Estimation of Physico-Chemical Characteristics of Suspended Particulate Matter (SPM) at Construction Sites: A Statistical Regression-Based Model

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Summary: Among many other sources, suspended particular matter (SPM) is generated from fine construction waste and materials (like sand, clay, silt and crushed stones etc) due to sweeping, wind blowing, traffic flow and other mechanical disturbances at the constructions sites. Characterization of this SPM is essential due to its effects on ecology, environment and human health. But sophisticated and expensive equipment, trained manpower, costly resources and continuous supply of energy, which the countries like Pakistan lack, are required for characterization. Therefore, this study aims at developing regression-based statistical models to estimate physico-chemical characteristics of SPM only by determining the corresponding characteristics of fine inert material at any construction site. A total of 168 samples, 84 of the fine inert material and similar number of samples of SPM, were collected during a period of nine months from June 2013 to February 2014 from a construction site at Lahore, Pakistan. The parameters for characterization included pH, electrical conductivity and concentrations of trace metals (Al, Ca, Ni, Fe and Zn) and ions (SO_4^{2-}, NO_3^- and Cl^-) both in inert material and SPM. The statistical analysis was performed using SPSS 16. Results showed highly significant correlation and regression between all the parameters. Significance of correlation and regression and data normality test of dependent variables (characterization parameters of SPM) indicated that regression-based models can be used for prediction of physico-chemical characteristics of the SPM by using the physico-chemical characteristics of fine inert material at any other/new construction site. Linear regression models [Y = a + b (x)] were developed to estimate and predict physico-chemical characteristics of SPM (Y). The models were applied at new construction site and differences between actual and estimated values showed that the model equations can reliably be used for characterization of SPM only by determining the corresponding characteristics of fine inert material at any/new construction sites.

Key words: Construction site, Fine inert waste material, Suspended particulate matter, Physico-chemical characterization, Estimation, Statistical regression.

Introduction

Construction is an important activity in terms of infrastructure and economic development [1, 2], but believed to be environmentally unfriendly due to generation of construction waste during various phases. Being important source of pollution locally and globally [3], construction activities and waste material cause serious environmental disruption and pollution [4-7] and inflict direct and indirect negative impacts on the natural environment and ecology [8, 9].

In developing and under-developed countries, like Pakistan, usually the construction material i.e., sand, clay, crushed stone and bricks etc, is not only placed openly in front of and/or around the construction sites at roads and streets during the whole construction process, but also the waste generated during the construction is not removed from the scene after the completion of the construction. Due to sweeping, wind blowing, traffic flow and other mechanical disturbances, a part of fine inert makes suspended particular matter (SPM) of varying sizes in the air. Rest of the large-sized inert waste erodes with the passage of time and more and more fine inert is produced, resulting in increased SPM in the ambient air around. Furthermore, during rains, a part of inert waste deposits on roads and around, dries and transforms into SPM due to traffic and other mechanical disturbances.

Resultantly, air becomes polluted with tiny dust particles and poses challenges for air pollution control policymakers. Cities and traffic areas especially suffer from high levels of particulate matter, where the yearly average values for particulate matter (PM) often exceed the threshold values regulated by law [10].

Several epidemiological studies have also demonstrated that SPM exposure, carrying various metals within, is responsible for life-threatening and

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serious health effects [10] including occurrence of acute respiratory infections, lung cancer, and chronic respiratory and cardiovascular diseases [11-15]. Many epidemiological and toxicological studies have also suggested that the health effects associated with exposure to particulate matter (PM) are related to the different physico-chemical properties of particulate matter [11-15]. Physico-chemical characterization is the characterization of the properties relating to both physical and chemical behaviour of a substance. Among many others, these properties include pH, electrical conductivity, boiling point, freezing point, size, shape and chemical composition of the substance [16].

The health impacts of SPM emissions are not restricted to the construction site, as fine particles (smaller than 2.5 µm in diameter) can travel further than coarser dust (particulate matter of 2.5-10 µm in diameter) and hence can affect the health of people living and working in the surrounding and far away [10, 17]. Each year, over two million deaths are estimated to occur globally as a direct consequence of air pollution through damage to the lungs and the respiratory system [16]. Among these, about 2.1 million are caused by inhalation of suspended particulate matter [18-20].

The enormous amount of construction activity has produced a large amount of fine inert waste over the past two decades in Pakistan. Hence, a wide range of pollutants, in the form of particulate matter of varying sizes carrying different toxic metals, continuously enter the urban environment during construction activities [21].

Concentration of metal contents in the SPM in Islamabad, Pakistan, was reported to be Ca (4.531 $\mu g\ m^{-3}$) Na (3.905 $\mu g\ m^{-3}$), Fe (2.464 $\mu g\ m^{-3}$), Zn (2.311 $\mu g\ m^{-3}$), K (2.086 $\mu g\ m^{-3}$) Mg (0.962 $\mu g\ m^{-3}$), Cu (0.306 $\mu g\ m^{-3}$), Sb (0.157 $\mu g\ m^{-3}$), Pb (0.144 $\mu g\ m^{-3}$) and Sr (0.101 $\mu g\ m^{-3}$) [22]. In the Midwestern United States, average urban levels of Fe, Pb, and Zn in $PM_{2.5}$ ranged from 0.04–0.07 $\mu g\ m^{-3}$, 0.001–0.005 $\mu g\ m^{-3}$, and 0.006–0.011 $\mu g\ m^{-3}$ while average rural concentrations were 0.03–0.04 $\mu g\ m^{-3}$, 0.002 $\mu g\ m^{-3}$, and 0.006 $\mu g\ m^{-3}$, respectively [23]. Analyzing the chemical data of the PM_{10} elements like Cl, Ca, Si, Al, Fe and Na have been reported at a residential building construction site in Salvador, Bahia, Brazil [24].

