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An integrative approach for determination of air pollution and its health effects in a coal fired power plant area by passive sampling

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HIGHLIGHTS

- Air pollution in a thermal power plant city in Turkey was investigated.
- NO_2, SO_2, ozone and VOC concentrations were measured by passive sampling method.
- Spatial and seasonal distributions of the pollutants were evaluated by using GIS.
- Power plants were noted as important sources especially for SO_2 and VOC levels.
- Cancer risks associated with inhalation of benzene were estimated.

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ABSTRACT

Ambient concentrations of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3) and volatile organic compounds (VOCs) were measured at several locations in Kütahya, a severely polluted city and also characterized as a thermal power plant city, in Turkey. Two-week extensive passive sampling campaigns were carried out in summer and winter at 108 sampling sites that were classified into three main groups as urban, rural and industrial. Spatial and seasonal distributions of the measured pollutants were evaluated employing Geographical Information System techniques. All pollutant concentrations showed an increasing pattern in winter, except for ozone. The concentrations of VOCs were substantially higher particularly at sampling sites with high traffic and population densities. Power plants were noted as important sources for VOCs since high concentrations were measured especially around the power plants. Highest NO_2 levels were observed in the city center while there was a general decrease in the concentration levels far away from the city center. Considerably higher SO_2 levels were observed in the settlements where local coal is used for residential heating. Seasonal variations in SO_2 concentrations were quite low around the thermal power plants indicating their important effect on atmospheric levels. A basic population exposure assessment was conducted for two largest settlements of the province (Kütahya city center and Tavşanlı) by combining population density maps with pollutant distribution maps of NO_2 and SO_2. Exposure to NO_2 and SO_2 were assessed separately according to a classification made for different degrees of exposure. Cancer risks associated with inhalation of benzene were also estimated. Higher risk values were obtained from the sampling sites with higher population densities, especially in winter. Risk values estimated for 95 sampling sites were higher than EPA's acceptable risk value (1×10^{-6}).

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1. Introduction

Industrialization and population increase are among today's most important problems that contribute to urban air pollution. The need to take measures to curtail air quality degradation to ensure quality and sustainable environment is more imperative now than ever before. However, like all other environmental problems, one of the most important exercises in air quality improvement is assessing the local factors that determine the air quality. Measures like shifting from coal to natural gas are not equally efficient in all urban areas. A typical example is Kütahya, the current study area where such measures did not improve the air quality compared to its neighboring cities. Air quality measurements in the province have been limited to only city center and have not yet been extended to the other parts of the province. To date, there has been no specific research on estimation of pollution sources and their related health risks in the city. The main pollution sources in and around the city are traffic, residential heating and industry. The thermal power plants located in the city are suspected to be one of the primary sources of air pollution in the region; partly due to their use of poor quality coal (high sulfur and ash content of the local lignite), and application of inefficient combustion techniques. This was the first order of importance for planning such an extensive sampling study in this city.

Major air pollutants emitted from thermal power plants that use coal are sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile and semivolatile organic compounds (VOCs and SVOCs), carbon dioxide (CO_2) and various elements. SO_2 is one of the most important pollutants emitted from power plants. In the USA for instance, contribution of thermal power plants to the total atmospheric SO_2 emissions is 59% (de Gouw et al., 2014). However, quantities of the pollutants emitted from the power plants are based on different parameters such as chemical composition of the coal and control technology (Agrawal et al., 2010; Sueyoshi et al., 2010). The pollutants measured in this study were SO_2, NO_2, ozone and VOCs. Among these, SO_2 and NO_2 are conventional air pollutants while ozone is a secondary pollutant (Krzyscin et al., 2007; Özden et al., 2008; Kulkarni et al., 2011; Özbay et al., 2011). Effects of these pollutants on human health and ecosystem have been studied extensively (Adame et al., 2012; Melkonyan and Kuttler, 2012). The other pollutant group (VOCs) is known to have both toxic and carcinogenic effects on human health, and also plays an important role in the formation of pollutants such as ozone and PAN (peroxyacetyl nitrates) by the reactions with nitrogen oxides (NO_x) in the presence of sunlight. Although solvent usage and internal combustion engines are the main anthropogenic sources of VOCs, they are also emitted from power plants to the atmosphere in significant amounts. It has been reported that 37% of total anthropogenic VOC emissions are released during power production processes (Fernández-Martínez et al., 2001).

