

# Assessment of PM<sub>2.5</sub> Chemical Composition and Air Quality Monitoring: Implications of Air Pollutants Emissions from a Night Market in Kaohsiung City, Taiwan

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## ABSTRACT

There are around 300 night markets in Taiwan, and they have been drawing an increasing number of tourists in recent years. As a result, public awareness over air quality in the night markets has grown tremendously. In response to this, a specific night market in Kaohsiung City was chosen for this study in order to characterize the existing air quality in and around the night markets. In this present study, we employed an Industrial Source Complex Short-Term (ISCST3) air quality model for the simulation of PM<sub>2.5</sub> diffusions. The model as a technique can simulate the pollutants emissions, diffusions, transportation, and pollution sources in specific areas and subsequently evaluate the influence between the source and the receiver. Therefore, we compared pollutants emissions data from several air quality monitoring stations with our sampling data of three different sampling sites in Kaohsiung City. The findings of this study showed that the average concentration of PM<sub>2.5</sub> was in the range of 29–61  $\mu\text{g m}^{-3}$  during opening hours of the night market, whereas the average concentration of PM<sub>2.5</sub> range was between 22–38  $\mu\text{g m}^{-3}$  before the night market opening hours. The concentration of metallic elements (ME) (Mg, Na, Cr, Mn, Fe, Cu, Al, Ba, Cd, Pb and Ca) was determined with the support of Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). During the night market opening hours, the result disclosed that the ME concentrations in PM<sub>2.5</sub> was in an increasing order as follows: Na > Fe > Al > Ca. With respect to the concentration of carbonaceous species, our results showed that the highest total carbon (TC) concentration was found to be 6.52  $\mu\text{g m}^{-3}$  during the downwind sampling interval. The highest elemental carbon (EC) and organic carbon (OC) concentration were found to be 6.53  $\mu\text{g m}^{-3}$  and 2.70  $\mu\text{g m}^{-3}$  of the PM<sub>2.5</sub> concentration, respectively. This study's findings have significant consequences for Taiwan policymakers and urban planners, particularly those responsible for coordinating environmental protection and economic development in cities. Therefore, policy actions to abate urban air pollution can be attained on diverse governing echelons, resulting in synergistic effects such as a reduction in climate change impacts.

**Keywords:** Night market, PM<sub>2.5</sub> emissions, Metallic elements concentrations, Air quality monitoring, Pollutants emissions, ISCST3 model

## 1 INTRODUCTION

According to the World Urbanization Prospect 2018 Revision, Asia and Africa's megacities are expected to experience a population rise of over 90% by 2050. Along with the increase in

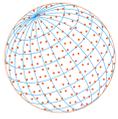
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population, cities economic growth activities have increased pollution levels from many industries (Jiang *et al.*, 2021; Kumari and Toshiwal, 2020). Thus, environmental pollution has become a severe concern due to the effects of tremendous population expansion on the environment, as well as unregulated urbanization, industry, and automation. The most evident impact is that air quality is deteriorating (Kanawade *et al.*, 2020; Hashim *et al.*, 2021).

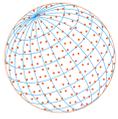
According to the Taiwan Environmental Protection Agency's air quality monitor, Kaohsiung City has by far the greatest ratio of poor air quality days to the total monitored days in Taiwan. In the heavily inhabited City of Kaohsiung, some of the considerable population concentrations are situated in the vicinity of several night markets. In the meantime, the number of night markets has exploded in recent years, attracting an increasing number of visitors. The night market is a very crowded outdoor cooking setting where many residents and visitors spend a significant amount of time. Indeed, the night market is an important part of Taiwan society and a distinctive venue that Taiwanese people are thrilled about. Notwithstanding that, food stalls in night markets, on the other hand, generally use fans or exhaust hoods to discharge or release their cooking fumes onto neighboring occupied places or directly above market streets. Excellent air quality at night markets not only improves the experience of market visitors, but it also safeguards market personnel and customers from exposure to detrimental air contaminants.

The night market industry has attracted numerous stalls and people around Taiwan, and hence has the ability to boost economic development. According to earlier figures, Taiwan has a large number of night markets, with over 300 operating in various locations across the island. Night markets are regarded as an integral element of Taiwanese culture (Sun *et al.*, 2012; Chen *et al.*, 2014). The majority of Kaohsiung City's neighborhoods are close to night markets, which attract thousands of people every day (Zhao *et al.*, 2011; Chen *et al.*, 2014; Liao, 2017). As a result, the levels of air pollution in the vicinity of these night markets should be evaluated, as they may pose major health risks.

Among air pollutants that are being researched nowadays, the current research trend is particularly focused on particulate matter (PM) in two size fractions, namely;  $PM_{2.5}$  and  $PM_{10}$ . The primary sources of  $PM_{2.5}$  include vehicle exhausts, soil dust, road dust, biomass burning, fossil fuel combustion, metal processing, and other anthropogenic activities (Lin *et al.*, 2020a, b; 2019; Huang *et al.*, 2020; Song *et al.*, 2021).  $PM_{10}$  refers to atmospheric particles with aerodynamic diameters less than or equal to 10  $\mu m$ , which are one of the most important pollution indicators used to characterize air quality (Canha *et al.*, 2019; Vu *et al.*, 2019; Mahato *et al.*, 2020). In addition to the primary sources on  $PM_{2.5}$ , cooking methods have a huge impact on the amount of air pollutants emitted into the atmosphere. However, several researchers have reported the amount of air pollutants ( $PM_{10}$ ,  $PM_{2.5}$ ,  $NO_x$ , and CO) emitted from the combustion of charcoal (Huang *et al.*, 2016; Hu *et al.*, 2021; Vicente *et al.*, 2018).

It is a common knowledge that atmospheric fine particulate matter pollution has been recognized as a serious public health concern nowadays.  $PM_{2.5}$  is a kind of fine suspended particulate, and it has a vast surface area, making it an excellent transporter of metallic elements (ME) and heavy metals alike (Sun *et al.*, 2019; Jiang *et al.*, 2019). The long-term exposure to  $PM_{2.5}$  has connection with several health issues such as cardiovascular disease and lung cancer (Wei *et al.*, 2015; Mcguinn *et al.*, 2019). In relation to the present study, the night markets opening hours could be one of the major  $PM_{2.5}$  emitted sources. Studies have indicated that air pollutants emitted from cooking activities have detrimental effects on human health (Salje *et al.*, 2014; Stabile *et al.*, 2015).

