An-Najah National University

Faculty of Graduate Studies

URBAN PARTICULATE MATTER HAZARD MAPPING USING GIS AND LOW-COST SENSORS IN NABLUS, PALESTINE

By

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Supervisor

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This Thesis was Defended Successfully on 07/06/2022 and approved by

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Dr. Sameer Shadeed Internal Examiner	Signature

Dedication

ما أعلمه أن وجودك ولو في البعد هو سندٌ هائلٌ لي...

لروح أمي الحبيبة..

خلود صالح

Acknowledgment

I am grateful to my supervisor Dr. Abdelhaleem Khader for his support, patience and guidance.

Thanks to Nablus Municipality and the Environment Quality Authority for providing important data, also to Eng. Mohammed Shreem for technical support.

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Declaration

I, the undersigned, declare that I submitted the thesis entitled:

URBAN PARTICULATE MATTER HAZARD MAPPING USING GIS AND LOW-COST SENSORS IN NABLUS, PALESTINE.

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: Tawfiq Saleh

Signature:

Date: 7/6/2022

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Abstract

Few of the air pollution studies were applied in the State of Palestine, all showed an increase in particulate matter concentrations above WHO guidelines. However, there is no clear methodology for selecting monitoring locations. In this study a methodology based on GIS and locally calibrated low-cost sensors was tested. A GIS-based weighted overlay summation process for the potential sources of air pollution (factories, quarries, and traffic) taking into account the influence of altitude and climate was used to obtain a particulate matter (PM) pollution hazard map for Nablus, Palestine. To test the methodology, eight locally calibrated PM sensors (AirUs) were deployed to measure $PM_{2.5}$ and PM_{10} concentrations for 55 days from 7-Jan to 2-Mar 2022. The results of the hazard map showed that 82% of Nablus is exposed to a very high and high hazard of PM pollution. It also shows an elevated $PM_{2.5}$ concentrations above WHO guidelines in all stations. In summary, the overall average for $PM_{2.5}$ and PM_{10} in Nablus was 48 and 55.2 $\mu g/m^3$ respectively Sensors' readings showed a good match between the hazard index and PM concentrations. This indicate the effectiveness of mapping methodology and the use of low-cost, locally calibrated sensors in characterizing air quality status to identify the potential remediation options.

Keywords: Air pollution, Hazard mapping, Low-Cost sensors, GIS, Palestine.

Chapter One
Introduction

1.1 General background

Ambient air pollution is a serious problem for many countries around the world. The increase in population, and thus the increase in human and industrial activities, caused noticeable increases in pollutant emissions, which led to many health, economic and social problems (Manisalidis et al., 2020).

Air pollution can be defined as the entry of foreign substances into the atmosphere. These materials may include gases, particles, biological materials, or any substances that may harm the health or well-being of living organisms, or cause spoilage or damage to the materials (Khader & Martin, 2019; Mayer, 1999). There are several schemes to classify air pollutants, based on their physical state it can be gases such as vapors and true gases, or liquids (Fogs, mists, or droplets) or solids (Dust, soot, fly ash, etc.). By the emission source, it is classified as anthropogenic (caused by human activity) like combustion, mining, agriculture, and industrial activity; or biogenic, which is naturally emitted by plants, bacteria, animals, soil/ocean microbes, and volcanoes. The United States environmental protection agency (US EPA) set the clean air act and established the National Ambient Air Quality Standards (NAAQS), for six criteria pollutants which are carbon monoxide (CO), lead (Pb), ground-level ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM), and sulfur dioxide (SO_2) (US EPA, 2020). Called “the mixture of mixtures", PM is a complex mixture of small particles and liquid droplets, which may include elemental carbon, organic chemicals, metals, acids (such as nitrates and sulfates), and soil and dust particles (Cascio et al., 2014). PM was classified according to its aerodynamic diameter into PM_{10}, which has an aerodynamic diameter of less than 10 micrometers, and $PM_{2.5}$, which has an aerodynamic diameter of less than 2.5 micrometers (Davidson et al., 2005).

The diameters were assigned based on the impact on human health. PM_{10} sticks in the Upper Respiratory Tract (URT): Mouth, Nose and Throat. $PM_{2.5}$ continues to the Lower Respiratory Tract (LRT): the trachea, the bronchi and bronchioles, and the alveoli, which make up the lungs. This may cause blockages in the alveoli, which have health risks to the lungs, the most common of which is respiratory failure. In terms of source of emissions, PM was classified into primary and secondary. The primary means that are emitted directly from the source such as: combustion, open burning, mining, rock crushing, industrial activities, construction, agricultural activities, road dust, wind erosion, smoking, etc. The secondary emission is formed from gaseous photochemical reactions as inorganic salts (mostly, ammonia sulfate and ammonium nitrate), also known as secondary organic aerosol (SOAs)

There is clear evidence for the effects of PM on human health, as well as on welfare and the economy. In brief, numerous epidemiological studies have proven that acute or chronic exposure to air pollutants such as $PM_{2.5}$ is associated with many respiratory and cardiovascular diseases, nervous and reproductive system, dysfunction, and cancer (Brook, 2005; Nowak et al., 2018; Rajak & Chattopadhyay, 2020; Sacks et al., 2020; WHO, 2000). Also, the effect of exposure to air pollution on social welfare is noticeable (Zhang et al., 2018). An interesting study by the EPA shows a correlation between higher gross domestic product (GDP) and lower pollutant emissions.

Several studies around the world that obtained evidence that chronic exposure to air pollution, especially $PM_{2.5}$ and NO_2, increases the spread and lethality of the Coronavirus (Covid-19) (Comunian et al., 2020). Air pollution affects the body's immunity, making people more vulnerable to pathogens (Copat et al., 2020; Yao et al., 2020). More details about PM effects are discussed in the literature review (Section 1.6).

EPA has set a list of methods for measuring PM that are called "reference methods", these methods requires the use of reference devices, or the "equivalent methods" that allow the use of other devices provided they are calibrated and tested with reference devices. The use of low-cost sensors as an equivalent method of measuring PM concentrations has increased due to the high cost of reference devices and the difficulty of handling them on site. AirU is a low-cost easy-to-use sensor that can measure PM_{10} and $PM_{2.5}$ concentrations. It can provide high-precision spatial measurements. The use of low-cost devices should be associated with field calibration to ensure reliable results (Castell et al., 2017; Miskell et al., 2017; Thompson, 2016).

In Palestine, the main sources of anthropogenic air pollution are quarries, factories, and traffic. Palestine is notably affected by seasonal dust storms, which are considered a source of biogenic air pollution. A few studies about air pollution have been performed, all of which have proven that the concentrations of pollutants exceed the guidelines of the WHO (Abdeen et al., 2014; Jodeh et al., 2017). These studies did not take into account the spatial change, the effect of altitude, and the seasonal dust storms. Moreover no clear methodology was used in selecting sampling sites. Random sites selection is not necessarily representative (Ott, 1977). The Site selection process must combine multi-criteria such as meteorology, pollution sources, and types of pollution sources in terms of impact on human health. Legislatively, Law No. 7 of 1999 stipulates the responsibility of the Environment Quality Authority to control concentrations of air pollutants that may cause harm and damage to public health or social welfare, and that these concentrations must be adhered to. In 2010 the Palestine Standards Institution issued Standard No. 801 for ambient air quality. The standard stipulates that the maximum allowable daily concentration of PM_{10} = 120 μg/m^3 (WHO standard = 50 μg/m^3. day), the standard did not mentioned pm2.5 at all.

The Geographic Information System (GIS) has been effectively used as a powerful spatial analysis method that allows the manipulation of different spatial data together with expert opinion to make judgments. GIS has been used in much of the literature for site suitability mapping and hazard mapping (Shadeed et al., 2018; Hacıoğlu et al., 2016;Kimbrough et al., 2008). This research aims to develop a PM hazard mapping methodology, and a selection criterion for low-cost PM sensors' locations, and to apply this methodology to the case of Nablus, Palestine.

1.2 Research Questions

1. How to effectively map PM hazards in the city of Nablus?

2. How do we select air pollution measuring locations that considers the different aspects of air quality?

1.3 Research Objectives

1. To develop a PM mapping methodology for the city of Nablus.

2. To develop selecting criteria for low-cost air quality sensors locations.

1.4 The Expected Outputs

1. A methodology for mapping PM in the city of Nablus.

2. Criteria for selecting locations for optimal sensors placement in the city of Nablus.

1.5 The Importance of the Study

Air pollution is a fundamental environmental issue and has a great relationship with health and the economy. The importance of this study is to develop an effective methodology to help air quality researchers choose appropriate measurement locations. Through the case study in the city of Nablus, easy-to-use maps for experts and non-experts will be presented. The maps will help decision-makers to take appropriate decisions, and help the community to understand the seriousness of the air pollution problem clearly.

1.6 Literature Review

1.6.1 Introduction

This section discuss the air pollution in terms of its impact on public health and well-being, the different methods of observation, and previous studies in Palestine.

1.6.2 Brief History of Air Pollution

This section discusses the chronology from our ancestors' observation of air pollution, to the recent past when serious regulations were implemented in the 1970s.

– 61– Seneca (Roman philosopher):

"*As soon as I had gotten out of the heavy air of Rome and from the stink of smoky chimneys thereof, which, being stirred, poured forth from whatever pestilential vapors and soot they had enclosed in them, I felt an alteration of my disposition*"

- 1190 – Moses Maimonides wrote of polluted cities:

"*…altered the Psychic Spirit…developed a dullness of understanding, failure of intelligence, and defect of memory*."

- 1307 – King Edward I of England bans coal burning:

"*Be it known to all within the sound of my voice, whosoever shall be found guilty of burning coal shall suffer the loss of his head*."

- 1661 – John Evelyn publishes FUMIFUGIUM The first serious document on air pollution and its health and welfare effects.
- Early 1800's – Beginning of the Industrial Revolution
- 1819, 1843, 1845 1st and 2nd English Select Committees Appointed to study air pollution problems.
- 1848, 1866, and 1875 – British Public Health Acts.
  Address smoke and ash pollution from coal furnaces.
- 1905, 1911 – Dr. Des-Voeux reports on smoke-fog deaths Coined the term "SMOG".
- 1907-1912 – U.S. industrial cities report smoke & SO_2 problems.
- 1940's, 1950's – Dr. Haagen-Smit finds L.A. air pollution is photo chemically based.
- 1947 – L.A. Air Pollution District formed.
- 1948 – Donora, PA – episode similar to Meuse Valley 17 deaths; 60% of area's population became ill 6 day event (Oct. 26-31).
- 1949 – 1st National Air Pollution Symposium in U.S.
- 1966 – Northeast U.S. has several severe winter inversion NY State had 160 added deaths due to Thanksgiving episode.
- 1970's – until present – Many rapid developments Passage of more air pollution laws and regulations (CAA 1970, '77, '90, and infinitum) Advances in knowledge of air pollution phenomena & regulation.

