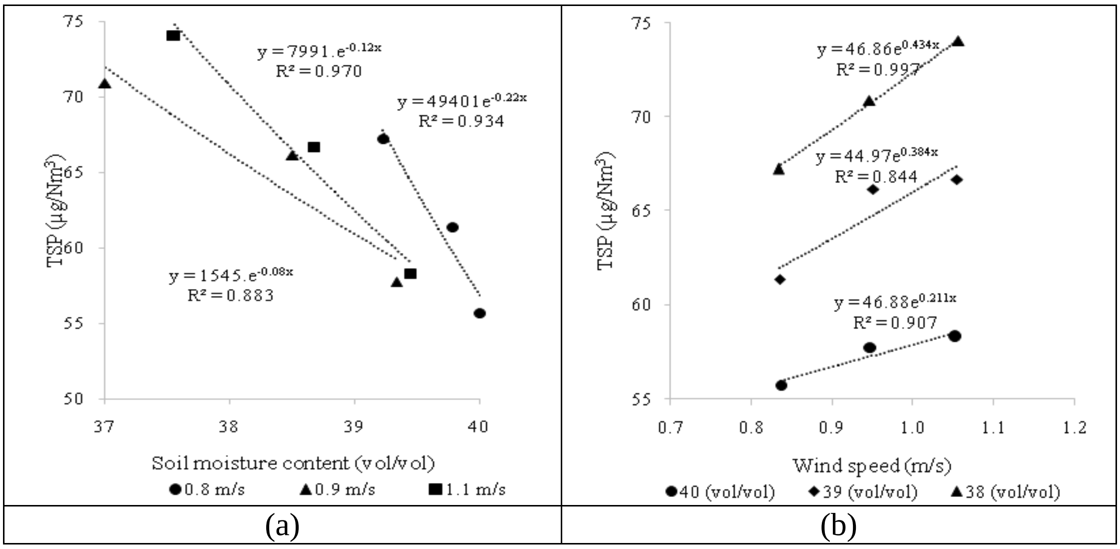

Figure 6: Correlation between TSP generations versus soil moisture content (vol/vol) (a) and wind speed (b) on CPL soil.

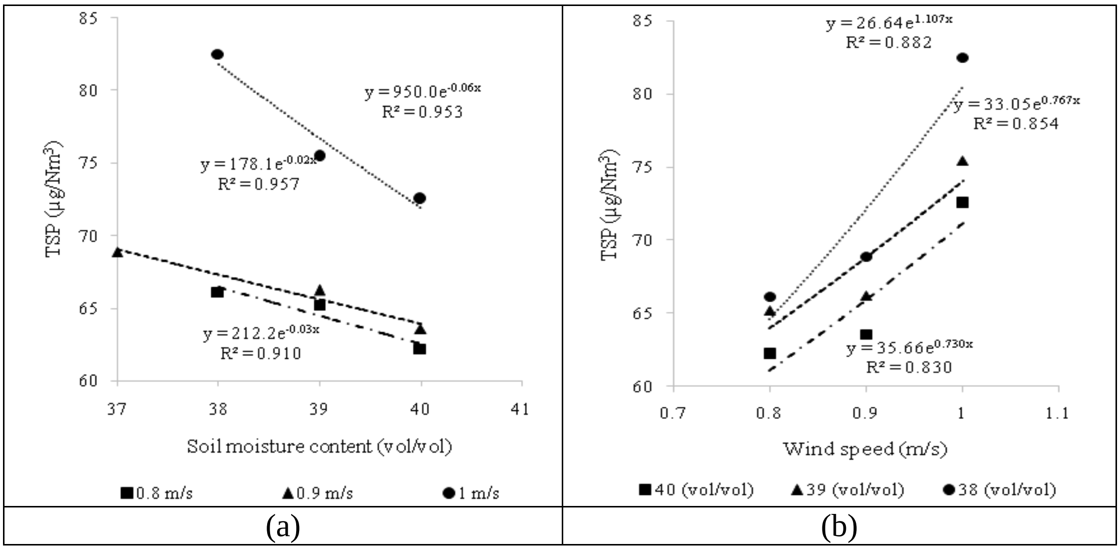

Figure 7: Correlation between TSP generations and soil moisture content (vol/vol) (a) and wind speed (b) on REG soil.

