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EMISSIONS MODELLING AND IMPACT ASSESSMENT OF FUGITIVE PARTICULATE MATTER IN ARID AND SEMI-ARID REGION

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Abstract: Countries in the developing arid and semi-arid regions (i.e. North Africa, Middle East, and Central Asia) are experiencing a large wave of urbanization and industrialization, adversely compromising the area's air quality. The hot climate and dry, arid conditions promote the emitting of fugitive Particulate Matter (fPM); particles emitted unintentionally by escaping a process (e.g. loading and unloading of materials, abrasion of road wear, or dust resuspensions) or emitted naturally by wind erosion. Over the recent years, particulate matter (PM) pollution in arid regions had become a topic of increasing concern due to the reported health hazards associated with its exposure. However, accurate determination of fPM introduces a big challenge in scientific research due to the uncertainty of their behaviour. In this study, we examined two sources that are believed to contribute significantly to fPM in arid regions: (1) emissions from loose Calcisols (i.e. soils with a substantial accumulation of secondary carbonate, common in dry and semi-dry regions) and (2) non-exhaust traffic induced emissions (from brake, tyre and road abrasion as well as resuspensions generated by passing vehicles). Field campaigns were carried out to measure fPM concentrations from loose soils at a construction site and a highly trafficked road within the city of Doha, Qatar. Fugitive Dust Model (FDM) was used in an iterative manner to calculate emission fluxes of fPM due to wind erosion, and fitted to a power function to establish the wind velocity dependence. Herein we present the results from the completed loose soil study and the preliminary impact assessment of the fugitive particulates.

Key words: *fugitive particulate matter, atmospheric dispersion, emission modelling***.**

INTRODUCTION

Countries in the developing arid and semi-arid regions (i.e. North Africa, Middle East, and Central Asia) are experiencing a large wave of urbanization and industrialization, adversely affecting the area's air quality. In 2008, outdoor air pollution contributed primarily to 7.3% of the total deaths in the UAE (Gibson *et al.*, 2013). Over the recent years, particulate matter (PM) pollution in these regions had become a topic of increasing concern due to the reported health hazards associated with its exposure (Tsiouri *et al.*, 2015). Fugitive particulate matter (fPM) are the unrestrained particles that escape to the atmosphere when applying a mechanical force on an exposed surface (i.e. emitted by non-point sources) (Hassan *et al.*, 2017). Source apportionment studies performed in highly populated Middle Eastern cities suggest that a large portion of PM_{10} particles in arid environments come from fugitive sources; eg. geological material, tyre and brake markers, and dust resuspensions (Saraga *et al.*, 2017).

In order to manage fPM emissions, emission sources and the quantity of pollutants released into the atmosphere must be identified. Therefore, emission inventories are the key for setting air quality guidelines, designing effective control measures and providing background data for air quality modelling . Developing a sound emission inventory requires dependable data that is often obtained from real-time measurements, laboratory experiments and available (national or international) databases (Chatzimichailidis *et al.*, 2014).

Most of the existing inventories, however, were developed for European and North American regions with a very little focus on fugitive sources (Pouliot *et al.*, 2012), and a remarkable lack of data on the developing arid and semi-arid regions. For example, Waked *et al.* (2012) composed the first spatially and temporally emission inventory for anthropogenic and biogenic sources in Lebanon. Emissions of CO, NO_x, SO_2, NMVOC, NH_3, PM_{10} and $PM_{2.5}$ from power plants, industry, and on-road transport were calculated following EMEP/EEA air pollutant emission inventory guidebook. Fugitive emissions such as windblown dust and road resuspensions, which are significant sources of dust in the arid environments, were not covered in his inventory.

The present study aims to contribute to a complete emission inventory of fPM sources, applicable for the arid and semi-arid environments of the developing regions. In this study, we examine the use of the multiple emission modelling approaches related to fPM and their effect on the metropolitan area of Doha city, the capital of the state of Qatar, including wind erosion from non-irrigated in-city bare lands (eg. construction sites) and the effect of the surrounding desert. The emission inventory compiled in this work is considered the first for the state of Qatar and will act as a preliminary assessment to highlight the significance of fPM emissions especially in urban environments.