With respect to  $PM_{10}$ , the source of  $PM_{10}$  particle could be divided roughly into two; from the natural occurrence (e.g., dust storms, slats, pollen, and volcanoes) and those that are related to human activities (e.g., power generation plants, transportation, incinerators, and domestic heating) (Dai *et al.*, 2018; Uroš *et al.*, 2019; Chen *et al.*, 2020; Mohd Nadzir *et al.*, 2020). Furthermore,  $PM_{10}$  is one of most crucial indexes of air quality monitoring (Liu *et al.*, 2020; Xu *et al.*, 2020), due to the fact that, the main composition of  $PM_{10}$  is inorganic ions, organic pollutants, heavy metal elements, bacterial, viruses, and others harmful substances (Mesquita *et al.*, 2014). Due to the fact that,  $PM_{10}$  has a small size; it could enter the human body via the respiratory tract, digestive tract, and skin. According to epidemiological studies, long-term exposure to high  $PM_{10}$  concentration could cause extensive damage to human body even cancerous changes in the respiratory, cardiovascular, immune, and endocrine systems (Rodopoulou *et al.*, 2014; Huang *et al.*, 2017; Carugno *et al.*, 2018; Gondalia *et al.*, 2019).



Carbon is one of the most abundant components in the atmospheric PM, accounting for roughly 20–60% of PM<sub>2.5</sub> concentration and primarily taking the forms of organic carbon (OC) and elemental carbon (EC). Atmospheric EC is emitted directly from primary human sources (Cui *et al.*, 2017), whilst OC can be emanated directly from sources such as primary particulates and secondary OC, which are formed by chemical reactions in the atmosphere with low vapor pressure. Particulate matter's OC and EC play important roles in global climate change, visibility deterioration, and human health (Lin *et al.*, 2020).

PM<sub>2.5</sub> has a huge surface area, making it a potential transporter of ME, heavy metals, germs, and viruses (Jiang *et al.*, 2019; Sun *et al.*, 2019), which can be breathed and absorbed by the alveoli or enter other organs by lung aeration, potentially causing asthma, bronchitis, and cardiovascular disorders (McGuinn *et al.*, 2019; Liu *et al.*, 2016). Several studies on heavy metals as PM<sub>2.5</sub> components and their origins have been conducted in countries such as China, Denmark, Turkey, and France (Hvidtfeldt *et al.*, 2019; Jiang *et al.*, 2019).

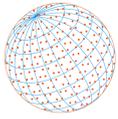
Public concern over the air quality in the night markets has dramatically increased over the past few years. While few studies have been focused on the air quality in the night markets, we decided to probe the situation of air indexes (PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>x</sub> and CO), particularly during the night market opening and non-opening hours. This is an attempt to investigate the air quality and implications of air pollutants emissions from the night market activities, such as cooking and road traffic in the surroundings.

To simulate spatial variations in air pollution concentrations, a variety of air diffusion models have been used. This is due to the fact that they specifically consider transmission and pollutant variations in the environment, air diffusion models are appropriate for simulating PM<sub>2.5</sub> concentrations in the air. They also have strong descriptive capacity for time variations (Lin *et al.*, 2021). Diffusion models that are commonly used include the steady-state Gaussian plume, Lagrangian-based trajectory, and grid models based on grid division. Popular diffusion models comprised of AERMOD, developed by the American Meteorological Society in conjunction with U.S. Environmental Protection Agency (U.S. EPA) (Rzeszutek *et al.*, 2017); industrial source complex short-term model (ISCST3), developed by U.S. EPA (Hanna *et al.*, 2001; Wesely *et al.*, 2002); community multiscale air quality (CMAQ) model developed by U.S. EPA (Binkowski and Roselle, 2003); CALPUFF developed by Exponent, Inc., USA (Levy *et al.*, 2002; Scire *et al.*, 2000); and the ALOHA model developed by U.S. EPA explicitly for the diffusion hazardous materials. These models have a variety of benefits and drawbacks, and they have been frequently utilized to simulate and compare air pollutant transmission in diverse studies (Asadi *et al.*, 2017; Butland *et al.*, 2020). Some of the most often used air diffusion models are listed in Table 1.

The ISCST3 model is a steady-state Gaussian plume model that may be used to assess pollution concentrations released by various industrial park sources. ISCST3 can simulate pollutant particle sedimentation; point, line, surface, and volume emission sources; distance role from wind direction; point source partition; and permits other topographic modifications. The Gaussian plume model is based on the premise that the vertical plume centerline concentration distribution is Gaussian, with the wind field direction serving as the plume centerline and maximum plume concentration flowing along it (Lee *et al.*, 2018). The ISCST3 model can handle a variety of sources, including point, volume, area, and open pit sources. It can assess pollution levels released by various sources in industrial parks. ISCST3 has been proved in numerous studies to be a better model for simulating the dispersion of air contaminants, notably from industrial sources (Bajoghli, 2019; Karuna *et al.*, 2017; Prakash *et al.*, 2017).

**Table 1.** Commonly used air diffusion models (Lin *et al.*, 2021).

Model Name	Developer	Type
AERMOD	U.S. EPA	Gaussian plume model
ISCST3	U.S. EPA	Gaussian plume model
CMAQ	U.S. EPA	Photochemical Modeling/Grid
CALINE4	California Department of Transportation	Gaussian plume model
CALPUFF	Exponent, Inc., USA	Gaussian plume model
HYSPLIT	National Oceanic and Atmospheric Administration (NOAA)	Trajectory
ALOHA	U.S. EPA	Hazard chemical modeling



Under this investigation, we employed ISCST3 air quality model for the simulation of PM<sub>2.5</sub> diffusion. The model as a technique can simulate the pollutants emissions, diffusions, transportation, and pollution sources in specific areas and subsequently evaluate the influence between the source and the receiver. We compared pollutants emissions data from several air quality monitoring stations of three different sampling sites in Kaohsiung City, namely; Dayi Junior High school, Sanmin Home Economics & Commerce Vocational High School, and Kaohsiung High Administrative Court. To better understand the impacts of various emissions on air quality changes, the selected monitoring sites were separated into three categories: downside, night market, and upside background, which included transportation (road traffic) locations.

This study aims to (1) document the concentrations of air pollutants from a night market in Kaohsiung City, (2) to assess the PM<sub>2.5</sub> chemical composition and air quality monitoring from a specific night market and its surrounding areas, and (3) to anticipate the implications of air pollutants emissions from a night market in Kaohsiung City. Our results can be utilized to explain variations in air pollutants at various sites, as well as to guide policymakers in developing mitigation strategies for future air quality improvement in urban areas.

