DETERMINATION OF EMISSION FACTORS FOR SOIL BORNE DUSTFALL AND SUSPENDED PARTICULATE IN AMBIENT AIR

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ABSTRACT

Two important factors contributing air quality deterioration, i.e. dustfall and suspended particulate, are obligatory parameters necessary to describe air quality. The research objectives were to measure the generated dustfall and suspended particulate in ambient air over a model area constructed of Oxisol as well as Ultisol soil and to determine the emission factors of dustfall and suspended particulate generation as affected by wind speed and soil moisture content over an area covered by both soil classes. The measurement of dustfall and suspended particulate was conducted in a laboratory scale tunnel where the land surface was covered by Oxisol and subsequently changed by Ultisol soil. The instruments used during the experiments were dustfall canister, blower, anemometer, moisture tester, tunnel, analytical balance, Petri dish, filter paper 10µ and universal oven. Result of the measurements showed that the average generated dustfall from Oxisol and Ultisol soil surface were 9 and 15 ton/km^2·month, respectively. The generated suspended particulate from Oxisol covered area was 150 µg/Nm^3 and for Ultisol area was 102 µg/Nm^3. The developed emission factor equations as affected by wind speed and soil moisture content are at this point ready for field implementation to predict the dustfall and suspended particulate generation over land covered by both soil types.

Keywords: dustfall, emission factor, oxisol soil, suspended particulate, ultisol soil.

INTRODUCTION

Dustfall and suspended particulate in ambient air were important factors contributing serious air quality deterioration. Both are ambient air quality parameters as stipulated in Indonesian Governmental Regulation (PP No. 41/1999) pertaining on Air Pollution Control. Thus, they were two obligatory parameters that must be presented to describe environmental baseline assessment or air quality. By definition [1], dustfall comprises coarse solid and liquid particles, with an aerodynamic diameter >10µm, that are collected via gravitational settling in an open-mouth container for a designated period of time.

Suspended particulate is a complex mixture of particles that may be solid, liquid or both, suspended in the air and consisting of organic and inorganic substances [2]. They are generated not only by forest fire, eruption from active volcanoes, but also by bare lands, agricultural field operations [3], site preparation for construction sites [4] and traffic.

The finer parts of solid fraction of airborne pollutants are particulate matter with aerodynamic diameter less than 10µ, called PM_{10}, and less than 2.5µ also called as $PM_{2.5}$. The latest are important parameters with a lot of health impacts [5; 6; 7; 8] on human being and animal as well, such as cancer, silicosis, asthma and allergic diseases. Other research finding [9] indicated that atmospheric deposition of fine particulate matter is partially responsible for degradation of water clarity at Lake Tahoe, Nevada (USA).

Mathematical models to predict the amount of dust generated by wind or “wind-blown dust” have been compiled and deeply assessed by researchers [10]. An approach to assess dust emission potential based on study of a recreation area was carried out [11] where a mapping approach to assess dust emission potential was presented, which may serve as a template to assess other areas for this hazard. Map delineating units based upon surficial characteristics affecting dust emission (e.g., soil texture, rock cover, surface crusts and vegetation) was created. Seventeen surface units are grouped into four major classes (sand, silt and clay, rock covered, and active drainages).

The lack of relevant site specific emission factors, however, should be solved in order to precisely predict the amount of dustfall and suspended particulate that could be generated by those sources. Therefore, development of emission factors were paramount important in order to enable an accurate environmental impact assessment.

By now the emission factors used in Indonesia were those developed abroad where the natural and atmospheric conditions was greatly different. The definitive emission factors suited for such assessment in any Indonesian location is consequently necessary. Emission factors that practically could be used in the field are those in simple form, fit to the field conditions as well as those accommodate most important factors affecting the generated dustfall and suspended particulate.

The first objective of the research was to measure the generated dustfall and suspended particulate in ambient air over a model area constructed of Oxisol soil. The second objective was to measure the generated dustfall and suspended particulate as in the first objective for Ultisol soil. The third objective was to determine the emission factors of dustfall and suspended particulate generation as affected by wind speed and soil moisture content over an area covered by Oxisol and Ultisol soil.