METHODOLOGY

For this work, the greater metropolitan area of Doha in the State of Qatar was selected. The study covers a period of three months (April to June 2015). During the same period, the first airborne particulate matter characterization was conducted for the state of Qatar (Saraga *et al.*, 2017). Impact of the fugitive particulate matter is a result of the a) specific soil, land use characteristics, and supernatant activities, b) interaction between soil and surface meteorology, and c) the atmospheric transfer of particulates to the surrounding area. The selected approach for each of the above phenomena is described in the following paragraphs.

Emissions Modelling

Emissions modelling of the fugitive particulate matter was based on two specific approaches. The first approach is based on the well-established and validated model of Schaap *et al.* (2009) for the regional modelling of particulate matter. This model has been developed on the principles of the proposed atmospheric dust cycle by Marticorena and Bergametti (1995). Later, others (e.g. Liora *et al.* (2015)) elaborated on the parameters of these models and proposed improvements. However, in this work, the original regional modelling scheme was selected as a baseline with no later modifications. The second modelling scheme (Figure 1) is based on a simpler approach but its parameters were developed and validated in our own field studies that characterized emissions from the local surface soil (i.e. Calcisols) (Hassan *et al.*, 2016). More details can be found in the related literature.

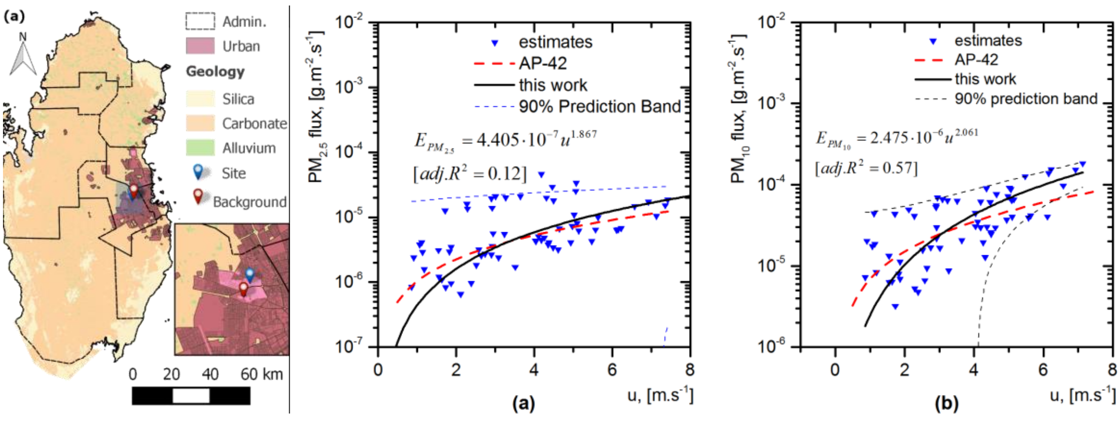

Figure 1. Details of the emissions field study (inset) and the developed (a) $PM_{2.5}$ and (b) PM_{10} emission factors for the local surface soil type (i.e. calcisols) (Hassan *et al.*, 2016).

Land use mapping and inventory

Most methodologies for the estimation of fugitive particulate matter emissions are based on the land use mapping. For the current study area, there are two soil databases. One is the Harmonized World Soil Database (HWSD) (FAO, 2014) which provides surface soil (0-100cm) data. The other is based on a recent geological study focused on the State of Qatar (West and Al-Mulla, 2013) and our own mapping of the exposed (barren) land within the metropolitan area. Both maps were scaled to a resolution of 2x2 km^2 and the clay-sand-silt compositions were processed. The former is necessary for the Schaap *et al.* (2009)

model calculations. Following the availability of land-use mapping and emissions modelling, three distinct scenarios were formed, these are presented in Table 1.

Table 1. Modelling Scenarios

ID	Land Use	Emission Model
HWSD	Harmonized World Soil Database (FAO, 2014)	Regional Modelling for Particulate Matter (Schaap *et al.*, 2009)
QGIS	Qatar Centre for GIS (West and Al-Mulla, 2013)	Regional Modelling for Particulate Matter (Schaap *et al.*, 2009)
OWN	Qatar Centre for GIS (West and Al-Mulla, 2013) and barren-land own-mapping	Emission Factors for Calcisols (Hassan *et al.*, 2016)

