Environmental Assessment of Suspended Particulate Matter over the Kabul City, Afghanistan

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Atmospheric particulate has harmful effects on human health. Predicting dust and aerosol emission and transport would be helpful to reduce harmful effects but, despite numerous studies, prediction of dust events and contaminant transport in soil remains challenging. In this study, we focused on main roads as a major resource of air pollution. Hence, the objectives of this research are to reproduce the SPM concentration distribution, optimize the calculation conditions such as meteorological data and SPM emitting rate, and to predict the reduction of SPM concentration due to the progress of the paving of the main roads. The diurnal PM_{10} concentration was collected from NEPA monitoring station. By making wind rose diagram using Ms.Excel, we consider wind speed during 2015 FY. Furthermore, either meteorological and emission data are used as an input data for METI-LIS to predict air pollution condition. The average of daily total PM_{10} concentration from 2014 to 2015 is 275 μg/m^3. Meanwhile, the higher mass concentration of PM_{10} is exceed 1000 μg/m^3, indicating that meteorological parameters play a predominant role. If we compare this amount of concentration with national air quality standard (150 μg/m^3) then it will 6-7 times more than the standard amount. The meteorological factors, roads width, and their situation are strongly influenced the simulation results while to using the METI-LIS tool. Due to paving roads, air pollution is drastically reducing about 81 %.

Key Words : *atmospheric particulate, human health, SPM, NEPA, METI-LIS, PM_{10} concentration*

1. INTRODUCTION

PM is an air pollutant consisting of a mixture of solid and liquid particles suspended in the air. These suspended particles vary in size, composition, and origin. Particles are often classified by their aerodynamic properties because (a) these properties govern the transport and removal of particles from the air; (b) they also govern their deposition within the respiratory system, and (c) they are associated with the chemical composition and sources of particles. These properties are conveniently summarized by the aerodynamic diameter, which is the size of a unit-density sphere with the same aerodynamic characteristics[11)].

Atmosphere particulates or aerosols contain all liquid and solid particles, excluding pure water, that exist in the atmosphere under normal circumstances. Most of these are a result of direct emissions as particles from the various natural and anthropogenic sources while others form from the condensation of certain gasses and vapors that are emitted into the atmosphere or are a result of chemical transformations. Thus, like gaseous pollutants, atmosphere particulates can also be broadly classified as primary and secondary aerosols. A full description of them requires specification of their concentration, size distribution, chemical composition phase (liquid or solid), morphology, and biological activity. Several terms are commonly used in characterizing the particulate- laden cloud masses[2)].

PM has many sources and can be in either primary or secondary in origin and can be either a dry or wet state. It is produced naturally (e.g., pollen, spores, salt spray, and soil erosion) and by human activity (e.g., soot, fly ash, and cement dust)[10)]. Primary PM is emitted directly and can be either coarse or fine, whereas secondary PM, which tends to be finer in size, is formed in the atmosphere through physical and chemical conversion of gaseous precursors such as nitrogen oxides (NO_x), sulfur oxides (SO_X), and volatile organic compounds (VOC_S)[9]. Thus, Arya, S.P. (1999) classified atmospheric particulates on the basis of chemical composition and biological viability into three categories: (1) trace metal particles, (2) nonviable carbonaceous particles, and (3) viable particles.

Particulate matter has a negative impact on human health and plays a role in climate change. To develop effective mitigation strategies to reduce the concentration of both $PM_{2.5}$ and PM_{10} one needs to establish the origin of particulate matter. To date, the Government has not compiled a comprehensive inventory of air pollutant emissions or not even an inventory of greenhouse gas emissions. Likewise, no source apportionment has ever been conducted to evaluate how much of the various sources contribute to particulate matter (PM) air pollution[3].

Because of three decades war in Afghanistan, the Kabul city has been swamped by emigrants from the neighboring country. Kabul's infrastructure is designed for about 500,000 residents, but it now supports more than 4 million. The overcrowded city is full of wood- burning stoves, and gas-powered generators are commonly used to supply electricity that a war-ravaged grid cannot provide. Cars use leaded gasoline, and residents sometimes burn plastic tires to stay warm[5].

