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# The Spatiotemporal Distribution of PM2.5 and its Relationship to Land-Use Patterns and Special to Land-Use and People in Hangzhou

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Research

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**ABSTRACT:**

Assessments have quantified the burden of air pollution at the national scale in China; air quality managers would benefit from assessments that disaggregate health impacts over regions and time. The air quality in Hangzhou City, which is one of the central cities of the Yangtze River Delta Urban Agglomeration, was not in great condition. We used the monitoring sites data and MODIS remote-sensing Aerosol optical thickness (AOT) for the inversion of the $PM_{2.5}$ concentration map for all four seasons in 2015. Next, we combined the land use data, population density data, and school data (kindergarten, primary school, and middle school) to analyze their correlation; we found that the seasonal variation characteristics of $PM_{2.5}$ concentration distribution was winter > spring > autumn > summer. For the different land use type in winter and spring, 59.86% and 56.62% land area showed the $PM_{2.5}$ >50μg/m$^3$, respectively. In autumn, 54.38% of the land area exposure was $PM_{2.5}$ 35~50μg/m$^3$. In summer, the $PM_{2.5}$ concentration was lowest, at 70.01%, and the land surface area showed $PM_{2.5}$ <35μg/m$^3$. Increasing the forest landscape performs the function of absorbing and filtering the particulate air pollution, resulting in high $PM_{2.5}$ concentration at this landscape. It was also discovered that only 9.06% of the population lived in an environment that met the national air quality standards. Specifically, only 1.66% (14,055) of infants and juveniles were living in $PM_{2.5}$ <35μg/m$^3$. Considering the lag health effects of long-term $PM_{2.5}$ exposure, it is necessary to track these infants' and juveniles' health conditions from now until they enter into adulthood. This should enable us to more effectively eliminate the $PM_{2.5}$ that is harmful to our health. We firmly believe that not only in Hangzhou, but also spanning all of China, many infants and juveniles live in a severely polluted environment in which we need to pay close attention, as their future health is directly relative to the future prosperity of the country as a whole.

**Keywords:** PM2.5; spatial and temporal variations; Land surface landscape; infants and juveniles

## 1. INTRODUCTION

In the haze days, $PM_{2.5}$ particle concentration occupied about 56.7%~75.4% of the total suspended particles and accounted for more than 80%~90% of $PM_{10}$ (the particles measured ≤10μm in diameter of aerody-

namics) [1]. The high exposure of babies to $PM_{10}$ turned out to be one of the primary causes of decreased head and body size [2], and the long-term exposure to high concentrations of $PM_{2.5}$ was associated with serious health complications including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), lung cancer (LC), and acute lower respiratory infection (ALRI) [3-10]. Ambient fine particulate matter ($PM_{2.5}$) pollution ranked sixth among all risk factors for global premature mortalities and disability-adjusted life-years (DALYs) [11, 12]. Song, et al. [13] used the national air quality monitoring stations in 367 cities in China between the years 2014 and 2016, which resulted in the population's attributable mortality rate (10-5 y-1) showing 112.0 in the current year analysis, and 124.3 in a 10-year time lag analysis. Considering the lag health effects of long-term $PM_{2.5}$ exposure [13, 14], the health risks of infants and juveniles who live long-term amidst a severely polluted environment would increase drastically; we, as a people, must take responsibility for paying more attention to these potential health risks and improving their overall living environment.

Most PM comes from both rapid industrialization and motorization [15, 16]. The pollution problem spread widely in European and North American cities in the 1950s and 1960s, but has since become more pronounced in developing countries (e.g., India, China) [17, 18]. In China, over the last few decades, rapid economic development has led to worsening air quality [19-21], with nearly none of the population living in areas meeting the World Health Organization (WHO) Air Quality Guidelines (AQG) of $PM_{2.5}$ 10 $\mu g/m^3$ [22-26]. Between the years 2004-2012, over 93% of people in China lived in areas where $PM_{2.5}$ exceeded China's National Air Quality Standard for Grade II of 35 $\mu g/m^3$ [27]. This was mainly a result of the quick economic development and population urbanization in China. Land surface properties such as roads, construction, human behavior, and vegetation can directly filter pollutants and indirectly influence the air movement through its heterogeneous urban canopies [28]. A better and clearer understanding of spatial and temporal variations of $PM_{2.5}$ can contribute to the population's effective exposure to a different $PM_{2.5}$ concentration, and then subsequently the adoption of effective measures to mitigation harm by air pollution will follow.