Atmospheric Dispersion Modelling

The latest CALPUFF model (v7.2.1), coupled with the interface from Lakes Environmental Software was chosen to calculate the atmospheric dispersion of particulate matter. CALPUFF is a non-steady state Lagrangian Gaussian puff model that has been developed since 1990. The same configuration was used for all three modeling scenarios in order to evaluate their differences on the final impact assessment. CALPUFF was modified to expand the hard-coded constraints on the number of total sources that can be handled simultaneously. Two modified versions were compiled using the Lahey/Fujitsu Fortran Express v7.3 (Windows) and PGI Fortran v16.10 (Unix). Both were verified using the original compiled model with accuracy up to the inherent numerical error. Verification results are not shown here for brevity. Meteorological input was provided in the form of MM5 weather data based on a parameterization described at an earlier work (Gopalaswami *et al.*, 2015).

RESULTS AND DISCUSSION

Figure 2 presents the total estimated PM10 emissions for the three scenarios (Table 1) and the 3 months period (April to June 2015). The emission patterns, among the scenarios, are not that different but still not at the same level. There is a significant difference between the HWSD and the other two scenarios. In "OWN" the total PM10 emissions are less than 75 g.m^{-2}. The HWSD scenario presents emissions more than 50 g.m^{-2} even up to the level of 300 g.m^{-2} for regions that are "exposed" to higher intensity winds (e.g. Northwestern coastline).

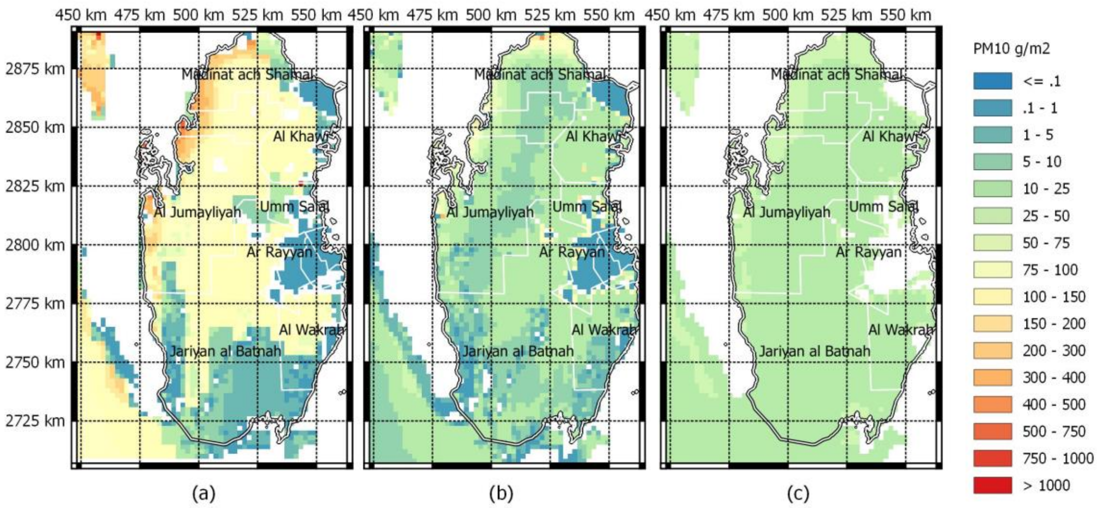

Figure 2. The total estimated PM10 emissions for the period April to June, 2015 for the three modelling scenarios a) HWSD, b) QGIS, and c) OWN.

The probability function of each of the three scenarios is illustrated in Figure 3. It supports the findings of the emission maps and showcases, even more, the differences between the approaches. In addition, HWSD and QGIS show a bimodal behavior but no specific distribution could be recognized. Emissions in OWN have a single mode and could potentially follow a log-normal distribution.

