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成都市土壤中有机磷阻燃剂的污染特征及来源分析

Pollution characteristics and sources of OPEs in the soil of Chengdu City

关键词: [有机磷酸酯](#) [阻燃剂](#) [污染](#) [来源](#) [土壤](#)基金项目: [国家自然科学基金\(No.21407014\)](#); [四川省科技支撑计划项目\(No.2015GZ0240\)](#); [成都信息工程大学中青年学术带头人科研基金\(No.J201415\)](#)

作者 单位

印红玲 成都信息工程大学资源环境学院, 成都 610225

李世平 成都信息工程大学资源环境学院, 成都 610225

叶芝祥 成都信息工程大学资源环境学院, 成都 610225

梁金凤 成都信息工程大学资源环境学院, 成都 610225

游俊杰 成都信息工程大学资源环境学院, 成都 610225

摘要: 在建立土壤中痕量有机磷酸酯阻燃剂(OPEs)的GC-MS实验室分析方法基础上,定量分析了成都市主城区表层土壤中7种典型OPEs(磷酸三丁酯(TnBP)、磷酸二异辛酯(TEHP)、磷酸三乙氧乙酯(TBEP)、磷酸三苯酯(TPhP)、磷酸三氯乙酯(TCEP)、磷酸三氯丙酯(TCPP)、磷酸三(2,3-二氯丙基)酯(TDCPP))的含量及分布特征,采用插值法和聚类分析研究其空间分布,运用相关性分析和正定矩阵因子分解法对土壤中OPEs的来源进行了探析.结果表明,成都市主城区表层土壤中7种OPEs(Σ 7OPEs)的含量水平在 $31.6\sim 211\text{ ng}\cdot\text{g}^{-1}$ 之间,算术平均值为 $99.9\text{ ng}\cdot\text{g}^{-1}$.所有样品中TBEP均为含量最高的单体,其含量占 Σ 7OPEs总含量的52%~92%.从空间分布来看,成都市西北至东南沿线为OPEs的主要分布带,三环外东北和西南则为OPEs的低值带.聚类分析结果表明,OPEs的谱特征与上述空间分布特征具有一致性,可分为2类地区:第1类地区位于主要分布带,属高值区(Σ 7OPEs平均值为 $133.1\text{ ng}\cdot\text{g}^{-1}$),第2类地区位于低值区(Σ 7OPEs平均值为 $60.2\text{ ng}\cdot\text{g}^{-1}$),两类地区的谱特征差异主要体现在TCEP与TBEP的百分含量上.相关性研究表明,TnBP与TCEP之间可能有较强的同源性,TBEP、TPhP、TnBP三者之间也可能具有较强的同源性,而TEHP与其他种类OPEs可能不具有同源性.正定矩阵因子分解结果表明,OPEs主要来源有2个,不饱和聚酯树脂产品制造业、建筑物装潢/室内源对成都市土壤中OPEs的贡献率分别为43%和57%.

Abstract: Seven types of typical organophosphates ester (OPEs) in the surface soils of urban Chengdu, including Tri-n-butyl phosphate(TnBP), Tris(2-ethylhexyl) phosphate(TEHP), Tributoxyethyl Phosphate(TBEP), Triphenyl Phosphate(TPhP), tri(2-chloroethyl) phosphate(TCEP), Trichloropropyl phosphate(TCPP) and Tridichloropropyl phosphate(TDCPP), were measured using GC-MS. Spatial distribution of these compounds was analyzed using interpolation and clustering method, and their sources were identified using correlation and positive matrix factorization(PMF) methods. The pollution levels of the total OPEs (Σ 7OPEs) in the urban surface soils ranged from $31.6\text{ ng}\cdot\text{g}^{-1}$ to $211\text{ ng}\cdot\text{g}^{-1}$ with the mean of $99.9\text{ ng}\cdot\text{g}^{-1}$. TBEP dominated the profile in all soil samples and accounted for 52%~92% of the Σ 7OPEs. Samples with high concentrations were found in the area from northeast to southeast with the mean level of $133.1\text{ ng}\cdot\text{g}^{-1}$, and the samples with low levels were only observed in the northeast and southwest areas outside of the third ring road with the mean level of $60.2\text{ ng}\cdot\text{g}^{-1}$. The areas with high and low levels were consistent with those of cluster analysis characterized with two typical groups. The relative contributions of TCEP and TBEP were different in the two groups. The correlation studies showed that TnBP and TCEP probably had similar sources while TBEP, TPhP and TnBP likely came from other similar sources. However, TEHP and other OPEs may not come from similar sources. The results of PMF showed that OPEs were mainly from the production progress of unsaturated polyester resin and decoration/indoor sources, contributing 43% and 57% to the OPEs in Chengdu urban surface soils, respectively.

Key words: [organophosphate esters](#) [flame retardants](#) [pollution](#) [sources](#) [soil](#)

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