Occurrence and sources of natural and anthropogenic lipid tracers in surface soils from arid urban areas of Saudi Arabia

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ABSTRACT

Soil particles contain a variety of natural and anthropogenic organic components, and in urban areas can be considered as local collectors of pollutants. Surface soil samples were taken from ten urban areas in Riyadh during early winter of 2007. They were extracted with dichloromethane-methanol mixture and the extracts were analyzed by gas chromatography-mass spectrometry. The major compounds were unresolved complex mixture (UCM), plasticizers, n-alkanes, carbohydrates, n-alkanoic acids, hopanes, n-alkanols, and sterols. Vegetation detritus was the major natural source of organic compounds ($24.0\pm15.7\%$) in samples from areas with less human activities and included n-alkanes, n-alkanoic acids, n-alkanols, sterols and carbohydrates. Vehicular emission products and discarded plastics were the major anthropogenic sources in the soil particles ($53.3\pm21.3\%$ and $22.7\pm10.7\%$, respectively). The anthropogenic tracers were UCM, plasticizers, n-alkanes, hopanes and traces of steranes. Vegetation and human activities control the occurrence and distribution of natural and anthropogenic extractable organic matter in this arid urban area.

Capsule:

This work shows that human activities are critical factors that influence the characteristics and distribution of EOM in soils of arid urban regions.

Key words: soils, biomarkers, lipids, petroleum residues, plasticizers.

64

1. Introduction

Biogenic and anthropogenic organic matter (OM) is a major carbonaceous fraction in different ecosystems (e.g. Hansell and Carlson, 2014; Lischke et al., 2014; Schmidt et al., 2011). The occurrence and concentrations of OM in urban and rural/remote region soils vary spatially and seasonally (Fraser et al., 1998; Kononova, 2013; Oros et al., 2002; Trendel et al., 2010). One of the primary sources of OM in soil is material from plant litter. Other sources include anthropogenic organic chemicals such as pesticides and fossil fuel residues from vehicles (Al-Mutlaq et al., 2005, 2007; Rushdi et al., 2005, 2013; Yang et al., 2013). The composition, properties and distribution of this OM controls the formation of soil organic matter (SOM) and humification processes (Kononova, 2013; Scholes et al., 1997; Schmidt et al., 2011). Microbial activity and biomass are also important factors in SOM formation and alteration (Schmidt et al., 2011). Therefore, SOM varies in composition and properties. The major studies on soil OM have focused on bulk properties (Kögel-Knabner, 2000; Martin and Haider, 1986), whereas extractable organic matter (lipid) studies are relatively few (Otto and Simpson, 2005; Rogge et al., 2012; Rushdi et al., 2005, 2006). Less attention has been paid to the lower molecular weight OM (Kögel-Knabner, 2000).

Lipid compounds usually comprise 1-5% of the total SOM. They are derived from plants, fungi, bacteria and mesofauna, and generally consist of n-alkanes, n-alkanols, wax esters, fatty acids, steroids, terpenoids and acyl glycerols (Oros et al., 2002). These products are a result of decomposition and exudation of OM from various sources (Miller and Donahue, 1995). Lipids can be found either free in the soil matrix, chemically bound

87 in humic and fulvic material, or absorbed to soil particles (Kononova, 2013; Schmidt et

88 al., 2011).

89 Thus, characterization and identification of organic compounds and OM contents

90 of surface soils are important for understanding the OM composition and compound

91 sources that may be introduced to the different environmental compartments, such as for

92 example: (1) absorption into the food chain, (2) advection into the atmosphere via dust

93 resuspension, machinery and/or human activities, and (3) wash-in to water reservoirs. It

94 will also aid to better understand the various effects on human health and environmental

95 assessment processes.

96 The extractable organic matter (EOM) of surface soil has not been fully

97 characterized for the Arabian Peninsula region. The preliminary results have shown that

98 soil and sand dusts from Kuwait and Saudi Arabia contained a mixture of natural and

99 anthropogenic OM (Al-Mutlaq et al., 2002, 2007; Rushdi et al., 2005, 2006). Based on

100 aliphatic hydrocarbon contents of soil from Riyadh, the natural and anthropogenic

101 sources ranged from 20 to 57% and from 30 to 55% of the total lipid tracers, respectively

102 (Rushdi et al., 2005). Soil and sand samples from the vicinity of Kuwait City showed that

103 the natural sources ranged from 15 to 78% and the anthropogenic sources ranged from 8

104 to 88% of the total lipid compounds (Rushdi et al., 2006).

105 The research hypotheses of this work are: (1) the EOM sources in soils of an

106 urban arid region is mainly from traffic emissions; and (2) the sources of natural EOM

107 are relatively low and are primarily from soil microbiota with lesser contributions from

108 vegetation. Therefore, the main objectives of this work are to: (1) determine the chemical

109 composition of the solvent EOM in soils from arid urban areas in Saudi Arabia, (2)

110 identify the main sources of the EOM, and (3) examine the relative changes in the source

4

111 abundances of the EOM. Consequently, surface soil samples were collected from various

112 locations such as public parks, streets, and agricultural fields in the city of Riyadh to

113 investigate the occurrence of natural biogenic and anthropogenic lipid compounds.

114

115 **2. Experimental Methods**

116 *2.1.   Sampling and Extraction Procedure*

117   Surface oil samples were collected in November 2007 from different metropolitan

118 areas of the city of Riyadh in Saudi Arabia to characterize their solvent extractable lipid

119 contents by gas chromatography-mass spectrometry (GC-MS) analysis. The samples

120 were taken by scraping the uppermost layer (~1cm) of the soil in a 30 cm^2 area of

121 exposed surface. The locations of the samples were chosen to represent urban areas in

122 and around Riyadh, ranging from highly populated, with different human activities such

123 as public markets (OL), governmental site (NZ), industrial area (MN), rural areas with

124 limited human impact (OG), and areas with agriculture (AQ, JZ, DR) (Fig. 1).