The present paper was basically focused on PM_{10} rather than other pollutants in Kabul city. The aims of this research are as follows:

a) To reproduce the SPM concentration distribution, and to optimize the calculation conditions such as meteorological data and SPM emitting rate.
b) To prediction of the reduction of SPM concentration due to the progress of the paving of the roads.

2. CURRENT SITUATION IN KABUL

(1) Roads condition

In and around Kabul city there is no bypass route to pass south to north or east to west so that a driver can avoid traffic crowding in the central area. Hense, the driver is forced to inflow to the city center congested and this situation has been accelerating the increase of traffic congestion in the city.

The severe and lingering traffic congestion in Kabul is causing by several factors in need of improvement, including the lack of driving manners as evidenced by the forcible entry into the traffic flow at intersections and driving in the wrong direction. The arbitrary crossing of roads by pedestrians also causes the disorderly traffic flow of vehicles.

Simultaneously, the existing drainage system of the roads in Kabul is utterly poor (**Fig.2**). Specially during winter from December to March, melting snow becomes long-lasting standing water on unpaved road surfaces and the resulting muddy roads are a safety as well as a health hazard.

Roads traffic activity and emissions from vehicles is a dominant immediate source of air pollution over Kabul city. The transport sector faces challenges of illegal import of used vehicles, continued use of timeworn and poorly maintained vehicles (some vehicles are more than 50 years old), passenger and cargo overloading of vehicles, poor quality of transport fuel, and limited road capacity leading to air pollution.

Fig.1 Traffic congestion in Kabul city

Fig.2 Municipality workers collecting mud after rain.

Fig.3 Traffic activity and emission from vehicles.

(2) Solid waste

Solid waste generation, types, and characteristics change during the four seasons of the year in Kabul. Many factors are involved in it, that force and also put a sort of limitation on poor people to adjust themselves to the harsh winter by burning the waste for fuel purposes during the entire year which leads to weather and environmental changes.

Waste processing is always a problem in Kabul. Every day tons of rubbish are collected from houses and corners of the streets before being thrown to the final waste dumping point or landfill outside the capital. The municipal workers are mostly working in the waste collection points, transportation and collection of waste from the main roads, water channels, and carry them to the landfills; these workers do not collect waste from the households. Dump sites and collection points are visible everywhere around the city in a much-unplanned manner; landfills are situated approximately 16 – 20 Km away from the center of the city which is not standard at all.

Fig.4 Dustbins of solid waste along the road (by TORABI, 2016)

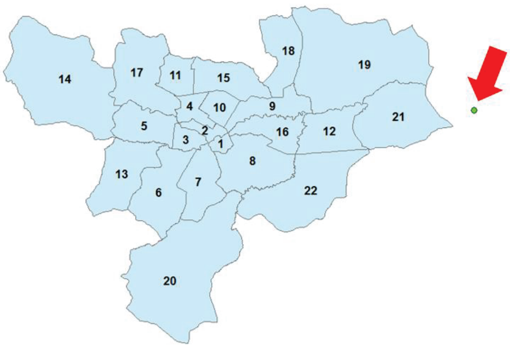

Fig.5 Location of Gazak landfill

(3) Population

Kabul is the most populous and urbanized area of Afghanistan with an estimated population of around four million. The City's population grew from 1.78 million in 1999 to around four million in 2016, reaching growth rates as high as 15% a year in 2002 that later slowed to 1.25%. Kabul population densities are higher in the periphery than in the city center; thus, Kabul is less centralized than other cities in Asia with similar densities.

Kabul is the focal point of administration, education, industry, trade, and communication in Afghanistan. Lack of sufficient employment prospects and basic utility services in remote provinces have prompted people to move to Kabul and other urban areas. Kabul's rapid growth has led to a proliferation of informal housing with 80% of the population living in informal settlements covering two-thirds of the residential areas. Houses are scattered in the poorly planned city, resulting in problems of transportation, sanitation, waste management, and air pollution.