1.6.3 Air pollution and Public Health

An important study conducted in 300 Districts in the United States confirms that a slight increase of not more than 1 $\mu g/m^3$ in $PM_{2.5}$ leads to an 8% increase in the Covid-19 mortality rate (Wu et al., 2020). In many countries, the quarantine has led to a decrease in human mobility and industrial activities, which led to a decrease in emissions of pollutants such as $PM_{2.5}$ and PM_{10}, and a significant decrease in the air quality index (Bao & Zhang, 2020; Liu et al., 2021). The quarantine can slow the spread of disease not only because of social distancing, but also because it can improve the ambient air quality (Xinhan Zhang et al., 2021).

A study in the United States found evidence that air pollution is associated with hospital admissions for heart failure, heart failure deaths associated with an increase in $PM_{2.5}$ concentrations they estimate that a slight decrease of $PM_{2.5}$ concentrations (about 3.12 $\mu g/m^3$) could prevent 8,000 heart failure cases and save 0.3 billion dollars per year (Shah et al., 2013) Some reports indicated the effect of air pollution on semen quality and lower fertility rate. In Spain, (Nieuwenhuijsen et al., 2014) studied the effect of particulate matter and nitrogen oxides on the general fertility rate (number of live births per 1000 women aged between 15 and 44 years for each census area) taking into account maternal age and economic and social status at the district level. They found a statistically significant decrease in fertility rates with increasing levels of air pollution. A study by (Miller et al., 2012) showed that exposure to $PM_{2.5}$ leads to vasoconstriction (narrowing of the blood vessels) which leads to hypertension that increases thrombosis and thus heart ischemia. They also explain that the ability of drug formulations to reduce the cardiovascular risk of air pollution remains uncertain and needs to be tested, and that controlling and reducing pollutants from their source is the best solution.

For pulmonary diseases, (Doiron et al., 2019) analyzed data from 300,000 UK citizens (biobank data) with land use data and $PM_{2.5}$ maps taking into account the patient's circumstances (nature of work, smoking, height, weight, and age). The results indicate that an increase of 5 $\mu g/m^3$ in $PM_{2.5}$ concentration leads to a significant decrease in lung functions such as forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1). Which is a major cause of diseases such as chronic obstructive pulmonary disease (COPD), asthma, and even lung cancer.

There is strong evidence from numerous studies showing the relationship between air pollution, especially PM pollution, and hundreds of thousands of lung cancer deaths annually. Evidence for the association of air pollution with breast cancer is limited and more study is needed (Turner et al., 2020).

Increasing evidence links exposure to particulate air pollution with cognitive impairment, and problems with the nervous system. Limited evidence links PM exposure during pregnancy to an increased risk of autism (Block et al., 2012; Costa et al., 2019; Power et al., 2018).

1.6.4 Air pollution and well-being

Studies have shown a link between exposure to PM and mental health problems such as depression taking into account the individual income, age and gender of test samples (Orru et al., 2016; Petrowski et al., 2021) . As air pollution affects the productivity of employees, also in educational institutions there is clear evidence of the association of air pollution with the psychological state, IQ and test results of students (Du et al., 2018; Salthammer et al., 2016).

1.6.5 Air pollution monitoring with low-cost sensors

In recent years, the use of low-cost light scattering-based sensors has increased significantly, and these techniques have proven to be effective due to their low cost and the possibility of providing realistic readings of different PM concentrations. Beijing Plantower Co., Ltd, presents a series of precision air sensors certified by the ISO9001 Quality Management System. Several papers have tested these sensors, compared them with reference devices, proven the effectiveness of these sensors, and recommended field calibration to ensure more accurate results (Kelly et al., 2017; Sayahi et al., 2019). The AirU package was developed by the University of Utah's College of Engineering. The package contains a Plantower Particulate Matter Sensor (PMS) 3003 that is a laser-based detector that draws air through a fan into the chamber and exposes it to a laser and converts light scattering into $PM_{2.5}$ and PM_{10} concentrations(Becnel et al., 2019).

The technical parameters of the sensor are:

1. Measurement diameters: 0.3-1.0µm 1.0-2.5µm 2.5-10µm.
2. Measurement units: µg/m3.
3. Response time: <10s.

In addition to the PM sensor, AirU contains:

1. Temperature and relative humidity sensor.
2. CO, and NO2 metal oxide-based sensor.

3. GPS location chip.
4. SD cards that store One-minute averaged data from all sensors.

The full data sheet of (PMS) 3003 is shown in Appendix A.

1.6.6 Hazard Mapping with GIS

GIS is an effective tool that is widely used in hazard and site suitability mapping in all areas. It allows quick and easy visualization of study areas. Providing good spatial representation, the maps are a powerful and clear tool for presenting complex results in a simplified manner thus bridging the gap between experts and users. GIS supports the weighted overlay summation process that overlays several rasters using a common measurement scale and weights each according to its importance which has been widely used in many hazard mapping studies (Anh et al., 2014; Chung et al., 2019; Lahr & Kooistra, 2010; Nadal et al., 2011). An interesting study used GIS to apply the suitability analysis approach to establish air quality monitoring stations, the suitability analysis model can be an effective tool for improving existing air quality monitoring networks and drawing the optimum routes for future expansions in monitoring air quality within urban areas (Alsahli & Al-Harbi, 2018).

1.6.7 Air Pollution in Palestine

A few studies about air pollution have been done all of which have proven that the concentrations of pollutants exceed the guidelines of the WHO. (Jodeh et al., 2017) measured indoor and outdoor PM concentrations in four roadsides and four houses in Nablus using a Grimm 31-Channel Portable Aerosol Spectrometer Model No.1.109. The PM results were 3 times higher than the guidelines. This study did not take into account the spatial change, the effect of altitude, and the seasonal dust storms, moreover no clear methodology was used in selecting sampling sites, and no information about the calibration of the Spectrometer.

A regional study by (Abdeen et al., 2014) measured $PM_{2.5}$ concentrations in Palestine, Jordan and Israel, 11 stations for one year using multichannel air samplers, designed and built specifically for the project. Their results showed that concentrations of $PM_{2.5}$ across the 11 stations varied from 20.6 to 40.3 $\mu g/m^3$, with an average of 28.7 $\mu g/m^3$. These results seem realistic, but the use of only 11 measurement stations in a regional area needs reconsideration.

Research accomplished by (Khader & Martin, 2019) used AirU devices calibrated using Mini-Vol to measure PM_{10} and $PM_{2.5}$ concentrations in 3 different sites in Nablus city. The selected stations represent different potential targets of pollution and different altitudes, but no clear methodology was used in selecting these locations and hence there is no evidence that these locations represent the air quality in the city. They found that $PM_{2.5}$ concentrations exceeded the guidelines of WHO (25 μg / m^3). 24 hours, in the 3 sites most of the time and considered that the average readings in the 3 stations are the average concentration of $PM_{2.5}$ for the city of Nablus = 38.2± 3.6 μg / m^3. While the PM10 concentrations exceeded the guidelines of the WHO guidelines (50 μg / m^3). 24 hours at different proportions in the 3 stations at the same time (at one site 64% of the time, and 15% to 28% of the time at the other two sites). Their numbers indicate that most of the pollution comes from $PM_{2.5}$ Also, the time series of PM_{10} and $PM_{2.5}$ concentrations indicated some occasional elevations in concentrations and they used a model to trace the origins of air masses to correlate occasional elevations with seasonal dust storms.

A previous study by (Saleh & Khader, 2019) in Tulkarm, Palestine, found a relationship between lung function and PM measurements in the city. 3 stations were assigned based on potential PM sources from quarrying, traffic and industries. A fourth station is in a suburb near the city. PM concentrations were measured at those stations for a month using locally calibrated AirUs, during which lung function of volunteers from those sites was measured (3 times every 3 days) using a manual spirometer. The results showed that lung function was the worst near the quarries, followed by the industrial settlement (Jishuri) followed by the city center where the traffic density was high, and the best results were in the suburb. There was a good correlation between PM concentrations and the lung efficiency of the population.

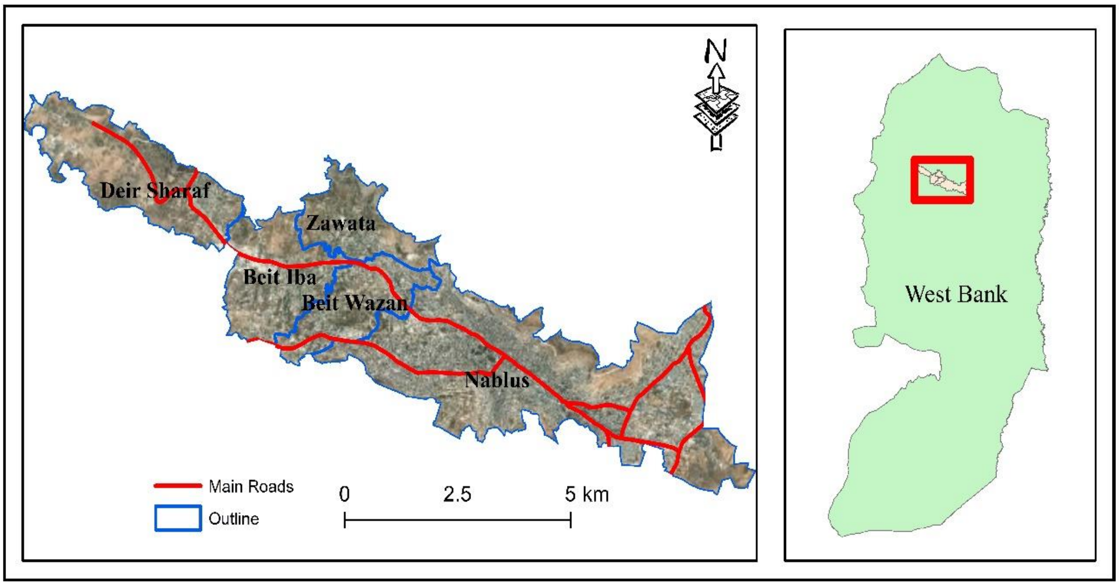
Chapter Two

Study Area

The study area (Figure 1) includes the city of Nablus in addition to the surrounding communities of Beit Wazan, Deir Sharaf, Beit Iba and Zawata. All these communities are located in the same valley and share the same potential pollution sources. In this research, these residential communities is called Nablus**.** Nablus is located in the north of the West Bank with population in 2017 of 166,328 capita (PCBS, 2018).