125   After air drying, each sample was sieved to obtain the fine particles (<125μm)

126 before extraction. The extraction was performed twice by adding a mixture of

127 dichloromethane/methanol (40 mL 3:1 v/v) to about 5 g of the particles of each sample,

128 ultra-sonicating for 20 min, and then filtering through pre-extracted glass microfiber

129 filters (*Whatman®,* GF/A filters). Each total extract was concentrated under nitrogen

130 blow-down at room temperature to approximately 1.0-1.5 mL before GC-MS analysis. A

131 50 μL aliquot of each total extract was also derivatized with silylating reagent [N,O-

132 bis(trimethylsilyl)trifluoroacetamide, BSTFA, *Pierce Chemical Co*] by the standard

133 procedure before analysis by GC-MS. This derivatizing agent replaces the H in hydroxyl

groups with a trimethylsilyl [(CH$_3$)$_3$Si, i.e., TMS] group for better GC resolution of polar
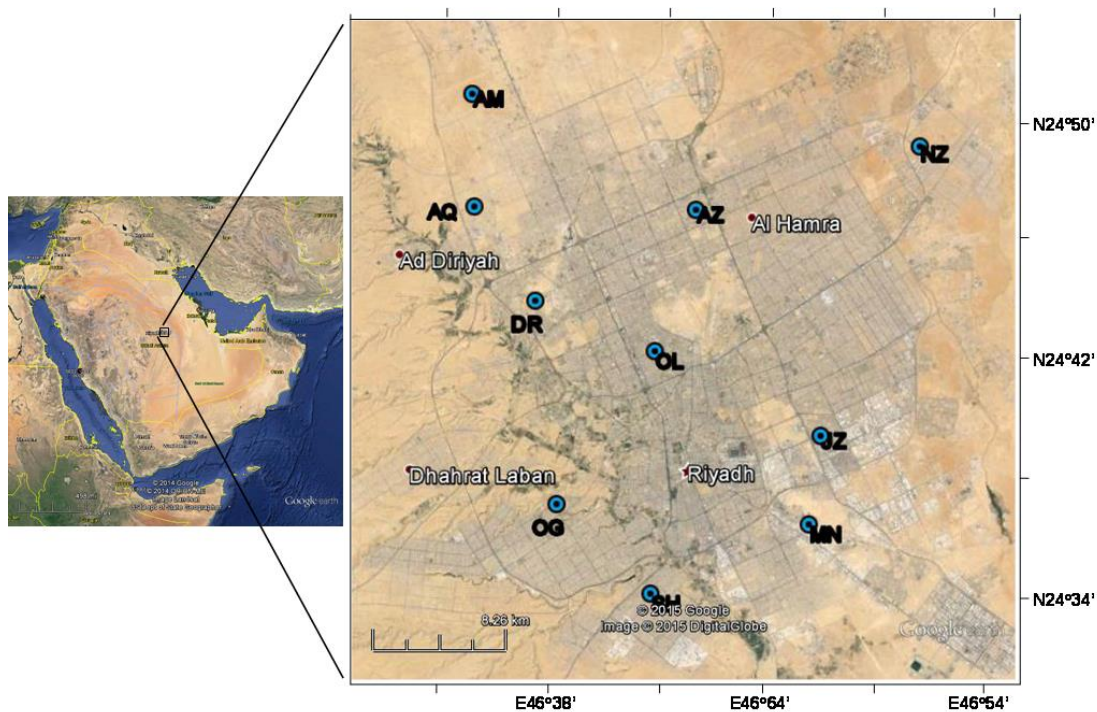
compounds.

Figure 1. Map showing the sampling sites and locations of the soil samples.

2.2.   Instrumental Analysis

The analyses of the total and silylated extracts were carried out by GC-MS, using an

Agilent 6890 GC coupled to a 5973 Mass Selective Detector with a DB-5 (*Agilent*) fused

silica capillary column (30 m x 0.25 mm i.d., 0.25µm film thickness) and helium as the

carrier gas. The GC was temperature programmed from 65°C (2 min initial time) to

300°C at 6°C min^{-1} (isothermal for 20 min final time). The MS was operated in the

electron impact mode at 70 eV ion source energy. The data were acquired and processed

with an Agilent ChemStation.

Compounds were identified by GC retention index and comparison of mass spectra with those of authentic standards, literature and library data, or characterized mixtures. Unknown compounds were characterized by interpretation of the fragmentation pattern of their mass spectra. The concentrations of the compounds in ng g^{-1} sample were obtained from ratios of peak areas in the total ion current traces of the samples versus the peak areas of a mixture of quantitative standards.

2.3.   Quality Control

Throughout the study, emphasis has been placed on the technical accuracy of the research. This applied to sample collection, analytical chemistry, biomarker tracer determination, and geochemical interpretation. All solvents used in the analytical workup procedure were tested for possible contaminants. Procedural blanks were analyzed to provide a qualitative and quantitative assessment of background contamination introduced by laboratory procedures. Blank extracts were performed through the entire project with batches of three samples. The contamination background levels were insignificant in all procedural blanks. The recoveries of external standards (tetracosane for n-alkanes; hexadecanoic acid for n-alkanoic acids, alkyl alkanoates and n-alkanols; sitosterol for triterpenoids; glucose for monosaccharides; and sucrose for disaccharides) ranged from 72 to 105%.

3. Results and Discussion

The total extract compositions of the soil samples from the metropolitan Riyadh area are given in Table SM1 (Supplementary Material) and vary in contents depending on

169   the locations and human activities. This variation is illustrated by the data for samples

170   from the city center (Fig. 2a, sample OL) and outside the city (Fig. 2b, sample OG). The

171   EOM consists mainly of mixtures of n-alkanes, n-alkanoic acids, sterols, n-alkanols,

172   carbohydrates hopanes, plasticizers, and UCM (unresolved complex mixture, mainly of