Average concentrations of various trace metals in PM_{10} at various locations in Dhanbad, Jharkhand, India were found as 8.5 $\mu g\ m^{-3}$ (Fe), followed by 1.43 $\mu g\ m^{-3}$ (Cu), 0.60 $\mu g\ m^{-3}$ (Zn), 0.39 $\mu g\ m^{-3}$ (Mn), 0.28 $\mu g\ m^{-3}$ (Cr), 0.050 $\mu g\ m^{-3}$ (Cd), 0.24 $\mu g\ m^{-3}$ (Pb) and 0.0096 $\mu g\ m^{-3}$ (Ni) [25].

Research needs to be performed to determine the pollution impact on the environment during construction activities. In this connection, determination of physico-chemical characteristics of the fine inert material on ground and SPM generated due to this fine inert at and around construction sites is imperative to monitor and control the atmospheric quality of the cities [15].

As compared to ambient air's, the determination of most of the physico-chemical characteristics of fine inert is technically easy and comparatively inexpensive owing to readily available equipment and trained manpower. But, on the other hand, air pollution monitoring for determination of physical and chemical characteristics of SPM, not only needs sophisticated and expensive equipment but also needs highly trained manpower and costly resources, including continuous supply of energy, which the countries like Pakistan lacks and suffering acute shortage.

Keeping in view all the issues and problems, there is s need to develop a mechanism to estimate physical and chemical characteristics of SPM only by determining the physico-chemical characteristics of fine inert material at the construction sites.

Therefore, this study aims at developing regression-based statistical models to estimate physico-chemical characteristics of SPM only by determining the corresponding characteristics of fine inert material at any construction site.

Experimental

The physico-chemical properties chosen for this study included pH and electrical conductivity (EC) and concentrations of metals including Aluminum (Al), Calcium (Ca), Nickel (Ni), Iron (Fe) and Zinc (Zn) and a few ions like sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) keeping in view the possibility of prevalence at construction site and their impacts on human health. The pH and electrical conductivity affect human skin and cause regulatory and auto-regulatory physiological dysfunctioning and disorder of human body resulting in many medical complexities and issues, while the metals and ions in particulate matter affect respiratory system, cardiovascular system, cause cancer, genotoxicity, neurotoxicity, immunotoxicity, affect eyes, liver, pancrease and glucose metabolism [26].

Site Selection

A construction site at the Link Road, Model Town, Lahore, the metropolitan city and provincial capital of the Punjab Province of Pakistan, was selected for collecting samples of fine inert at the ground and particulate matter in the surrounding/ambient air.

Time and Duration of Samples Collection

A total of 168 samples, 84 of the fine inert material and the similar number of samples of the SPM were collected during a period of nine months from June 2013 to February 2014 from a construction site for characterization and developing relationship between physico-chemical characteristics of fine inert material and corresponding characteristics of SPM. Samples of both the fine inert and SPM were collected for four weeks in different seasons: 04-10 June 2013 (Week 1), 19-25 October 2013 (Week 2), 25-31 December 2013 (Week 3) and 08-14 February 2014 (Week 4). On each day of the sampling week, three samples each in the morning, noon and afternoon were collected. In total, 21 samples of each fine inert material and corresponding SPM were collected during each week.

Fine Inert Sample Collection

Samples of fine inert material were taken with stainless steel utensil from the top surface (0-6 inches) using the pattern as shown in the Fig 1. Four subsamples were collected from four corners (subsample 1, 2, 3 and 4) and one subsample was collected from centre (subsample 5) of the pile/heap/mound of the fine inert material from which the suspended particulate matter was being generated. All the five subsamples were then mixed thoroughly and grind to make a composite sample of at least 200 gram.

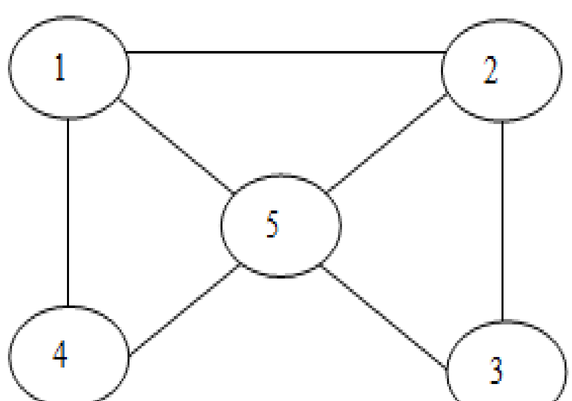

Fig. 1: Pattern for inert material sampling from ground at the construction site.

Particulate Matter Sampling

Suspended particulate matter (SPM) sampling was carried out according to the guidelines of National Environmental Quality Standards (NEQS) Pakistan Environmental Protection Agency (PAK-EPA) using high volume sampler (Casella, UK) designed to comply with BS 3405 and ISO 9096.

Physico-Chemical Analysis of Inert Material and SPM

Samples of both inert fine material and SPM were analyzed for pH and electrical conductivity (EC) using the standards methods [27]. Trace metals including Aluminum (Al), Calcium (Ca), Nickel (Ni), Iron (Fe) and Zinc (Zn) were analyzed using Atomic Absorption Spectrophotometer (AAS) following the method of US-EPA (Compendium Method IO-3.2) [28]. Similarly, anions i.e. sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) were analyzed using the standard methods of analysis (APHA, 2005) [29].

For pH and electrical conductivity measurement, fine inert material and SPM were separately dissolved in de-ionized water to make slurry. The pH and electrical conductivity (µs/cm) were measured using hand-held pH meter (HANNA Instruments Model # HI 9812) and EC meter (HANNA Instruments Model # HI 9812), respectively.