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METHODS

The measurement of dustfall and suspended particulate were conducted in a laboratory scale tunnel where the land surface was covered by Oxisol soil and subsequently changed by Ultisol soil. The materials and instruments used during the experiments were a set of dustfall canister [AS-2011-1], blower [Hercules; Ø 60 cm; 220 V; 170 W], digital anemometer [Lutron AM-4201], digital moisture tester [OGA TA-5], tunnel [7.6 m length; 0.76 m width; 2.4 m height], analytical balance [OHAUS Aventuror Pro], Petri dish [Ø=80 mm], filter paper 10 µ [Whatmann #41] and universal oven [UNB 400]. The experimental procedure is presented schematically in Figure-1.

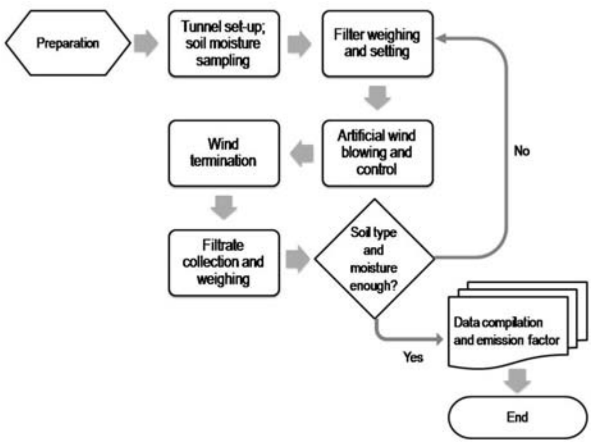

Figure-1. The steps of the experimental procedure.

The Oxisol soil sample was taken from Bubulak Village, Bogor Municipality, whereas the Ultisol soil sample was collected from Jasinga Sub-District, Bogor Municipality, Indonesia. A layer of 3 cm depth Oxisol soil was used to cover the surface of the tunnel. Three dustfall canisters were set-up at one end of the tunnel whereas a fan was set up at the other opposite end to generate artificial wind in the tunnel. Three levels of wind speed were controlled in the range of 0.8-1.3 [m/s] by adjusting the power level of the blower.

The generated soil borne dustfall in ambient air due to the blowing wind in the tunnel was then passively collected by the dustfall canister and subsequently detained by the filter installed in the canister. After 12 hours sampling campaign, the wind blowing period was stopped and the filtrate was then kept in a stabilisation chamber under controlled relative humidity (RH) and temperature in the laboratory prior to weighing.

The concentration of the dustfall in ambient air of the tunnel was calculated by considering the canister catchment area, exposure time span and mass difference between filter and the filtrate. A correlation between wind speed and the associated dustfall generation was then developed.

The role of soil moisture content on the dustfall concentration was incorporated in the study. This was carried out by recording the soil moisture content three times per day which was used to develop correlation between soil moisture content and the generated dustfall.

All of these steps were then repeated for the second soil type, i.e. Ultisol. The generation of suspended particulate due to the blowing wind on the soil surface was measured by active sampling during the blowing wind episode. The ambient air was sucked by using High Volumetric Air Sampler [Staplex; TFIA-2] for two hours. The gained filtrate was then kept in a stabilisation chamber under controlled relative humidity and temperature prior to weighing. The concentration of the suspended particulate in ambient air in the tunnel was calculated by considering time exposure, volumetric air flow rate of the HVAS and the mass difference between filter and the filtrate. This procedure was repeated for other soil type under various soil moisture contents.

RESULT AND DISCUSSIONS

Result of the measurements showed that the average generated dustfall from Oxisol soil surface was about 9 ton/km^2·month whereas for Ultisol was 15 ton/km^2·month. The national threshold limit of dustfall parameter is 10 ton/km^2·month for settlement areas and 20 ton/km^2·month for industrial areas. The result that may be achieved using same soil type from different locations could vary due to local weather condition such as relative humidity and air temperature, and soil organic matter content as well as different soil moisture.
Research conducted in Fuxin, China [12] showed that dust emission from a coal mine waste areas were 17.7-23.5 ton/km^2·month. The maximum threshold limit in those areas, i.e. 50 ton/km^2·month, however, is much higher than the Indonesian norm. Another finding carried out in Chicago [13] indicated that dustfall concentration at any housing area was in between 129-247 µg/ft^2·hour which was equal with 1.0-1.9 ton/km^2·month.

