$PM_{0.1}$ in Southeast Asian Cities

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$PM_{0.1}$ (particles with a diameter ≤ 0.1 μm), nanoparticles (NPs), or ultrafine particles (UFPs) were interchangeably used in the scientific communities. $PM_{0.1}$ originated from both natural and human sources.

Keywords: Asia ; air pollution ; health risk ; PM0.1

1. $PM_{0.1}$ Mass Concentration in Southeast Asia Atmosphere

The $PM_{0.1}$ fractions in the ambient PM have a very low particle mass concentration but a huge number of particles [1]. Most particles by numbers lie below 0.1 μm (100 nm), and they are in the $PM_{0.1}$ range; however, their concentration in terms of mass per volume is very low. No standards for ambient $PM_{0.1}$ have been adopted in Asian countries. The European Committee for standardization announced that the Condensation Particle Counter (CPC) is a standard protocol to measure UFPs [2]; however, only the emission standard for diesel and gasoline direct injection engine road vehicles must meet a type-approval of UFPs for non-volatile particles of >23 nm diameter (The Solid Particle Number >23 nm method; SPN23) [3]. The most widely used measure UFPs is particle number concentration (PNC) due to their tiny volume and mass concentration. The estimated concentration based on 10 μg/m^3 in $PM_{2.5}$ found that $PM_{2.5}$ 1 particle/cm^3 equal to $PM_{0.02}$ (<20 nm) 2.4 × 10^6 particle/cm^3, or PM_{10} 1 particle/cm^3 similar to UFPs 1.0 × 10^6 particle/cm^3 [4]. The particle number concentration and surface area are suitable for measuring UFPs' small mass concentration in the past decades [1].

The average $PM_{0.1}$ mass concentration in SEA has shown in the past decade. The initial study of ambient $PM_{0.1}$ in SEA and published in an international peer-review journal is based on a survey in Thailand from 2014 to 2105 [5]. The $PM_{0.1}$ in Bangkok and Chiang Mai, Thailand, was 14.80 ± 1.99 and 25.21 ± 4.73 μg/m^3, respectively. Bangkok is the capital city in Thailand and one of the densest populated cities in SEA. The high episode of $PM_{0.1}$ in Chiang Mai arises from biomass fires in the dry season (February–April).

In Thailand, $PM_{0.1}$ in Pathumthani, in Bangkok Metropolitan Region areas, also elevated mass concentrations in wet and dry seasons [6]. In Hat Yai, southern Thailand [7], $PM_{0.1}$ was 10.17 ± 2.23 μg/m^3 representing PM concentrations lower than in other parts of Thailand; moreover, Zhao et al. (2016) [8] reported that they compared $PM_{0.1}$ during the dry season (Mar-Apr 2016) in many cities, including Chiang Mai, Bangkok, Songkhla, Riau, Ho Chi Minh City, Phnom Penh, and Kuala Lumpur. The study found that mass concentration (μg/m^3) decreased in the order, Phnom Penh (18.9) > Chiang Mai (16.5) > Hanoi (15.4) > Ho Chi Minh City (13.1) > Riau (12.4) > North Bangkok (11.9) > Hat Yai (10.9) > Kuala Lumpur (9.3) > Bangkok (7.7).

The higher mass concentration in Upper SEA countries than in lower SEA countries due to the dry season during that period that the open biomass burning has been reported by several researchers [5][9][10]. PMs increased every dry season (February–April), and they started to rise around February and peaked in March before decreasing by mid-April [5]. The primary emission source of PMs worsening during the dry season in these areas was identified as open biomass burning, including forest fire and crop residue burning [5][6]. The above-mentioned corresponded with the accumulated fire hotspot locations that were high in the dry season and low in the wet season. Each active fire location represents the center, approximately decreasing by mid-of 1 km pixel flagged as one or more actively burning hotspots/fires [9]. Generally, $PM_{0.1}$ is derived from diesel exhaust, and it was sensitive to biomass burning in this area [5]. In addition, ambient $PM_{0.1}$ in Vietnam and Indonesia is very progressive. In Indonesia, the study by Amin et al. (2021a) [11] and Putri et al. (2021) [12] suggested that the $PM_{0.1}$ mass concentration in the dry season is higher than in the wet season in all monitoring sites. In addition, the mass concentrations by different monitoring sites have attention as follows, urban > suburban > rural. In Vietnam, many studies of $PM_{0.1}$ in Hanoi, the capital city in Vietnam, are more progressive than in other SEA cities [8][13][14][15][16][17][18]. The results show that mass concentrations in different environments in Hanoi ranged from 1 to 17 μg/m^3.