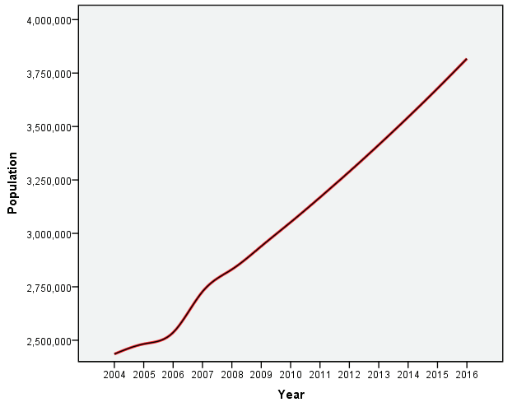

Fig.6 Growth of population in Kabul city (Million)
Source: Central Statistics Organization.

2. METHODOLOGY

(1) Study area

The Kabul city with 22 districts has 1030 km^2 area. For the current research, the air pollution concentration of the 4th district's main roads was selected as a case study. (**Fig.7**) The 4th district is located at the north side of the city, which has 11.6 km^2 area. Main roads in this area have not good status, most of them are unpaved; during the traffic transit and blowing of the wind it creates much pollution and sometimes no one can not see each other even at 20 meters. The air quality monitoring station is located in the 4th district (34°32'35.19"N- 69° 8'19.29"E).

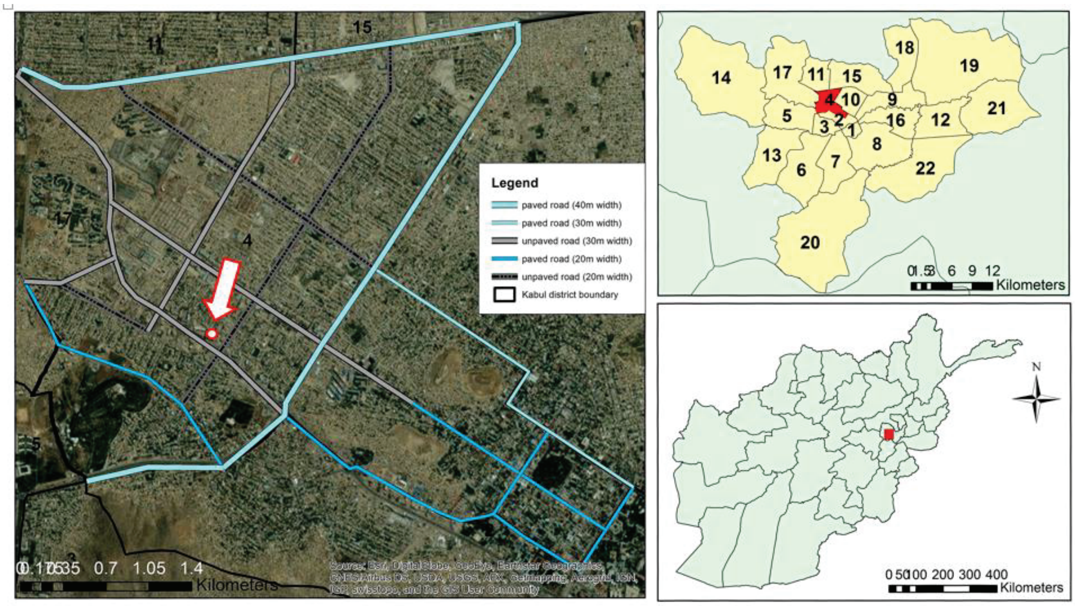

Fig.7 The study area and monitoring station.

(2) Data collection

Due to the simulation of air pollution in Kabul and to makes a dispersion model for main roads of the 4th district, the METI-LIS tool required geographical data, emission data, and meteorological data. The diurnal emission rate of PM_{10} was collected from monitoring station of national environmental protection agency (34°32'36.41"N- 69° 8'18.10"E). The meteorological data includes wind direction, wind speed and temperature of the selected area, which has been gathered from the monitoring station of the meteorological department (34°33'19"N- 69° 12'51"E).

From either theoretical and a practical standpoint, we cannot adapt the emission data and meteorological data of one selected point to all of the areas, because the emission rate, wind direction, wind speed and temperature of other areas can be different rather than the first point. Unfortunately, due to the lack of enough monitoring stations in Kabul city, we were facing too many problems to estimate and find the exactly effected areas to specify the air pollution concentration at a specific point.