Bryant [14] explored fundamental aspects of the biological, mineralogical and textural components of dust. Data collected were quantifying important aspects of the dust cycle, including particular anthropic interventions and system dynamics such as the interplay between glacial processes and dust emission and the impacts of dust. It also provided new insights via data sets which begin to quantify factors which may control the nature and magnitude of dust emissions, and via the development of gross relationships between surface roughness and emission thresholds, an estimation of spatial and temporal limits on sediment supply. This allows us to begin to understand and quantify the complex spatial and temporal relationships that can exist between sediment supply and the transport capacity of the wind for specific sources of dust.

The average generated suspended particulate from Oxisol covered area was 150 µg/Nm^3 and for Ultisol area was 102 µg/Nm^3 whereas the national threshold limit of suspended particulate parameter in ambient air is 230 µg/Nm^3 (Figure-2).

A research on measurement of total suspended particulate (TSP) in ambient air carried out in Henan

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Province, Central of China [15] revealed that the spatial TSP average was high in spring and winter days at a level of approximately 530 μg/m^3 and low in summer days at 456 μg/m^3. In this research, approximately 750 total suspended particulates (TSPs) and coarse particulate matter (PM_{10}) filter samples from six urban sites and a background site and >210 source samples were collected in Jiaozuo City, China, during January 2002 to April 2003.

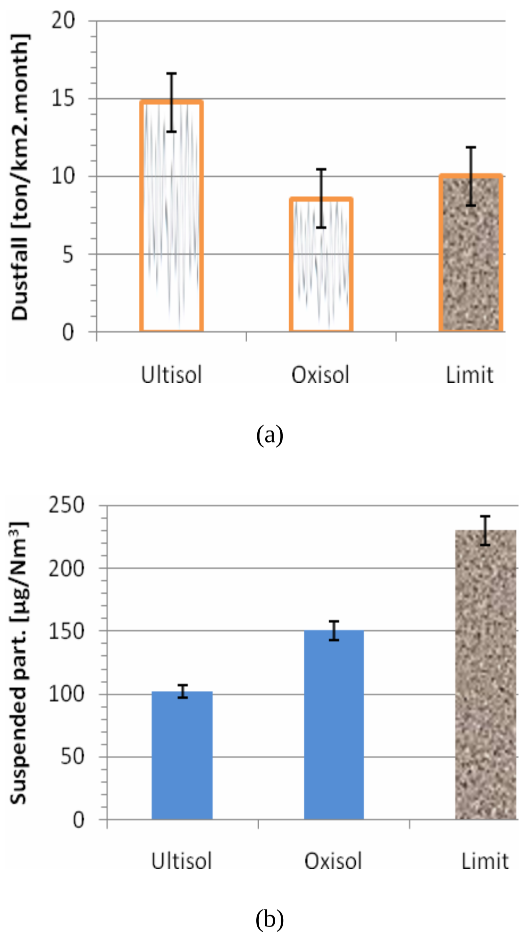

Figure-2. Dustfall (a) and suspended particulate (b) generation over Ultisol and Oxisol soil area.

Statistical data analysis showed that the Pearson correlation (r) between wind speed and the generated dustfall from Ultisol soil was 0.988 whereas Pearson correlation between soil moisture content and the generated dustfall from the same soil was -0958. Therefore, the relative contributions of wind speed and soil moisture content were 0.508 and 0.492, respectively. Compilation of the Pearson correlations and relative contribution of wind speed and soil moisture content for Ultisol and Oxisol soil on the generated dustfall and suspended particulate is presented in Table-1.

Schematic representation of the generated dustfall in ambient air as affected by wind speed and soil moisture content is presented in Figure-3. It is clearly shown that Ultisol soil generates more dustfall than the Oxisol soil at the same wind speed level.

The implication of such condition is that at the same wind speed and soil moisture content, any land processing activity over an area covered by Ultisol soil would imply worse environmental impact than those covered by Oxisol soil since Ultisol soil generates more dustfall than Oxisol. This could be stated that the higher the dustfall concentration in ambient air, the poorer the air quality.