## 2 METHODS

### 2.1 Description of Sampling Sites

The present study has focused on Kaohsiung City as an administrative city government and the largest city in the southern parts of Taiwan. Table 2 abridges the locality and environmental description of the three designated sampling locations. The locations of the three sampling spots are equally shown in Fig. 1. The upwind site (22°40'28.5"N/120°17'33.5"E) is located on the roof of a 4-story building with the height of 12 m above the ground. Whereas the downwind site (22°39'43.2"N/120°17'56.7"E) is situated on the roof of a 3-story building with the height of 10 m above the ground. The night market sampling site (22°40'01.0"N/120°18'04.3"E) is situated on the ground. The three sampling sites of the study areas as indicated in Fig. 1, shows that the topography of the study area is much high in the west-northwest, low in the southeast, and mountainous in the north, which is unfavorable to the transport and dispersion of pollutants. The Dayi Junior High School is located adjacent to mountainous area, and the southwest and northwest sides of the topography mat, whereas the Kaohsiung High Administrative Court is located in a comparatively flat area, which is favorable to the transport and diffusion of pollutants. The meteorological data considered under this investigation comprised of ground monitoring station meteorological data as well as high-altitude meteorological data. Wind direction, wind speed, temperature, and relative humidity were also equally considered as meteorological data.

### 2.2 Sampling Intervals and Method

The fine particulate (PM<sub>2.5</sub>) sampling was conducted into two phases at both locations (upwind and downwind sites) on the 16<sup>th</sup>–17<sup>th</sup> April 2019. Two low-volume ambient air samplers (PQ200 by BGI, Inc., USA) were used to collect two sets of samples (from upwind and downwind sites) at the same time on a 47 mm quartz fiber filter with a flow rate 16.7 L min<sup>-1</sup>. The first phase was conducted at the night market during the pre-opening period (6 a.m.–18 p.m.). The second phase was conducted during the night market opening period (18 p.m.–6 a.m.). Therefore, 4 samples were collected from upwind and downwind sites during the whole sampling period. At the night market sampling site, the traditional pollutions (NO<sub>x</sub>, SO<sub>2</sub> and CO) were collected via air

**Table 2.** The location of sampling sites and the weather situation.

Sampling region	Sampling sites	Abbreviations	Latitude	Longitude	Altitude (m)	Site description
Downside	Kaohsiung High Administrative Court	KC	22°39'43.2	120°17'56.7"	10	On the roof
Night market site	Sanmin Home Economics & Commerce Vocational High School	SM	22°40'01.0"	120°18'04.3"	1	On the ground
Upside	Dayi Junior High School	DY	22°40'28.7"	120°17'33.5"	12	On the roof

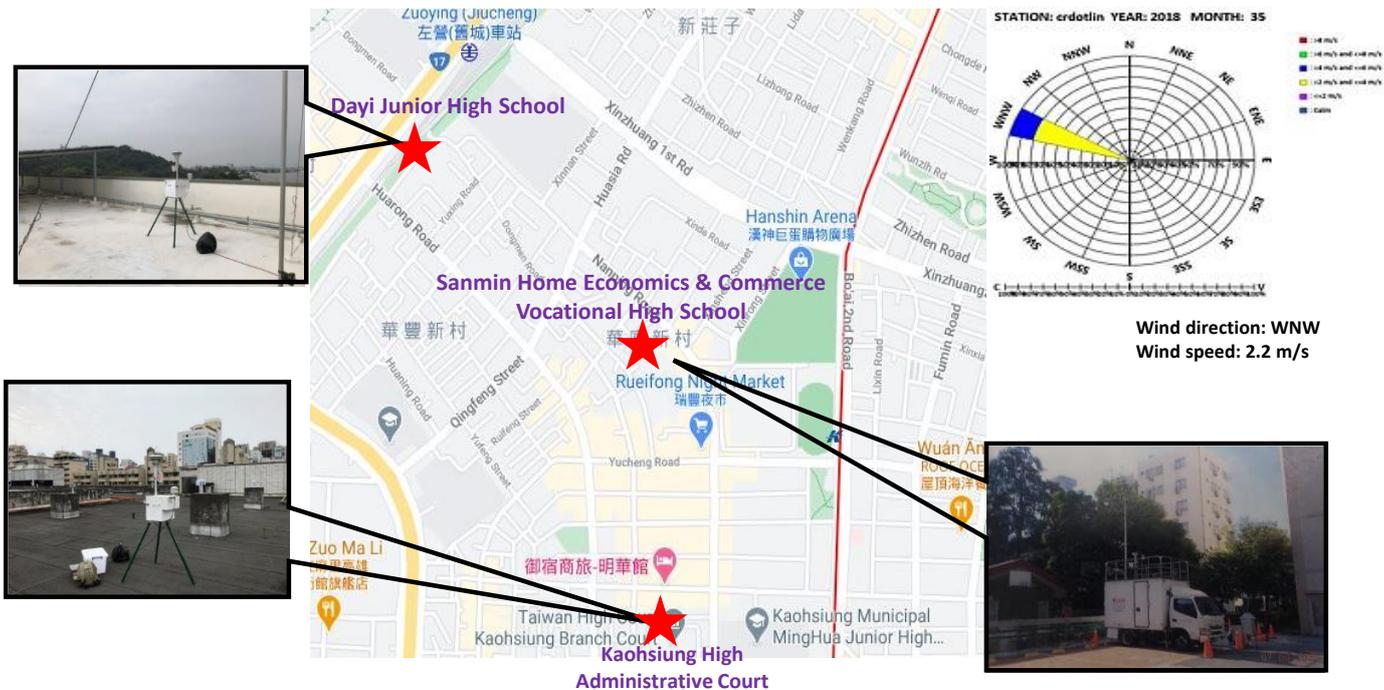
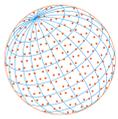


Fig. 1. Schematic diagram of the sampling sites.

quality-monitoring vehicle (from Cheng Shiu Super Micro Mass Research & Technology Center) on the 16<sup>th</sup>–17<sup>th</sup> April 2019. In the meantime, the PM<sub>2.5</sub> sampling was also conducted at this stage.

### 2.3 Chemical Component Analysis

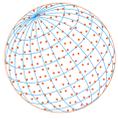
After finishing the sampling of PM<sub>2.5</sub>, the quartz fiber filters were stored for a while in a box with 30–40% relative humidity to preserve the chemical equilibrium, before being sent to the lab for conditioning, weighing, and further chemical analysis. Prior to the chemical analysis, all of the PM<sub>2.5</sub> filters were separated into four portions.