The often-used approaches for estimating $PM_{2.5}$/$PM_{10}$ concentration are either based on remote-sensing data or are derived from monitor-based data. We know the profile of aerosol particle liquidity in space; with the sparse discontinuity of the ground environment observation station, it is difficult to reveal both aerosol particles' spatial and temporal distributions as well as transmission characteristics in a wide space [29]. Aerosol optical thickness (AOT) data obtained from the Moderate Resolution Imaging Spectroradiometer has been proven to be a potentially useful predictor of $PM_{2.5}$ concentrations [30, 31]. However, due to dissimilarities in surface characteristics, meteorological conditions, and the aerosol fine mode fraction [32, 33], the application of using AOT as a proxy for reflecting spatial patterns of PM also has limitations [34, 35]. In this case, the combination of the dispersed monitoring sites data and MODIS remote-sensing retrieval could be an effective inversion of the spatiotemporal distribution of $PM_{2.5}$ concentration.

In this study, we are focusing on Hangzhou City, which is one of the central cities of the Yangtze River Delta Urban Agglomeration; we explored its atmospheric environment (Figure 1a) and found that, as a tourist city, Hangzhou City's air quality condition was not in sufficient shape [36-50]. Liu et al. [27] analyzed the atmospheric $PM_{2.5}$ mass concentration variation characteristics in Hangzhou from 2011 to 2014 and concluded that the peak appeared in 2013 (52.2 $\mu g/m^3$) and is closely related to the motor vehicle emissions and changes in meteorological conditions. Jin et al. [41] found where the $PM_{2.5}$ particle concentration occurred, including 21.6% caused by automobile fumes, 16.7% caused by burning coal, and 12.2% caused by ash, soil, and concrete buildings. Land use types of urban areas also have a significant impact on the spatial distribution of urban $PM_{2.5}$ [40]. According to the spatial distribution of $PM_{2.5}$ in the region, the reasonable spatial layout of land use type is carried out in combination with weather and terrain conditions, which are conducive to the long-term control of particle pollutants.

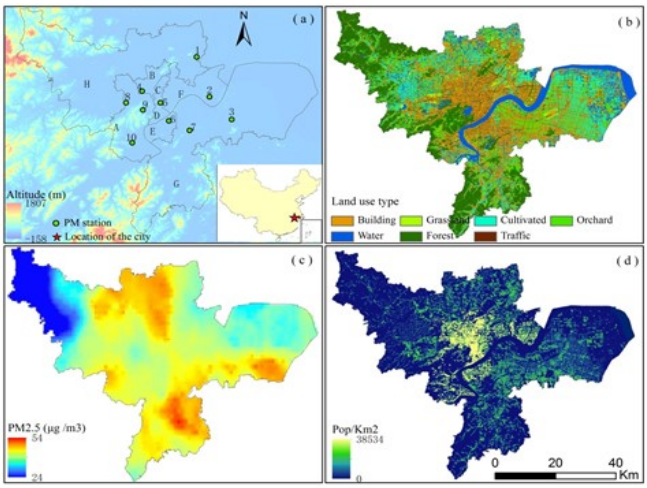


**Figure.**1 (a) Spatial distribution of 10 $PM_{2.5}$ monitoring stations in the eight study districts (A Xihu; B Gongshu; C Xiacheng; D Shancheng; E Binjiang; F Jianggan; G Xiaoshan; H Yuhang), 1~10 are the monitoring stations; (b) the Land-use map of urban district in Hangzhou; (c) the annual $PM_{2.5}$ concentration spatial distribution in Hangzhou in 2015; (d) the people density spatial distribution in 2015. $Km^2$.

In this study, our main objective is as follows: first, to clear spatial and temporal variations of the $PM_{2.5}$ mass concentration on Hangzhou roofing landscapes in 2015; next, to examine the empirical relationships between the spatiotemporal changes of $PM_{2.5}$ and the land use types; next, to analyze the population density distributions exposed to different $PM_{2.5}$ concentrations; and finally, to clear the distribution of schools (kindergarten, primary school, and middle school) under different $PM_{2.5}$ mass concentrations. Our results are aimed toward simplifying the tracking of potential health problems in infants and juveniles into adulthood based on the $PM_{2.5}$ resulting in lagging, long-term health hazards.

## 2. MATERIALS AND METHODS

### 2.1. Study Area

Hangzhou city, the capital city of the Zhejiang Province, covers an area of 16,596$km^2$ and includes thirteen districts; this study covers the central main urban area including eight districts: Shancheng, Xiacheng, Jianggan, Gongshu, Xihu, Binjiang, Yuhang, and Xiaoshan (Figure.1a). The study area was 3,376 $km^2$, the population density was 2,111.96 Pop/$km^2$ in 2015, and the vehicles were $2.23\times10^6$, (http://www.hzfc.gov.cn/web). The terrain of the flat, high-west low east has a gentle slope inclination. Hangzhou annually experiences a humid subtropical climate with four distinctive seasons characterized by long, hot, humid summers and chilly, cloudy winters. The average annual precipitation is 1,438 mm, abundant during summer and relatively low during winter. In late summer, Hangzhou suffers from typhoon storms. The prevailing surface winds are main southerly during summer and northerly during winter. The atmospheric structure is relatively stable, and temperature inversion often occurs in late autumn and winter [36].

