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Assessing sources of airborne mineral dust and other aerosols, in Iraq

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ABSTRACT

Most airborne particulate matter in Iraq comes from mineral dust sources. This paper describes the statistics and modeling of chemical results, specifically those from Teflon® filter samples collected at Tikrit, Balad, Taji, Baghdad, Tallil and Al Asad, in Iraq, in 2006/2007. Methodologies applied to the analytical results include calculation of correlation coefficients, Principal Components Analysis (PCA), and Positive Matrix Factorization (PMF) modeling. PCA provided a measure of the covariance within the data set, thereby identifying likely point sources and events. These include airborne mineral dusts of silicate and carbonate minerals, gypsum and salts, as well as anthropogenic sources of metallic fumes, possibly from battery smelting operations, and emissions of leaded gasoline vehicles. Five individual PMF factors (source categories) were modeled, four of which being assigned to components of geological dust, and the fifth to gasoline vehicle emissions together with battery smelting operations. The four modeled geological components, dust-siliceous, dust-calcic, dust-gypsum, and evaporate occur in variable ratios for each site and size fraction (TSP, PM10, and PM2.5), and also vary by season. In general, Tikrit and Taji have the largest and Al Asad the smallest percentages of siliceous dust. In contrast, Al Asad has the largest proportion of gypsum, in part representing the gypsiferous soils in that region. Baghdad has the highest proportions of evaporite in both size fractions, ascribed to the highly salinized agricultural soils, following millennia of irrigation along the Tigris River valley. Although dust storms along the Tigris and Euphrates River valleys originate from distal sources, the mineralogy bears signatures of local soils and air pollutants.

1. Introduction

Airborne mineral dust severely impacts human health (Bu-Olayan and Thomas, 2011; Engelbrecht et al., 2009a,b) as well as daily operations and activities in Middle Eastern countries, including Iraq. Major particulate matter (PM) contributions come from natural dust sources such as soils (Buringh, 1960), exacerbated by agricultural (Al-Awadhi et al., 2005; Al-Awahdi et al., 2003) and other human activities (Al-Awadhi, 2001), as well as diesel vehicle emissions, oil refineries, construction, and industry in the region. Desertification over the past decades and wind erosion in the Sistan region of southeastern Iran is responsible intense dust storms, affecting regional air quality and severely impacting on human health (Rashki et al., 2013). From an electron microscopic study on individual aerosol particles collected over Riyadh in Saudi Arabia, Pósfai et al. (2013) established the relationship between mineral dust particles in the atmosphere and cloud droplet nucleation.

The Enhanced Particulate Matter Surveillance Program (EPMSP) provided measurements of the chemical and physical properties of airborne mineral dusts and other aerosols at 15 sites in the Middle East (Engelbrecht et al., 2008; Engelbrecht et al., 2009a,b). Observed chemical variations point to spatial and temporal differences amongst the sites over the year-long sampling period (Kutiel and Furman, 2003), related to differences in regional soil mineralogy (Kahlaf et al., 1985), transport patterns, local industries, and seasonal meteorology. PM concentration levels often far exceed those of international health standards during severe dust storms (Draxler et al., 2001; Engelbrecht et al., 2008, 2009a). The major goal of the above mentioned surveillance was to determine levels of potentially harmful trace elements such as lead, arsenic, and other heavy metals. The elemental and ion compositions, together with X-ray diffractometry and SEM based individual particle-chemistry also provided supporting evidence of aerosol mineralogy (Engelbrecht et al., 2009a).

We show that statistical analysis of the chemical data provides a better understanding of chemical interrelationships and mineral assemblages, typical of airborne dust and pollutant sources impacting in the region. Methodologies applied include the calculation of correlations, Principal Components Analysis (PCA), and Positive Matrix Factorization (PMF) modeling. Chemical data from

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filter sets collected at the six military sites in Iraq were statistically analyzed – data mining results from the Teflon® filter set are presented in this paper.

2. Regional setting

2.1. Terrain

The Syrian Desert occupies much of western Iraq, and the Arabian Desert much of the country to the south and southwest. Iraq is composed of broad arid plains, with two regularly flooded valleys of the Tigris and the Euphrates Rivers, transecting the country from northwest to southeast (Fig. 1). These river valleys are narrow for the first third of their flows in Iraq, before opening into broad flood plains north of Baghdad, creating a well-watered agricultural terrain. Elevations along the river valleys decrease from north to south, from Syria at 335 m and Turkey at 550 m, to 30–55 m a few kilometers to the north of Baghdad and to 9–25 m in the lower Mesopotamia flood plain, and southward towards the Shat Al-Arab delta and the Persian Gulf. The southernmost river valley is marshy, with areas that become seasonal lakes. Northern Iraq includes part of the Taurus Mountain Range, which extends into the Anatolian Plateau in Turkey. Elevations in this part of the country range from 1525–2745 m near that border, with a few peaks above 3350 m. Northeastern Iraq shares the western portion of the Zagros Mountains with Iran.