Figure 1

Location map of the study area



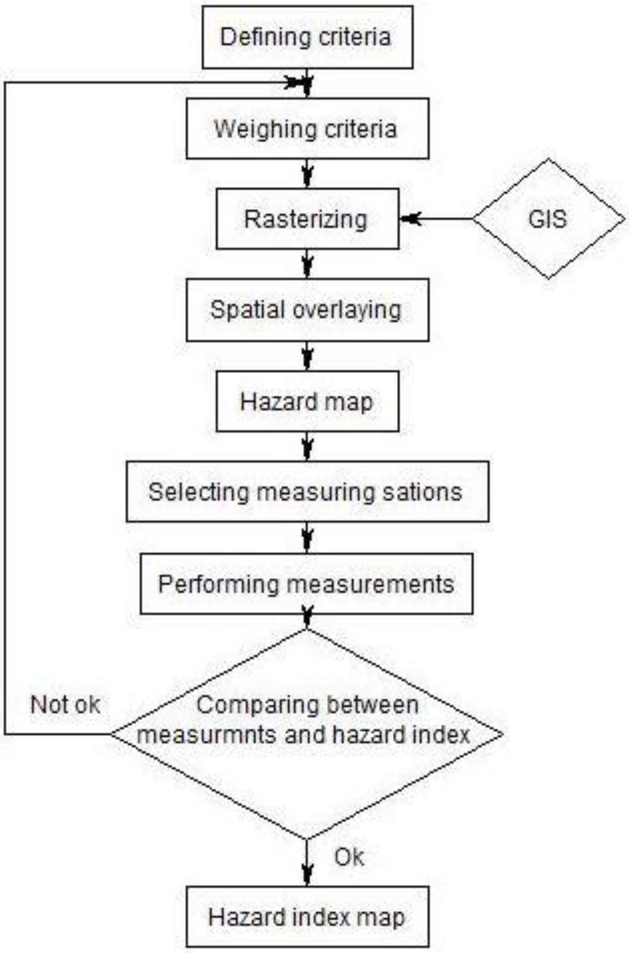
Topographically, it is a valley between two mountains, with an altitude in the range of 220-915 m above means sea level (AMSL). The climate of the area is a Mediterranean climate that is hot and dry in summer, and mild and rainy in winter. The northwest winds are the prevailing wind direction in Nablus, and the annual average wind speed is 10 km/hr. In winter, the average high temperature reaches 13.4 C°, while the lowest drops to 7.5 C°. In summer, the highest temperatures are recorded, the average maximum temperature reaches 25.7 C°, while the average minimum temperatures reaches 23.3 C°. The annual average relative humidity is 61, Studies indicate that the expected climate change scenarios in the region will be an increase in temperatures accompanied by a decrease in precipitation rates (S. Shadeed, 2013).

Most of the land use is residential, commercial, and industrial, with only 3% green area according to Nablus municipality. The topography of the study area, combined with multiple sources of air pollution creates a potential air quality problem that might affect human health. The main sources of anthropogenic air pollution are quarries, factories, and traffic. There are many factories of different sizes and activities especially in the industrial area located east of the city, in addition to Israeli industrial settlements. There is also a group of quarries, especially in the area of Beit Iba and Deir Sharaf. The city is considered a high traffic area where there are about 38,538 licensed vehicles in the governorate, in addition to visitors' vehicles. The area is notably affected by seasonal dust storms, which are considered a source of biogenic air pollution (Khader & Martin, 2019). The main factor affecting these criteria is the climate that controls the dispersion of particles in the atmosphere as a factor of distance from the source of pollution. Each criterion is weighted based on an expert decision. After that GIS is used for the weighted summation process. Finally, based on the produced map the PM concentration is measured in different areas using AirU sensors. The key output of this research is a site suitability map for low-cost air quality sensors. This map aims to identify the most polluted areas and the most influential source of pollution. This will assist decision-makers in Palestine in setting standards for pollutant concentrations and taking real actions to reduce the risk of air pollution.

Chapter Three
Methodology

3.1 Introduction

The methodology of this research starts with defining the criteria and assigning weights to each criteria. After that GIS is used to create raster maps for the study area representing the spatial relation of the possible emission sources with altitude and wind data. These maps then are overlaid to create the hazard index map for the study area. To validate the map monitoring stations are selected based on the hazard index, to compare the sensors readings with the hazard index for each station. The overall methodology is shown in the following flow chart.



3.2 Defining Criteria

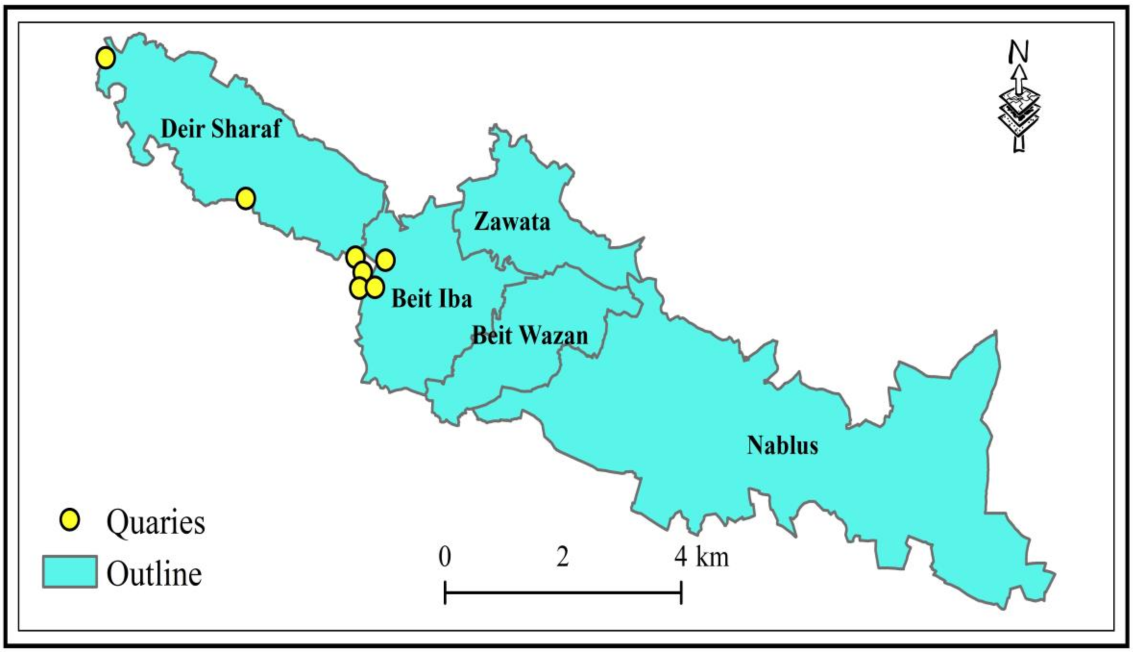
The potential local anthropogenic sources of PM in Nablus are quarries, industries, and traffic. The factors that affects these criteria are wind speed, direction, and altitudes (Khader & Martin, 2019).

3.2.1 Quarries

Quarries spatial distribution information were obtained from the portal of spatial information in Palestine (GeoMOLG). Figure 2 shows the distribution of 7 quarries and stone crushers in Nablus, which are concentrated in the northwestern part of the city.

Figure 2

Quarries distribution in Nablus



3.2.2 Industries

A list of all industries was obtained from Nablus municipality (Table 1). The list was revised and the industries were classified from 1 to 3 based on the industry's potential expected PM emissions. For example, a stone-cutting industry was given 3, a sweets bakery was given 2, and laundry was given 1.The industries with the color-coded classification are shown in Figure 3. There is an Israeli industrial area near the study area, called the “Kedumim” settlement (Figure3), according to (Vanguard & Resettlement, 2019), this settlement includes a large number of industries such as paper, cleaning materials, iron, plastic pipes, and others. Therefore, the entire area is considered an industry with a classification of 3.

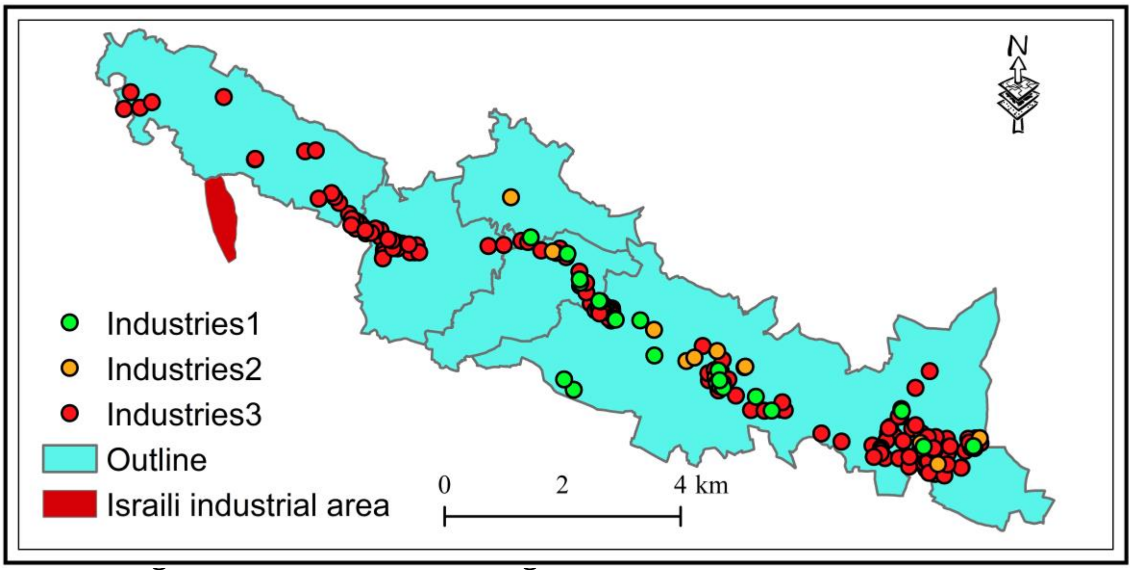
Table 1

The list of industries type, count, and classification

Type	Count	Hazard class	Type	Count	Hazard class
Bakery	2	3	Tahini	13	3
Bricks	5	3	Tannery	2	3
Carpentry	1	3	Tiles	10	3
Chemical	3	3	Wash jeans	5	3
Concrete	1	3	Sweets	3	3
Crusher	2	3	Farm	3	2
Factory	8	3	Restaurant	4	2
Food	4	3	Roasted	1	2
Gas station	1	3	Transfer station	1	2
Olive mill	3	3	Stone saw	20	3
Oven	5	3	Car wash	2	1
Slaughter-house	2	3	Construction	1	1
Soap	2	3	Garage	1	1
Stone cutting	75	3	Laundry	3	1

Figure 3

Industries distribution in Nablus.