### 2.2. Data

#### *2.2.1. $PM_{2.5}$ Data*

Terra – MODIS, the atmospheric aerosol optical thickness (AOT) (Collections 5, MOD04-3K) acquired from NASA/GSFC (Goddard Space Flight Center) LAADS (Level 1 and Atmosphere Archive and Distribution System). AOT data was extracted from aerosol particles over land surfaces by 0.55$\mu$m per day. Validated real-time hourly concentrations of $PM_{2.5}$ from January 2015 to December 2015 in Hangzhou were downloaded from the National Environmental Monitoring Centre (CNEMC, http://www.cnemc.cn/) (Figure .1a). Consider the time match with the MODIS AOT as well as the transformational hourly $PM_{2.5}$ station point data that averages daily.

#### *2.2.2. Other Data*

For building the model between the whole layer of AOT and the dry particle mass concentration near the ground, one needs vertical correction and humidity correction for the model. All meteorological data comes from renanlysis data by NCEP (http://dss.ucar.edu/), including a comprehensive set of observation data covering multiple elements spanning a wide range and an extended period of time.

The land use map supplied by the Second Surveying and Mapping Institute of Zhejiang Province had a scale of 1:10,000 and was manually produced based

on high- resolution aerial photos in 2015 (Figure. 1b). The number of student data and the schools' spatial distribution map was collected by the Hangzhou Education Bureau, and the population data was collected from census data.

### 2.3. Method

We needed to finish three steps in order to realize the spatial distribution $PM_{2.5}$ concentration (Figure. 2) first at MODIS AOT inversion and calibration; the second step realized the match well between some satellite data and $PM_{2.5}$ monitoring data; the third step involved building regression modeling between $PM_{2.5}$ monitoring data and the collected satellite data. Based on other papers [51-55], the remote sensing inversion algorithms for the MODIS aerosol optical thickness (AOT) products in this paper adopted dark target algorithm. Second, some effective pixel data was collected that matched well with the satellite transit data. Finally, the geometric mean value of the effective pixel data was used to establish a line regression model between AOT and $PM_{2.5}$ mass concentration. To achieve the AOT and $PM_{2.5}$ regression modeling, the essential step was to finish AOT calibration and water vapor calibration; this approach refers to Levy et al [56], and the simulation process is as follows (Figure. 3).