(3) Statistical analysis

For analysis of meteorological data, a MS. Excel was used to give a succinct view of how wind speed is typically distributed in Kabul. The result of analyzing is obtained as a diagram, which is called wind rose.

(4) METI-LIS dispersion model

An atmospheric dispersion model is a mathematical expression relating the emission of material into the atmosphere to the downwind ambient concentration of the material. The heart of the matter is to estimate the concentration of a pollutant at a particular receptor point by calculating from some basic information about the source of the pollutant and the meteorological conditions[7)]. For the present, the stochastically based Gaussian type model is the most useful in modeling for regulatory control of pollutants.

In the present study, the PM_{10} concentration was simulated using the METI-LIS version 2.03 which is a Gaussian dispersion model developed on the basis of the ISC model of the U.S.EPA. In 1996, Ministry of Economy, Trade, and Industry (METI - Japan) has developed and used this model, when air contamination issues are included in the Air pollution prevention Act in Japan[8)]. Researches comparison shows that the performance of the model is better than that of the original ISC model.

This program can make calculations for point sources (fixed sources of emissions such as factories) and line sources (mobile emission sources, such as traffic). The calculation method designated in our study was for line sources. Crucial input data are emission rate and other emission condition such us the location and road width. The measured 24 hour PM_{10} was processed to match the pattern required by the program and were used as inputs to the model.

Meanwhile, wind direction, wind speed, temperature, and stability class were the meteorological data required for our analysis.

Sources with line-shaped characteristics are calculated in the model by numerically assimilating the point source plume equation[6]:

$$c(x,y,z)=\frac{Q}{2\pi\sigma_Z u}\exp\left(\frac{-y^2}{2\sigma^2 y}\right)\left[\begin{aligned}&\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right)\\&+\exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\end{aligned}\right] \quad (1)$$

Where c is a concentration at a given position (g/m^3), Q is the pollutant emission rate (g/s), x is the downwind (m), y is the crosswind (m), z is the vertical direction (m) and u is the wind speed (m/s) at the h height of the release. The σ_y, σ_z deviations describe the crosswind and vertical mixing of the pollutant.

4. RESULT

(1) Environmental data survey

The city of Kabul suffers from poor air quality and it is congestion. In recent years, the ambient air quality in the city has extremely deteriorated that it can be ranked among the dirtiest cities in the world. Epidemiological studies by the ministry of public health indicate cardiovascular and respiratory diseases resulting from air pollution in Kabul are increasing the country's crude mortality rate by four percent a year. If we apply the four percent increase in mortality due to air pollution to the exist population of Kabul, then an extra 3,000 persons may be losing their lives due to air pollution per year.

Air quality during late fall and winter is reportedly deteriorated by indoor air pollutaion emissions arising from increased use of ovens, stoves, and open fires. Electricity deficiencies and lack of fuel wood for warming the rooms mean that households resort to burning some packaging materials that may cause toxic fumes.

Research shows in urban springtime conditions that with average wind speed over 5 m/sec the PM_{10} concentrations started to increase because the wind itself had sufficient velocity to lift the particles from road surfaces and the ground. Likewise, PM_{10} concentrations increased with wind speeds below 4 m/sec. In light winds the traffic-induced turbulence lifts the particles into the air and the concentrations remain high because of poor mixing of air masses due to low wind speeds, low atmospheric mixing height, and possibly inversion.

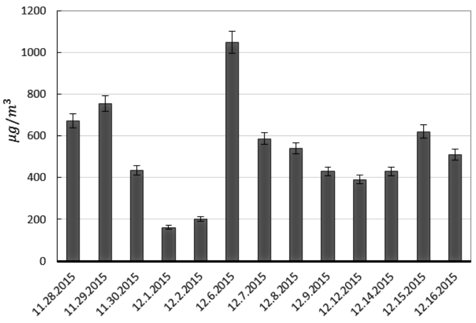

Fig.8 Diurnal variation of PM_{10} concentration.