A total of 187 air pollutants have been identified as hazardous air pollutants by US Environmental Protection Agency (USEPA) and most of them are VOCs. Within the scope of the IRIS program, (EPA IRIS, 2015), EPA evaluates periodically, the effects of environmental pollutants on human health. Respiratory-induced cancer risk is calculated by using Unit Risk Factor and ambient concentrations. Several studies are present in literature about risk analysis of VOCs, however, there are limited studies carried out in Turkey (Durmusoglu et al., 2010; Scheepers et al., 2010; Sofuoglu et al., 2011; Dumanoglu et al., 2014; Civan et al., 2015).

The public perception about poor air quality and consequent health effects is that these problems can be attributed to the presence of thermal power plants located within the borders of the province. Since the air quality measurement studies are very limited, an extensive sampling study that covers all the province was planned to investigate the air quality of the city. Specific objectives of this study were: (1) to determine spatial and seasonal distributions of ambient concentrations of SO_2, NO_2, ozone and 45 VOCs, (2) to estimate the number of people under risk by using geographical information systems (GIS) and measured pollutant concentrations, and (3) to assess cancer risks due to inhalation exposure to benzene in the study area. To our knowledge, this is the first detailed and extensive scientific study investigating many pollutants simultaneously in Kütahya Thermal Power Plant Region.

2. Materials and methods

2.1. Study area and sampling program

The study area is Kütahya, a province in the Aegean region of Turkey, located in the inner western part of the country. The province has a population of 571,554 (http-1). The topography of the city is characterized not only with mountains and hills but also lowlands lying in the Northwest-Southeast direction. The main pollutant sources in the region are traffic, residential heating and industry (especially power plants and mining). Coal is the most commonly used fuel for residential heating and industrial activities due to its abundance as well as proximity of the lignite reserves around the city. Overall the province, 104,191 tons domestic lignite and 9260 tons imported lignite were consumed in winter season of 2014 (KDEU, 2015). Although, natural gas has been used in residential areas of some main districts (Kütahya City Center, Emet, Gediz, Tavşanlı), the villages in the region ($n = 550$) having 50% of the population still use lignite in winter. In addition to lignite, totally 247.5 million Nm^3 natural gas was also used for industrial activities and residential heating in the region in 2014. The city is characterized as a thermal power plant city due to the presence of three thermal power plants: Seyitömer Thermal Power Plant (600 MW), 20 km; Tunçbilek Thermal Power Plant (365 MW), 50 km; and Orhaneli Thermal Power Plant (210 MW), 105 km away from the city center. Tunçbilek Thermal Power Plant is also located in the close vicinity of the second largest city of the province, Tavşanlı. Among these plants, Tunçbilek and Seyitömer Power Plants are located within the sampling area that have a total annual lignite consumption of 9 million tons. An annual total of 10,561,539 tons lignite was consumed at three power plants in 2014 (KDEU, 2015). Other potential industrial pollution sources located in and around the city have been identified as; sugar, ceramic, food, transportation, construction materials, boron mining and magnesite industries. All sampling sites as well as industrial facilities within the sampling area were shown in Fig. 1. A more detailed map showing the sampling site numbers was also presented in Fig. S1. Traffic remains another important pollutant source with 12 highways and 46 major urban roads in the region. Daily number of 37,844 vehicles were traveling on highways and fifty-three percent of total vehicle traffic was flowing on three major highways (Kütahya-Bilecik, Kütahya-Afyon, and Kütahya-Balıkesir) in the city (KDTB, 2015). Kütahya-Bilecik highway has the highest traffic density among them. Kütahya has high urban traffic volume also inside the city. Total number of vehicles traveling in the city was 184,661 for 2014 and majority of fleet composition were consisting of passenger cars (60%). Light duty vehicles (minibus & pick-up truck) and heavy duty vehicles (bus & truck) represented about 36%, and 4%, respectively. Traffic counts were not available for city centers.

Passive sampling was performed for the assessment of spatial and seasonal distributions of the organic (VOCs) and inorganic (NO_2, SO_2, O_3) pollutants in Kütahya. The sampling area is 130×120 km^2 that includes not only the city center but also the city counties (Fig. 1). Ambient air samples were collected in two

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