Table-1. Pearson correlations and relative contribution of wind speed and soil moisture content on the generated dustfall and suspended particulate.

1. Dustfall			
		Wind speed	**Soil moisture**
Ultisol	R	0.988	-0.958
	R^2	0.977	0.918
	C	0.508	0.492
Oxisol	R	0.976	-0.941
	R^2	0.953	0.885
	C	0.509	0.491
2. Suspended Particulate			
Ultisol	R	0.952	-0849
	R^2	0.907	0.720
	C	0.529	0.471
Oxisol	R	0.851	-0.811
	R^2	0.725	0.658
	C	0.512	0.488

R=Pearson correlation; R=coefficient of determination; C=relative contribution.

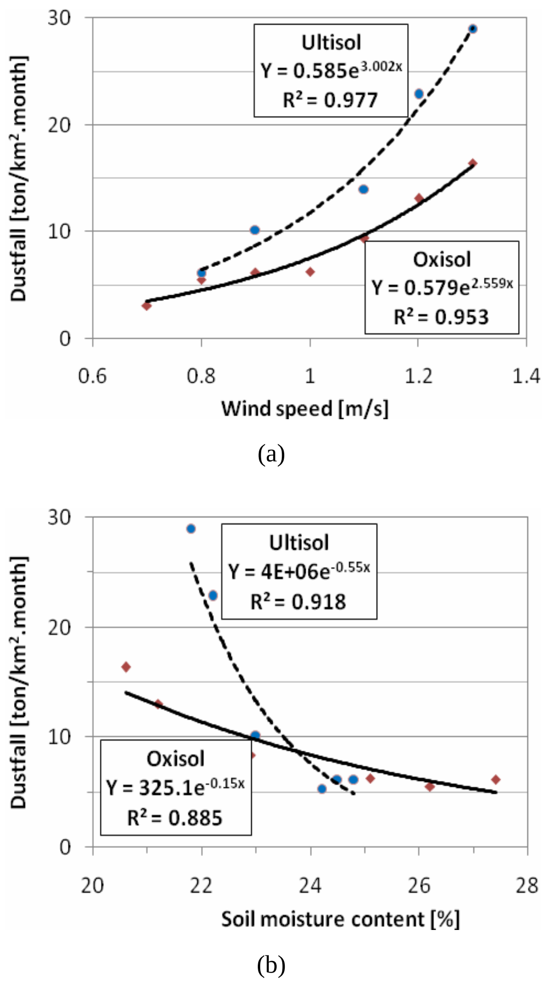

Figure-3. Dustfall generation over ultisol and oxisol soil as affected by wind speed (a) and soil moisture content (b).

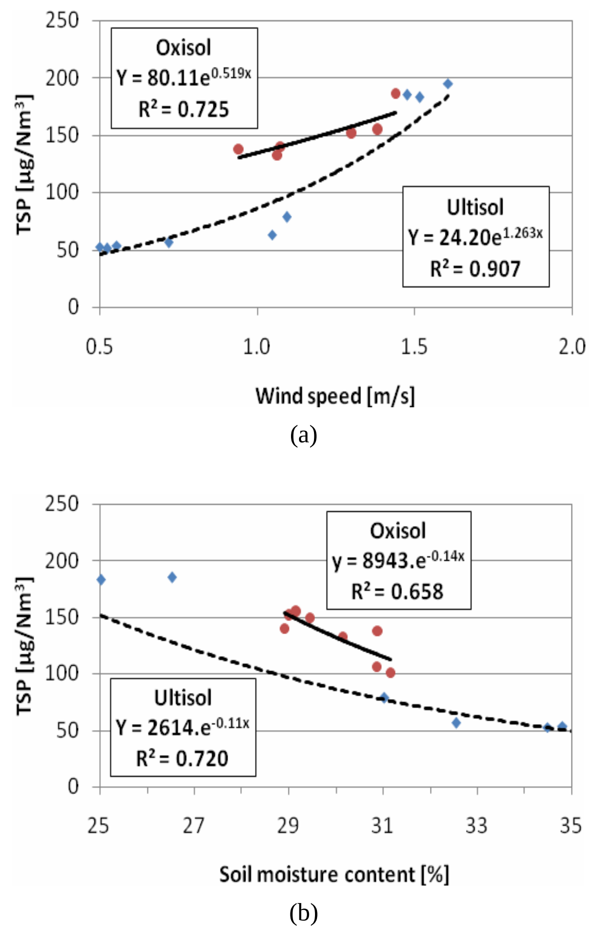

Figure-4. Suspended particulate generation over Ultisol and Oxisol soil as affected by wind speed (a) and soil moisture content (b).