The quarter of quartz fiber filter was digested by microwave digestion method in 15 mL mixed acidic solution (HNO<sub>3</sub>:HCl = 3:7) by heating it up to 150°C for 0.5 h, and then diluted to 50 mL with deionized (DI) water for additional investigation of ME. During the absorption procedure, DI water was poured into the remaining solution for multiple times with the intention of removing the digesting solution's acidity. Twelve (12) ME of PM<sub>2.5</sub>, comprising of Na, Ca, Al, Fe, Mg, Cr, Mn, Fe, Cu, Ba, Cd, and Pb were examined with the help of Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) (Perkin Elmer, Model Optima, 2000DV).

The carbonaceous species consisting of elemental, organic, and total carbons of PM<sub>2.5</sub> had been assessed with the support of elemental analyzer (EA) (Carlo Erba, Model 1108). Before random sampling, the quartz fiber filters were prepared. The elemental analyzer was functioned through an oxidation procedure at 1020°C and a reduction procedure at 500°C, with constant heating for 15 min. Besides, the organic carbon (OC) component was removed from one eighth of the quartz fiber filters by heating it with hot nitrogen gas (340–350°C) for 30 minutes before determining the amount of elemental carbon (EC). The remaining eighth of the quartz fiber filter was evaluated without heating, and the carbonaceous species were classified as total carbon (TC) as a result. By subtracting elemental carbon (EC) from total carbon (TC), the amount of organic carbon (OC) was estimated.

### 2.4 Simulation Method of PM<sub>2.5</sub> Emissions

The air quality model selected was the Industrial Source Complex Short-Term (ISCST3) type of the ISC (Industrial Source Complex) model series. The model can simulate the emissions, diffusions, transportation, and settlement of pollution sources in the areas to evaluate the influence between the source and the receiver. The ISCST3 model has been modified so that it could be applied to



the calculation of complex terrains and dry settlements of the gas. It was used for short-term (an hour) to long-term (a year) period as well as for rural and urban simulations. We employed ISCST3 model to simulate the PM<sub>2.5</sub> emitted during the night market business period and the data of the regional air quality monitoring stations (Nan-zi, Ren-wu, Zuo-ying, Ai-guo, Zuo-yi and Qian-jin) to simulate the influence of the night market on the concentration of PM<sub>2.5</sub> surrounding areas during the night market business period. Finally, the spatial mapping software Surfer 9.0 was used to draw the concentration diffusion diagram as indicated in Fig. 2.

### 3 RESULTS AND DISCUSSION

#### 3.1 Diffusing Situation of PM<sub>2.5</sub> Simulating by ISCST3 Model

As presented in Fig. 2, the wind direction is WN; the speed was 2.5 m s<sup>-1</sup>. The simulated diagram of PM<sub>2.5</sub> concentration (μg m<sup>-3</sup>) is from the night market sampling data. During the night market opening hours, the PM<sub>2.5</sub> concentration from the night market was found to be in the range of 29 to 61 μg m<sup>-3</sup>. The average of concentration was 45 μg m<sup>-3</sup>. During the night market non-opening hours, the PM<sub>2.5</sub> concentration data from the night market was found to be in the range of 22 to 38 μg m<sup>-3</sup>. The average of concentration was 25 μg m<sup>-3</sup> during the sampling time. Several related reports have employed different air pollution diffusion models to simulate and analyze pollutant distributions and consequently offer valuable inputs to air pollution management and decision-making, with ISCST3, AERMOD, and Caline4 being the most prominent techniques. Prakash *et al.* (2017) evaluated simulation results using ISCST3 and Caline4 to estimate the dissemination of air pollution from point and line sources. They discovered that the ISCST3 model predicted NO<sub>x</sub> and SO<sub>2</sub> concentrations well, but Caline4 predicted PM<sub>10</sub> concentrations better. ISCST3 and Caline4 were also applied by Karuna *et al.* (2017) to forecast vehicle emissions as well as to monitor and forecast ambient air quality. They discovered that ISCST3 forecasts were the most accurate in terms of NO<sub>x</sub> and SO<sub>2</sub> concentrations, while Caline4 overestimated NO<sub>x</sub> levels. Gulia *et al.* (2014) employed AERMOD, ADMS-Urban, and ISCST3 to estimate air quality at a particular intersection in Delhi, India. They discovered that ISCST3 was better at forecasting CO

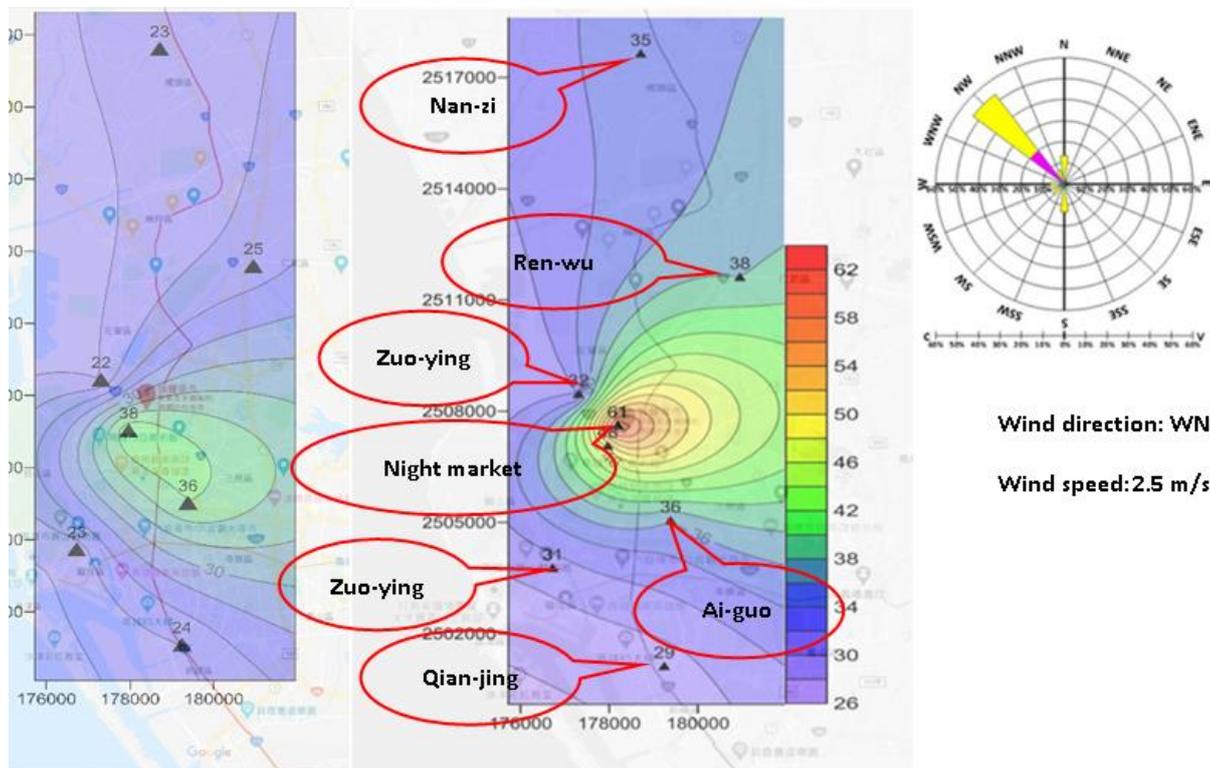
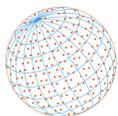