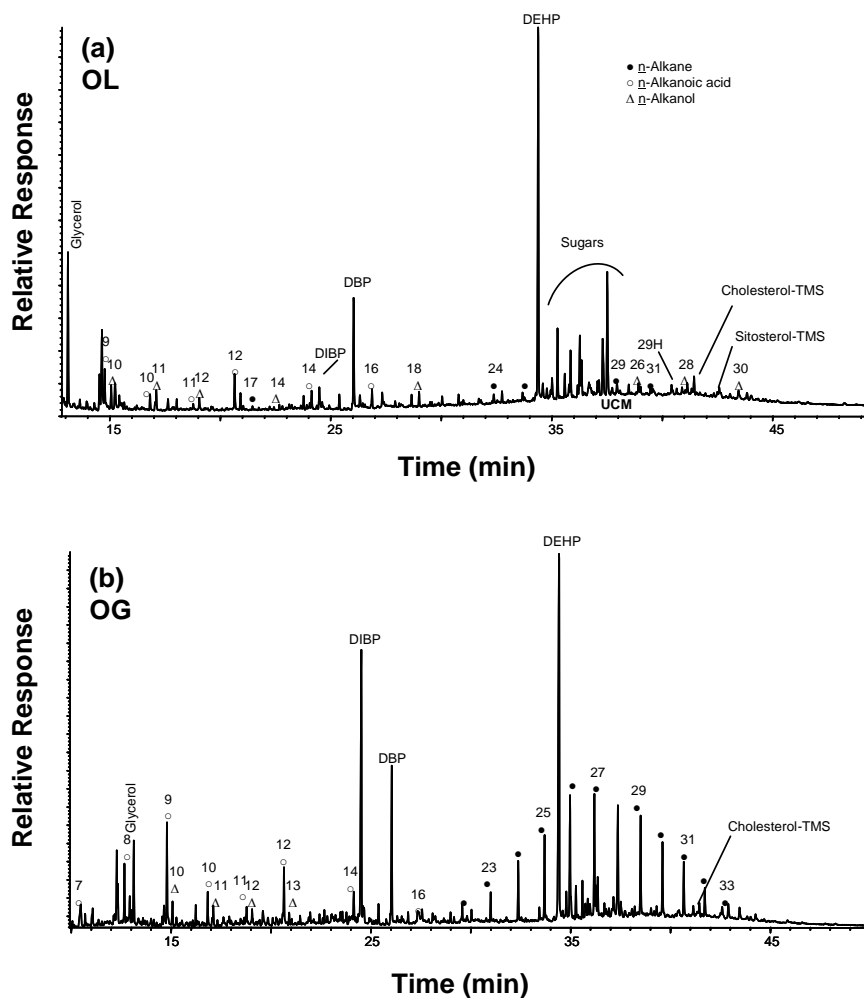173   branched and cyclic hydrocarbons from petroleum products, Simoneit, 1985).

**Figure 2.** GC-MS total ion current traces of total extracts of the soil samples from outside
and in the city of Riyadh showing the major organic components: a) OL (center); b)
OR (outside the city) (Numbers refer to the carbon chain length and symbols are:
DIBP= diisobutyl phthalate, DBP= dibutyl phthalate and DEHP = diethylhexyl
phthalate, H = hopanes, and UCM = unresolved complex mixture).

174

175   The n-alkanes were detected in all samples and ranged from C_{13} to C_{35} with a

176   maximum concentration (C_{max}) at nonadecane, eicosane or heneicosane for some samples

177   and heptacosane, nonacosane or hentriacontane for others (Fig. 3a,b; Table SM1). The

178   concentrations of the total n-alkanes ranged from 0.10 to 4.28 $\mu g\ g^{-1}$ with an average

179   value of $1.64 \pm 1.53\ \mu g\ g^{-1}$.

180   The n-alkanoic acids ranged from C_6 to C_{18} with a C_{max} at octanoic and nonanoic

181   acids in all samples, except sample JZ where the C_{max} was at tetradecanoic acid (Table

182   SM1). Their total concentrations ranged from 0.06 to 2.29 $\mu g\ g^{-1}$ with an average value of

183     $0.70 \pm 0.69\ \mu g\ g^{-1}$. The n-alkanols were also present in all samples and ranged from C_{10} to

184   C_{30} with a C_{max} at tetradecanol, hexadecanol, octacdecanol, octacosanol or triacontanol.

185   The total concentrations of n-alkanols ranged from 0.06 to 0.43 $\mu g\ g^{-1}$ with an average

186   value of $0.17 \pm 0.12\ \mu g\ g^{-1}$.

187   Sterols were found in all samples and included mainly cholesterol, brassicasterol,

188   campesterol, stigmasterol and sitosterol. The maximum concentration was either

189   cholesterol or sitosterol. The total concentration of sterols ranged from 0.03 to 0.35 $\mu g\ g^{-1}$

190   (mean = $0.12 \pm 0.11\ \mu g\ g^{-1}$). The carbohydrates in the soil samples included glucose,

191   sucrose and mycose as well as glycerol (sugar alcohol). The maximum concentration was

192   glucose, sucrose or mycose. The total concentrations of carbohydrates ranged from 0.18