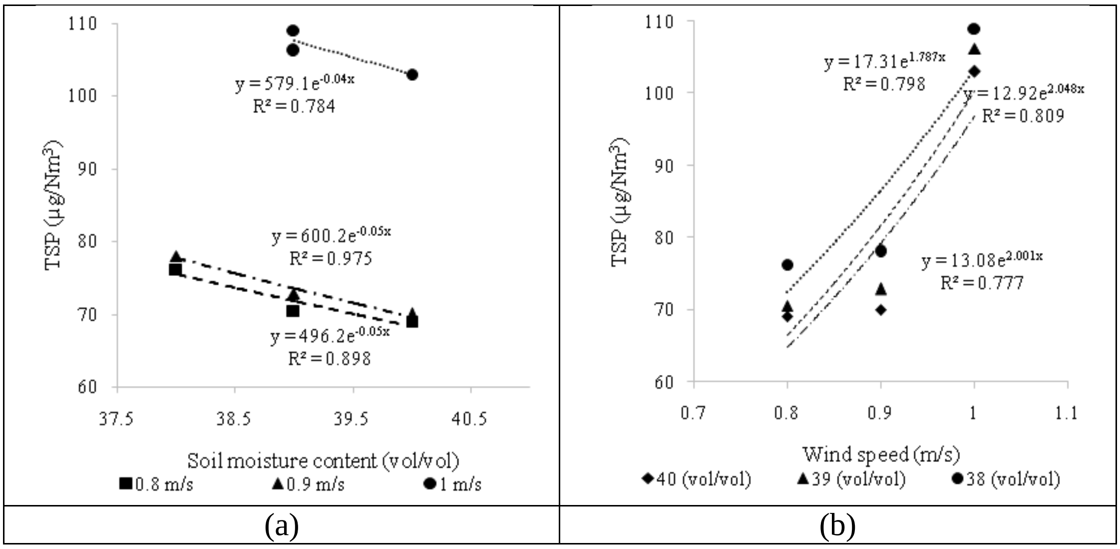

Figure 8: Correlation between TSP generations versus soil moisture content (vol/vol) (a) and wind speed (b) on CMG soil.

Overall, the generation of TSP from the four soil types was positively correlated with wind speed but negatively correlated with soil moisture content as indicated in Figure 5, 6, 7, and 8. This result is corresponding to the result of the research carried out by Yuwono et al. [24] and Rochimawati et al. [23]. Moreover, is in line with the results of research conducted by Jinyuan et al. [19] in the North China dust where a major component of aerosols in the atmosphere was largely caused by the soil surface that has low soil moisture content (dry land) and high wind speeds during the spring.

The emission factor is theoretically a form of simplification expression to obtain TSP generation value in the real condition. However, in reality, there are other factors that cause difference between the amount of the TSP generation in the field and those generated from laboratory scale.. The amount of TSP generation in the real condition could be different due to soil moisture content and unstable wind speed, wind direction, local circumstances such as high buildings as wind obstacles, industries producing the TSP in ambient air, vegetation, topography (valleys and mountains of the state), and meteorological factors or local weather. TSP emission factor on RYP, CPL, REG and CMG were presented in Eq. (4), (5), (6), and (7).

$$E_{RYP} = (41161\,e^{-0.20A}) \times 0.33 + (168\,e^{0.4U} \times 0.30) + (12\,e^{0.03V}) \times 0.37 \quad (4)$$

$$E_{CPL} = (79992\,e^{-0.12A}) \times 0.33 + (46.9\,e^{0.4U}) \times 0.30 + (58\,e^{-0.01V}) \times 0.33 \quad (5)$$

$$E_{REG} = (178\,e^{-0.03A}) \times 0.36 + (26.6\,e^{1.1U}) \times 0.33 + (68\,e^{-0.01V}) \times 0.30 \quad (6)$$

$$E_{CMG} = (600\,e^{-0.05A}) \times 0.36 + (12.9\,e^{2.1U}) \times 0.30 + (66\,e^{-0.01V}) \times 0.34 \quad (7)$$

Variable "A" in the above equation represents soil moisture content of the RYP, CPL, REG and CMG soil, "U" is the wind speed (m/sec), "V" is the percentage of vegetation cover. The emission factor is expressed as E_{RYP} for TSP from RYP soil (µg/Nm³), E_{CPL} for TSP from CPL soil (µg/Nm³), E_{REG} for TSP from REG soil (µg/Nm³), E_{CMG} for TSP from CMG soil (µg/Nm³).

These emission factors, unfortunately, cannot be used to determine the chemical composition of TSP, while, in fact, both chemical and physical characteristics of TSP are crucial as starting point for an impact assessment of anthropogenic TSP generation on air quality change. Research conducted by Chow et al. [31] and Che et al. [32] are examples of those concerning on chemical aspects of samples and physical properties of aerosol components, including TSP.

Conclusion

The conclusions that can be drawn from the research are as follows:

1. Generation of TSP is correlated positively with the wind speed, but negatively with soil moisture content and vegetation cover.
2. Generation of TSP from RYP, CPL, REG, and CMG did not exceed the threshold limit of national standard for ambient air.
3. The emission factors of TSP as affected by wind speed, soil moisture content, and percentage of vegetation cover have been developed and readyly implemented in the field as a tool for air quality change assessment.

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