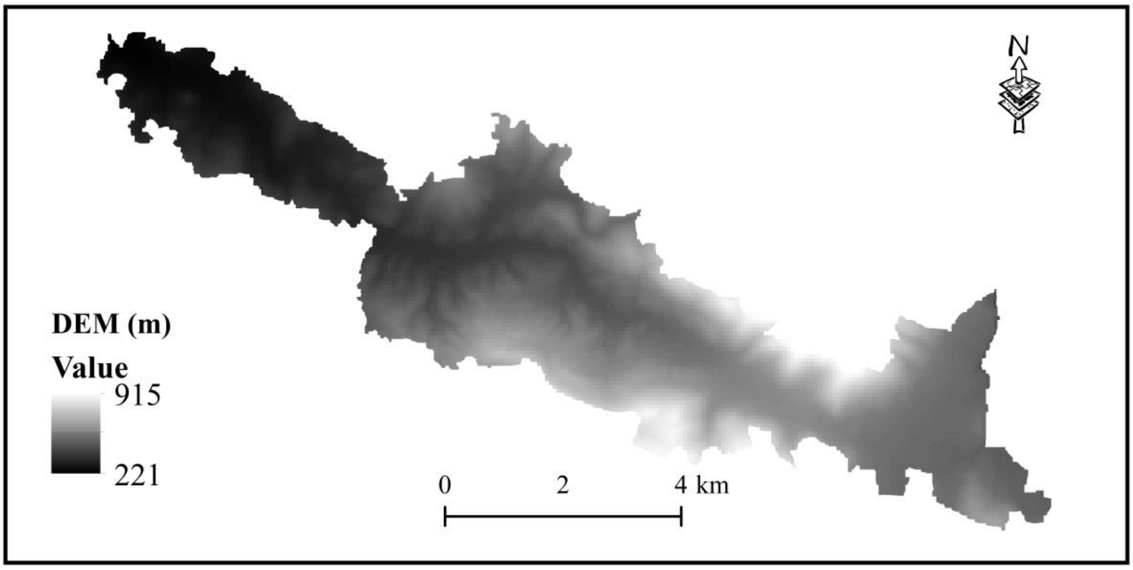


3.2.4 Altitude

The altitude data were obtained from the digital elevation model (DEM) available at (GeoMOLG), as shown in Figure 4.

Figure 4

DEM for Nablus.

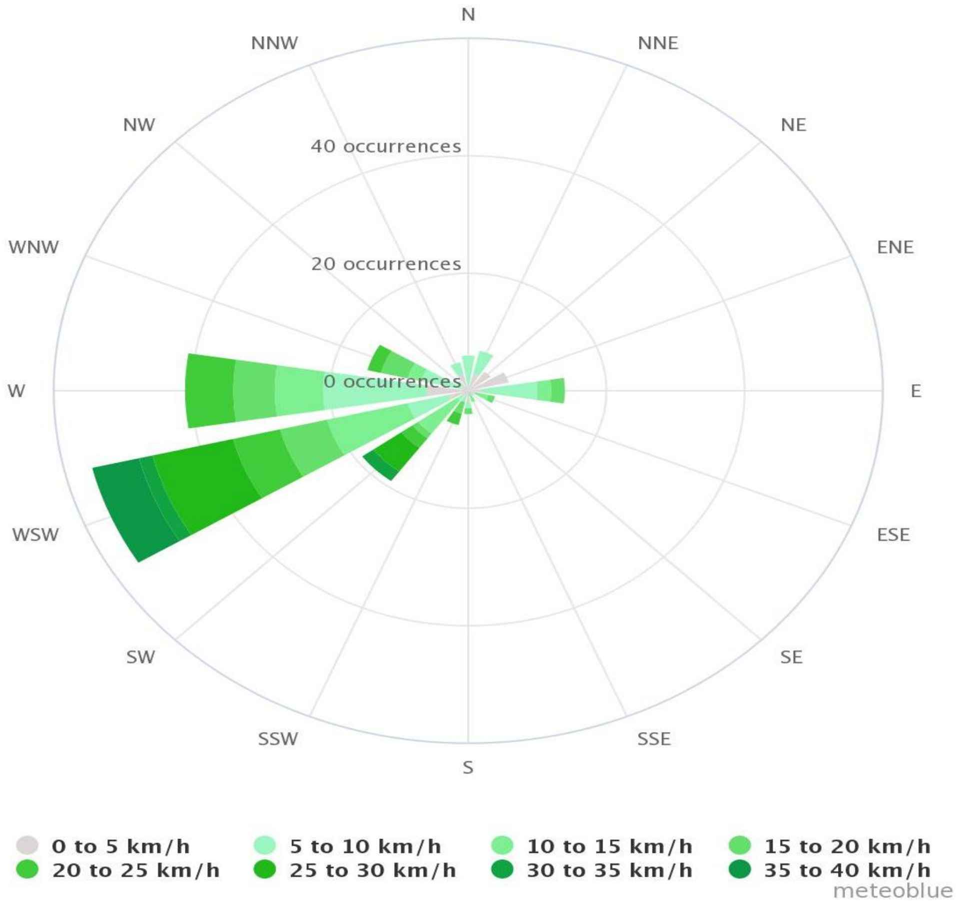


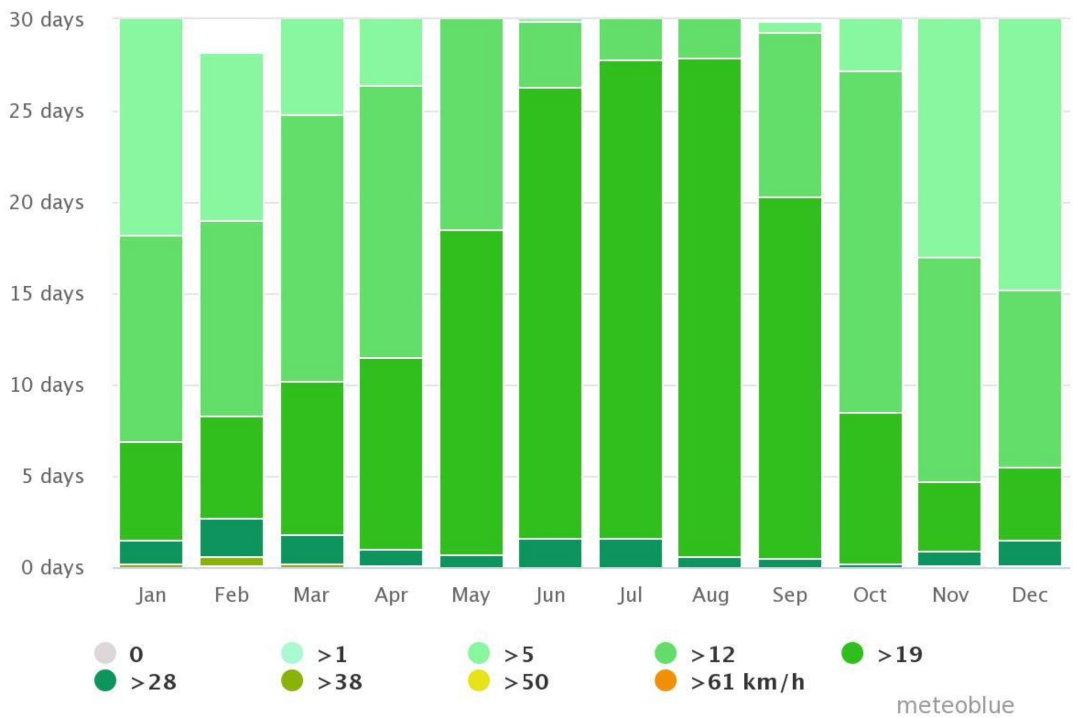
3.2.5 Wind direction and speed

Wind direction and speed data were obtained from (the Meteoblue), which provides the wind rose that shows how many hours per day the wind blows from the indicated direction at 569 m AMSL at the point 32.22 N 35.25 E in Nablus, the Meteoblue diagrams are based on 30 years hourly weather simulations that gives good indications of climate patterns and expected conditions. As shown in figure 5.

Figure 5

Wind rose and wind speed data in Nablus (the Meteoblue).





3.3 Weighing criteria

After defining, the four criteria layers were weighted, the weights were selected in a semi-quantitative manner by subject matter experts. They are basically subjective not objective. This is due to the high variability of sources and the local nature of most of them, which limits the availability to find similar weights from literature. The industries and quarries were given the highest priority followed by roads and altitude in a subjective order as shown in Table 2.

Table 2

Criteria and sub-criteria weights.

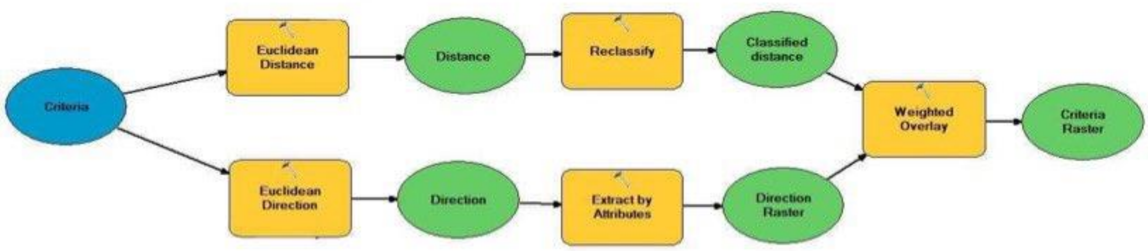
Criteria	Weight %	Sub-criteria	Influence %
		I1	17
Industries	30%	I2	33
		I3	50
		R1	17
Roads	20%	R2	33
		R3	50
Queries	30%	Q	100
Altitude	20%	A	100

3.4 Rasterization

The GIS model shown in Figure 6 was used to overlay the criteria and the weights to create the hazard map.