193   to 3.22 $\mu g\ g^{-1}$ with an average concentration of $0.73 \pm 0.76\ \mu g\ g^{-1}$.
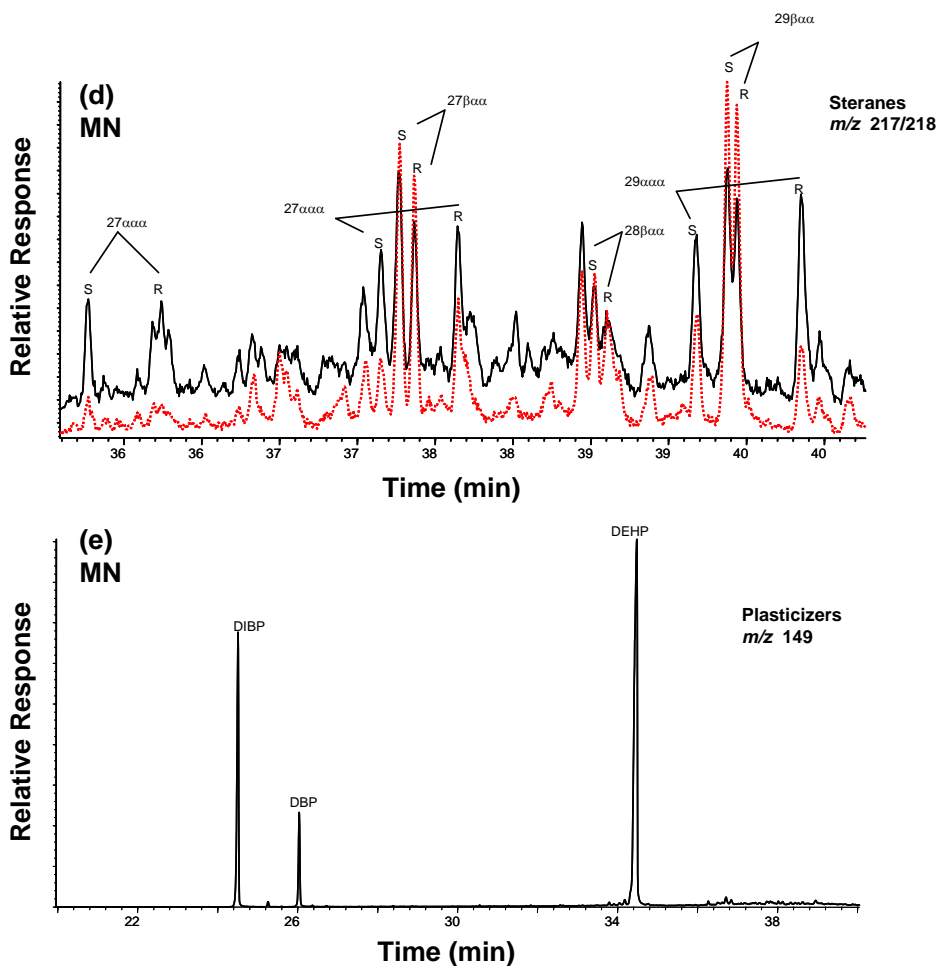
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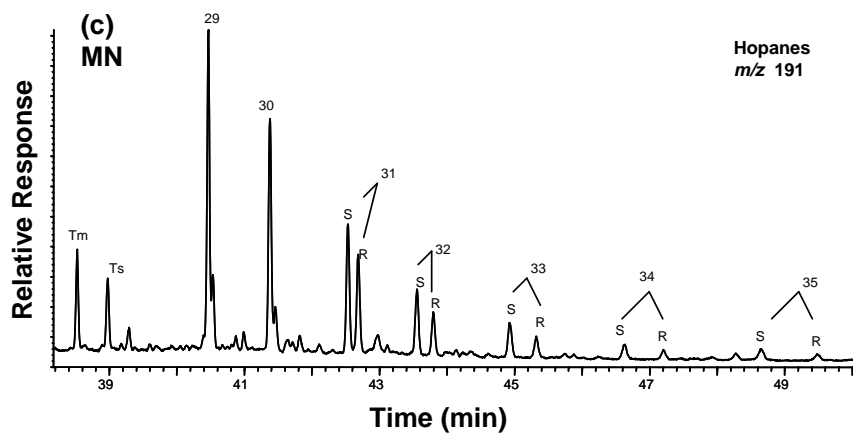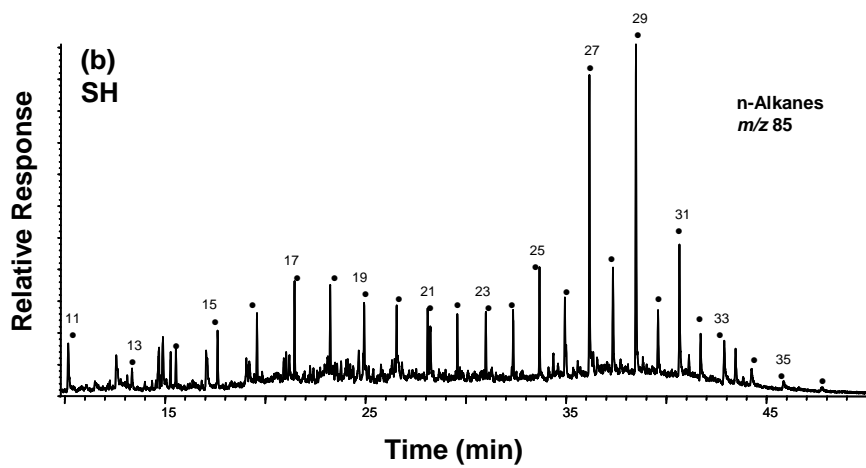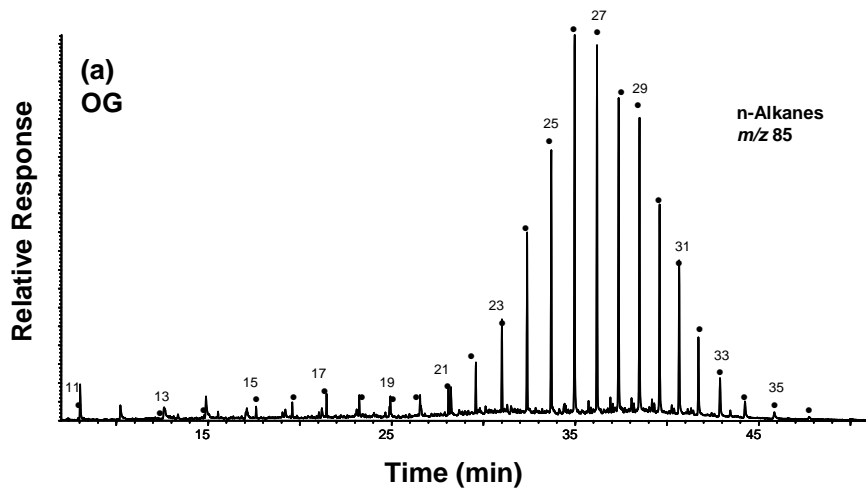
Figure 3. Examples of typical GC-MS key ion plots for various compound series found in the soil samples: a) OR and b) SH, *m/z* 85 for n-alkanes; c) MN, *m/z* 191 for hopanes; d) MN, *m/z* 217 and 218 for steranes, and e) MN *m/z* 149 for phthalate plasticizers.