Table 1 National air quality standards for Afghanistan

Parameter	Unit	Time-weighted average	Maximum allowable concentration
TSP	μg/m^3	24 hours	300
PM_{10}	μg/m^3	Annual	70
		24 hours	150
$PM_{2.5}$	μg/m^3	Annual	35
		24 hours	75
Nitrogen dioxide (NO_2)	μg/m^3	Annual	40
		24 hours	80
Sulfur dioxide (SO_2)	μg/m^3	24 hours	50
Ozone (O_3)	μg/m^3	8 hours	100
Carbon monoxide (CO)	μg/m^3	8 hours	10
		1 hour	30
		Half hour	60
Lead (Pb)	μg/m^3	Annual	0.5

Air quality data which has been recorded by NEPA (**Fig.8**) shows that the high levels of particulate matter (PM_{10}) is more than 1000 μg/m^3 in Kabul. If we compare this amount of concentration with national air quality standards (**Table 1**) then it will 3, 4 even 7 times more than the standard amount. Furthermore, the reason for immediately changing in concentration mainly depend to the wind speed, humidity, and traffic congestion.

Particles can either be directly emitted into the air (primary PM) or be formed in the atmosphere from gaseous precursors such as sulfur dioxide, oxides of nitrogen, ammonia and non-methane volatile organic compounds (secondary particles). Primary PM and the precursor gasses can have both man-made (anthropogenic) and natural (non-anthropogenic) sources. Anthropogenic sources include combustion engines (both diesel and petrol), solid-fuel (coal, lignite, heavy oil and biomass) combustion for energy production in households and industry, other industrial activities (building, mining, manufacture of cement, ceramic and bricks, and smelting), and erosion of the pavement by road traffic and abrasion

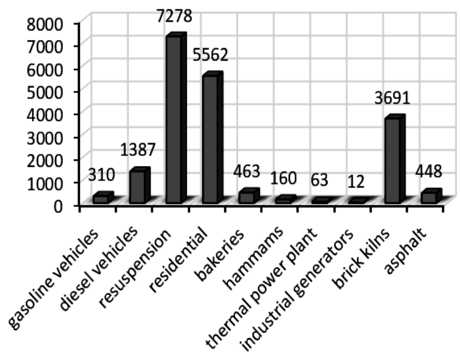

Fig.9 Inventory of Emission of PM in Kabul (Annual Emissions, Tons). Source: (ADB, 2006)

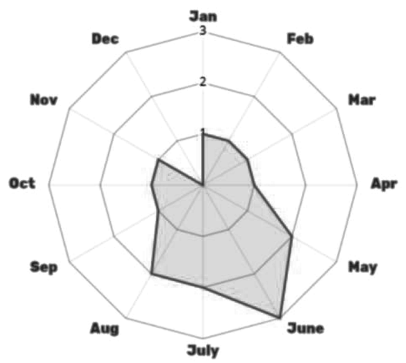

Fig.10 Wind rose for the considered case base meteorological data

of brakes and tyres. Secondary particles are formed in the air through chemical reactions of gaseous pollutants. They are products of the atmospheric transformation of nitrogen oxides (mainly emitted by traffic and some industrial processes) and sulfur dioxide resulting from the combustion of sulfur-containing fuels. Secondary particles are mostly found in fine PM. Soil and dust resuspension is also a contributing source of PM, particularly in arid areas or during episodes of long-range transport of dust[12)].

(2) Calculation results of PM_{10} emission

Table 2 shows the calculated parameters and **Table 3** shows the roads specifications which were used for calculation.

Table 2 Calculation condition.

Wind direction	N, NW
Temperature	20°c
Stability class	A, B, C, DD
Line source	Main roads
Roads width	20m, 30m, 40m
Pollutant	PM_{10}

Table 3 Roads specifications.

Features	Paved roads	Unpaved roads
Roads width (40m)	9.69 Km	-
Roads width (30m)	3.07 Km	10.12 Km
Roads width (20m)	8.68 Km	6.87 Km
Total length	21.44 Km	16.99 Km
Percentage (%)	55.79 (%)	44.21 (%)
Total roads length	38.43 Km	

Table 4 Specification of roads in case all are paved.

Features	Paved roads
Roads width (40m)	9.69 Km
Roads width (30m)	13.19 Km
Roads width (20m)	15.55 Km
Total roads length	38.43 Km

We divided the 4^{th} district area into 50×50 grids. Likewise, Wind speed contributes to how quickly pollutants are lift from the surface of the roads. However, strong winds don't always disperse the pollutants. Resuspension is high from surfaces that have much loose material of suitable size to be entrained into the air. Good examples of such situations are unpaved roads, which have several orders of magnitude higher emissions than paved roads.