Figure 6

GIS model performed on each criterion

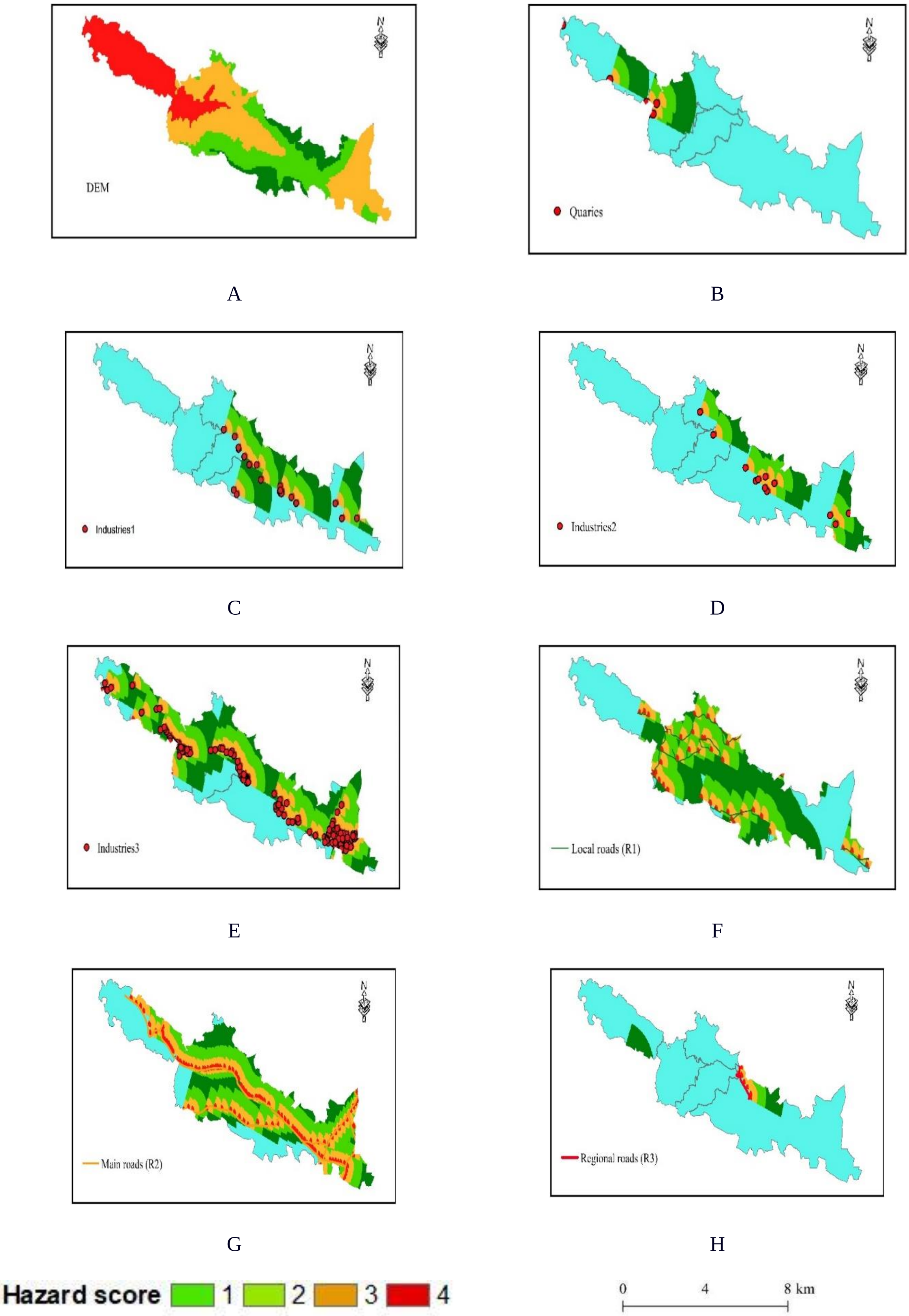


For each criterion (quarries, factories, and roads) the Euclidian distance tool was used to calculate for each cell, the Euclidean distance to the closest source. Then the distance rasters were reclassified into 4 classes (200, 500, 1000, and 2000 m), which makes the classified distance rasters. In parallel, the Euclidian direction tool was used to calculate, for each cell, the direction, in degrees, to the nearest source. The effective directions according to the wind rose that is southwest into northeast values (202.5°-292.5°) were extracted from the attribute to make the direction raster.

Finally, the weighted overlay tool was used to overlay the two rasters with the same percent of influence for the direction and distance and a scale value of 1 for all the direction values. The DEM raster was reclassified based on natural breaks into 4 classes. For all the criteria the resulted raster was reclassified into 4 classes, no 4 indicates the nearest place to the source of pollution in the effective wind direction, and so on. These classes are the hazard score. Figure 7 (a-h) shows the hazard score for each criterion individually.

Figure 7

Hazard score for each criterion



3.5 Weighted overlaying

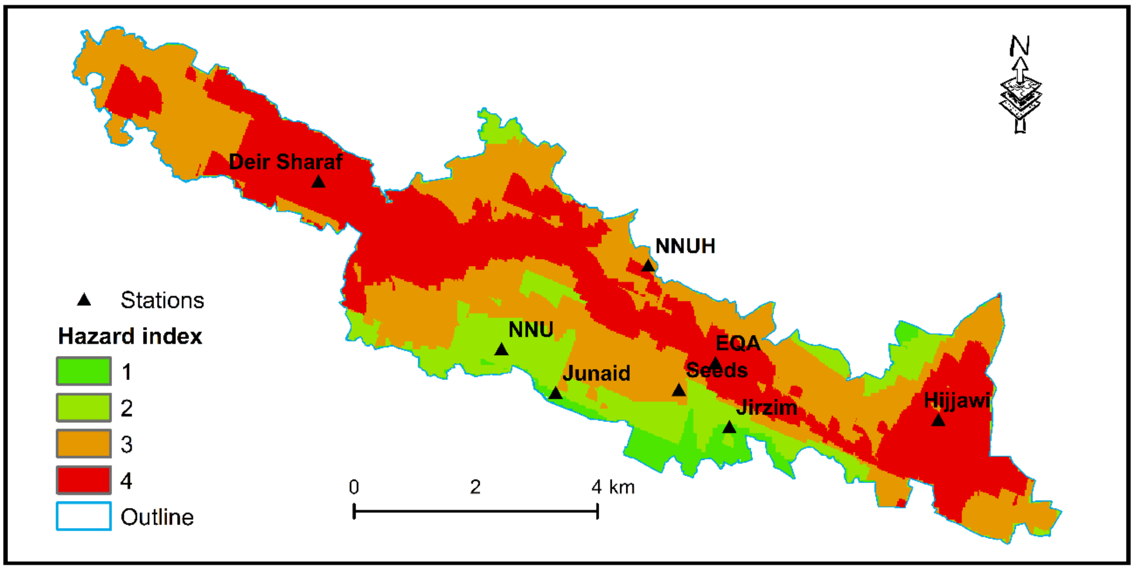
The GIS weighted overlay summation tool was used to calculate the air pollution hazard index, this tool overlaid criteria rasters based on their weights resulting in the hazard index map (Figure 8).

3.6 Selecting measuring locations

Based on the hazard map, eight measuring locations were selected. The locations were distributed to cover the geography of the study area and the different hazard classes as much as possible as shown in Figure 8.

Figure 8

Measuring stations



3.7 Calibration of AirUs

In this research Low-cost monitoring devices (AirUs) were used to measure the concentrations of $PM_{2.5}$ and PM_{10}. AirUs was developed by the University of Utah, USA, and verified by the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) in the USA. It utilizes Particulate Matter Sensor (PMS) 3003 which is a laser-based detector that draws air through a fan into the chamber and exposes it to a laser and converts light scattering into $PM_{2.5}$ and PM_{10} concentrations. It also contains a set of sensors for temperature, relative humidity, CO, and NO_2 sensors. It stores a One-minute averaged data from all sensors.

The use of AirUs requires field calibration, three AirUs were calibrated for local PM by (Khader & Martin, 2019) using a Mini-Vol. The Mini-Vol is a reference device verified by the EPA. It is a filter based low-volume sampler that draws ambient air at a rate of 5 l/s on a filter, the weight difference of the filter before and after use multiplied by the amount of air drawn in the operating period (flow rate multiplied by operating time) results in the concentration of the pollutant. By operating the Mini-Vol and AirUs together at different periods and under different pollution conditions power calibration equations have been derived from the relation between the $PM_{2.5}$ concentrations from each device as shown in Figure 1 in appendix c. The equations showed an acceptable coefficient of determination (R^2) for all sensors.

PM_{10} readings were not directly through the Mini-Vol but were calibrated by multiplying the PM_{10} data (before calibration) with the ratio of calibrated to non-calibrated values of $PM_{2.5}$. Although this is not ideal, the authors suggested that this method is sufficiently indicative for this application because the goal is to compare regions relatively in terms of PM Concentrations.

The other five AirUs were co-calibrated for $PM_{2.5}$ with the three calibrated ones, all sensors were operated for three days in the same conditions. Then a power equation was derived for seven sensors based on the previously calibrated sensor of the highest R^2. The equations showed an acceptable R^2 for all sensors. By these equations the sensor readings could be adjusted to become realistic. The calibration equations are shown in Figure 2 in appendix c.

To ascertain the realism of calibration equations, the sensor readings were corrected, the result shown in figures 3 and 4 in appendix c , showed that the readings of all sensors in the same conditions are significantly similar.

3.8 Performing measurements

In the selected locations eight AirUs were deployed and operated for 55 days from 7-Jan to 2-Mar 2022. The location of the device was chosen within the measurement site in a safe place that is not exposed to rain but exposed to ambient air because the sensors are not waterproof. Table 3 shows the device ID and the hazard index in each measuring location.

Table 3

The AirU ID and the hazard index for each measuring location.

No	Location	ID	Hazard index
1	EQA	Unit A	4
2	Hijjawi	Unit F	4
3	Deir Sharaf	Unit C	4
4	NNUH	118	3
5	Seeds	Unit E	3
6	NNU	84	2
7	Junaid	Unit D	1
8	Jirzim	Unit B	1

After the measurement period ended, the devices data were collected and analyzed, $PM_{2.5}$ was substituted in the calibration equations, and PM_{10} values were multiplied by the percent of calibrated to non-calibrated values of $PM_{2.5}$. A sample result sheet is shown in Appendix B.

Chapter Four

Results and Discutient

Air pollution hazard map for Nablus was obtained based on the spatial overlaying of the potential air pollution sources (factories, quarries, and traffic) taking into account the impact of climate (wind direction and speed) and altitudes. Figure 9 shows the hazard index map for Nablus. The hazard map shows that 82% of the study area has a very high and high hazard of PM pollution (hazard indices 3 and 4), while the rest of the area has medium and low hazard (hazard indices 1 and 2). The area of each hazard index is shown in Table 4. Eight sites were selected for measurement based on the hazard index, as shown in the map.

Figure 9

Hazard index map and locations of monitoring stations

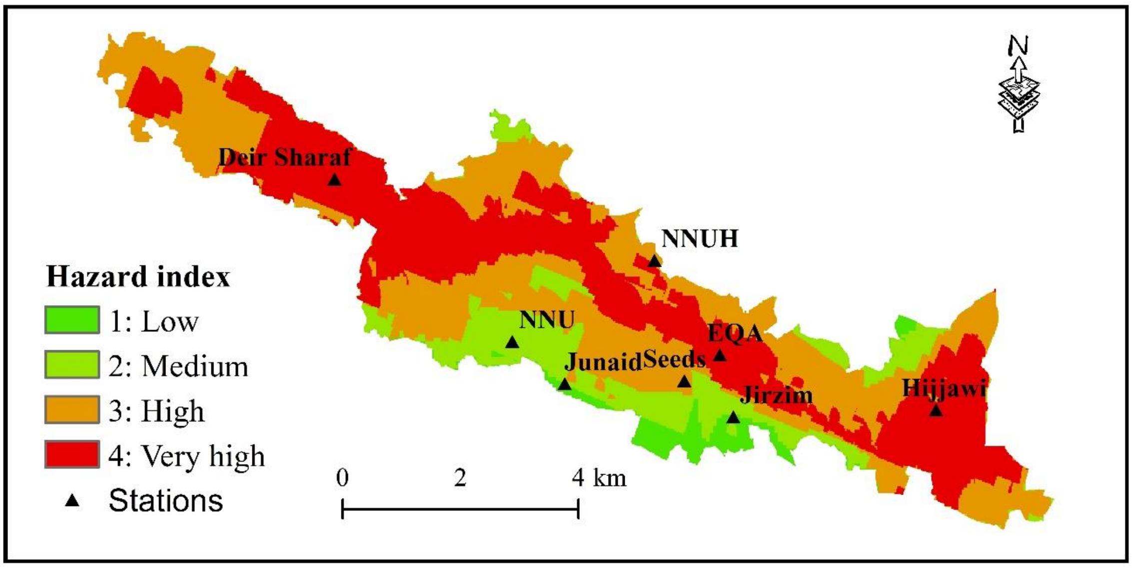


Table 4

Area of each hazard index in Nablus

Hazard index	Area km^2	% of the total area
Low	1.5	3.84
Medium	5.54	14.17
High	16.05	41.04
Very high	16.02	40.96