196

197   Hopanes, biomarkers for petroleum residues (Peters and Moldowan, 1993;

198 Simoneit, 1985), were found to range from C_{27} to C_{35}, with a C_{max} at 29 and 30 (e.g. Fig.

199 3c), and concentrations from 0.02 to 3.35 µg g^{-1}, mean 0.47$\pm$1.08 µg g^{-1}. The C_{27} to C_{29}

200 steranes were only detectable in the sample from Manakh (MN) at a concentration of

201 7.36 µg g^{-1} (Fig. 3d). Plasticizers, including diethyl-, dibutyl-, dioctyl-phthalates and

202 dioctyl adipate, were significant components of these samples (Figs. 2 and 3e), with

203 concentrations ranging from 0.37 to 8.03 µg g^{-1} and mean of 2.49$\pm$2.40 µg g^{-1}.

11

204   The UCM concentrations were high in some samples and ranged from 0.0 to

205   83.28 μg g^{-1}. The average concentration of the UCM was 9.59 ± 26.03 μg g^{-1}.

206   The results indicate that both natural biogenic and anthropogenic sources are the

207   main inputs of the EOM to the soil samples of the city of Riyadh. Therefore, the entire

208   data set was statistically analyzed by principal component analysis (PCA) techniques

209   using the SPSS (IBM-Statistical Package for the Social Sciences, version 21) software to

210   understand the similarity among the different sites. The output of the PCA analysis,

211   explaining 85.1% of the variance, is shown in Figure 4a where two site groups were

212   recognized. The first group (C1 explains 47.1%) included the sites AQ, NZ, DR, OG,

213   AZ, JZ and OL; and the second one (C2 explains 25.4%) included the AM, MN and SH

214   sites. The MN site was in an industrial area and the AM and SH sites were in an area

215   where large trucks usually gather and idle before entering the city. The rest of the sites

216   were in different locations inside the city. This indicates that the locations and the type of

217   human activities have an impact on the characteristics and distributions of EOM in the
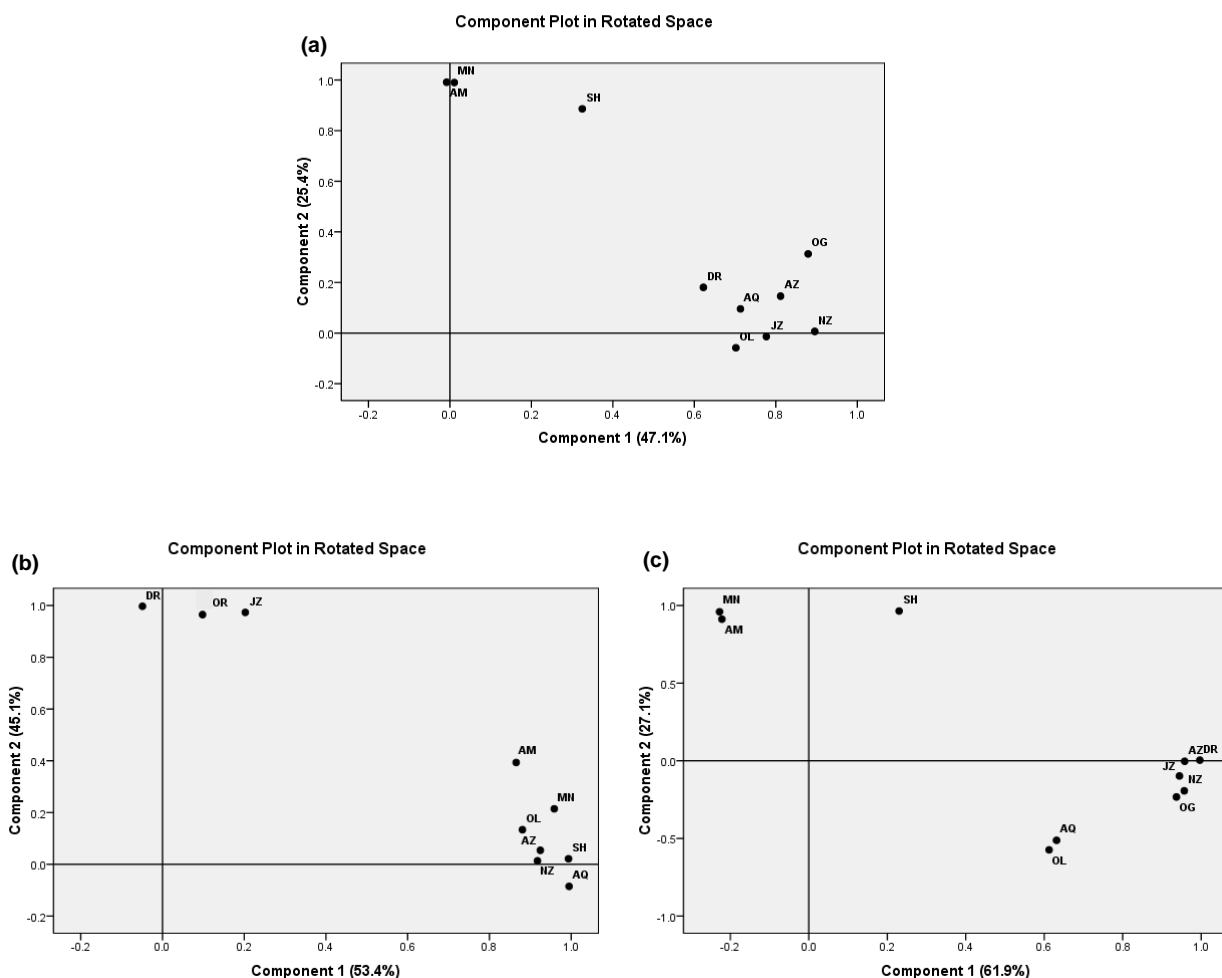
218   region.

Figure 4. Plots showing the statistical outputs of principal component analysis (PCA) for: (a) entire compounds; (b) natural biogenic compounds and (c) anthropogenic compounds.