Fig. 2. Simulating PM<sub>2.5</sub> diffusion with the ISCST3 model.



concentrations, while ADMS-Urban was much better at predicting NO<sub>2</sub> concentrations, and all three models were accurate at predicting CO and PM<sub>2.5</sub> concentrations. Different modeling methods and/or landscape feature processing could cause variances in model performance. Bajoghli (2019) explored AERMOD and ISCST3 models for the simulations of pollutant dispersion from factory chimneys. They demonstrated that AERMOD was exceptional as compares to ISCST3, although ISCST3 calls for less input data, which was advantageous for small-area investigations. The present investigation also demonstrates that ISCST3 is an excellent model for simulating air pollutants from the night market, particularly for the assessment of PM<sub>2.5</sub> chemical composition and air quality monitoring.

### 3.2 Differences in Metallic Elements Concentrations in PM<sub>2.5</sub>

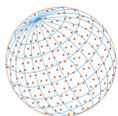
Various ME concentrations in the PM<sub>2.5</sub> under this study are displayed in the Table 3. The PM<sub>2.5</sub> concentration from the night market site during the opening period was recorded as follow: Na had the maximum concentration of 4590 ng m<sup>-3</sup>, while Fe was recorded with the second highest concentration of 1820 ng m<sup>-3</sup>, and Al with the concentration of 1600 ng m<sup>-3</sup>. While during the pre-opening period, the PM<sub>2.5</sub> concentration was recorded as follow: Fe had the highest concentration of 1340 ng m<sup>-3</sup>, followed by Al the second highest concentration of 1100 ng m<sup>-3</sup>, and Na with the concentration 928 ng m<sup>-3</sup>. In the non-opening period, the PM<sub>2.5</sub> concentration was recorded as following: Na had the highest concentration of 3570 ng m<sup>-3</sup>, followed by Fe with the second highest concentration of 1430 ng m<sup>-3</sup>, Ca and Al with a similar concentration of 806 ng m<sup>-3</sup>. According to our sampling results, Na could have probably originated from oil-based cooking activities due to the use of large amount of salt when the night market opening (Zhang *et al.*, 2017; Zhao *et al.*, 2019). The majority of Fe, Al and Ca could have probably been derived from emission of vehicles when the night market was opened (Lin *et al.*, 2020). Our findings are in consistent with those of Ojekunle *et al.* (2018), who found that in a study conducted in Nigeria, ME for example Cd, Cr, Ca, Cu, and Zn all had greater amounts in PM<sub>2.5</sub> than the WHO criterion. Almost one-third of the Zn in air dust was attributed to pollutant emissions from vehicles such as diesel automobiles in a research done in Great Britain by Harrison *et al.* (2012). Comparatively, Liu *et al.* (2018) conducted a similar study in Beijing, China, on the importance of emission reduction for PM<sub>2.5</sub>-bound ME in various seasons. They discovered that Ca was one of the ME noted in yearly trends in higher emission levels, with resuspended dust modeling the highest bulk contribution to PM<sub>2.5</sub>-bound ME.

In a single ICP investigation, the source of metallic species and their consequences on human well-being at absorptions of up to 30 ambient ME may be determined concomitantly with a ±55 ppm precision (Watson, 2010). Mg, Na, Cr, Mn, Fe, Cu, Al, Ba, Cd, Pb, and Ca were among the atmospheric ME discovered in this research. These ME have been discovered to have a significant impact on human health. In their investigation of MEs pollution in Asia from 2000 to 2007, Fang *et al.* (2010) discovered that exposure to particular MEs can provide a variety of dangers to humans. Excessive exposure to Fe, for example, can cause pneumoconiosis, whereas excessive exposure to Zn can cause heart disease and hypertension. Notably, they also discovered that Cr(VI) is carcinogenic and can induce asthma and liver damage, among other things (Banu *et al.*, 2017; Oruko *et al.*, 2020).

In many instances, Cr species have the ability to enter the eukaryotic system and initiate imprudent interactions with intracellular reductants, such as ascorbate and glutathione, resulting

**Table 3.** Metallic element concentrations in the PM<sub>2.5</sub> (ng m<sup>-3</sup>).

Sampling location	Sampling interval	Metallic elements										
		Na	Ca	Al	Fe	Mg	Cr	Mn	Cu	Ba	Cd	Pb
Upwind	(06:00–18:00)	859	1310	870	844	933	459	502	642	483	741	1310
	(18:00–06:00)	769	666	769	759	769	459	502	642	478	652	666
Downwind	(06:00–18:00)	875	1190	947	1120	773	511	497	647	488	595	1190
	(18:00–06:00)	2860	825	1020	1310	853	502	502	647	478	600	825
Pre-open hours	(14:00–18:00)	928	922	1100	1340	853	698	492	745	947	488	922
Open hours	(18:00–02:00)	4590	1060	1600	1820	817	600	492	733	486	601	1060
Non-open hours	(02:00–06:00)	3570	806	806	1430	778	563	502	736	483	600	806



in Cr(V) and/or Cr(IV) intermediates, free radicals, and Cr(III) end-products (Oruko *et al.*, 2020). The cytoplasmic intermediates are oxidized to Cr(VI), which rapidly interacts with DNA protein multiplexes and changes their normal biological functions (Sun *et al.*, 2019) in addition to damaging their DNA that has genotoxic and mutagenic implications (Oruko *et al.*, 2020). Furthermore, Cr(VI) species can amass in the placenta and harm the growth of the fetus, resulting in birth abnormalities and a decline in reproductive health (Banu *et al.*, 2017).