Generation of suspended particulate originated from both soil sample types in ambient air is presented in Figure-4. The exponential trend of the suspended particulate generated from Ultisol soil was higher than those by Oxisol soil. It means that at higher wind speed the generated suspended particulate from Ultisol soil in ambient air would be higher than Oxisol soil. Laboratory analysis showed that Ultisol soil samples contain 27.48% sand, 23.34% dust and 49.18% clay. This textures indicate that the biggest fraction of Ultisol soil is clay which means that it would potentially emit a lot of fine fraction (<2 µm) of soil crust into the atmosphere if the soil surface is blown by wind.

On the other hand, however, laboratory analysis on soil sample showed that Oxisol soil contains 7.28% sand, 20.21% dust and 72.51% of clay. It indicated that potential emission of soil borne fine particles in the ambient air such as suspended particulate of Oxisol soil would be much higher than those generated by Ultisol soil.

Based on the relative contribution presented in Table-1 and the associated equations depicted in Figures 3 and 4, the emission factor of dustfall and suspended particulate generation as influenced by wind speed and soil moisture content for Ultisol soil can be formulated in Eqn. (1) and Eqn. (2) as follows:

$$e_{Ult.DF} = (0.585e^{3.002V})*0.508 + (4*10^{6}e^{-0.55M})*0.492 \quad (1)$$

$$e_{Ult.SP} = (24.20e^{1.263V})*0.529 + (2614e^{-0.11M})*0.471 \quad (2)$$

Where e_{Ult-DF} is emission factor of dustfall for Ultisol soil (ton/km^2.month), e_{Ult-SP} is emission factor of suspended particulate for Ultisol soil (µg/Nm^3), V is wind speed (m/s) and M is soil moisture content (%).

The emission factor for dustfall and suspended particulate generation for Oxisol soil are expressed in Eqn. (3) and Eqn. (4) as follows:

$$e_{Oxi.DF} = (0.579e^{2.559V})*0.509 + (325.1e^{-0.15M})*0.491 \quad (3)$$

$$e_{Oxi.SP} = (80.11e^{0.519V}) * 0.512 + (8943e^{-0.14M}) * 0.488 \quad (4)$$

Where $e_{Oxi\text{-}DF}$ is emission factor of dustfall for Oxisol soil (ton/km^2·month), $e_{Oxi\text{-}SP}$ is emission factor of suspended particulate for Oxisol soil (μg/Nm^3), V is wind speed (m/s) and M is soil moisture content (%).

Those emission factors can at this point be implemented directly in the field as an approach to predict the quantitative impact of any activity such as land clearing, construction site preparation, deforestation and so forth, on air quality deterioration due to land surface cover change by simply inputting local prevailing wind speed and average soil moisture content. These emission factors are locally fit to areas covered by Oxisol or Ultisol soil types. The advantage of the use of these emission factors is the easiness to implement it for any environmental prediction such as in quantitative assessment on air quality change due to any activity that causes land opening.

CONCLUSIONS

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

a. The generated dustfall in ambient air over a model area constructed of Oxisol and Ultisol soils were successfully measured in [ton/km^2·month] unit according to the pertinent national standard. The amount of generated suspended particulates for Oxisol and Ultisol soil were yet under the threshold limit of 230μg/Nm^3.
b. The emission factors (e) of dustfall and suspended particulate generation over an area covered by Oxisol and Ultisol soil as affected by wind speed and soil moisture content have been developed.
c. The possible impact of these findings is that the emission factors are currently ready for field implementation by simply inputting the local soil moisture content and wind speed.

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REFERENCES

[1] Micovic V., A. A. Juretic, N. Matkovic and G. Crevelin. 2010. Dustfall measurement in Primorsko-Goranska County, 1975-2008. *Arh Hig Rada Toksikol*. 61: 37-43.