Concentrations of trace metals (Al, Ca, Ni, Fe and Zn) in inert material were determined by mixing/dissolving one gram of fine inert material/waste was in 4ml of aqua regia and digesting in light heat for the period of one hour. Subsequently, 10 ml of de-ionized water was added and filtered through 0.45 micron millipore filter. The filtrate was then analyzed in Atomic Absorption Spectrophotometer (PerkinElmer 1210) for determining the concentrations of aluminum (Al), calcium (Ca), nickel (Ni), iron (Fe) and zinc (Zn).

For determining trace metals in SPM, the filter paper with SPM was burnt at 700ºC for 15 minutes. Later, one gram of ash was dissolved and digested in 4 ml of aqua regia in light heat for the period of one hour. 10 ml of water was added and filtered through 0.45 micron millipore filter. The filtrate was then analyzed in Atomic Absorption Spectrophotometer (PerkinElmer 1210) for concentrations of aluminum (Al), calcium (Ca), nickel (Ni), iron (Fe) and zinc (Zn).

For determination of concentrations of ions both in inert and SPM, 50 gram of inert material similar amount of SPM were dissolved in 100 ml of water and filtered through ordinary filter. The filtrate was processed in HACH Spectrophotometer for determination of concentrations of sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) ions.

Statistical Analysis

To address the research question and achieve the objective of the study, correlation and statistical linear regression analysis was done to predict the values of response variables (dependent variables: physico-chemical characteristics of SPM) through explanatory variables (independent variable: physico-chemical characteristics of inert matter/material/waste) [30]. Enter method of linear regression analysis was used.

Values of pH and electrical conductivity and concentrations of aluminum (Al), calcium (Ca), nickel (Ni), iron (Fe) and zinc (Zn) metals and sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) ions in the particulate matter were taken as dependent variables, while the values of pH and electrical conductivity and concentrations of metals and ions mentioned above in the inert matter/waste were taken as independent variables.

The next step of the study consisted of correlation and simple linear regression analysis of the data in order to identify the relationship between the dependent variable Y (physico-chemical characteristics of suspended particulate matter) and the independent variables X (physico-chemical characteristics of suspended particulate matter) [30]. All analyses were made using the SPSS 16 Statistical Package for correlations and regression analysis for calculating regression coefficients, including regression constants and slopes for dependent variables against the predictor (independent variables).

Confirmatory Tests

Before developing regression models for prediction of dependent variables, a test of the hypothesis of data normality of the dependent variable was also conducted to confirm whether simple linear regression can be used for prediction or not [30].

Regression Models

After regression analysis, regression equations, using constants and slopes, were developed for determining pH and EC, concentrations of five trace metals and three ions in the particulate matter from the corresponding values/concentration of the inert material of waste.

Results and Discussions

The results of the statistical analysis are presented in five parts – (1) comparison of the average values and concentration of physico-chemical characteristics of inert waste material and that of suspended particulate matter (Fig. 2), (2) two tailed Pearson correlations of physico-chemical characteristics of inert waste to the corresponding physico-chemical characteristics of suspended particulate matter at 0.01 level (Table-1), (3) analysis of variance (ANOVA) of regression analysis (Table 2), (4) simple linear regression lines with R^2 values (Fig. 3-12), and (5) statistical models for determining values and concentrations of physico-chemical characteristics (y) of suspended particulate matter in the air with determined values/concentrations of physico-chemical characteristics of inert matter at new location (x), regression constant (a) and value of slope (b) of the regression curve, at any new locations (Table-3).

Table-1: Pearson correlation (two tailed) between various physico-chemical characteristics of inert material and particulate matter.

S No	Characteristics (Inert vs PM)	Pearson Correlation Coefficient (r)	P value	Significance at 0.01 level
1	pH to pH	0.778	0.000	Significant
2	EC to EC	0.494	0.000	Significant
3	Al to Al	0.708	0.000	Significant
4	Ca to Ca	0.792	0.000	Significant
5	Ni to Ni	0.757	0.000	Significant
6	Fe to Fe	0.813	0.000	Significant
7	Zn to Zn	0.945	0.000	Significant
8	SO_4^{-2} to SO_4^{-2}	- 0.485	0.000	Significant
9	NO_3^- to NO_3^-	0.592	0.000	Significant
10	Cl^- to Cl^-	0.830	0.000	Significant

Correlations Analysis

In correlation analysis, correlation coefficient (r) is estimated, which ranges between -1 and +1 and quantifies the direction and strength of the linear association between the two or more variables. The correlation between two variables can be positive (i.e., higher levels of one variable are associated with higher levels of the other) or negative (i.e., higher levels of one variable are associated with lower levels of the other). The sign of the correlation coefficient indicates the direction of the association, while magnitude of the correlation coefficient indicates the strength of the association. Estimation or prediction of future values is not possible through correlation analysis. Table-1 shows two-tailed Pearson correlations between values/concentrations of physico-chemical characteristics of inert material and SPM. The P-values ($P<0.000$) indicate that all the correlations were highly significant at 0.01 level.

The correlation coefficient (r) ranges from highest 0.945 to lowest 0.484. The highest correlation has been found in case of Zn (0.945), followed Cl^- (0.830) and Fe (0.813), whereas, lowest correlation has been determined in case of SO_4^{2-} (0.485), followed by electrical conductivity (0.494) and NO_3^- (0.592). All the correlations are positive, except for of sulfate. The negative correlation of sulfate is surprising and needs further investigation for digging out the reason behind this unanticipated behavior.