Additionally, Cu may cause various health issues such as lung cancer, interstitial fibrosis, and pulmonary granuloma, whilst Cd and Pb exposure can result in blood poisoning, anemia, and itai-itai illness. These MEs might find their way into coastal waterways and estuaries, posing a serious threat to aquatic animals' lives and activities, as well as posing a significant risk of death. As a result, MEs buildup in marine ecosystems has become a major global issue. Contamination with MEs could have disastrous consequences for the environment's ecological balance, as well as a severe impact on aquatic life diversity (Oruko *et al.*, 2020). Fish are among the species of animals that are unable to escape the detrimental impacts of these ME contaminants (Banu *et al.*, 2017). Wang *et al.* (2019) investigated the health risks of PM<sub>2.5</sub> in student dormitories at a Chinese university and discovered that MEs in the dormitory were made up of a mix of emissions from coal burning and industrial activities. Wei *et al.* (2019) highlighted that exposure to pollutant emissions could lead to the occurrence of myopia. They stressed out that continuous exposure to PM<sub>2.5</sub> and NO<sub>x</sub> can worsen ocular surface pain and, later, retinal inflammation, raising the likelihood of myopia development.

### 3.3 Carbonaceous Species of PM<sub>2.5</sub>

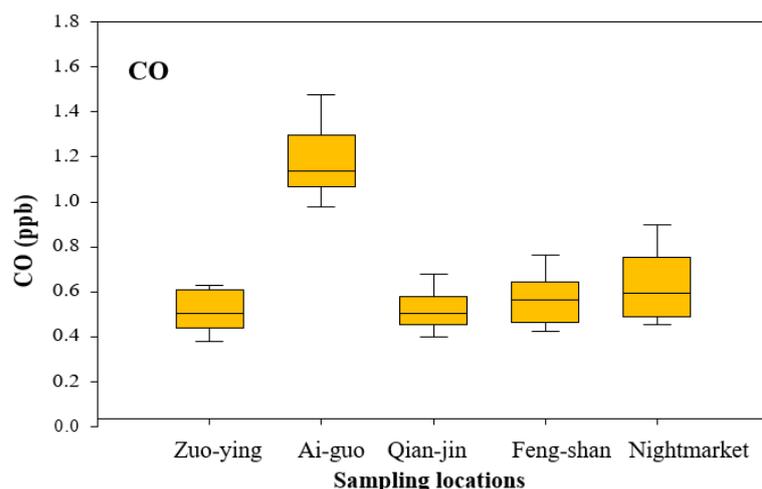
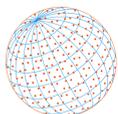
Atmospheric carbonaceous compounds in the aerosol particles entail mostly of EC and OC. Engine lubricating fluid, unburned fuel, and modest amounts of incomplete combustion and pyrolysis products were all found in the organic material (Chen *et al.*, 2019). EC is the product of incomplete combustion from the vehicles fuel, and residential coal burning. While the biomass burning was thought to produce more OC (Pani *et al.*, 2019). Our results in Table 4, showed the concentration of organic carbons was in the range of 0.17 to 2.70  $\mu\text{g m}^{-3}$ , the highest and lowest interval of concentration were 2.70 and 0.46  $\mu\text{g m}^{-3}$ , respectively. The EC concentration was in the range of 2.52 to 6.53  $\mu\text{g m}^{-3}$ , the highest and lowest interval of concentration were 6.53 and 2.52  $\mu\text{g m}^{-3}$ , respectively. We found that at the upwind site (06:00–18:00) the OC/EC ratio was 1.07. The other sampling period (18:00–06:00), the OC/EC ratios was 0.992. According to the study by Watson *et al.* (2010), OC/EC ratios were in the range of 0.7–2.4 are mostly from vehicles exhausts. Furthermore, the upwind sampling site was located near the main traffic area. Therefore, the air quality of upwind sampling site was seriously impacted by traffic conditions. On the other hand, at the downwind sampling site (06:00–18:00) the OC/EC ratio was observed to be 0.081. The other sampling period (18:00–06:00), the OC/EC ratios was 0.026 and the results showed that the elemental carbons was the primary contaminant. Notwithstanding that, most of the TC species are generally ascribed to metallic species and other PM<sub>2.5</sub> components and additional PM<sub>2.5</sub> components for instance, the concentrations of the major common three main inorganic ions in PM<sub>2.5</sub>, SO<sub>4</sub><sup>2-</sup> (sulfate), NO<sub>3</sub><sup>-</sup> (nitrate), and NH<sub>4</sub><sup>+</sup>, (ammonium) (Jiang *et al.*, 2019).

### 3.4 Traditional Pollutants

As presented in Fig. 3, the carbon monoxide (CO) 24-hour average concentration was observed in several air quality monitoring stations (Zuo-ying, Ai-guo, Qian-jin and Feng-shan) and night market sampling site. According to the CO average concentration data of the air quality monitoring

**Table 4.** The concentration of the carbonaceous species ( $\mu\text{g m}^{-3}$ ).

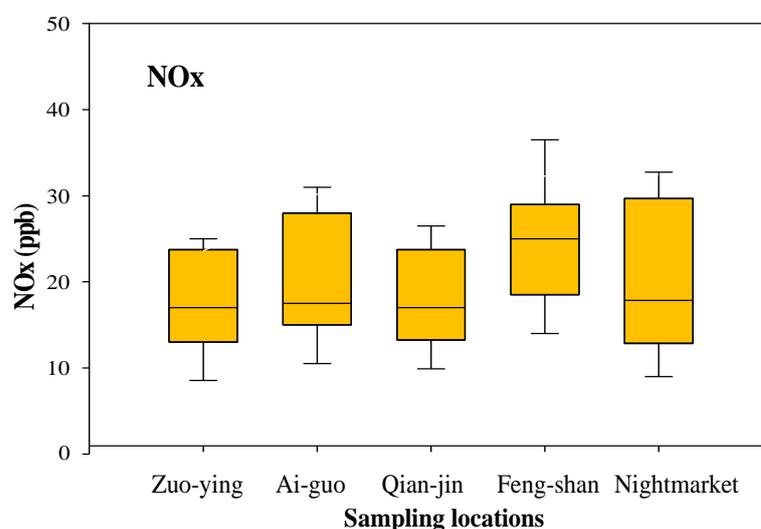
Location	Sample intervals	TC ( $\mu\text{g m}^{-3}$ )	EC ( $\mu\text{g m}^{-3}$ )	OC ( $\mu\text{g m}^{-3}$ )	OC/EC ( $\mu\text{g m}^{-3}$ )
Upwind	(06:00–18:00)	5.22	2.52	2.70	1.07
	(18:00–06:00)	5.04	2.53	2.51	0.992
Downwind	(06:00–18:00)	6.13	5.67	0.46	0.081
	(18:00–06:00)	6.52	6.53	0.17	0.026
Pre-open hours	(14:00–18:00)	5.40	4.72	0.68	0.144



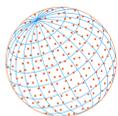
**Fig. 3.** Carbon monoxide (CO) 24 hours average concentration.