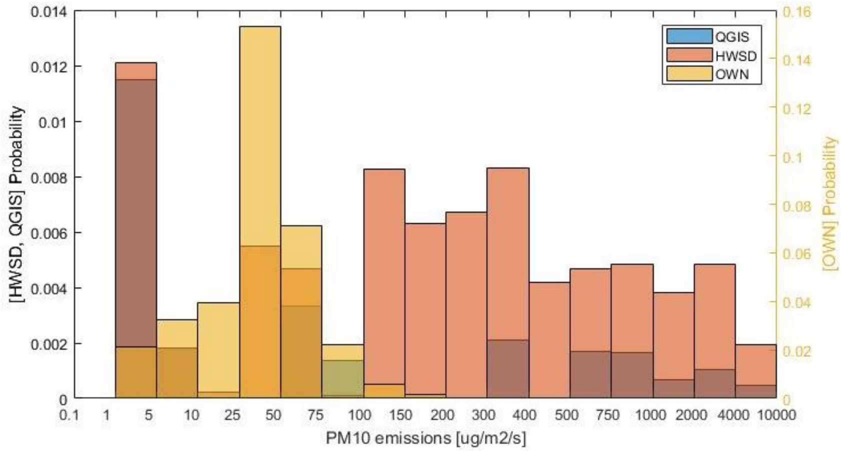

Figure 3. Probability density functions of the hourly PM10 emissions [μg.m^{-2}.s^{-1}] for the three scenarios.

Finally, Figure 4 presents the ground level concentrations following the three modelling scenarios in comparison with field measurements. Field measurements were collected for the three months study period using both particle counters and volume samplers. Details of the field measurements are given elsewhere (Saraga *et al.*, 2017). We observe that none of the scenarios has a very good agreement with the measurements. HWSD and QGIS capture, in most cases, but overestimate the level of the severe events. OWN approaches better the measurements' variability and level, but it generally underestimates PM levels. Nevertheless, it is closer to the actual measurements, most probably because it includes an additional type of source, the construction sites (barren land) within the city.

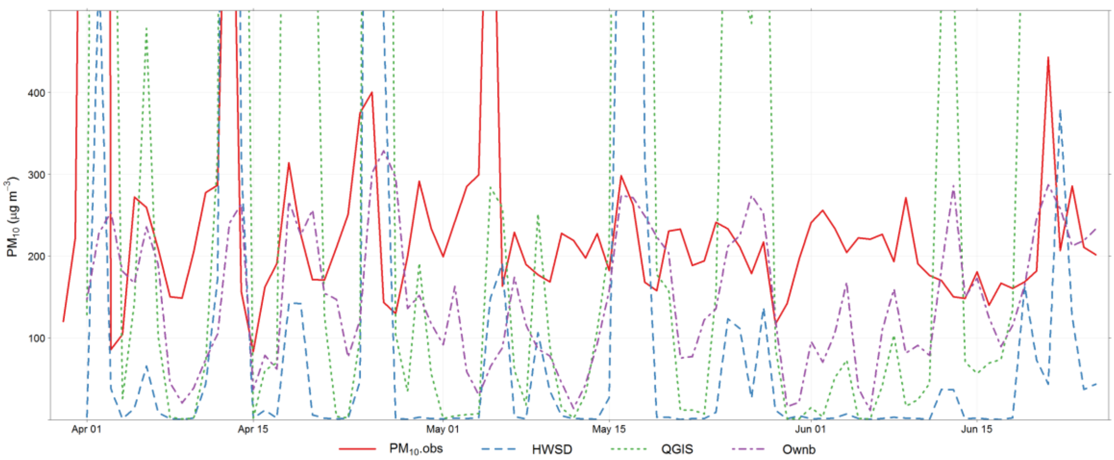

Figure 4. Daily averages of ground level PM10 concentrations [μg.m^{-3}] for the three scenarios and the field measurements (excluding severe dust events periods with values >400 μg.m^{-3}).

CONCLUSIONS

The differences between the three scenarios and emissions modelling approaches are profound although all results are plausible. Previous works (Liora *et al.*, 2015) have shown similar levels for dry regions such as arid areas of North Africa. However, in most cases, the results were successfully evaluated against particulate matter measurements located hundreds of kilometers away and not very close to the actual source. On the other hand, the preliminary assessment in this study is not as successful. For the HWSD and QGIS, the derived ground level concentrations are two to three times higher than the expected during severe dust events (Figure 4); the opposite is happening during normal days. This, by itself, constitutes a reason to question the validity of the selected emission modelling approach and/or of its parameterization. For example, HWSD and QGIS are using the same emissions model but the driving parameters are different and probably critical. On the other hand, using OWN approach results in similar level concentrations, compared to the field measurements while the temporal variability is also captured. The overall agreement is still not satisfactory. OWN approach underestimates concentrations but significant fPM sources have not been included yet (i.e. traffic, industry, sea salt, and transboundary transfer).

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