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Association between respiratory health and indoor air pollution exposure in Canakkale, Turkey

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ABSTRACT

Indoor air quality (IAQ) measurements were conducted in three different towns (*i.e.* Centre, Lapseki, and Can) in Canakkale, Turkey ($n = 121$) throughout the year. All indoor environments were selected randomly among the volunteer participants of a previous health survey. Particulate matter (PM), Total Volatile Organic Compounds (TVOCs), Total Bacteria Concentration (TBC), Total Mold Concentration (TMC), and Carbon dioxide (CO_2) together with temperature and relative humidity (RH) were measured monthly. Together with IAQ measurements, bronchial hyper-responsiveness indicators such as forced vital capacity (FVC) and forced expiration volume (FEV_1) of the occupants of the homes were measured by monthly Pulmonary Function (PF) test. Furthermore, a comprehensive survey was given to the participants. The measured IAQ parameters showed seasonal and spatial variations ($p < 0.05$). Among them, the highest levels of TVOC, CO_2, and PM were found in the winter, while the highest levels of both TBC and TMC were found in the summer. In general, levels of IAQ parameters and asthma prevalence were the highest in Can (*i.e.* industrial area). Also, IAQ adversely influenced the respiratory health of participants in Can ($p < 0.05$). Shortness of breath was the most prominent respiratory symptom. Negative associations between asthma and FEV_1/FVC ratio, and between respiratory symptom score (RSS) and FEV_1/FVC, support the idea that the PF test can be a good indicator for (early) prognosis of respiratory diseases.

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1. Introduction

As people spend a large part of their time indoors, indoor air pollution has recently constituted an important agenda for public health. Air pollution can be both the causative agent of chronic and acute respiratory diseases and can affect the medical prognosis of existing diseases [1]. According to recent records from Turkish Ministry of Health, respiratory diseases are ranked third (*i.e.* 10% of all diseases), following cardiovascular diseases and cancers [2]. Due to increasing concerns regarding respiratory diseases worldwide, the World Health Organization (WHO) planned an emergency action to reduce the global burden of respiratory diseases called the Global Alliance Against Chronic Respiratory Diseases (GARD), in cooperation with national and international organizations [3]. Studies showing the associations between respiratory health and Indoor Air Quality (IAQ) indicate the importance of regional and personal factors such as age, gender and existence of related diseases [4,5]. IAQ affects respiratory health, as well as the prevalence and prognosis of asthma, chronic obstructive pulmonary disease (COPD), acute respiratory diseases, lung cancer, interstitial lung diseases, and mortality rate [6,7]. In addition to various adverse health outcomes of indoor air pollutants, they also may cause a weak immune system which results in an increase in respiratory tract infections [8]. The linkage between indoor air pollution and lung cancer was found to be associated with passive smoking and different fuel smokes according to studies conducted in China and the USA [9,10]. It was pointed out that creating environmentally friendly indoor environments for asthmatic and non-asthmatic building occupants is crucial [11]. Hence, from the point of view of health, public awareness should be increased to achieve good IAQ [12].

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IAQ covers large groups of parameters from organic (*e.g.* volatile organic compounds and formaldehyde) and inorganic constituents (*e.g.* inorganic gases and particles) to microbial (*e.g.* bacteria and mold) constituents together with thermal comfort parameters such as temperature and humidity [13,14]. Among them, fine particles penetrate deep into the lung and serve as carrier media for toxic gases and viruses, which result in more significant effects than coarse particles [15]. Levels of indoor PM were influenced by several factors, such as air exchange rate, outdoor PM levels, and PM related human activities [16–25]. Daily and long-term variations in concentration of fine particles particularly were found to be associated with mortality, an increase in occurrence of cardiovascular and respiratory diseases, admission to hospital and emergency room, acute respiratory tract infection, and premature birth [26–32].

Airborne bacteria and mold can be found between 10 and 10^4 CFU m^{-3} in typical indoor environments, depending on factors that enable propagation of bioaerosols, such as presence of humans, pets, and potted plants, temperature, and humidity [33,34]. Elevated levels of bioaerosols are related to asthma, allergic rhinitis, hypersensitive pneumonia, sick building syndrome (SBS), infection, and allergic and toxic effects and can be crucial for people who already have allergies and respiratory diseases [35–44].

Volatile organic compounds (VOCs) comprise a large group of compounds in the air. Penetration of traffic and/or industry related outdoor air into indoor air, and usage of solvent-including consumer, building, and decorating products are the major contributors to indoor VOCs [45–48]. In addition to the carcinogenic effects of several VOCs, it was found that VOCs are related to asthma and asthma related symptoms [49–51]. It was documented that inadequate ventilation together with VOCs, coming from plastic products, resulted in sick building syndrome of headache, fatigue, and mucous membrane irritation among office workers [52].