Four landforms (Omer, 2011) can be distinguished in Iraq, (i) the sedimentary plain in the northeast occupying 30% of the land surface, receiving an annual rainfall of 50–200 mm, (ii) the desert plateau in the west occupying 39% of the land surface, similarly receiving 50–200 mm annual rainfall, (iii) the mountainous region in the north and northeast occupying 21% of the land surface, receiving 400–1000 mm annual rainfall, and (iv) the undulating terrain forming a transitional area between the low plains and the mountains in the north and northeast, being 10% of the land surface, and receiving 250–450 mm rainfall. However, there is great variation in annual rainfall, especially in the region receiving on average less than 400 mm of rain per annum. Roughly 90% of the annual rainfall in Iraq occurs in winter between the months of November and April.

Fig. 1. Six aerosol and soil sampling localities in Iraq, showing Tikrit, Balad, Taji and Baghdad along the Tigris River valley, and Al Asad and Tallil close to and to the west of the Euphrates River.

The soils in Iraq can be divided into four physiographic regions (Buringh, 1960).

(1) Lower Mesopotamian plain: It is approximately 600 km long and 200 km wide, beginning 100 km northwest of Baghdad and ending near the Persian Gulf. The broad plain of the Tigris and Euphrates Rivers is mainly formed by sedimentation of fluvial material, composed of a variety of largely arid alluvial soils, often containing gypsum. As a result of the arid climate and agricultural practices, the soils in this region have become extensively salinized and sometimes alkalinized. This region of Iraq is of importance due to its irrigation practices since ancient times. The plain can be sub-divided into regions with different soil conditions, mainly as a consequence of varying soil forming and sedimentation processes, as well as hydrological conditions.
(2) Desert regions: The extensive western part of the country is consists of a gypsum and limestone desert, with partly sandy and pebbly desert terrain and extensive sand dunes in the south. There are many marshy depressions and lacustrine areas of former lakes, all strongly saline, in the southeast.
(3) Uplands and hilly region: These extend from the lower Mesopotamian plain to the Zagros mountains in northeastern Iraq. There is a transition from deeply weathered reddish-brown soils to the uplands consisting of shallow soils, overlying gypsum, mud, sandstone, limestone and gravel.
(4) Mountain region: This is part of the Zagros mountains along the northeastern border of Iran, consisting of multiple parallel mountain ranges of limestone and metamorphic rocks, separated by valleys of deeply weathered soils, a few of which are important to agriculture.

2.2. Climate and land use

Except for a small part in the northeast, the whole country has an arid or desert, subtropical continental climate (Omer, 2011). Summers are hot and completely dry while winters are cool. Temperatures are more or less similar throughout the country except in the mountainous northeast. The monthly mean maximum temperatures for July range from 38–43 °C, although the maximum in June, July, and August can reach 50 °C. The monthly mean minima for January range between 1 °C in the southwestern desert and the northeastern foothills, to −8 °C in the central part of the river plain. The lowest minima are about −14.5 °C in the northern desert, −11 °C in the foothills and −8 °C in the central part of the river plain. Near the coast the lowest minimum is −4.5 °C, in part ascribed to the effect of the cold Persian Gulf waters. Because of very high evaporation, crops in the Mesopotamia region cannot survive without extensive irrigation from the Tigris and Euphrates Rivers.

The summer months are marked by two types of wind. The southern and southeasterly Sharqi is a dry, dusty wind with occasional gusts of up to 80 km/h, occurring from April to early June and from late September through November. This wind is often accompanied by violent dust storms, with plumes rising to several thousand meters. From mid-June to mid-September the Shamal is the prevailing wind, blowing from the north and northwest. It is a consistent, steady wind, blowing dust across Iraq and other countries along the Persian Gulf, including Kuwait, Qatar, the United Arab Emirates, and Bahrain.

Land potentially available for agriculture is less than 27% of the total area of Iraq, of which approximately half is suitable for flood irrigation. Irrigation potential was estimated in 2006 at over 5.15