[2] J. D. Joksic, M. J. Stojanovic, A. Bartonova, M. B. Radenkovic, K-E Yttri, S. M. Besarabic and L. Ignjatovic. 2009. Physical and chemical characterization of the particulate matter suspended in aerosols from the urban area of Belgrade. *J. Serb. Chem. Soc*. 74(11): 1319-1333.

[3] B. Holmén, D. Miller, A. Hiscox, W. Yang, J. Wang, T. Sammis and R. Bottoms. 2008. Near-source particulate emissions and plume dynamics from agricultural field operations. *J Atmos Chem* 59: 117-134.

[4] K. T. Su, Y. M. Chang, W. H. Hu, S. S. Chen, C. H. Wu and C. K. Lin. 2010. Comparison of reduction efficiency of woven straw for entrained emissions of particulate matter with diameters less than 10 mm (PM_{10}) and less than 2.5 mm ($PM_{2.5}$) from exposed areas at construction sites. *Can. J. Civ. Eng*. 37: 787-795.

[5] B. Ostro, A. Tobias, X. Querol, A. Alastuey, F. Amato, J. Pey, N. Pérez and J. Sunyer. 2011. The Effects of Particulate Matter Sources on Daily Mortality: A Case-Crossover Study of Barcelona, Spain. *Environmental Health Perspectives.* 119(12): 1781-1787.

[6] A. Momoh, S. E. Mhlongo, O. Abiodun, C. Muzerengi, M. Mudanalwo. 2013. Potential implications of mine dusts on human health: A case study of Mukula Mine, Limpopo Province, South Africa. *Pak J Med Sci.* 29(6): 1444-1446.

[7] A. C. Chu, G. C. Fang, I. C. Lin and T. Y. Chou. 2008. Measurement and analysis of ambient air particulates and ionic species for composition and concentration studies at the western coast of central Taiwan. *Toxicology and Industrial Health.* 24: 137-145.

[8] M. T. Kleinman, C. Sioutas, J. R. Froines, E. Fanning, A. Hamade, L. Mendez, D. Meacher and M. Oldham. 2007. Inhalation of Concentrated Ambient Particulate Matter Near a Heavily Trafficked Road Stimulates Antigen-Induced Airway Responses in Mice. *Inhalation Toxicology*. 19(Suppl. 1): 117-126.

[9] D. Zhu, H. D. Kuhns, S. Brown, J. A. Gillies, V. Etyemezian, A. W. Gertler. 2009. Fugitive Dust Emissions from Paved Road Travel in the Lake Tahoe Basin. *J. Air and Waste Manage. Assoc.* 59: 1219-1229.

[10] Y. K. Park and S. H. Park. 2010. Development of a New Wind-Blown-Dust Emission Module Using Comparative Assessment of Existing Dust Models. *Particulate Science and Technology*. 28: 267-286.

[11] B. T. McLaurin, D. Goossens and B. J. Buck. 2011. Combining surface mapping and process data to assess, predict, and manage dust emissions from

natural and disturbed land surfaces. *Geosphere.* 7(1): 260-275.

[12] Y. Chen, Y. Jiang, H. Wang, D. Li. 2007. Assessment of ambient air quality in coal mine waste areas - a case study in Fuxin, China. *New Zealand Journal of Agricultural Research.* 50: 1187-1194.

[13] D. E. Jacobs, S. Cali, A. Welch, B. Catalin, S. L. Dixon, A. Evens, A. P. Mucha, N. Vahl, S. Erdal, J. Bartlett, “Lead and Other Heavy Metals in Dust Fall from Single-Family Housing Demolition”, *Public Health Reports*, 128: 454-462, 2003.

[14] R. G. Bryant. 2013. Recent advances in our understanding of dust source emission processes. *Progress in Physical Geography*. 37(3): 397-421.

[15] Y. Feng, Y. Xue, X. Chen, J. Wu, T. Zhu, Z. Bai, S. Fu and C. Gu. 2007. Source Apportionment of Ambient Total Suspended Particulates and Coarse Particulate Matter in Urban Areas of Jiaozuo, China. *Journal of the Air and Waste Management Association*. 57: 561-575.