In either **Fig.11** and **Fig.12** variety colors show that by changing the emission rate dute to wind speed of different places has different air pollution concentration. From outside to center the concentration is in increasing. It means purple color areas has the highest and the blue color has the lowest amount of PM_{10} concentrations. In **Fig.11** the highest amount of concentration is 800 $\mu g/m^3$, due to paving roads (**Fig.12**) air pollution is greatly reducing about 81%. Temperature and sunlight (solar radiation) play an important role in the chemical reactions that occur in the atmosphere to form photochemical smog from other pollutants.

In the light of the above, there are two fundamental assumptions that need to be considered: (i) the amount of dust available on streets is generally not known but due to the contribution of resuspension to PM that has been quantified before and after washing the street (Yu et al., 2006), it can be said that the available dust on the street is greater than its contribution to the PM concentration; (ii) once it is known that the existing dust on the road does not limit the maximum amount provided by traffic on the resuspension, it is necessary to estimate the limitation that the rain has on the amount of dust that can be resuspended.

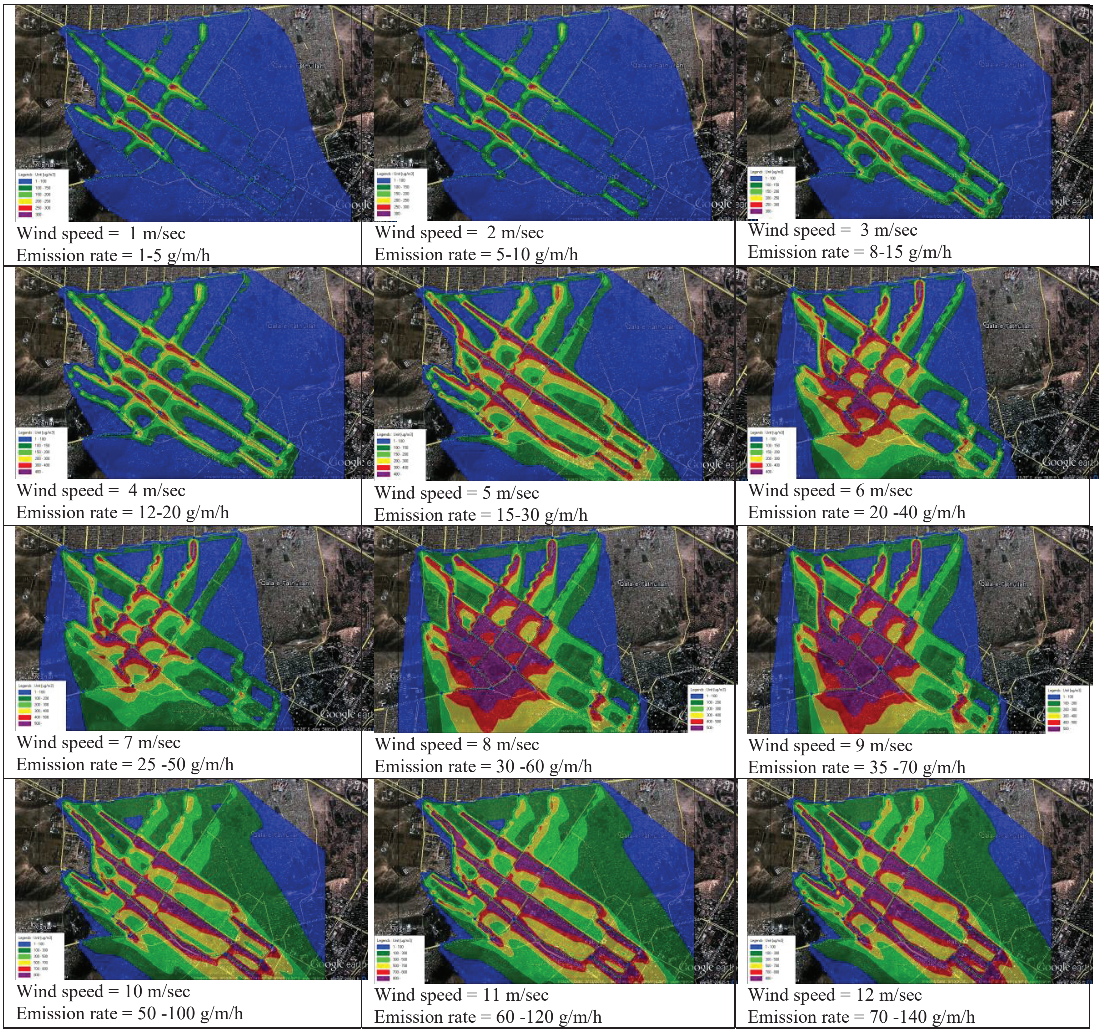

Fig.11 Distribution of of modeled PM_{10} concentrations from vehicular traffic in 4th didtrict of Kabul

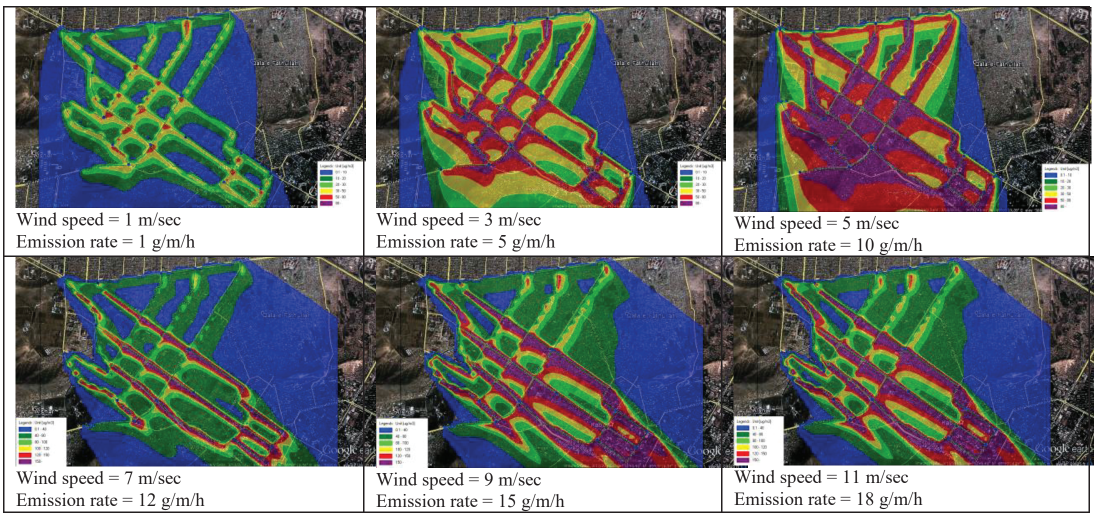

Fig.12 Distribution of modeled PM_{10} concentrations from vehicular traffic in case all roads are paved.

5. DISCUSSION

Roads traffic has long been distributed as one of the most significant sources of air pollution in urban areas. Cheap vehicle speeds, high traffic volumes, and complex topographical features (i.e., tall building and closely spaced streets) all contribute to elevated levels of particulate matter. In Kabul city, suspended particulate pollution contributes to an estimated 3000 deaths each year. The many health and environmental impacts associated with particulate matter underscore the importance of understanding particulate emissions and concentrations. For the dwellers of the city, a breath of fresh air cannot be purchased for any price in most days of the year. To watch the city landscape from an advantage point, it looks like it has caught fire.

6. CONCLUSION

1) Because of the bowl-shaped topography of the Kabul city, high elevation, and weak prevailing winds during the late fall and winter months, especially during the evening and early morning hours, Kabul is strongly affected by the thermal and topographical stagnation regime and high levels of air pollution.
2) The meteorological factors, roads situation are strongly influenced the simulation results while to using the METI-LIS tool.
3) Due to paving roads air pollution is drastically reducing about 81%.
4) To determine particulate matter concentrations near roadways, engineers must currently rely on generic emission factors that are highly uncertain. This research will enable a more realistic assessment of the environmental impacts of traffic on particulate air pollution.

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