2

220

3.1.   *Natural biogenic sources*

The occurrence and distribution of vegetation wax lipids, such as n-alkanes (in part), n-alkanols, and sterols, validates the natural source input from higher plant biomass to the soils, as well as carbohydrates indicate input from plant detritus (e.g. roots) and microbial/fungal activity in the soils (Otto and Simpson, 2005; Simoneit, 2006; Trendel et al., 2010). Plant wax n-alkanes show a C_{max} in the range of 25 to 33, which depends on

227 the plant species, as well as the season and locality (e.g. Simoneit, 1977; Buch and

228 McInerney, 2013; Eglinton and Hamilton, 1967). A CPI (here the ratio of

229 $\sum(C_{23}+C_{25}+C_{27}+C_{29}+C_{31}+C_{33}+C_{35})$-to-$\sum(C_{22}+C_{24}+C_{26}+C_{28}+C_{30}+C_{32}+C_{34})$ value of >1.0

230 is also an indicator of natural sources, whereas a CPI ~1.0 (Table SM1) supports a source

231 from fossil fuel utilization (Bray and Evans, 1961; Mazurek and Simoneit, 1984). The

232 odd numbered n-alkanes were dominant in the NZ, DR, SH, AZ and JZ samples, with

233 CPI ranging from 1.4 and 2.5, whereas samples from AM, OG, MN and OL showed no

234 significant carbon number preference with CPI of 0.8 to 1.1 (Table SM1). This odd

235 carbon number preference (CPI >1) of the n-alkanes supported by the C_{max} mainly at 29

236 and/or 31 is distinctive of higher plant waxes (e.g. Table SM1, Fig. 3b, Buch and

237 McInerney, 2013; Carr et al., 2014). The contribution of wax n-alkanes were calculated

238 following the method developed by Simoneit et al. (1991) and found to range from 0.01

239 to 0.31 µg g^{-1} in these samples.

240 The presence of long chain n-alkanols and minor n-alkanoic acids (>C_{20}), with

241 primarily only the even carbon number homologs in the series, is another indicator for

242 plant wax (e.g. Hitchcock and Nichols, 1971; Simoneit, 1989; Table SM1). The n-

243 alkanoic acids (<C_{20}) with a strong even carbon number predominance and C_{max} at 16,

244 are from multiple sources including microbiota and vascular plant waxes, cutin and

245 suberin (Holloway, 1982; Simoneit, 1989). The absence of unsaturated n-alkanoic acids

246 indicates extensive oxidation and biodegradation of the biomass components in the soils.

247 The even carbon numbered n-alkanols ranging from C_{18} to C_{30} with a C_{max} at 28 and 30

248 are from vascular plant wax typical of desert environments (Simoneit, 1989). The

249 occurrence of high levels of short chain n-alkanols (<C_{18}) with a C_{max} at 10, 11 and 12

250 indicate biodegradation and oxidative processes of the plant wax as well as microbial
251 activities in soils.

252   Steroids can be derived from vascular higher plants, microbial activity in the soil,
253 and cooking in urban areas (Huang and Meinschein, 1976; Rogge et al., 1991). The
254 phytosterols, mainly campesterol, stigmasterol and sitosterol, in the samples from outside
255 the city are derived from vegetation (Simoneit et al., 1983). The presence of cholesterol
256 at relatively high concentrations in most of the soil samples (e.g. AQ, AM, AZ, MN and
257 OL; Table SM1) indicates microbial and/or cooking activities in the area (Rogge et al.,
258 1991;   Thompson   et   al.,   2013).   The   ratio   of   cholesterol-to-
259 (campesterol+stigmasterol+sitosterol) was used to estimate the dominant sources of
260 sterols in soils (Table SM1). The sites of AQ AM and MN were found to have higher
261 ratios indicating that microbial activities and possibly cooking as a result of evening
262 picnics in these areas were the major sources of sterols.

263   The carbohydrates are comprised mainly of primary saccharides produced by
264 photosynthesis and utilized by biota for energy, with minor metabolites. Complex
265 carbohydrate biopolymers (e.g. cellulose) in soils undergo enzymatic and hydrolytic
266 degradation to simple sugars (i.e., glucose) (Gleixner et al., 2002). Glycerol, the simplest
267 reduced sugar, is derived from the hydrolysis of glyceride lipids and is a significant
268 carbohydrate component of the soils (mean concentration 0.17 µg g^{-1}, Table SM1). The
269 total saccharide concentrations are low in these soils (0.16 to 3.22 µg g^{-1}, mean 0.90 µg g^{-1}
270 ^{1}, Table SM1), compared to an example from a temperate region (3.77 to 23.71 µg g^{-1};
271 Medeiros et al., 2006). Also mycose (a.k.a. trehalose), the recognized fungal saccharide
272 (Niederer et al., 1989), is low compared to sucrose or glucose (Table SM1). This
273 indicates that fungal activity in these soils is minor. The ratio of sucrose-to-mycose was

274 used to explore the microbial/fungal activities in these soil samples. The ratios were low

275 in the sites of DR, OL and MN due greater fungal activity there. Moreover, the small

276 sugar levels in these samples confirm low primary production and alteration of soil

277 biomass.

278 The results of these natural compounds were also analyzed by principal

279 component analysis (PCA) to understand the similarity among these sites in terms of

280 natural components. The PCA analysis output (explaining 98.5% of the variance with an

281 Eigen value of > 1) is shown in Figure 4b where two groups were recognized. The first

282 group included the AQ, AM, NZ, SH, AZ, MN and OL sites (explained by 53.4% as C1

283 dominant) and the second group included the DR, OG and JZ sites (explained by 45.1%

284 as C2 dominant). The former sites are mainly located in areas with less vegetation and

285 relatively high human activities, where the latter sites are located in the city outskirts of

286 Riyadh in areas of relatively low human activities and more vegetation. This indicates

287 that the vegetation cover has an impact on the characteristics and distributions of the

288 natural EOM in the region.

289

290 *3.2. Anthropogenic sources*

291 Fossil fuel components such as n-alkanes, biomarkers (e.g. hopanes and steranes,

292 Fig. 3c,d and Table SM1), and UCM, as well as the plasticizers (Table SM1 and Fig 3e)

293 indicate anthropogenic inputs from traffic and litter (plastics) (Al-Mutlaq et al., 2002;

294 Rushdi et al., 2005). The n-alkanes with a carbon number predominance of about unity

295 (i.e., CPI ~ 1.0, Bray and Evans, 1961), after subtraction of the wax n-alkane contribution

296 (Simoneit et al., 1991), suggest a source from vehicle/traffic emissions. Crude petroleum,

297 the primary source of gasoline and diesel fuels, and lubricating oils, contains n-alkanes

16

298 ranging up to about C_{35} with essentially no carbon number predominance (CPI ~ 1)

299 (Simoneit, 1984) and with lower carbon number maxima in the range of C_{22} to C_{25}

300 (Simoneit, 1984). These results indicate that fossil fuel utilization is a major input of

301 organic matter to the soil samples, quite obvious for the AM and MN sites (Table SM1).