The calibrated AirUs were operated in the eight sampling stations for 55 days from 7-Jan 2022 to 2-Mar 2022. Figure 10 (a) shows the 24 hours average of $PM_{2.5}$ concentrations in the eight stations, and Figure 10 (b) shows the 24 hours average of PM_{10} concentrations for the same stations during the same period. The figures shows that the PM concentrations were found to be highly variable and exceeded the WHO guidelines most of the time. Table 5 shows the dates in which the maximum and minimum concentrations occurred and the percentage of days for which the concentrations exceeded the WHO guidelines to the total number of measuring days in the eight sampling stations. The measuring results show that the average daily $PM_{2.5}$ concentrations exceeded the WHO guidelines (25 µg/m^3/day) 73% to 100% of the time in all stations. The average $PM_{2.5}$ concentration in the eight stations was 48 µg/m^3. For PM_{10}, the average daily concentrations exceeded the WHO guideline (50 µg/m^3/day) 58% to 87% of the time in all locations except Junaid, NNU, and NNUH. The average PM_{10} concentration in the eight locations was 55.2 µg/m^3. The values show that $PM_{2.5}$ are approximately 79% to 92% of PM_{10}. This indicates that most of the PM pollution in Nablus is composed of fine particles smaller than 2.5 µm. unfortunately, the sensor measurements in NNUH station only lasted for 26 days due to some vandals tampering with it. A closer look at the developed hazard map and PM values shows that the PM concentrations are commensurate with the hazard index that was proposed through the PM hazard map, the stations with high PM concentrations are located in the high hazard index region and so on. However, local sources of air pollution are expected to affect the measurements, such as the presence of smokers or a construction site near the sensor. Therefore, the researcher recommends providing a larger number of sensors and placing at least two devices at each measuring site.

Figure 10 a

Average daily PM2.5 concentration in each measuring station.

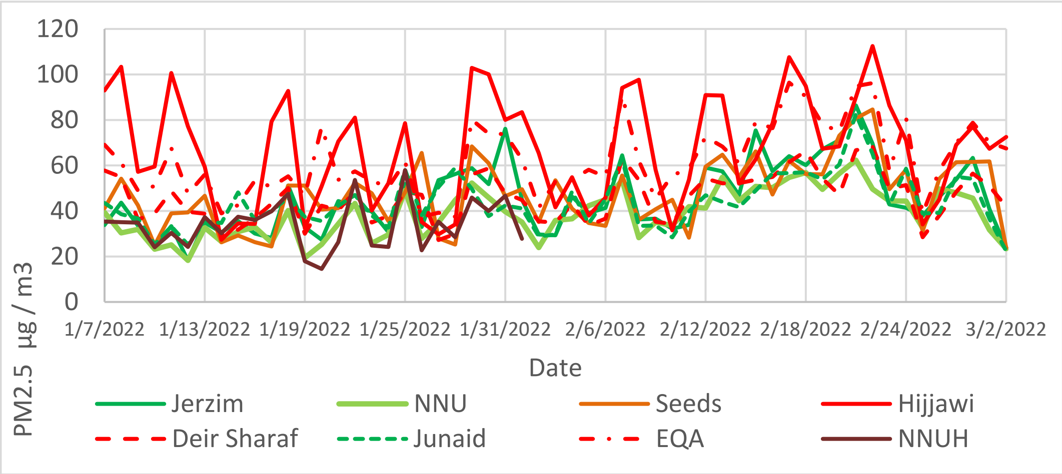


Figure 10 b

Average daily PM_{10} concentration in each measuring station.

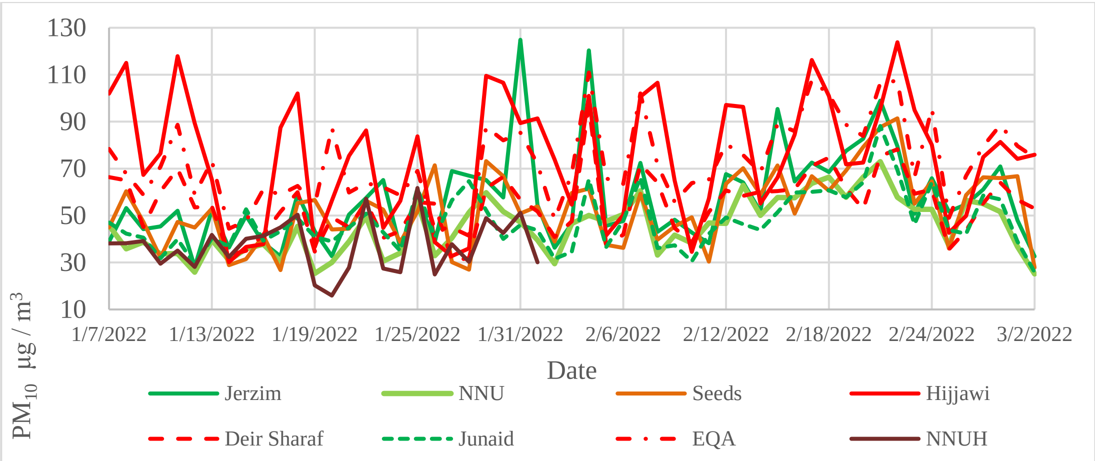


Table 5

The dates in which the maximum and minimum values occurred and the percentage of days for which the concentrations exceeded the WHO guidelines to the total number of measuring days in the eight sampling stations.

Station	**Hazard index**	**Average ± 95% CL**	**n/N ***	**PM2.5 Max. value**	**Date**	**Min. Value**	**Date**
Jerzim	1	45.36 ± 4.13	52/55	86.37	21-Feb	18.18	12-Jan
Junaid	1	43.60 ± 3.13	54/55	82.53	21-Feb	22.36	2-Mar
NNU	2	38.76 ± 2.93	50/55	62.32	21-Feb	18.26	12-Jan
Seeds	3	47.58 ± 3.98	51/55	84.61	22-Feb	23.78	2-Mar
NNUH	3	33.78 ± 4.30	19/26	57.94	25-Jan	14.52	20-Jan
Hijjawi	4	67.43 ± 6.46	55/55	112.48	22-Feb	27.35	14-Jan
EQA	4	62.37 ± 4.25	55/55	96.41	17-Feb	37.47	28-Jan
Deir Sharaf	4	45.70 ± 2.85	55/55	68.25	22-Feb	27.22	27-Jan
Station	Hazard index	Average ± 95% CL	n/N*	PM10 Max. value	Date	Min. Value	Date
Jerzim	1	57.28 ± 5.44	33/55	124.88	31-Jan	28.12	12-Jan
Junaid	1	47.40 ± 3.26	19/55	88.15	21-Feb	25.91	2-Mar
NNU	2	45.33 ± 3.21	22/55	72.96	21-Feb	25.14	2-Mar
Seeds	3	52.72 ± 4.20	32/55	91.41	22-Feb	26.76	17-Jan
NNUH	3	36.96 ± 4.51	4/26	61.74	25-Jan	15.92	20-Jan
Hijjawi	4	74.73 ± 7.00	43/55	123.84	22-Feb	30.14	14-Jan
EQA	4	72.63 ± 4.8	48/55	110.94	4-Feb	41.40	28-Jan
Deir Sharaf	4	54.42 ± 3.58	36/55	96.82	4-Feb	30.75	27-Jan

*n/N is the percent of days in which the value exceeded the guidelines to the number of sampling days.

Chapter Five

Conclusions

In this study. GIS-based weighted overlay summation process was used to develop an air pollution hazard map for Nablus by weighing the criteria of potential air pollution sources (factories, quarries, and traffic) with weights of 30%, 30%, and 20%, respectively, with a weight of 20% for altitude. Taking into account the wind speed and direction. The results of the hazard map showed that 82% of Nablus is exposed to a high and medium hazard of particulate air pollution. Based on the hazard index, eight low-cost AirU sensors were deployed in different sites and measured PM_{10} and $PM_{2.5}$ concentrations for 55 days. The results showed a matching between the hazard index and PM concentrations, also there is an increase in PM_{10} and $PM_{2.5}$ 24 h concentrations above WHO guidelines in all sites. In summary, the $PM_{2.5}$ overall average in the Nablus was 48 µg/m^3, while the overall PM_{10} average was 55.2 µg/m^3. The matching between the PM concentrations with the hazard map gives an impression of the effectiveness of the mapping methodology and the use of low-cost sensors in characterizing the PM situation in urban areas. This helps decision-makers to take appropriate decisions. Further studies can be conducted using a denser network of sensors to determine more area specific PM levels, local source strengths and the impact of seasonal dust storms.

List of Abbreviations

Abbreviation	Meaning
GIS	Geographic information systems
EPA	Environmental protection agency
NAAQS	National ambient air quality standards
PM	Particulate matter
WESI	Water and environmental studies institute
WHO	World health organization
AMSL	Above mean sea level
MOLG	Ministry of local governorate
EQA	Environment quality authority
DEM	Digital elevation model
NNU	An-Najah National University
NNUH	An-Najah National University Hospital

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Appendices

Appendix A

PMS 3003 data sheet

龙戈电子
LONGGE DIANZI

GuangZhou LOGOELE Electronic Technology Co., Ltd

Laser dust sensor

(With adapter cable, connected directly to the computer USB port)

Company address: guangzhou city, guangdong province town of huadu district xinhua 27 public avenue

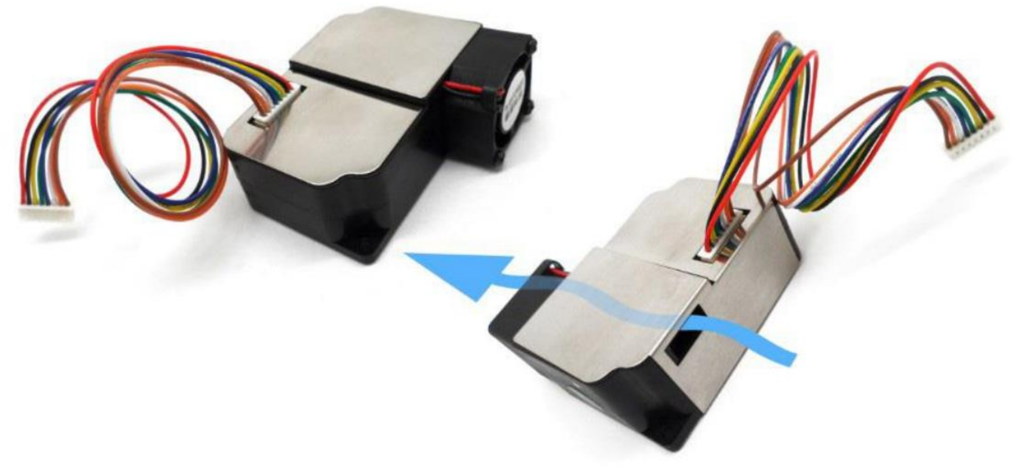
TELL：13622275829 QQ: 956183509 E-mail: logoele@163.com

Taobao site：http://auto-ctrl.taobao.com/ Web site: www.logoele.com

alibaba：http://shop1362104267267.1688.com/ Speed sell tong:http://www.aliexpress.com/store/727356