Simple Linear Regression Analysis

Correlation quantifies the degree to which two variables are related, but does not fit a line through the data points. On the other hand, simple linear regression finds the best line that predicts one variable from another. From correlation an index describing the linear relationship between two variables can be obtained; while in regression the relationship between the variables can be predicted and can be used to predict dependent variable from the independent variable. Figs 3-12 illustrate simples linear regression lines between determined/observed values/concentrations of physico-chemical characteristics of inert material (independent variable: along x-axis) and corresponding characteristics of SPM (depended variable: along y-axis), along with the R^2 values (the coefficient of determination). R^2 (coefficient of determination) is an important concept in regression analysis and is believed to be one of the parameters to verify and confirm the efficiency and validity of regression model for estimation purpose. The maximum R^2 value is found in case of Zn (0.892) followed by Cl^- (0.688), while SO_4^{2-}, followed by electrical conductivity, exhibit the minimum value of R^2 as 0.235 and 0.244, respectively. Usually it is considered that higher the value of R^2, the better the model will fit the data and greater will be the explanatory power of the regression. But only R^2 is insufficient to decide about the goodness of fit of model. Smaller R^2 value always does not mean model is not good for estimation. In such cases, R^2 is interpreted with ANOVA significance for proper model interpretation. In this study, R^2 value for SO_4^{2-} and electrical conductivity are only 24%, but their ANOVA results are significant and hence only 24% explained variation cannot be neglected and can be considered for estimation of the dependent variables.

Table-2 shows that regressions were found significant at 0.01 level in case of all physico-chemical characteristics.

All the curves/graphs, except Fig 10, demonstrated that values/concentrations of physico-chemical characteristics of suspended particulate matter decreased as compared to values/concentrations of physico-chemical characteristics of inert material. However, in case of Fig 10, the concentration of sulfate in SPM (dependent variable) increased as compared to concentration of sulfate in inert matter (independent variable). Nonetheless, the extent of increase or decrease depends upon slope of the corresponding regression line/curve.

Table-2: ANOVA of regression analysis of physico-chemical characteristics of fine inert material and suspended particulate matter

S No	Characteristics	Coefficient of Determination (R^2)	F value	P value	Significance at 0.01 level
1	pH	0.606	125.970	0.000	Significant
2	EC	0.244	26.435	0.000	Significant
3	Al	0.501	82.492	0.000	Significant
4	Ca	0.627	137.761	0.000	Significant
5	Ni	0.572	109.725	0.000	Significant
6	Fe	0.660	159.393	0.000	Significant
7	Zn	0.892	678.326	0.000	Significant
8	SO_4^{-2}	0.235	25.217	0.000	Significant
9	NO_3^-	0.351	44.355	0.000	Significant
10	Cl^-	0.688	181.169	0.000	Significant

Data Normality Tests

Though, correlation and regression analyses of all the characteristics were found significant, but before developing regression models for the prediction of the dependent variables, a data normality test of the dependent variable was conducted to confirm whether simple linear regression can be used for the prediction of the dependent variable or not. After confirmation of the normality of the dependent variables, regression based models were established [30].

Statistical Regression-Based Models

Table-3 shows simple linear regression-based models [Y = a + b (x)] developed for determining the values and concentrations of each physico-chemical characteristics in suspended particulate matter (dependent variables) at any other construction site, by determining only the values and concentrations of corresponding physico-chemical characteristics of inert material (independent variables) at the new site. In the model [Y = a + b (x)], Y is value/concentration of physico-chemical characteristics of SPM (dependent variable: to be estimated at new location), (a) and (b) are the values of constant and slope of regression line/curve, respectively (both determined for each and every physico-chemical characteristics in regression analysis), and x is the value/concentration of physico-chemical characteristics of inert material (independent variable) determined at the new location.