302 The contribution of total petroleum residues ranges from 0.48 to 98.86 µg g^{-1} of the total

303 EOM.

304 The presence of hopane and sterane biomarkers in the samples confirms the input

305 from traffic emissions (Simoneit, 1984). Hopanes and steranes are present in exhaust

306 particles from both auto and diesel engines (Simoneit, 1985). This particulate matter falls

307 out and becomes entrained in urban soil. The C-22 S/(R+S) epimer ratios of the

308 homohopanes (C_{31} and C_{32}), which have been used as maturity indices for petroleum

309 (Seifert and Moldowan, 1978), range between 0.36-0.65 in the soil samples from the city,

310 further indicating the anthropogenic petroleum product inputs (Table SM1). Evidently,

311 crude oil products are one of the major inputs of the OM to the soils. The predominant

312 petroleum component is derived from engine lubricating oil in vehicle emissions, and that

313 with direct oil leakage from vehicles is represented by the UCM (Table SM1). These

314 petroleum residues were detected in samples from areas where truck traffic and industrial

315 factories are major activities (e.g. AM, MN, OG, SH). The absence of levoglucosan and

316 PAHs indicates that organic compounds from biomass burning, i.e., soot fallout

317 (Simoneit et al., 1999) are not a detectable input.

318 Discarded plastics (e.g. shopping bags) are probably the major sources of the

319 plasticizers in the soils of Riyadh, because we have not detected them in blank sample

320 analyses of solvents or the analytical procedures. The contribution of plasticizers in the

321 soil OM ranges from 0.37 to 8.03 µg g^{-1} of the total EOM.

322   The results of the anthropogenic compounds were also analyzed by the PCA

323   statistical analysis to investigate the similarity among the different sites based on the

324   anthropogenic components. The PCA analysis output (explaining 89.0% of the variance

325   of an Eigen value of > 1) is shown in Figure 4c where two site groups were observed.

326   The first group (C1 and explains 61.9% of variance) included the AQ, NZ, DR, OR, AZ,

327   JZ and OL sites, which are inside the city with relatively more vegetation and

328   landscaping. The second group (C2 and explains 27.1% of the variance) includes only

329   sites AM, SH and MN, which are characterized by the presence of stop stations for large

330   trucks and industrial factories with little vegetation. This indicates that the types of

331   human activities have an impact on the characteristics and the distribution of

332   anthropogenic sources of the EOM in the area.

333   .

334   *3.3.   Anthropogenic versus natural sources*

335   It is obvious that the contribution of natural biogenic versus anthropogenic

336   sources varies and depends on the locations of the soil samples (Fig. 5). The contributions

337   from natural sources (mainly vegetation) ranged from 1.5 to 46.0% of the total EOM in

338   the soils of the city. These values are relatively lower than those reported previously (20-

339   57%, Rushdi et al., 2005). This is attributed to less vegetation and arid conditions in and

340   around Riyadh.

341   The anthropogenic sources were found to range from 54 to 99% of the total EOM.

342   This includes fossil fuel combustion and unintentional crude oil leaks and spills (31 to

343   99%, based on n-alkanes, hopanes, steranes and UCM, and market place and leisure

344   related activities 6% to 39% based on plasticizers, Figs. 5 and 6). The results confirmed

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345 that traffic is the major source of detrital anthropogenic OM and pollutants in Riyadh.

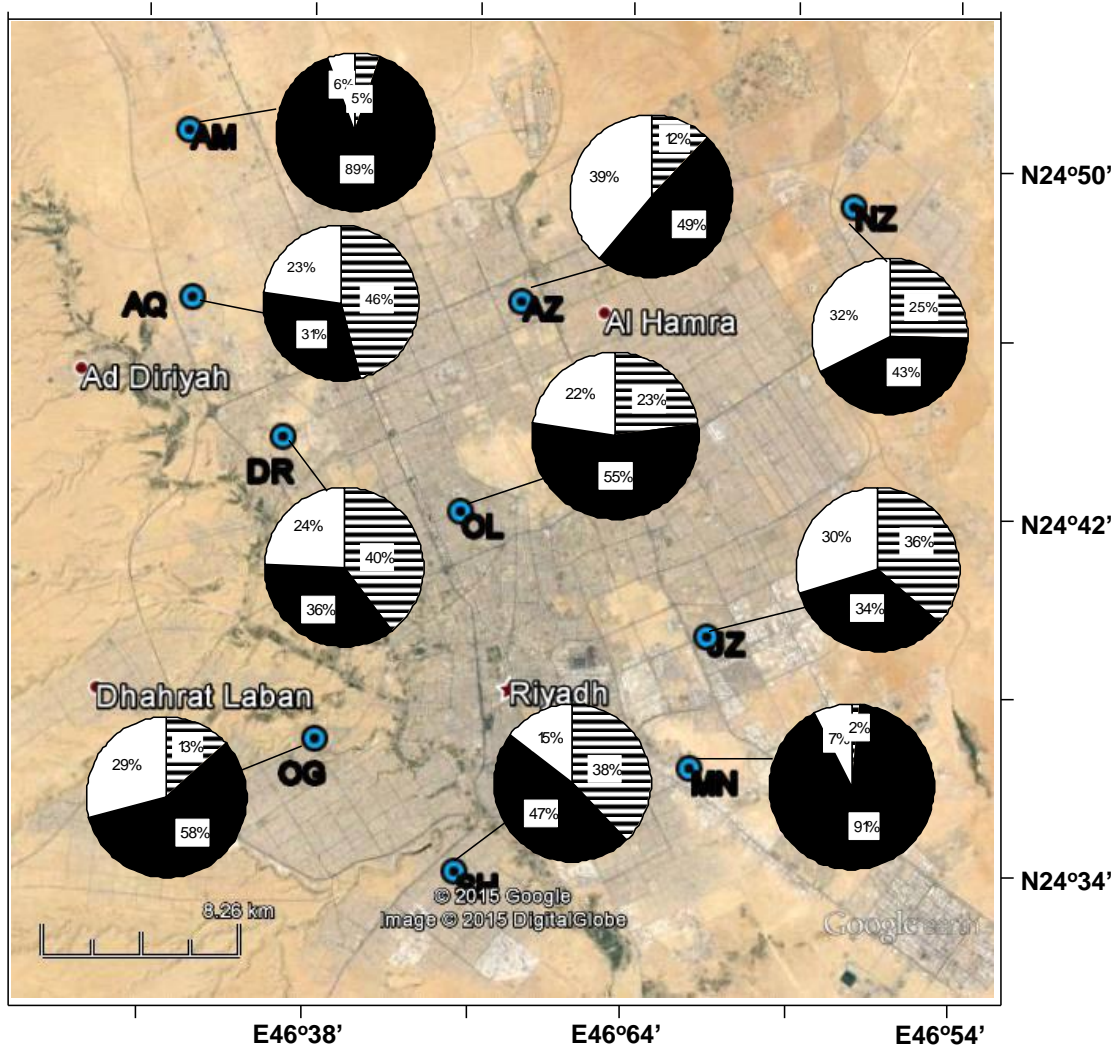346 Littering is another major source of organic pollutants in soils of the city (Fig. 6).