Laser dust sensor

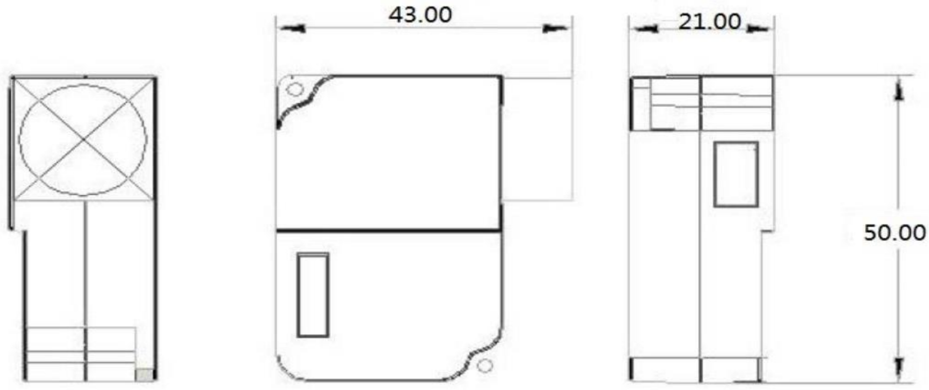
PM1.0 PM2.5 PM10



Company address: guangzhou city, guangdong province town of huadu district xinhua 27 public avenue
TELL: 13622275829 QQ: 956183509 E-mail: logoele@163.com
Taobao site: http://auto-ctrl.taobao.com/ Web site: www.logoele.com
alibaba: http://shop1362104267267.1688.com/ Speed sell tong:http://www.aliexpress.com/store/727356

Digital pins interface definition

PIN1	VCC	VCC 5V
PIN2	GND	GND
PIN3	SET	Set the pin /TTL level@3.3V
PIN4	RXD	RXD /TTL level@3.3V
PIN5	TXD	TXD /TTL level@3.3V
PIN6	RESET	RESET /TTL level@3.3V
PIN7\8	NC	NC



Product name: high accuracy laser type PM1.0 PM 2.5 PM10 Dust Sensor module

Description: PMS3003 Using laser light scattering principle to get air 0.3 ~ 10 Micron particulate concentration, stable and reliable data;

Built-in fan, digital output, high integration;

Features

Data is accurate: laser testing, stability, consistency;

Quick response: scene change response time is less than 10 Seconds;

Ease of integration: serial output (or IO Output port can be customized), comes with A fan;

High resolution: resolution smallest particle diameter 0.3 Micron;

Scope of application:

PM1.0 PM2.5 PM10 Detectors, cleaners

Working principle

Using laser light scattering principle: when the laser light to detect the location of Particles will produce a faint light Scattering, the scattering of light in particular directions of wave and particle diameters,Through the different particle size of waveform classification system Taking into account the conversion formula you can get different sizes of particles in real time Concentration, in accordance with the calibration method Official unit of concentration;

Technical parameters:

1 Measurement diameters: 0.3-1.0um 1.0-2.5um 2.5-10um

2 Measurement units: ug/m3

3 Measurement accuracy: ug/m3

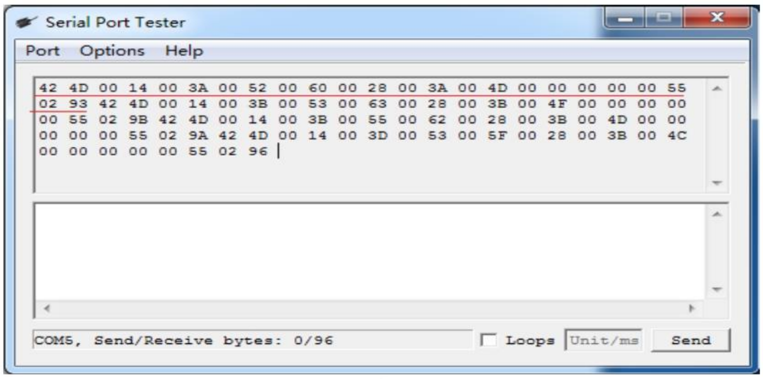
4 Response time: <10s

5 Work current: 5V200ma@ Work State 5V2ma@ Standby Fitness

6 Data interface: serial (3.3VTTL Level)

7 Module dimensions: 65x42x23mm

Laser dust serial data display:



Start character 1	0x42 (Fixed)	
Start character 2	0x4d (Fixed)	
Frame length upper eight bits	······	Frame length = 2×9+2 (Data + check digit)
Frame length lower eight bits	······	
Data 1 upper eight bits	······	Data 1 represents PM1.0 concentration (CF=1, standard particulate matter) Units ug / m3
Data 1 lower eight bits	······	
Data 2 upper eight bits	······	Data 2 represents PM2.5 concentration (CF=1, standard particulate matter) Units ug / m3
Data 2 lower eight bits	······	
Data 3 upper eight bits	······	Data 3 represents PM10 concentration (CF=1, standard particulate matter) Units ug / m3
Data 3 lower eight bits	······	
Data 4 upper eight bits	······	Data 4 represents PM1.0 concentration (Atmospheric Environment) Units ug / m3
Data 4 lower eight bits	······	
Data 5 upper eight bits	······	Data 5 represents PM2.5 concentration (Atmospheric Environment) Units ug / m3
Data 5 lower eight bits	······	
Data 6 upper eight bits	······	Data 6 represents PM10 concentration (Atmospheric Environment) Units ug / m3
Data 6 lower eight bits	······	
Data 7 upper eight bits	······	Data 7 (Retention)
Data 7 lower eight bits	······	
Data 8 upper eight bits	······	Data 8 (Retention)
Data 8 lower eight bits	······	
Data 9 upper eight bits	······	Data 9 (Retention)
Data 9 lower eight bits	······	
Data and check upper eight bits	······	Checksum = Start character 1+ start character 2 + ... + data 9 lower eight bits
Data and check lower eight bits	······	

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Data 1.2.3 Read the to value is a TSI For standard data.

Data 4.5.6 Reading to the value of value is an atmosphere as the standard.

TSI Profile

TSI As a leader in the design and production of precision measuring instruments, TSI Collaborative researchinstitutes as well as customers around the world for many disciplines of measuring instruments Development of standards, including: atmospheric sciences, airflow, fluid dynamics, indoor air quality, and bio-hazardous. Located in United States territory's corporate headquarters And local offices throughout Europe and Asia makes TSI Every corner of the world. Every day, our dedicated staff in turning research into reality.

Appendix B

PM_{10} and $PM_{2.5}$ sample results sheet

	Jirzim station			
	Before calibration		After calibration	
	$PM_{2.5}$ $\mu g/m^3$	**PM_{10}** $\mu g/m^3$	**$PM_{2.5}$** $\mu g/m^3$	**PM_{10}** $\mu g/m^3$
1/7/2022	14.06	16.16	33.81219643	38.8623822
1/8/2022	21.13	25.77	43.61766725	53.1958015
1/9/2022	13.89	18.29	33.55605776	44.1857665
1/10/2022	8.37	15.52	24.44913188	45.334591
1/11/2022	13.74	21.45	33.32907542	52.0311985
1/12/2022	5.21	8.06	18.17870827	28.1229153
1/13/2022	14.8	22.21	34.91389952	52.3944398
1/14/2022	11.98	14.25	30.59222864	36.3889197
1/15/2022	15.26	21.38	35.58833733	49.8609864
1/16/2022	11.67	14.89	30.09495869	38.3987948
1/17/2022	10.47	12.14	28.12136712	32.6068192
1/18/2022	27.28	31.54	51.1698416	59.16044
1/19/2022	13.4	17.7	32.81111348	43.3400529
1/20/2022	10	11.96	27.32547748	32.6812711
1/21/2022	21.72	24.67	44.37504776	50.4020455
1/22/2022	19.99	27.275	42.13139479	57.4854324
1/23/2022	18.26	29.88	39.81364069	65.1495939
1/24/2022	12.08	14.14	30.75160588	35.9956711
1/25/2022	27.86	31.34	51.84721734	58.323467
1/26/2022	13.49	15.84	32.94869584	38.6884612
1/27/2022	29.35	37.8	53.56357879	68.9847795
1/28/2022	31.73	37.77	56.23888497	66.9443015
1/29/2022	34.11	37.74	58.83992659	65.1016954
1/30/2022	27.8	31	51.77739079	57.7373782
1/31/2022	51.46	84.46	76.08648479	124.878828
2/1/2022	22.27	26.9	45.07416261	54.4452166
2/2/2022	11.41	13.97	29.67406309	36.3318722
2/3/2022	11.206	17.77	29.34129925	46.5281892
2/4/2022	23.25	60.43	46.30402565	120.350635
2/5/2022	17.71	20.68	39.05972506	45.6101137
2/6/2022	19.38	22.37	41.32307227	47.6985101
2/7/2022	39.47	44.37	64.46059948	72.4630555
2/8/2022	15.71	18.67	36.24077636	43.069083
2/9/2022	15.96	21.03	36.60021336	48.2269729
2/10/2022	13.01	17.29	32.21087315	42.8075324
2/11/2022	14.09	15.91	33.85727657	38.2306083
2/12/2022	34.27	39.28	59.01230333	67.6394303
2/13/2022	32.78	36.61	57.39511278	64.1011311
2/14/2022	23.84	26.18	47.03508108	51.6517795
2/15/2022	50.71	64.16	75.39139431	95.3877314

2/16/2022	32.84	36.87	57.46076022	64.5121263
2/17/2022	39.08	44.25	64.06171364	72.5366128
2/18/2022	35.36	40.29	60.17869572	68.5689946
2/19/2022	42.09	48.62	67.10301068	77.5136227
2/20/2022	46.2	53.73	71.12715837	82.7199615
2/21/2022	63.03	72.23	86.37037021	98.9771829
2/22/2022	44.57	50.96	69.54794628	79.5190339
2/23/2022	20.58	24.33	42.904462	50.7223304
2/24/2022	19.44	30.94	41.40299822	65.8955126
2/25/2022	16.86	23.01	37.87707437	51.6934449
2/26/2022	23.18	27.46	46.21683123	54.7503963
2/27/2022	29.56	33.57	53.80282734	61.1015194
2/28/2022	38.33	42.97	63.29040508	70.9519621
3/1/2022	18.99	22.36	40.80127315	48.0419414
3/2/2022	7.92	10.94	23.61896543	32.6251871
Average	23.67647273	29.66154545	45.35778908	57.289595

Appendix C

Figures

Figure C.1

Previous calibration results of three sensors by (Khader & Martin, 2019)