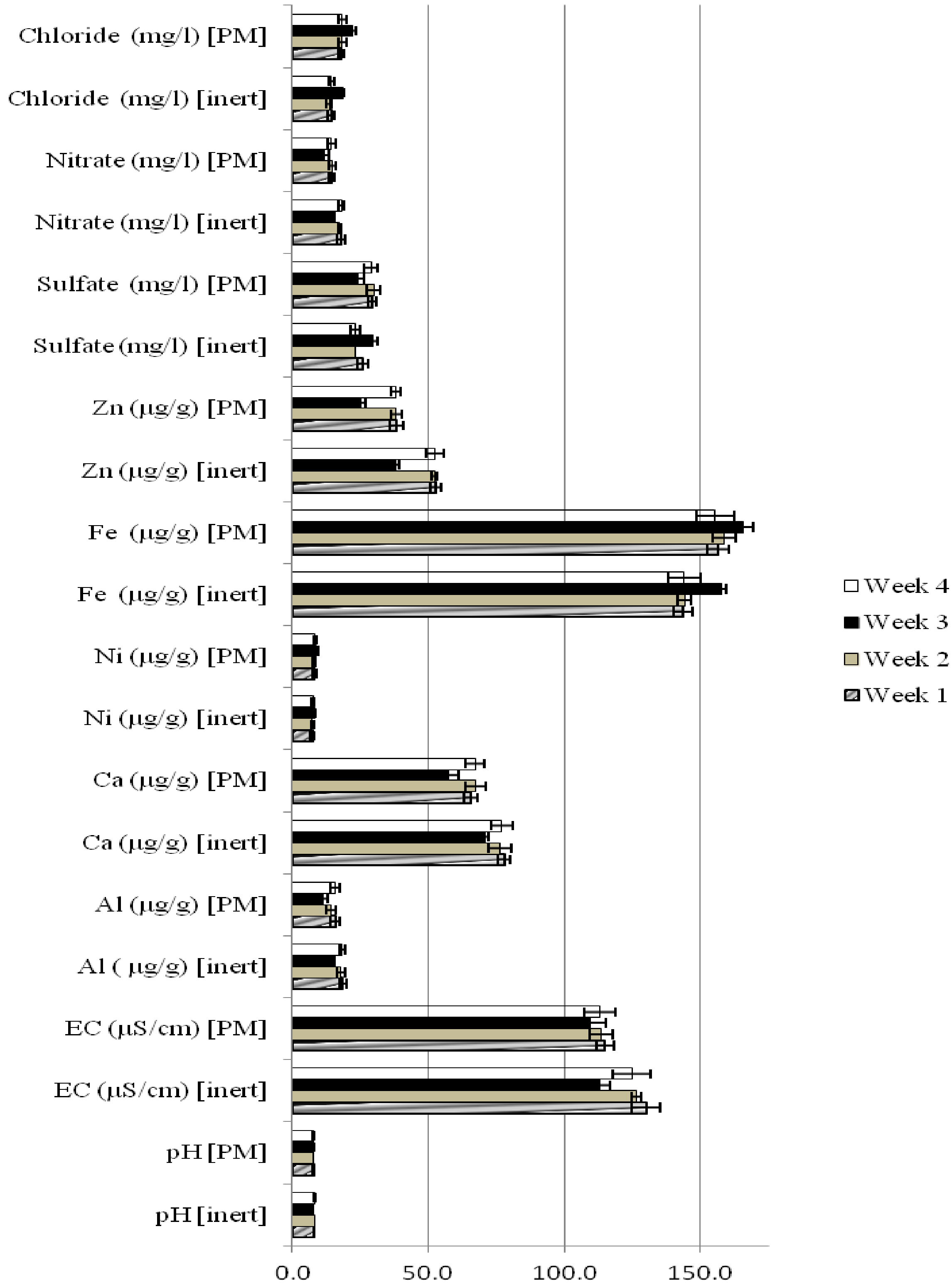

Fig. 2: Comparison of average physico-chemical characteristics of fine inert material and suspended particulate matter during four weeks.

Table-3: Statistical regression-based models (Y = a + b.x) for estimation of various physico-chemical characteristics of suspended particulate matter.

S No	Characteristics	Unit	Constant(a)	Slope (b)	Statistical model for dependent variable in particulate matter [y = a + b(x)]
1	pH	-	-1.264	1.136*	Y= -1.264 + 1.136 (x)
2	EC	(µS/cm)	73.014	0.323*	Y= 73.014 + 0.323 (x)
3	Al	(µg/g)	-3.120	0.996*	Y = -3.120 + 0.996 (x)
4	Ca	(µg/g)	-9.270	0.977*	Y= -9.270 + 0.977 (x)
5	Ni	(µg/g)	2.031	0.825*	Y= 2.031 + 0.825 (x)
6	Fe	(µg/g)	30.430	0.881*	Y= 30.430+ 0.881 (x)
7	Zn	(µg/g)	-8.291	0.883*	Y= -8.291 + 0.883 (x)
8	SO_4^{-2}	(mg/l)	41.574	-0.532*	Y= 41.574 + -0.532 (x)
9	NO_3^-	(mg/l)	3.695	0.593*	Y= 3.695 + 0.593 (x)
10	Cl^-	(mg/l)	6.889	0.810*	Y= 6.889 + 0.810 (x)

*Significant at 0.01 level

Table-4: Validation of the regression based models by comparing estimated and actual values at the new construction site.

S No	Characteristics	Unit	Independent variable (x)	Dependent variable (Y) (estimated)	Dependent variable (Y) (actual)	% Difference
1	pH	-	7.6	7.3696	7.1	3.8
2	EC	(µS/cm)	145	119.849	135	-11.2
3	Al	(µg/g)	22.5	19.29	16.1	19.8
4	Ca	(µg/g)	81	69.867	73	-4.3
5	Ni	(µg/g)	11.5	11.5185	12.7	-9.3
6	Fe	(µg/g)	180	189.01	174	8.6
7	Zn	(µg/g)	60.7	45.3071	40.7	11.3
8	SO_4^{-2}	(mg/l)	31	25.082	29	-13.5
9	NO_3^-	(mg/l)	22	16.741	20	-16.3
10	Cl^-	(mg/l)	24.7	26.896	29.6	-9.1

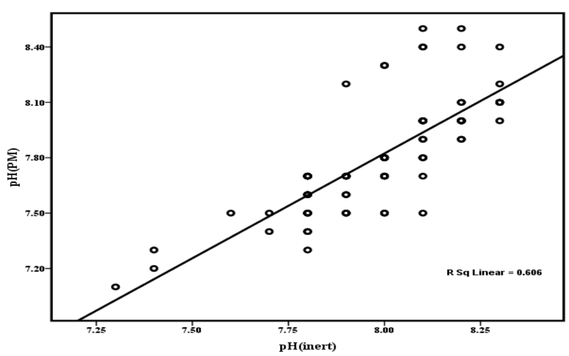

Fig. 3: Linear regression line between pH values of fine inert waste and SPM with R^2 value.

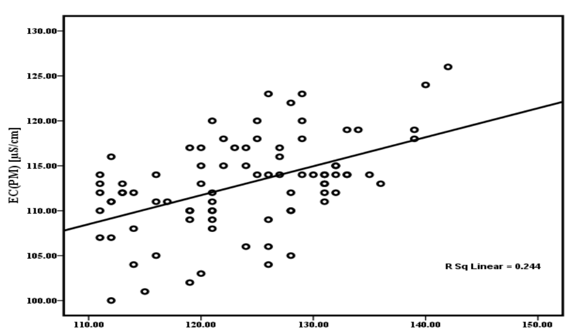

Fig. 4: Linear regression line between EC values of fine inert waste and SPM with R^2 value.