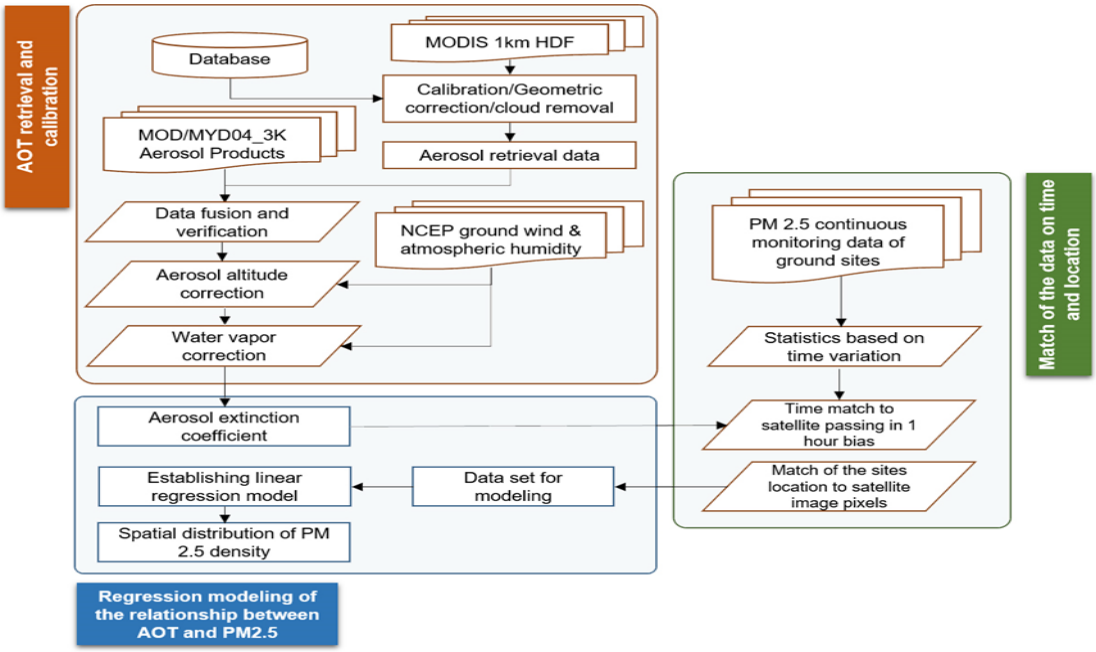


**Figure 2.** Based on the MODIS Aerosol optical thickness (AOT) inversion spatial $PM_{2.5}$ concentration flow chart

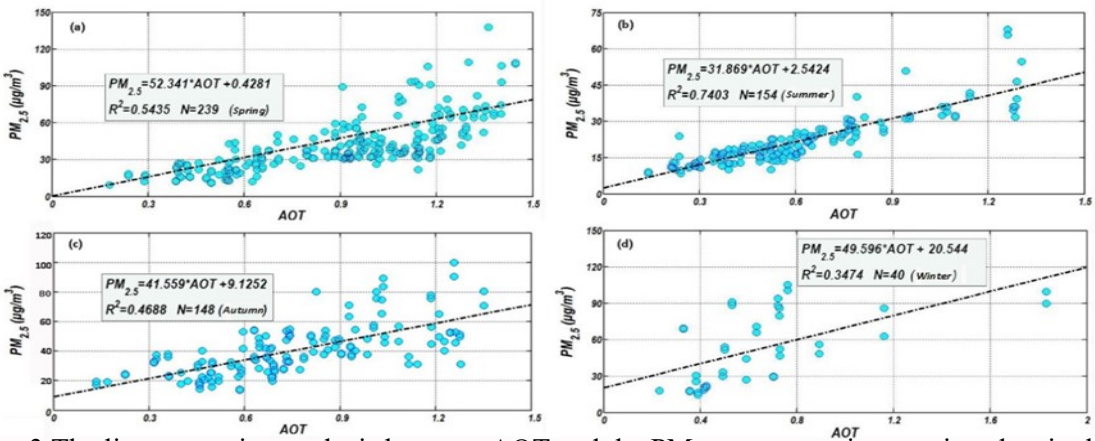


**Figure.3** The line regression analysis between AOT and the $PM_{2.5}$ concentration monitor data in the different seasons.

Based on the $PM_{2.5}$ concentration evident in all four seasons and CNEMC standards, we divided the spatial $PM_{2.5}$ concentration into three classes: <35μg/$m^3$ (non-polluted), 35-50μg/$m^3$(intermediate) and >50μg /$m^3$(heavy). The year was divided into four seasons based on the standards of the Chinese Meteorological Administration in order to calculate the seasonal mean, minimum, maximum, and standard deviation: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February).

Spatial interpolation was used based on the census data of streets and the building density to generate the population density map in 2015 (Figure. 2d). Then, we analyzed the quantitative relationship between the $PM_{2.5}$ concentration and the land use types in different seasons; the population density and the schools' distribution under the different $PM_{2.5}$ concentration range was significant regarding quantitative analysis.

## 3. RESULTS AND DISCUSSION

### 3.1. Line Regression Between AOT and the $PM_{2.5}$ Concentration

After AOT inversion and calibration and water vapor calibration were achieved, the line regression analysis was built between AOT and the $PM_{2.5}$ concentration among the seasons (Figure. 3). It was found that the model fitting correlation was varying in different seasons, the determination coefficient was between 0.347~0.740, and the accuracy order of the model was determined: summer > spring > autumn > winter. This season difference affected by some factors, such as the height of the atmospheric mixing layer in autumn and winter, was very low and was not conducive to the diffusion of air particle pollutants. In addition, in autumn and winter, where cold waves were frequent, the change of weather conditions led to increasing atmospheric pollutant space-time variability and the model fitting accuracy decreased. However, the results of the four seasons modeling met the needs of the article [56].

### 3.2. The spatiotemporal distribution in $PM_{2.5}$

In Hangzhou, the annual average of $PM_{2.5}$ concentration was 43μg/$m^3$ (std =5.28). This result displayed that Hangzhou's region air quality was well over 50% (53.0μg/$m^3$) than that of China in 2015 [13, 27]. Similar to other cities in 2015, Beijing was 80.8μg/$m^3$, Shanghai was 53.9μg/$m^3$, Guangzhou was 38.8μg/$m^3$, and Shenzhen was 29.9μg/$m^3$. The Beijing-Tianjin-Hebei area was 77.1μg/$m^3$, Yangtze River Delta area was 52.9μg/$m^3$, and Pearl River Delta area was 34.4μg/$m^3$ in 2015 (http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2015/GPEA%202015%20City%20Rankings_briefing_int.pdf). After 2013 experienced the peak PM value spanning all of China, the $PM_{2.5}$ concentration showed a significant declining trend. Like in Hangzhou, the $PM_{2.5}$ was 52.2 μg/$m^3$ in 2013 [43]. However, this measurement still had a long way to go in order to reach China's National Air Quality Standard for Grade II [22]; in China's total 366 cities, over 80% did not reach China's National Air Quality Standard for Grade II limit of 35μg/$m^3$ [57]. For the spatial distribution of the annual average, $PM_{2.5}$ was mainly focused in Gongchu, Shangcheng, Xiacheng, part of Xihu,Yuhang, and Xiaoshan (Figure. 1C). The mean $PM_{2.5}$ concentration was 50.27$\mu$m/$m^3$(std = 7.32) in spring, 24.87$\mu$m/$m^3$ (std = 4.40) in summer, 43.63$\mu$m/$m^3$(std = 5.66) in autumn, and 53.19$\mu$m/$m^3$(std = 6.92) in winter (Figure. 4a-d). Regarding spatial distribution, the lowest values all showed up in the northwest mountainous area (Figure. 4). Compared with the season variation of $PM_{2.5}$, the result for spatial distribution was winter> spring > autumn>summer. The seasonal characteristics of $PM_{2.5}$ concentration were consistent with the ground observation results in Hangzhou, and this year's variation was consistent with other cities, as well [58-62]. In winter, air pollution was still a serious issue that severely affected people's lives in China, and the administrative department continued struggling to find efficient ways to send this atmospheric pollution into remission.