2. Sources and Characteristics of $PM_{0.1}$ in Southeast Asia

Regarding the natural sources, primary $PM_{0.1}$ is mainly generated by forest fires, while lesser fractions come from maritime aerosols and volcanic eruptions [19][20]. On the other hand, anthropogenic sources of $PM_{0.1}$ include transportation (on- and off-road automobiles, diesel engines, airplanes, and shipping), industrial combustion processes including biomass combustion and waste incineration, cigarette smoking, and meat cooking [1]. So, the primary emission sources of $PM_{0.1}$ are both natural and anthropogenic sources. Most studies of emission sources of $PM_{0.1}$ in Asia are related to road vehicles [21][22][23]. In an urban area, traffic is the primary source of $PM_{0.1}$ emissions. Diesel engines dominate $PM_{0.1}$ in megacities, including Shanghai, China [24], Hanoi, Vietnam [13], and Bangkok, Thailand [5]. Diesel engines have about two times higher emission factors than gasoline engines [25]. On the other hand, forest fires emit particles that dominate traffic emissions, and the size distribution peaks at approximately 120 nm for a fresh aerosol plume [26]; moreover, Phairuang et al. (2019) [5] stated that open biomass burning in central and northern Thailand dominated the release of carbon components into the atmosphere. The $PM_{0.1}$ particle, primarily derived from motor vehicle emissions, is also strongly affected by open biomass burning in the upper part of Thailand. Hence, this activity significantly affects air quality during the dry season. Similarly, an ambient $PM_{0.1}$ study in Hanoi, Vietnam, showed high mass concentrations of $PM_{0.1}$ during rice straw burning periods [13]; however, some possibly essential sources, such as domestic wood burning, are poorly quantified in SEA [27].

The chemical composition study in NPs is still limited, especially in ambient $PM_{0.1}$ particles; however, a few publications have been from NPs and chemical composition sources. For instance, polycyclic aromatic hydrocarbons (PAHs) dominate PM emissions [27][28]. Most PAHs emissions are generated from incomplete combustion of natural and human sources, including vehicle exhaust, biomass burning, industrial activities, and coal combustion. Hata et al. (2014) [28] studied the characteristics of NPs emitted from biomass fuels burning in Asia. The result demonstrated that approximately 30% of the biomass fuels burning smoke had a mass of <100 nm. Additionally, PM smaller than 0.43 μm significantly contributed to the toxicity of PAHs and the fraction of Water-soluble Organic Carbon (WSOC). Similarly, Chomanee et al. (2018) [29] considered the PAHs in smoke plumes released from the para-rubber fuel-wood combustion; this result displays that the ultrafine ($PM_{0.07}$) smoke particles comprised the highest number of PAHs and Benzo[a]pyrene-Toxic Equivalence Quotient (BaP-TEQ). The important fraction of NPs had the most considerable emission of toxicity per unit PM mass compared to fine and coarse PM; this is a critical point to concentrate on smaller particles, especially NPs, on any emission sources due to a lack of reliable information on the origins and magnitudes in SEA countries [5].