The level of carbon dioxide (CO_2) can be an indicator of adequacy of ventilation [53] and a comfort parameter [54,55]. Although it was assumed that CO_2 concentration >1000 ppm may indicate unacceptable IAQ and inadequate ventilation, CO_2 concentration <1000 ppm does not guarantee healthy IAQ conditions [56,57].

Since the perception of IAQ in Turkey is quite new, studies conducted on finding the linkage between health and IAQ are limited so far. The aims of this study were *i)* to investigate the levels of IAQ parameters of Total Bacteria Concentration (TBC), Total Mold Concentration (TMC), Total Volatile Organic Compounds (TVOCs), Carbon dioxide (CO_2), and Particulate Matter (PM) in three different towns in Canakkale throughout the course of a year; *ii)* to compare IAQ levels both on seasonal and spatial basis; *iii)* to estimate general and respiratory health conditions (by pulmonary function test and questionnaires) of the participants; and *iv)* to find the associations between respiratory health and IAQ parameters. The results of this study will help to increase public awareness of the importance of providing better IAQ to achieve the goal of a "healthy air = healthy people", particularly in developing countries such as Turkey and to provide an overview to understand the linkage between IAQ and health.

2. Material and method

2.1. Study design

IAQ measurements were conducted in three different towns (*i.e.* Canakkale center, Lapseki, and Can) in Çanakkale, Turkey ($n = 121$). Çanakkale is a small college city, located on the farthermost west coast of Turkey. Its climate has a transient character between the Mediterranean and Black Sea regions: snowy days are limited, whereas rainy days are more frequent. The main rainy season in Çanakkale is spring, especially the month of May. The most prominent characteristics of the meteorology of Çanakkale are relatively high wind speeds (wind speed ≥ 7 m s^{-1} at 50 m above the sea level) and the annual number of windy days (average: 180 days $year^{-1}$) [58,59]. Canakkale center (*i.e.* Center, $n = 46$) represents an urban site; Lapseki ($n = 36$) represents a rural site; and Can ($n = 39$) represents a semi-urban and industrial site (*i.e.* coal mining facilities, a lignite-based power plant, and a ceramic factory). The locations of the sampling sites together with their characteristics are given in Fig. 1. Among these three sites, Can has a bowl-shaped topography, posing a disadvantage to the majority of the local people who live at the lowest altitudes of the town [60]. The name of the town Can comes from its topographical shape, a "campane".

All indoor environments (*i.e.* living room of the homes) were selected randomly among the volunteer participants of a previous health survey within the context of *Canakkale HealthAir Study* conducted in the sampling sites of this study. Any known dampness in the sampling sites and essential complaints by the occupants were not recorded prior to the study. Our primary aim was to choose sampling sites that were representative of the extensive socioeconomic status of the towns. Monthly sampling campaigns were conducted at all sampling sites from August 2013 to August 2014. Each sampling site ($n = 121$) was monitored once a month. Seasonal average values of the measurements given here omit the measurement results for August 2013. Since no air quality measurement was conducted in August 2014, only the results of June–July 2014 were taken into account as summer values within the context of this manuscript. Thus, the results gathered between September–November 2013 represent the fall, December 2013–February 2014 represent winter, March–May 2014 represent spring, and June–July 2014 represent summer in this study.

Target indoor air pollutants, measured in this study were PM, VOCs, TBC, TMC, and CO_2 together with indoor temperature and relative humidity (RH). Also, exact values of meteorological parameters (*i.e.* temperature, RH, wind speed and direction, cloudiness, and rain amount) were gathered from the Turkish Meteorological Institute. Pulmonary function (PF) tests and health surveys were administered to 121 participants. Together with IAQ measurements, bronchial hyper-responsiveness indicators, such as forced vital capacity (FVC) and forced expiration volume (FEV_1) of the participants were measured by PF test once a month. Furthermore, a comprehensive survey was given to the participants in order to find the linkages among IAQ, building and environmental factors, socioeconomic factors, and symptoms/illnesses related to IAQ.

2.2. Questionnaire

A detailed questionnaire was given to an occupant of each sampling site ($n = 121$). Firstly participants (age > 18) were selected randomly and then the IAQ measurements were conducted in the homes of the participants. One participant per sampling site was chosen. Participants were chosen among the occupants who spent most of his/her time in this environment and were most probably available throughout the 12-month sampling campaign. Since none of the potential participants were informed regarding the objective of the questionnaire before the first sampling campaign, the participant population consisted of people with and without respiratory symptoms, which minimized the selection bias for the participants. Additionally, descriptive information regarding the building/environment of the sampling sites was gathered.

The questionnaire contained questions on *i)* the characteristics of the building/environment; *ii)* socioeconomic status of the occupants; *iii)* current health conditions of the participants, including existing illness(es) related to respiratory symptoms, and

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