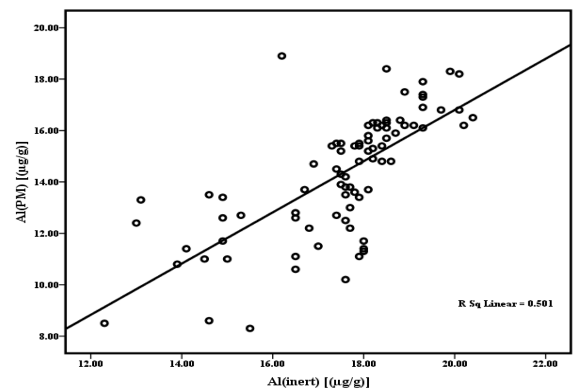

Fig. 5: Linear regression line between Al concentrations of fine inert waste and SPM with R^2 value.

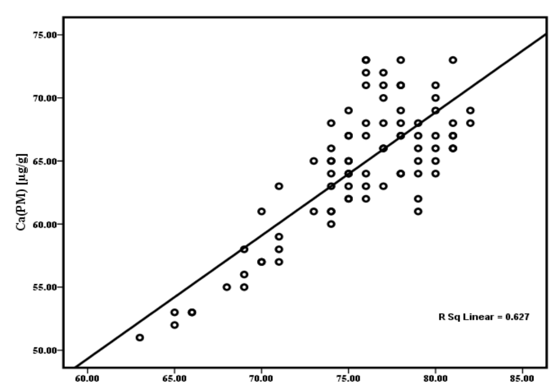

Fig. 6: Linear regression line between Ca concentrations of fine inert waste and SPM with R^2 value.

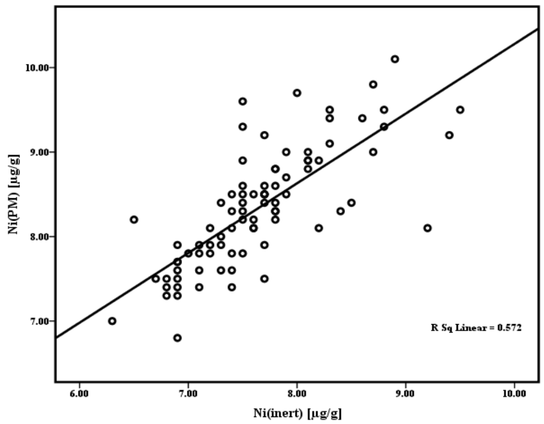

Fig. 7: Linear regression line between Ni concentrations of fine inert waste and SPM with R^2 value.

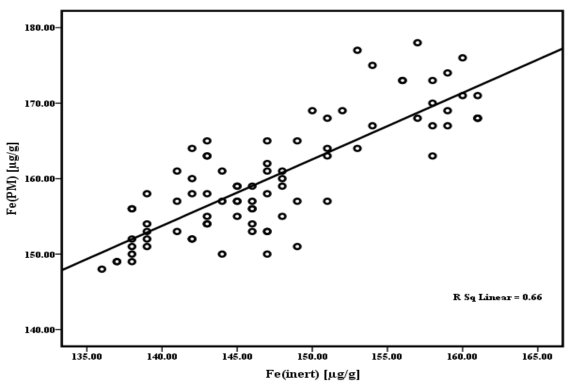

Fig. 8: Linear regression line between Fe concentrations of fine inert waste and SPM with R^2 value

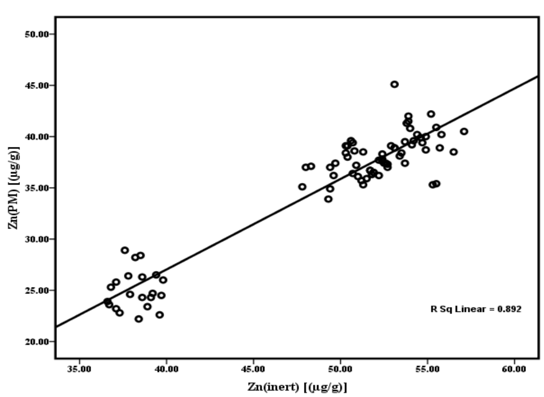

Fig. 9: Linear regression line between Zn concentrations of fine inert waste and SPM with R^2 value.

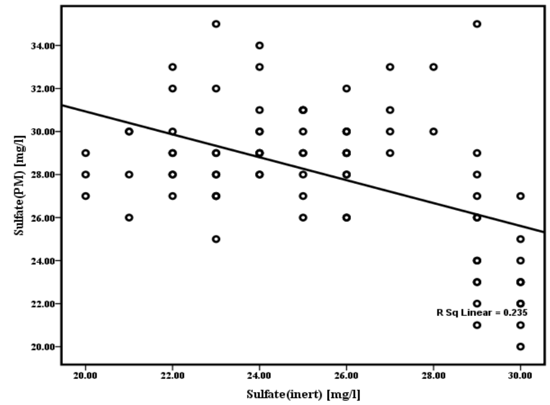

Fig. 10: Linear regression line between SO_4^{2-} concentrations of fine inert waste and SPM with R^2 value.