Secondary $PM_{0.1}$ aerosol is mainly generated from atmospheric photochemical of gaseous precursors and by condensation of semi-volatile vapors. Such new particle formation can occur during low relative humidity and wind speed at quiet pre-existing particle surface areas and global radiation [30]. Reche et al. (2011) [31] described that new particle formation in an urban area in Europe during warmer and sunny climates is essential to air pollution. In SEA, Thuy et al. (2018) [13] stated that Secondary Organic Carbon (SOC) is more dominant in smaller particles than in larger particles; and the SOC in $PM_{0.1}$ contributes up to 42.7% of the OC level in Hanoi, Vietnam. The secondary atmospheric $PM_{0.1}$ in the SEA environment remains poorly understood. Based on the chemical, optical, and thermal properties of such samples, these carbon components can be broadly classified into two main fractions, i.e., organic carbon (OC) and elemental carbon (EC). The source of OC can be primary (POC) and secondary emissions (SOC), while EC is mainly emitted from primary sources [7][13]. The importance of carbonaceous particulate matter (OC and EC) in the Earth's climate system is becoming more broadly recognized due to its ability to induce climate changes by directly disrupting the Earth's radiative balance via the extinction of incoming solar radiation and indirectly by serving as cloud condensation nuclei (CCN). Carbonaceous particulate matter was also demonstrated to significantly influence air quality and human health [5][11][20].

3. Health Concerns of $PM_{0.1}$

$PM_{0.1}$ strongly believes in high toxic properties because a high surface area can absorb many poisonous substances. After they penetrate the human organ systems, allowing translocation and interactions to a human body organ and highly potential deeply into circular systems via respiratory mechanism [32]. The World Health Organization (WHO 2013) [33] suggested that the epidemiological data on $PM_{0.1}$ are too scarce to estimate or use in policy-making for air quality control management of $PM_{0.1}$. The Health Effects Institute (HEI 2013) [34] reflected that the ongoing evidence did not convincingly support the suggestion that $PM_{0.1}$ alone can account for actual conduct for the adverse effects that have been associated with atmospheric pollutants such as $PM_{2.5}$ and PM_{10}.

In health risk assessment, toxicity equivalent concentration (TEQs), calculations based on toxic equivalent factors (TEFs), can be used to estimate health risks associated with PAHs [27]. High concentrations of PMs containing PAHs are well-known in symptoms, i.e., eye irritation, diarrhea, vomiting, and nausea. The detrimental effects of PAHs hang on the

mechanism of exposure. Benzo[a]pyrene (BaP) is the well-known PAH to cause cancer on a laboratory scale resulting long term exposure. The BaP-TEQ is a widely used indicator to estimate the exposure to PAHs to human health. On the other hand, there have been limited studies on the characteristics of $PM_{0.1}$ and toxic PAHs in the Southeast Asian environment; moreover, it is vital to note that finer particles are a more significant source of carcinogenic properties and cause more human health consequences than larger particles due to their higher surface area that can absorb many toxic elements.

Phairuang et al. (2021, 2022) [35][36] investigated the health risk of $PM_{0.1}$ and its trace elements, such as Aluminium (Al), Barium (Ba), Potassium (K), Iron (Fe), Chromium (Cr), Copper (Cu), Nickel (Ni), Sodium (Na), Manganese (Mn), Magnesium (Mg), Titanium (Ti), Lead (Pb), and Zinc (Zn), on humans in Bangkok and Hat Yai, Thailand. PM's primary sources were road traffic, industry, and biomass burning. In addition, the total cancer risk from all carcinogenic elements was high in adults, indicating that the carcinogenic risk is within a tolerable risk assessment range.

Guan et al. (2017) [37], in a study conducted in China, reported that increasing 10 $\mu g/m^3$ in $PM_{2.5}$ from any emission source was linked to a 3.1% increase in the risk of hospitalization as well as a 2.5% increase in mortality. Crippa et al. (2016) [38] reported that the short-term exposure to the burning of agricultural residues and peat-land fires in heavy haze episodes in 2015 from Indonesia might have caused 11,880 excess mortalities. Most studies have stated the adverse effect of inhaled atmospheric $PM_{0.1}$ on human health to continue lacking in SEA. Three are still limited information between $PM_{0.1}$ and disease; however, there have not become fully aware of the critical hazards of ambient $PM_{0.1}$ on human health [1].

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