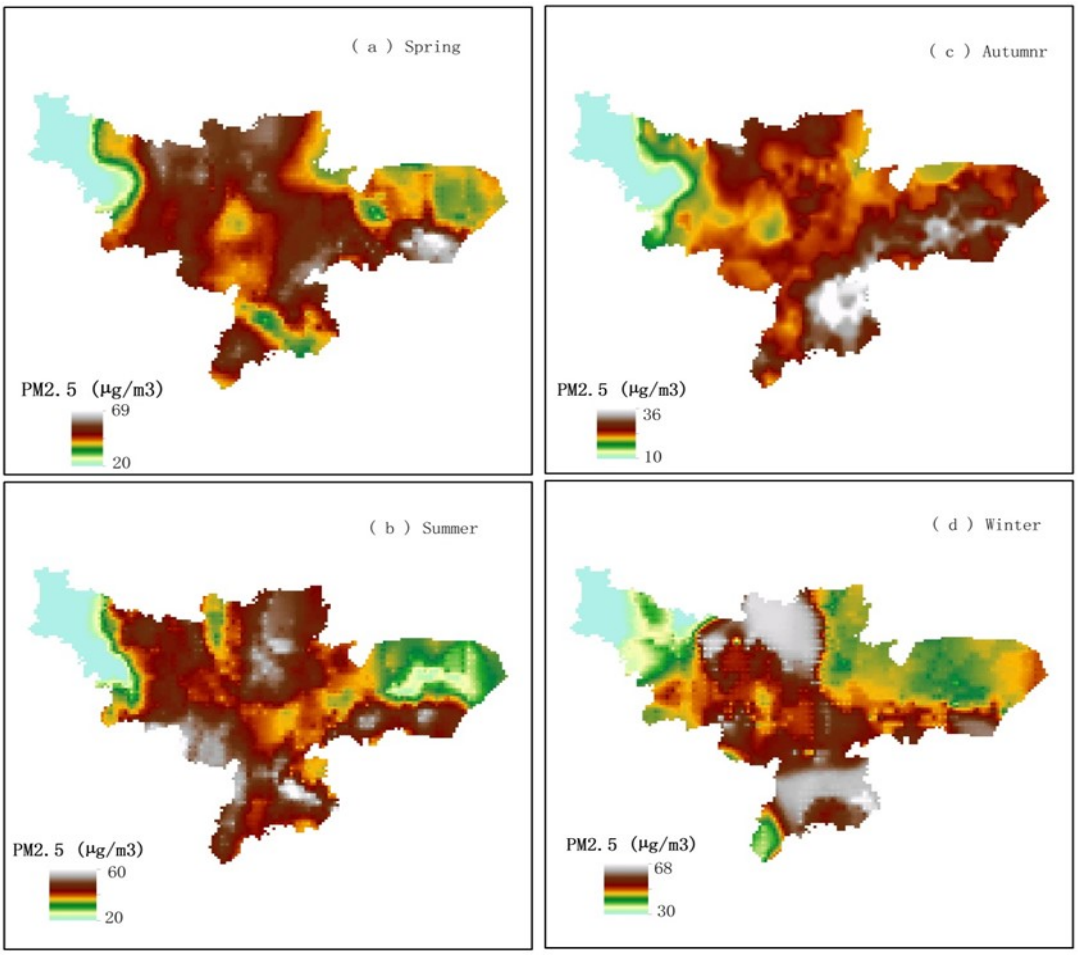


**Fig 4.** The $PM_{2.5}$ concentration spatial distribution in four seasons in Hangzhou.

Among a study of eight districts in four seasons, the Xiacheng district showed three seasons with the highest mean value (Figure. 4, Table 1); the values equaled 54.10 μg/$m^3$ in spring, 29.73μg/$m^3$ in summer, and 45.27μg/$m^3$ in autumn. The Gongshu district showed the highest value in winter, which was 61.08μg/$m^3$. The lowest mean value $PM_{2.5}$ concentration for all four seasons appeared in the Yuhang district: the values were 47.65μg/$m^3$ in spring, 23.31μg/$m^3$ in summer, 39.41μg/$m^3$ in autumn, and 54.63μg/$m^3$ in winter. Interestingly, the Xiaoshan district showed the largest maximum value in all four seasons, with 68.54μg/$m^3$ in spring, 35.95μg/$m^3$ in summer, 59.63μg/$m^3$ in autumn, and 67.97μg/$m^3$ in winter (Table 1). Additionally, the spatial distribution showed multiple "hot areas" in all four seasons (Figure. 4).