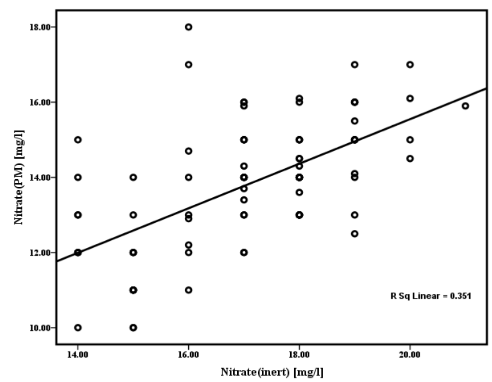

Fig. 11: Linear regression line between NO_3^- concentrations of fine inert waste and SPM with R^2 value.

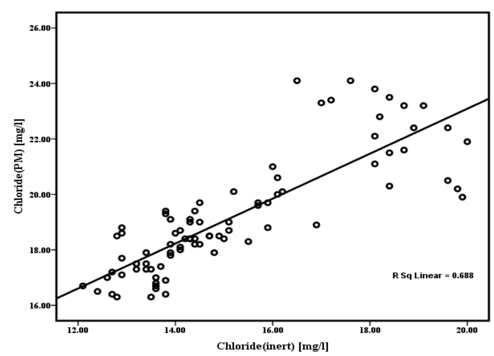

Fig. 12: Linear regression line between Cl^- concentrations of fine inert waste and SPM with R^2 value.

Therefore, at any new construction site/location, using the statistical regression models given in Table 3, values/concentrations of pH and EC and concentrations of aluminum (Al), calcium (Ca), nickel (Ni), iron (Fe) and zinc (Zn) metals and sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) ions in suspended particulate matter in air can be estimated/calculated only by determining the corresponding values/concentrations of pH and EC and concentrations of aluminum (Al), calcium (Ca), nickel (Ni), iron (Fe) and zinc (Zn) metals and sulfate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) ions in the inert matter on ground at any construction site. This easy way of estimation of physico-chemical characteristics of suspended particulate matter can help monitor air and particulate matter pollution; develop guidelines and preventive measure for the workers at the construction sites and save the people from toxic and lethal effects of suspended particulate matter load with toxic metals.

Validity of the Models

At a new construction site, also at Lahore, Pakistan, physico-chemical characteristics on both inert material and particulate matter were determined. Moreover, the values/concentrations of physico-chemical characteristics in the inert waste were estimated by using model established with help of regression based models. The estimated and actual values/concentrations were compared in the Table-4 [30]. The percentage difference varied from -16.3 in case of NO_3^- to 19.8 in case of Al. The minimum difference was found in case of pH (3.8%), followed by Ca (-4.3%), Fe (8.6%) and Cl^- (-9.1). However, all the differences were less than 20%, which underlines the reliability of the statistical models established for estimating physico-chemical characteristics.

Geographical Boundaries

The basic idea of estimating physico-chemical characteristics of suspended particulate matter from the physico-chemical characteristics of the corresponding soil or fine inert material is logical and rationale and assumed to be workable worldwide. However, generation of particulate matter and its physico-chemical characteristics greatly depends upon local inert material and environment and metrological and climatic conditions. Therefore, specific regression-based models need to be developed for various geographical areas in different parts of the world having its own and distinctive environmental, meteorological and climatic conditions.

Limitations

These models are applicable in dry periods only when there is no rainfall. Obviously, when there will be rainfall, no particulate matter will be generated from the fine inert material even if there is a massive mechanical disturbance at the construction site. Secondly, it will pertinent to mention here that particulate matter monitoring is recommended only in dry and sunny days/weeks only. As these models are developed primarily for estimating physico-chemical characteristics as part of particulate matter monitoring, hence there is no question to apply these models in the rainy days and during wet periods.

Conclusions

This article presents a new method to estimate physico-chemical characteristics of suspended particulate matter by determining the corresponding parameters of fine inert matter by simple linear regression models. Linear regression-based models [Y = a + b(x)] were developed by finding the slope and constant/intercept of the fitted line – the regression coefficients. The models developed were tested for validity by comparing the actual and estimated values of dependent variables at a new construction site in the same city. The percentage difference varied from -16.3% in case of NO_3^{-1} to 19.8% in case of Al. The minimum difference was found in case of pH (3.8%), followed by Ca (-4.3%), Fe (8.6%) and Cl^- (-9.1%). However, all the differences were less than 20%, which underlines the reliability of the statistical models established for estimating physico-chemical characteristics. Based on the underlying data, it is possible to predict physico-chemical characteristics of suspended particulate matter only by determining the corresponding parameters of fine inert material at the construction site with some limitations.

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References

1. L. C. Foo, I. A. Rahman, A. Asmi, S. Nagapan and K. I. Khalid, Classification and Quantification of Construction Waste at Housing Project Site, *Int. J. Zero Waste Gen.*, **1**, 1 (2013).
2. S. O. Babatunde, Quantitative Assessment of Construction Materials Wastage in the Nigerian Construction Sites, *J. Emerg. Trends in Eco. & Manag. Sci.*, **3**, 238 (2012).
3. T. Pinto and V. Agopyan, Construction Wastes as Raw Materials for Low-Cost Construction