stations, the maximum average concentration is 0.76 ppb, with the minimum average concentration of 0.71 ppb and daily average concentration is 0.51 ppb at the Zuo-ying air quality monitoring station. The maximum average concentration was 1.62 ppb, the minimum average concentration is 0.95 ppb and the daily average concentration was 1.18 ppb at the Ai-guo station. At Qian-jin station, a maximum average concentration of 0.71 ppb was recorded, while the minimum average concentration of 0.33 ppb and a daily average concentration of 0.52 ppb was also reported. Furthermore, a maximum average concentration of 0.85 ppb, a minimum average concentration of 0.42 ppb along with a daily average concentration of 0.57 ppb was reported at Feng-shan station. Yet a maximum average concentration of 0.92 ppb, with a minimum average concentration of 0.39 ppb and the daily average concentration of 0.63 ppb were observed at night market sampling site. By evaluating the CO concentration data, we found out that the concentration at the Ai-guo station was much higher than others air monitoring stations. The Ai-guo station have many incomplete combustion activities, particularly from the surrounding temples.

As indicated in Fig. 4, the nitrogen oxides (NO<sub>x</sub>) 24-hour average concentration in several air quality monitoring stations and night market sampling site. According to the NO<sub>x</sub> concentration results of the air quality monitoring stations, the maximum average concentration was 29 ppb, with a minimum average concentration of 4.3 ppb and a daily average concentration data of 17 ppb at Zuo-ying station. However, a maximum average concentration of 38 ppb, while the



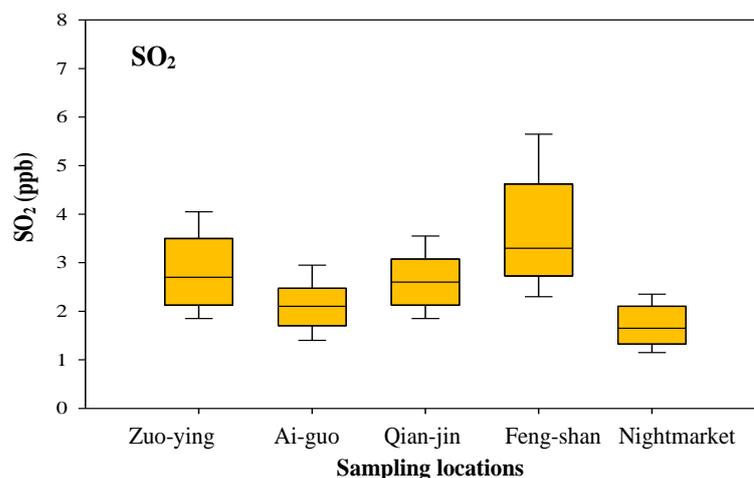
**Fig. 4.** Nitrogen oxides (NO<sub>x</sub>) 24 hours average concentration.



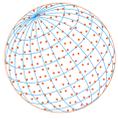
minimum average concentration of 9.1 ppb and the daily average concentration of 20 ppb were reported at Ai-guo station. At Qian-jin station, a maximum average concentration of 27 ppb, with a minimum average concentration of 7.4 ppb and a daily average concentration of 17 ppb was equally reported. On the other hand, a maximum average concentration of 39 ppb, with the minimum average concentration of 11 ppb and a daily average concentration of 24 ppb was account for at Feng-shan station. Nevertheless, a maximum average concentration of 34 ppb, with a minimum average concentration of 7.1 ppb and a daily average concentration of 20 ppb was recorded at the night market sampling site. Upon evaluating the NO<sub>x</sub> concentration results, we found out that the concentration at the Ai-guo station was much higher than others air monitoring stations. It was therefore discovered that the location of Ai-guo station was at the main traffic road, thus the vehicles influenced the concentration. Based on the past research, in many urban areas, one the of the most important sources of air pollution is road traffic with major contribution to NO<sub>x</sub> emissions (Santoso *et al.*, 2021). For instance, in the UK, 23% of total NO<sub>x</sub> was generated by cars and light duty vehicles (LDVs) (Wakeling *et al.*, 2016).

Fig. 5 depicts the sulfur dioxide (SO<sub>2</sub>) 24-hour average concentration in several air quality monitoring stations and night market sampling site. According to the SO<sub>2</sub> concentration results of the air quality monitoring stations, the maximum average concentration was 7.0 ppb, with the minimum average concentration of 1.8 ppb and the daily average concentration data of 2.9 ppb at the Zuo-ying station. The maximum average concentration is 4.1 ppb, whereas the minimum average concentration was 2.1 ppb and the daily average concentration was observed to be 2.1 ppb at the Ai-guo station. A maximum average concentration of 4.3 ppb and a daily average concentration of 2.6 ppb was reported at the Qian-jin station. The Feng-shan station had a maximum average concentration of 6.5 ppb, with a minimum average concentration of 2.1 ppb and a daily average concentration of 3.6 ppb. In addition, the night market sampling site had a maximum average concentration of 3.4 ppb, with a minimum average concentration of 1.7 ppb and a daily average concentration of 1.7 ppb. Based on the analysis of the SO<sub>x</sub> concentration results, we found out that the concentration at the Feng-shan station was much higher than other stations. According to the IEA (2016), almost all sulfur oxides originate from the production of energy. Besides, the location of Feng-shan station is in the proximity of Dafa industrial park. Thus, it can be concluded that the industrial park is the main resource of SO<sub>2</sub> concentration at the Feng-shan station.

Furthermore, petrochemical industrial zones have been reported as another major causes of pollution the environment in a number of countries, with dangerous air pollutants discharge accounting for a significant portion of that damage (Lin *et al.*, 2021). For instance, CO, SO<sub>2</sub>, NO<sub>2</sub>, ozone, suspended particulate matter, and other air pollutants in Malaysian cities, are mostly attributable to industrial emissions or combustion (Dahari *et al.*, 2019; Khan *et al.*, 2018; Sulong *et al.*, 2017). Elsewhere, industrial pollution has been reported to be frequent in Spanish cities within 5 km of industrial zones, with elevated benzene, dioxin, and PCB concentrations. As a result,



**Fig. 5.** Sulfur dioxide (SO<sub>2</sub>) 24 hours average concentration.



cancer mortality is up to 17% higher in exposed areas than in non-exposed ones (Fernández-Navarro *et al.*, 2017). This study investigated the chemical composition of PM<sub>2.5</sub> and air quality monitoring while taking into consideration the implications of air pollutants emissions from a night market in Kaohsiung City, Taiwan. Few public schools and government institutions were observed to be likely affected by air pollutants emissions from the night market, and the residents in the vicinity of the affected areas are more likely to be exposed to higher air pollutants and health risks. The simulated results under this investigation are compatible with Taiwan's overall air pollution season (winter and spring). The ultimate underlying reason is that the major predominant wind of the northeast monsoon and the cold high pressure system that travels from China passing across Taiwan in the winter and spring (Lin *et al.*, 2021). As a result of the mountains, half of Taiwan is usually affected by weak synoptical weather, which is linked to the lowest wind speeds and greatest PM<sub>2.5</sub> concentrations (Lin *et al.*, 2021; Hsu and Cheng, 2019). In addition, pollution is likely to build up in the upwind areas, especially in central and southwestern Taiwan (Cheng and Hsu, 2019; Hsu and Cheng, 2019). Also, the northeast monsoon inclines to transport pollution from west China into this region (Lin *et al.*, 2021).