### 3.3. Correlation analysis between land use and the spatial distribution of $PM_{2.5}$ concentration

For the seven land types in the study area, the building area occupied 26.86% (905.84$km^2$), the water area was 12.87% (434.22$km^2$), the grassland was 4.94% (166.23$km^2$), the forest area was 26.31% (887.42$km^2$), cultivated land was 11.95% (403.07$km^2$), traffic land was 5.38%(181.53$km^2$), and orchard land was 11.67% (393.91$km^2$) (Figure. 1b). We gathered statistics for the area percentage of seven land use types according to the three classes of $PM_{2.5}$ concentration (Table 2). The resulting data concluded that in spring, at $PM_{2.5}$ < 35μg/$m^3$, the land surface area accounted for 4.16%; at $PM_{2.5}$ between 35~50μg/$m^3$, the land surface area accounted for 39.23%, and at $PM_{2.5}$> 50μg/$m^3$, the land surface area accounted for 56.62%. During summer, at $PM_{2.5}$< 35μg/$m^3$ the land area accounted for 70.01%, between 35~50μg/$m^3$ the land surface area accounted for 30%,

and no area accounted for > 50μg/m$^3$. During autumn, the <35μg/m$^3$ area only accounted for 5.17%, 54.38% was between 35~50μg/m$^3$, and was 40.44 was > 50μg/m$^3$. For winter, 59.86% land area was >50μg/m$^3$, 34.84% land area was between 35~50μg/m$^3$, and only 5.28% land area was < 35μg/m$^3$. For the different land types, the forest area accounted for the largest proportion. Ranking below 35μg/m$^3$ $PM_{2.5}$ concentration, the values were 3.49% in spring, 23.39% in summer, 3.93% in autumn, and 4.35% in winter. Interestingly, the forest land type measured $PM_{2.5}$ between 35~50μg/m$^3$. In spring, autumn, and winter, the largest area proportion was calculated at 13.76%, 15.49% and 14.81%, respectively; in summer, the largest area proportion was building land (24.12%). For the building land type, spring, autumn, and winter showed the largest area proportion of the $PM_{2.5}$ >50μg/m$^3$ (Table 2). The building land means more population activities, which resulted in more air pollution sources [27]. The forest type had a high vegetation roof cover; however, it occupied the high area proportion in $PM_{2.5}$ between 35~50μg/m$^3$. The main reason for this result was that, as air moves through the forest landscape, the filtering of particulate air pollution results in higher pollutants within forests and other green spaces [17, 63, 64]. Janhäll [28] has advocated that increasing the vegetation barriers should help absorb and filter the particulate air pollution.

**Table 1.** The $PM_{2.5}$ concentration in the eight districts of Hangzhou by four seasons in 2015, including maximum, minimum, mean and standard deviation value.

| | | Shangcheng | Xiacheng | Jianggan | Xihu | Gongshu | Binjiang | Yuhang | Xiaoshan |
|---|---|---|---|---|---|---|---|---|---|
| Spring | Max | 51.69 | 58.7 | 57.11 | 58.97 | 59.49 | 54.13 | 61.18 | 68.54 |
| | Min | 47.67 | 49.04 | 45.38 | 46.53 | 48.84 | 48.26 | 23.48 | 41.07 |
| | Mean | 50.32 | 54.1 | 52.21 | 51.94 | 53.87 | 51.26 | 47.65 | 51.8 |
| | Std | 0.94 | 3.06 | 2.77 | 2.64 | 2.54 | 0.92 | 10.29 | 4.61 |
| Summer | Max | 28.14 | 31.95 | 32.78 | 34.94 | 31.76 | 29.3 | 33.03 | 35.95 |
| | Min | 24.28 | 26.79 | 22.37 | 23.89 | 23.4 | 23.34 | 10.84 | 16.69 |
| | Mean | 25.87 | 29.73 | 27.11 | 28.43 | 27.38 | 25.49 | 23.31 | 24.96 |
| | Std | 1.02 | 1.13 | 2.29 | 2.27 | 2.26 | 1.33 | 5.36 | 3.50 |
| Autumn | Max | 45.88 | 46.51 | 47.77 | 45.85 | 45.63 | 46.06 | 50.95 | 59.63 |
| | Min | 41.76 | 43.76 | 41.9 | 40.16 | 42.51 | 43.41 | 24.83 | 40.8 |
| | Mean | 44.12 | 45.27 | 44.14 | 43.35 | 43.96 | 44.49 | 39.41 | 47.33 |
| | Std | 1.03 | 0.67 | 1.32 | 1.18 | 0.68 | 0.57 | 6.30 | 3.40 |
| Winter | Max | 57.09 | 64.74 | 64.43 | 65.57 | 65.42 | 59.97 | 66.47 | 67.97 |
| | Min | 53.03 | 54.21 | 46.9 | 48.26 | 53.83 | 51.7 | 44.06 | 44.06 |
| | Mean | 54.67 | 60.19 | 54.67 | 55.14 | 61.08 | 54.82 | 54.63 | 54.63 |
| | Std | 1.06 | 2.86 | 4.49 | 2.61 | 3.86 | 1.61 | 8.56 | 5.60 |