Products, *Sustainable Construction (Proc. 1st Conf. of CIB TG 16), C. J. Kibert, ed., Ctr. For Constr. and Envir.*, Gainesville, Fla: 335 (1994).
4. T. Esin and N. Cosgun, A Study Conducted to Reduce Construction Waste Generation in Turkey, *Build. & Environ.*, **42**, 1667 (2007).
5. A. Nugroho, T. Tanit T and S. Takano, Measurement of the Construction Waste Volume Based on Digital Images. *Int. J. Civil & Environ. Engg.*, **13**, 35 (2013).
6. J. Y. Wang, Z. Li and V. W. Y. Tam, Critical Factors in Effective Construction Waste Minimization at the Design Stage: a Shenzhen Case Study, China, *Resour. Conserv. & Recycl.*, **82,** 1 (2014).
7. A. Bakshan, I. Srour, G. Chehab and E. M. Fadel, A Field Based Methodology for Estimating Waste Generation Rates at Various Stages of Construction Projects, *Resour. Conserv. & Recycl.*, **100**, 70 (2015).
8. V. W. Y. Tam and C. M. Tam, Waste Reduction through Incentives: a Case Study, *Build. Res. & Info.*, **36**, 37 (2008).
9. G. F. Durrani and M. K. Baloch, Environmental Pollution, a Threat to Photoshynthesis in Healthy Plants, *J. Chem. Soc. Pak.*, **31**, 851 (2009).
10. D. A. Notter, Life Cycle Impact Assessment Modeling for Particulate Matter: A New Approach Based on Physico-Chemical Particle Properties, *Environ. Int.*, **82,** 10 (2015).
11. M. N. Assimakopoulos, A. Dounis, A. Spanou and M. Santamouris, Indoor Air Quality in a Metropolitan Area Metro using Fuzzy Logic Assessment System, *Sci. Total. Environ.*, **449,** 461 (2013).
12. J. Heinrich, E. Thiering, P. Rzehak, U. Krämer, M. Hochadel, K. M. Rauchfuss, U. Gehring and H. E. Wichmann, Long-term Exposure to NO_2 and PM_{10} and All-Cause and Cause-Specific Mortality in a Prospective Cohort of Women, *Occup. Environ. Med.*, **70**, 179 (2013).
13. R. Beelen, M. Stafoggia, O. Raaschou-Nielsen, Z. J. Andersen, W. W. Xun, K. Katsouyanni, K. Dimakopoulou, B. Brunekreef, G. Weinmayr and B. Hoffmann, Long-Term Exposure to Air Pollution and Cardiovascular Mortality: Analysis of 22 European Cohorts. *Epidemiology*, **25**, 368 (2014).
14. L. Xu, C. Xiaoqiu, C. Jinsheng, Z. Fuwang, H. Chi, D. Ke and W. Yang, Characterization of PM_{10} Atmospheric Aerosol at Urban and Urban Background Sites in Fuzhou City, China, *Environ. Sci. Pollut. Res.,* **19**, 1443 (2012).
15. N. Ahmad, L. A. Khan and A. Sattar, Potentiometric Stripping Analysis of Heavy Metals in Gasoline and Dust Particulate, *J. Chem. Soc. Pak.*, **13**, 74 (1991).
16. U. S. Akhtar, N. Rastogi, R. D. McWhinney, B. Urch, C. W. Chow, G. J. Evans, J. A. Scott, The Combined Effects of Physicochemical Properties of Size-Fractionated Ambient Particulate Matter on in vitro Toxicity in Human A549 Lung Epithelial Cells, *Toxicology Reports*, **1,** 145 (2014).
17. F. Resende, Master's Thesis, *Atmospheric Pollution Emission of Particulate Matter: Evaluation and Control at Construction Sites of Buildings*, University of São Paulo, São Paulo, Brazil (2007).
18. The World Health Organization, the Global Burden of Diseases, (2004). ISBN 978 92 4 156371 0. http://www.who.int/topics/global_burden_of_disease/en/
19. A. S. V. Shah, J. P. Langrish, H. Nair, D. A. McAllister, A. L. Hunter AL and K. Donaldson, Global Association of Air Pollution and Heart Failure: a Systematic Review and Meta-Analysis, *The Lancet*, **382**, 1039 (2013).
20. K. J. Chuang, Y. H. Yan, S. Y. Chiu and T. J. Cheng, Long-Term Air Pollution Exposure and Risk Factors for Cardiovascular Diseases among the Elderly in Taiwan, *Occup. Environ. Med.*, **68**, 64 (2011).
21. S Waheed, N. Siddique, M. Arif, M. Daud and A. Markwitz, Size-Fractionated Airborne Particulate Matter Characterization of a Residential Area Near Islamabad Airport by IBA Methods, *J. Radioanal. Nucl. Chem.*, **293**, 279 (2012).
22. M. H. Shah and N. Shaheen, Annual and Seasonal Variations of Trace Metals in Atmospheric Suspended Particulate Matter in Islamabad, Pakistan, *Water, Air & Soil Pollut.,* **190**, 13 (2008).
23. S. Kundua and A. Elizabeth, Composition and Sources of Fine Particulate Matter across Urban and Rural Sites in the Midwestern United States, *Environ. Sci. Process Impacts*, **16**, 1360 (2014).
24. P. S. Araújo, B. C. Dayana and J. B. Rita, Identification and Characterization of Particulate Matter Concentrations at Construction Jobsites, *Sustainability*, **6**, 7666 (2014).
25. B. Dubey, K. P. Asim and S. Gurdeep, Trace Metal Composition of Airborne Particulate Matter in the Coal Mining and Non–Mining Areas of Dhanbad Region, Jharkhand, India, *Atmospheric Pollution Research,* **3**, 238 (2012).
26. F. Nejadkoorki, *Current Air Quality Issues*, Intech Publishers, (2015).

27. https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GTM-24b.pdf
28. Appendix B to 40 CFR Part 50. 2008. *Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method)*, Final Rule. 40 CFR Part 50, Federal Register, Friday, April 17, (2008).
29. American Public Health Association (APHA). *Standard Methods for the Examination of Water and Wastewater*, 23rd, Washington, DC, (2005).
30. A. P. Kern, M. F. Dias, M. P. Kulakowski, L. P. Gomes, Waste Generated in High-Rise Buildings Construction: A Quantification Model Based on Statistical Multiple Regression, *Waste Management*, **39,** 35 (2015).