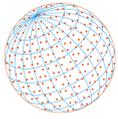
#### 4 LIMITATIONS OF THE STUDY

There are a few drawbacks to this study. Due to limited resources, the present investigation had only considered one night market as a sampling site, despite the fact that there are many night markets in Kaohsiung City and Taiwan in particular. In such circumstances, this particular night market located in a densely populated was subsequently considered for the present investigating.

In air quality monitoring data analysis, we assumed that the results could be generalized or replicated to other various night markets in Kaohsiung City, taking into consideration that all night markets have the same operational hours, i.e., pre-opening hours, opening hours and non-opening hours. The sampling intervals used in the study are based on the actual operational hours of the night markets in Kaohsiung City.

The results projected by this analysis are based on various meteorological parameters and other industrial activities in the proximity of the studied areas. The actual implications arising from air quality monitoring stations could vary from the various night markets, depending on the location of such night market. Due to the current restrictions on different business and economic activities since the outbreak of COVID-19, the concentration of chemical composition in the PM<sub>2.5</sub> could be much higher on normal business operations. In such a case, the current analysis and results will act as a base to formulate guidelines on the operations of night markets in Taiwan. This will help to drastically minimize the impacts of air pollutants emissions from the night markets in Kaohsiung City and in other places in Taiwan.

COVID-19 has serious effect on the air quality across the globe, particularly under the emergency lockdown. While the world is concerned about effective regulations for air pollutants emissions mitigation measures, this emergency lockdown has turned into an important step in the environment recovery, as emissions sources (such as night markets) were controlled by this swift move. As a result, the lockdown measure has resulted in a considerable reduction in air pollution contamination, allowing academics and governments to better understand the background and future strategies for pollution control (Albayati *et al.*, 2021). According to Kotnala *et al.* (2020), the air pollution level in the New Delhi (India) areas has declined more than in comparison to other areas as a result of the lockdown. Their results were based on data acquired from the Central Pollution Control Board (CPCB) in New Delhi's 12 air pollution monitoring sites. Particulate matter with diameters of 2.5 and 10 µg (PM<sub>2.5</sub> and PM<sub>10</sub>) had drastically declined by 200%. In addition to this, nitrous oxides (NO<sub>x</sub>) concentrations in CRRI-Mathura Road, Delhi, was observed to have been reduced from 342 ppb on January 12th, 2020 to 24 ppb on March 30<sup>th</sup>, 2020, a reduction of almost 1400% (Kotnala *et al.*, 2020). In an attempt to restrict the number of illnesses and prevent the spread of COVID-19 in communities, governments around the world, including Taiwan, have imposed quarantine and limited communication. With these restrictions (lockdowns) people were compelled to stay at home for longer periods of time, resulting in increasing indoor air pollution. According to the World Health Organization (WHO), 3.8 million people died in 2016



as a result of breathing contaminated indoor air. Certainly, smoking, cooking over an open flame, inadequate ventilation, and the use of chemicals, particularly volatile compounds, all contribute to poor indoor air quality (Hadi *et al.*, 2020b; Alalwan and Alminshid, 2020; Alminshid *et al.*, 2021). As a result of the quarantine, people are forced to stay indoors for an extended period of time, which increases the risk of significant diseases such as lower respiratory acute infections, chronic obstructive pulmonary disease, cardiovascular disease, lung cancer, and asthma (Ansari and Ahmadi Yousefabad, 2020).

Thus, the present study is one of the very few studies to assess the implications of air pollutants emissions from a night market in Kaohsiung City, Taiwan. This research work will be a valuable guiding tool for policymakers working on the implementation of the new emission standards, particularly PM<sub>2.5</sub> and traditional pollutants.

## 5 CONCLUSIONS

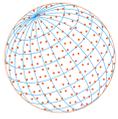
This study provides some new insights into the assessment of PM<sub>2.5</sub> chemical composition and air quality monitoring. The findings of this study contribute evidence about the implications of air pollutants emissions from a particular night market. According to our results, the PM<sub>2.5</sub> concentrations during the night market opening hours was about 1.6 times than the concentrations observed during pre-opening intervals. It is evident that the PM<sub>2.5</sub> concentration influenced by night market activities. Concerning the concentration of ME in PM<sub>2.5</sub>, the results demonstrated that the concentrations of (Fe, Al and Ca) can be attributed to the night market business activities. On the carbonaceous species, our results demonstrated that the element carbon and the organic carbon were influenced by traffic situations, which happened during the night market opening hours. The present study employed an Industrial Source Complex Short-Term (ISCST3) air quality model for the simulation of PM<sub>2.5</sub> diffusion in order to identify the hypothetically risk PM<sub>2.5</sub> areas as a reflection of air quality monitoring in the vicinity of night markets. Understanding and quantifying PM<sub>2.5</sub> chemical composition could help us to quickly identify key risky areas in the proximity of night markets and to what extent significant night market activities and operational hours may otherwise cause changes in air pollutants emissions and contamination levels. Overall, this study revealed that the night markets activities could contribute to poor air quality. In future research, we suggest that, in addition to schools and government agencies, other public avenues that can be considered as key risky areas in the proximity of night markets should be included in the investigation of this nature for enhanced risk prevention and mitigation.

## ACKNOWLEDGMENTS

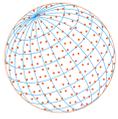
The authors would like to thank the National Sun Yat-sen University (NSYSU) and Kaohsiung Medical University (KMU), for financially supporting this research under the NSYSU-KMU Joint Research Project (NSYSUKMU 108-I004).

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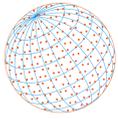
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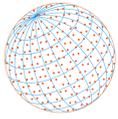
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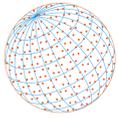
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