**Table 2.** The area percentage of the different land use type to the total study area percentage (%) by the three class of $PM_{2.5}$ concentration in the four seasons.

| Land use type | Class of $PM_{2.5}$ | Spring (%) | Summer(%) | Autumn(%) | Winter(%) |
|---|---|---|---|---|---|
| Grassland | 35 | 0.07 | 4.59 | 0.11 | 0.1 |
| Plowland | 35 | 0.13 | 11.52 | 0.25 | 0.16 |
| Building land | 35 | 0.17 | 2.51 | 0.26 | 0.25 |
| Traffic land | 35 | 0.05 | 4.92 | 0.07 | 0.07 |
| Forest | 35 | 3.49 | 23.39 | 3.93 | 4.35 |
| Water | 35 | 0.03 | 12.21 | 0.1 | 0.05 |
| Orchard | 35 | 0.22 | 10.87 | 0.45 | 0.3 |

| | | | | | |
|---|---|---|---|---|---|
| Grassland | 35-50 | 1.84 | 0.4 | 3.03 | 1.57 |
| plowland | 35-50 | 5.27 | 0.59 | 6.35 | 5.23 |
| Building land | 35-50 | 6.74 | 24.12 | 14.35 | 5.73 |
| Road traffic land | 35-50 | 1.41 | 0.55 | 3.11 | 1.38 |
| Forest | 35-50 | 13.76 | 2.82 | 15.49 | 14.81 |
| Water | 35-50 | 6.32 | 0.6 | 7.39 | 3.12 |
| Orchard | 35-50 | 3.89 | 0.92 | 4.66 | 3 |
| Grassland | >50 | 3.09 | 0 | 1.84 | 3.33 |
| plowland | >50 | 6.71 | 0 | 5.51 | 6.71 |
| Building land | >50 | 19.72 | 0 | 12.02 | 20.65 |
| Road traffic land | >50 | 4.02 | 0 | 2.29 | 4.02 |
| Forest | >50 | 8.95 | 0 | 6.78 | 7.03 |
| Water | >50 | 6.46 | 0 | 5.32 | 9.64 |
| Orchard | >50 | 7.67 | 0 | 6.68 | 8.48 |

### 3.4. Population Group Exposure under the Roof of the $PM_{2.5}$

For the annual mean $PM_{2.5}$ concentration in 2015, the spatial distribution of the population density was 249.18 Pop/km$^2$(±746.53) in $PM_{2.5}$ <35μm/m$^3$. The distributed area was 266.29km$^2$; between 35~50μm/m$^3$, the density was 1,521.60 Pop/km$^2$ (±3,584.08), and the area was 1,483.99km$^2$. The population density was 1,582.66 Pop/km$^2$(±3,124.79) for > 50μm/m$^3$ and the area was 1,188.18km$^2$. The result of these calculations determined the population mainly distributed in the high $PM_{2.5}$ concentration, where land surface also covered high density buildings. On the other hand, gaseous and particulate pollutants were also exposed due to human activity. Pollution from human activities has severely contributed to huge health impacts on mankind over a long period of time [65-67]. Considering the special group of infants and juveniles attending school, the younger individuals are less resistant to disease and daily exposure to the high $PM_{2.5}$ concentration can cause both current and future health problems. It is very important to pay attention to this group of individuals and closely monitor their state of health at all times.

In the study area, in 2015, the number of kindergarten institutions equaled 623 and the respective number of infants equaled 239,459; the number of primary school institutions equaled 265 while the number of respective students equaled 389,260; and the number of middle school institutions equaled 123 while the number of respective students equaled 217,959. By the different $PM_{2.5}$ concentration class, 294 kindergarten students distributed $PM_{2.5}$> 50 ug/m$^3$, 325 distributed 35~50 ug/m$^3$, and only four distributed <35 ug/m$^3$. Seven primary schools distributed < 35 ug/m$^3$; 147 distributed between 35~50 ug/m$^3$, and 111 distributed >50 ug/m$^3$. Two middle schools distributed < 35 ug/m$^3$, 123 middle schools distributed between 35~50 ug/m$^3$, and 71 middle schools distributed >50 ug/m$^3$ (Figure. 6, Table 3). These results concluded that at each of the aforementioned educational levels, only 1.66% (14,055) of infants and juveniles involved in the study lived in an environment that met the national air quality standard. This number was even below the national mean level, who living environment reached China's National Air Quality Standard for Grade II [13, 27, 68]. In addition, 41.97% (355,333) of infants and juveniles lived in a heavily polluted environment ($PM_{2.5}$ > 50 ug/m$^3$), and 56.49% (478,257) of infants and juveniles lived in an intermediately polluted environment ($PM_{2.5}$ between 35~ 50 ug/m$^3$), shown in the study area (Table 3). Although we only achieved statistics for the number of infants and juveniles by these three levels of schooling, their families and the schools near their