Figure 5. Pi plots of the petroleum residue (black), plasticizers (white) and natural (black and white stripes) fractions at different sites in Riyadh.
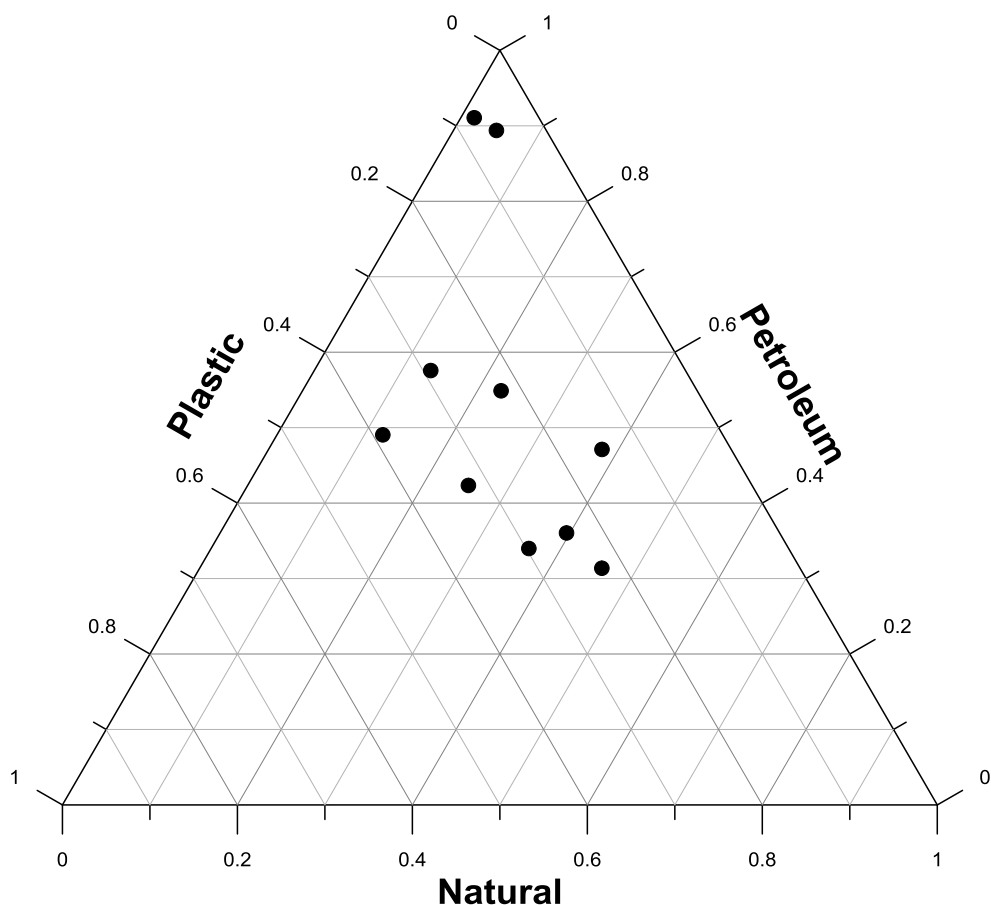
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Figure 6. Ternary diagram showing the EOM compound compositions from petroleum residues, plasticizers and natural inputs.

349

4. Conclusions

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351   The analysis of soil samples from the Riyadh metropolitan area showed that both

352 natural biogenic and anthropogenic sources contributed to their OM contents. The natural

353 sources of organic compounds are primarily from higher plant wax (i.e., vegetation) and

354 ranged from 1.5 to 46.0% of the total EOM of the soils. The natural components included

355 n-alkanols, n-alkanoic acids, n-alkanes (in part), and sterols, with concentrations lower in

356 the city compared to the surrounding rural areas. The presence of the natural compounds

357 from vegetation as major sources refuted the second hypothesis of this research (*the*

358 *sources of natural EOM are relatively low and are primarily from soil microbiota with*

359 *lesser contributions from vegetation*.).

360   The presence of n-alkanes with CPI ~1, hopanes, steranes, and UCM from urban

361 traffic emissions and plasticizers from plastic litter and detritus (e.g. shopping bags)

362 characterized the anthropogenic sources, and comprised from 54 to 99% of the total

363 EOM. This, reasonably validated the first hypothesis of this work (*the EOM sources in*

364 *soils of an urban arid region is mainly from traffic emissions*). The abundances of

365 anthropogenic organic compounds in the soils of the city depend on fallout/washout at

366 the sampling location and the types of urban activities.

367

368

369 **Acknowledgement**

372

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