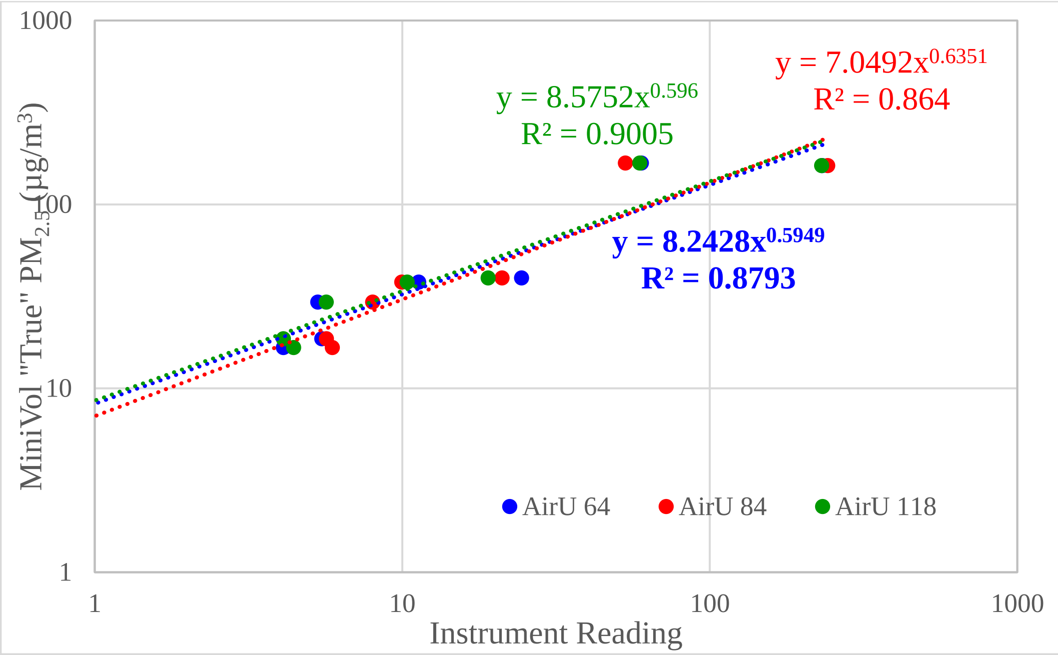


Figure C.2

Calibration results of the seven AirUs

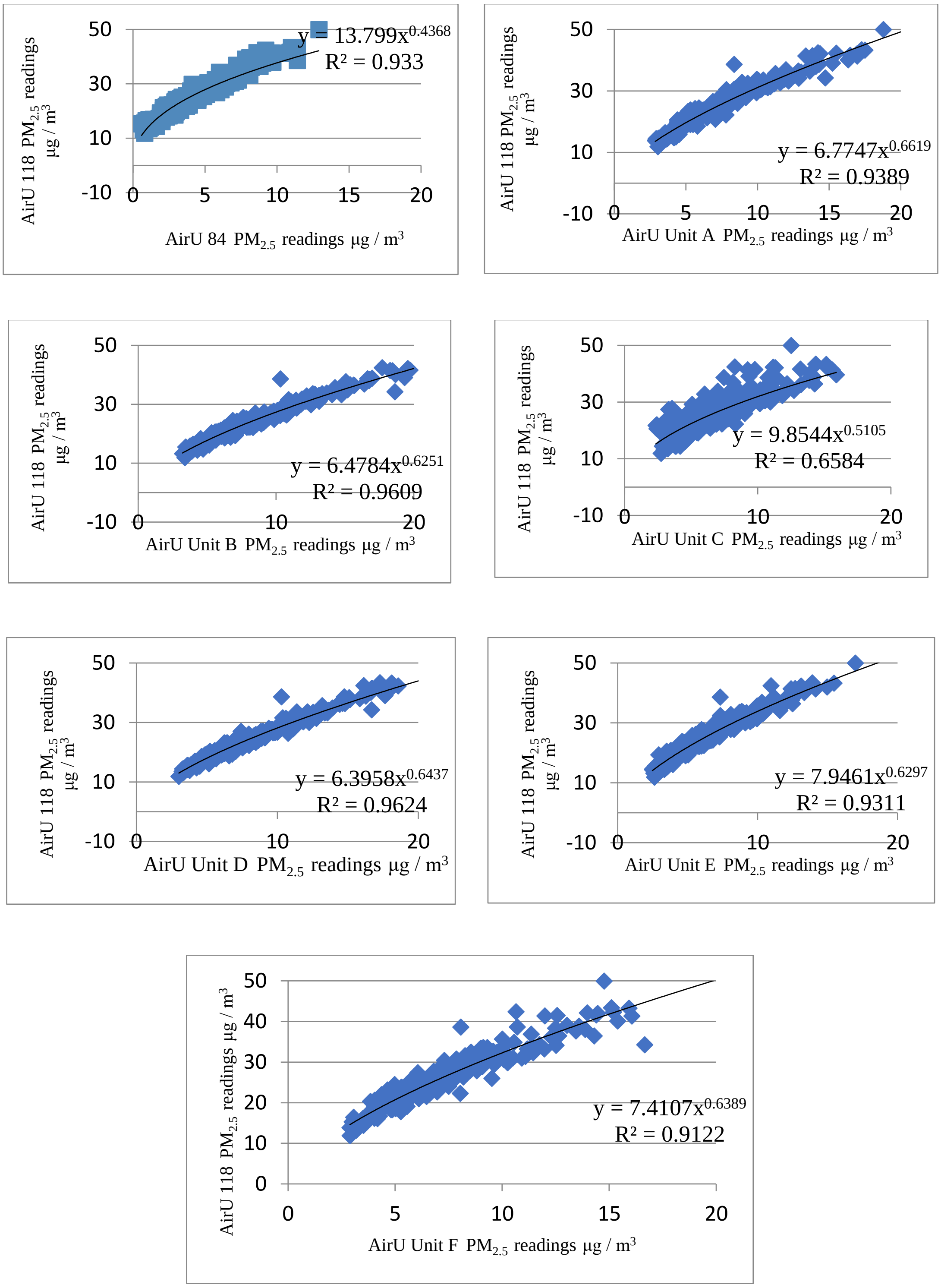


Figure C.3

AirUs pre-calibration results

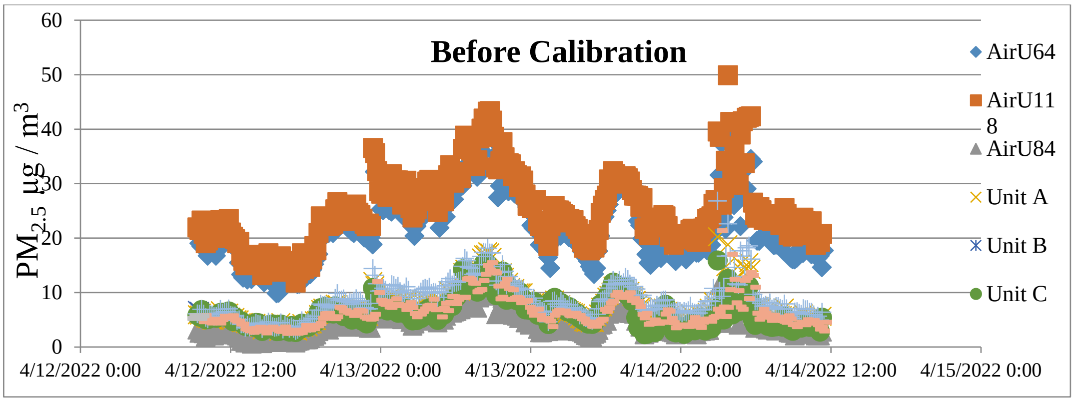
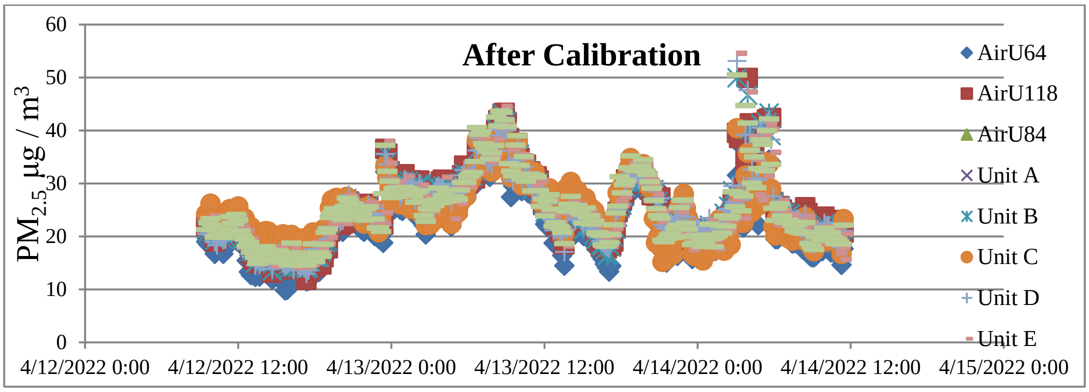


Figure C.4

AirUs post-calibration results



جـامعــــة النجاح الوطنية

كليـــة الدراســـــات العليـــا

رسم خرائط مخاطر جسيمات الهواء في المناطق الحضرية باستخدام نظم المعلومات الجغرافية وأجهزة استشعار منخفضة التكلفة في نابلس، فلسطين

إعداد

توفيق صالح

إشراف

د. عبد الحليم خضر

قدمت هذه الرسالة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياة والبيئة، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس–فلسطين.

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الملخص

تم تطبيق القليل من دراسات تلوث الهواء في دولة فلسطين، وأظهرت جميعها زيادة في تركيزات الجسيمات فوق إرشادات منظمة الصحة العالمية. ومع ذلك، لا توجد منهجية واضحة لاختيار مواقع المراقبة. في هذه الدراسة تم اختبار منهجية تعتمد على نظم المعلومات الجغرافية ومستشعرات منخفضة التكلفة ومعايرة محليًا. تم استخدام عملية جمع التراكيب الموزون القائم على نظم المعلومات الجغرافية للمصادر المحتملة لتلوث الهواء (المصانع والمحاجر والمرور) مع مراعاة تأثير الارتفاع والمناخ للحصول على خريطة مخاطر تلوث الجسيمات (PM) في نابلس ، فلسطين. لاختبار المنهجية, تم نشر ثمانية أجهزة استشعار مُعايرة محليًا (AirUs) لقياس تركيزات $PM_{2.5}$ و PM_{10} لمدة 55 يومًا من 7 يناير إلى 2 مارس 2022. وأظهرت نتائج خريطة المخاطر أن 82٪ من نابلس معرضة إلى مخاطر عالية جدًا وعالية من تلوث PM كما يُظهر ارتفاع تركيزات PM2.5 أعلى من الدلائل الإرشادية لمنظمة الصحة العالمية في جميع المحطات. باختصار، كان المتوسط العام لـ$PM_{2.5}$ و PM_{10} في نابلس 48 و 55.2 ميكروغرام / م 3 على التوالي. أظهرت قراءات أجهزة الاستشعار تطابقًا جيدًا بين مؤشر الخطر وتركيزات الجسيمات. يشير هذا إلى فعالية منهجية رسم الخرائط واستخدام مستشعرات منخفضة التكلفة ومعايرة محليًا في توصيف حالة جودة الهواء لتحديد خيارات العلاج المحتملة.

كلمات مفتاحية: تلوث الهواء، خرائط المخاطر، أجهزة استشعار منخفضة التكلفة، نظم المعلومات الجغرافية، فلسطين.