residential areas experience a similar atmospheric environment. Although children's disease attributed by $PM_{2.5}$ exposure was not separately studied, additional findings showed that China's leading mortality causes (stroke, IHD, LC, and COPD) could be attributed to $PM_{2.5}$ exposure to some extent [36, 69-71]. Considering the lag health effects of long-term $PM_{2.5}$ exposure, it is necessary to track the health status of infants and juveniles from now until they have entered into adulthood. In doing so, we can more effectively eliminate the harm $PM_{2.5}$ poses to our overall health.

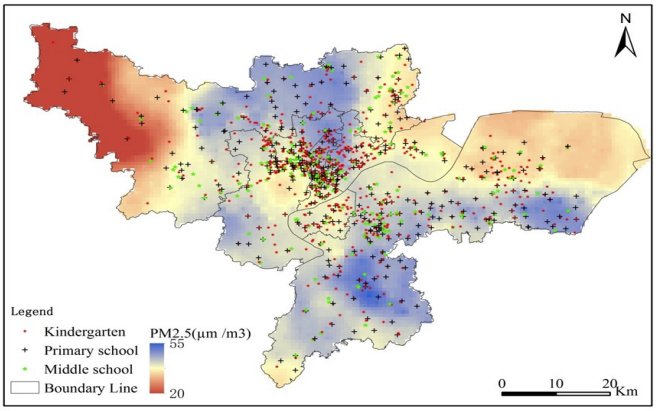


**Figure 6.** The Kindergarten, Primary and middle school distributed in the annual mean PM2.5 concentration.

**Table. 3** The number of Kindergarten, Primary School and the Middle Schools by the three class of annual $PM_{2.5}$ concentration and the population density.

| PM2.5 (ug/m3) | Kindergarten | Primary School | Middle School |
|---|---|---|---|
| 35 | 4 | 7 | 2 |
| 50 | 325 | 147 | 123 |
| >50 | 294 | 111 | 71 |
| Total School | 623 | 265 | 195 |
| Total population | 239459 | 389260 | 217959 |
| Mean (Pop/School) | 384 | 1469 | 1118 |

## 4. CONCLUSION

We used a combination of the dispersed monitoring sites data, land use data, and MODIS remote-sensing AOT to calculate the inversion of $PM_{2.5}$ concentration and its effects on the general population and students in Hangzhou in 2015. From our research, we were able to draw the following conclusions.

First, the seasonal variation characteristics of $PM_{2.5}$ concentration distribution was as follows: winter > spring > autumn>summer. For the eight main urban districts, the highest average value $PM_{2.5}$ concentration in spring, summer, and autumn all showed in the Xiacheng district, and the lowest value showed in the Yuhang district. However, in winter, the highest average value showed in the Gongshu district, and the lowest value also showed in the Yuhang district. In addition, the lowest value in all four seasons appeared in the Yuhang district.

Secondly, for the different land use types, we found that in winter and spring, 59.86% and 56.62% of the land area showed the $PM_{2.5}$ >50μg/m$^3$, respectively. Among the building area, we accounted for 20.65% in winter and 19.72% in spring. In autumn, 54.38% of the land area exposure equaled $PM_{2.5}$ 35~50μg/m3, and the forest type accounted for a large proportion (15.49%). In the summer, the air particulate content was lowest. 70.01% of the land surface area equaled $PM_{2.5}$ <35μg/m$^3$, and the forest type accounted for 23.39%. Increasing the forest landscape performs the function of absorbing and filtering the particulate air pollution with the goal of sending the pollution into remission.

Finally, based on the spatial distribution of different class $PM_{2.5}$ concentration, only 9.06% of the population lived in an environment that met the national air quality standards. For infants and juveniles, only 1.66% (14,055) lived in $PM_{2.5}$ <35μg/m$^3$; 56.49%

(478,257) lived in the intermediate pollution environment ($PM_{2.5}$ 35~ 50 ug/$m^3$); and 41.97% (355,333) of infants and juveniles lived in a heavy polluted environment ($PM_{2.5}$ > 50 ug/$m^3$) in the study area.

We firmly believe that not only in Hangzhou, but also spanning all of China, a devastating number of infants and juveniles currently live in an atmospheric pollution environment; action must be taken and attention must be paid in order to safeguard the future of the country.

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