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IAMU 2022 Research Project
(No. YAS20220202)

The Impact of Greenhouse Gas Emissions Due to Marine Port Activities on the City Air Quality, Toward the Achievement of SDG's

By

Arab Academy for Science, Technology and Maritime Transport

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The Impact of Greenhouse Gas Emissions Due to Marine Port Activities on the City Air Quality, Toward the Achievement of SDG's

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We would like to take this opportunity to express our sincere gratitude to **Capt. Eslam Saad** for his exceptional participation in this project, despite facing an unexpected and serious health issue. We were deeply saddened to learn about his diagnosis of a brain tumor, and our thoughts and well-wishes are with him during this challenging time. We hope for his complete recovery and restored health.

Capt. Eslam Saad's dedication and commitment to the project were truly commendable. He played a vital role in the initial 10 months of the project, diligently conducting field measurements and gathering essential data. His contributions have been invaluable, setting the foundation for our research.

Due to the severity of **Capt. Eslam Saad's** health condition and his urgent need for chemotherapy sessions, he is unable to actively participate in finalizing the report. In light of this, we would like to extend our heartfelt thanks to **Dr. Kareem Tonbol** and **Eng. Mohamed El Bawab** for graciously taking on the responsibility of completing the report on behalf of **Capt. Eslam Saad**. Their dedication and expertise have been pivotal in ensuring the accurate representation of his work.

In conclusion, we want to extend our deepest appreciation to **Capt. Eslam Saad** for his significant contributions to the project and wish him a swift and successful recovery. We also want to acknowledge the exceptional efforts of **Dr. Kareem Tonbol** and **Eng. Mohamed El Bawab** in finalizing the report on his behalf. Their dedication and support have been truly remarkable, and we are grateful for their invaluable contributions.

Abstract

Air pollution at port cities presents significant health and environmental challenges, prompting the need for comprehensive study and strategic intervention. This research focuses on assessing air quality at the Alexandria Port, a critical hub in the shipping industry. A multitude of pollutants including carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), PM2.5, and PM10 were considered, identifying potential sources and understanding their spatial distribution across the port and the surrounding areas.

The study method involved measuring these pollutants at 24 different locations inside and outside the port. These locations were strategically selected for their unique characteristics and the potential influence on air quality. The readings were then correlated with the Air Quality Index (AQI) to determine the health implications.

The results identified a notable variability in pollution levels across the selected sites, with certain locations exhibiting pollutant concentrations significantly above standard guidelines, indicating a risk to public health and the environment. Notably, locations A6, B9, B10, and B11 recorded an unhealthy level of CO concentration, a major pollutant derived primarily from vehicle exhausts and industrial combustion processes.

Given the significant impact of port activities on air pollution, the study proposes several strategic interventions to improve air quality and mitigate health risks. These strategies include implementing incentive schemes such as the Environmental Ship Index (ESI) to promote more ecologically friendly shipping practices, transitioning to Clean Marine Fuels (CMF) to reduce harmful emissions, and introducing Onshore Power Supply (OPS) to lower emissions from ships' auxiliary engines while docked.

This study presents a comprehensive assessment of air pollution challenges faced by Alexandria Port, proposing an integrative approach for air quality improvement. These insights and recommendations provide a roadmap for port cities to mitigate their environmental impact, improve public health, and move towards a sustainable future.

Keywords: GHGs, Port-city interaction, Air quality, Alexandria port, AQI, and Port air pollutants.

Executive Summary:

This comprehensive study centers on the pressing problem of air pollution within and around the Alexandria Port, a significant node in global shipping networks. Given the port's key role in economic activities, understanding the extent and impact of pollution emanating from its operations is of vital importance.

The research problem stems from the increasing environmental and health concerns associated with air pollutants produced by port activities. Pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter (PM2.5 and PM10) pose significant risks to public health and environmental sustainability. Consequently, our research aim is to identify the levels of these pollutants at different locations within and around the port, assess the risks, and propose sustainable strategies to improve air quality.

To achieve these objectives, the study adopts a systematic research methodology involving data collection from 24 specific locations within and outside the Alexandria port. The chosen locations, each with distinct characteristics, include various berths, the container bridge, the scrap terminal, the Chinese container terminal, and the shipyard, among others. Measurements were taken at each site to establish the concentration levels of the target pollutants, subsequently correlated with the Air Quality Index (AQI) to determine potential health impacts.

The analysis of the sampling round results revealed notable variations in pollutant levels across different sites and sampling periods. These fluctuations highlight the dynamic nature of air pollution and the importance of continuous monitoring to identify trends and potential environmental and health risks.

In the 7th sampling round, sites A6 and A11 showed significantly elevated levels of CO_2, NO_2, and PM2.5, indicating potential sources of emissions in these areas. Similarly, in the 8th sampling round, site A6 continued to exhibit high levels of CO_2, VOC, and PM2.5. These findings suggest the presence of localized pollution sources that require further investigation and targeted control measures.

During the 9th sampling round, site B5 demonstrated elevated levels of several pollutants, including CO_2, NO_2, SO_2, and PM10. These findings highlight the importance of monitoring and managing emissions in industrial areas to minimize their impact on air quality.

In the 10th sampling round, site A11 showed persistently high levels of CO_2, NO_2, and PM2.5, suggesting the presence of continuous emission sources in the vicinity. Similarly, site B3 displayed elevated levels of CO, NO_2, and PM10, indicating potential pollution sources that need attention.

The 11th sampling round revealed changes in pollutant levels at several sites. Site A11 exhibited significant increases in VOC, PM2.5, and PM10 levels, emphasizing the need for targeted interventions to mitigate pollution sources in the area. Site B4 showed elevated levels of CO_2, SO_2, and PM10, indicating the presence of local emission sources that require further investigation and control.

During the 12th sampling round, site A6 displayed higher levels of CO_2, NO_2, and PM2.5, suggesting ongoing pollution sources. Site A11 showed increased levels of VOC, PM2.5, and PM10, emphasizing the importance of addressing emissions in the area. Site B8 exhibited higher levels of CO, SO_2, and PM10, indicating the need for effective pollution control measures.

Overall, the findings from this project highlight the dynamic nature of air pollution and the importance of continuous monitoring to identify trends, localize pollution sources, and implement appropriate control measures. The variations in pollutant levels across different sites and sampling periods underscore the need for targeted interventions and policy measures to improve air quality and protect human health.

Upon identifying the critical pollution hotspots and their potential sources, the study advances several strategic interventions to address the identified challenges. These include the implementation of incentive schemes such as the Environmental Ship Index (ESI) to promote greener shipping practices, the use of Clean Marine Fuels (CMF) to reduce the harmful emissions from vessels, and the introduction of Onshore Power Supply (OPS) systems to curb emissions from auxiliary ship engines when docked.

The study provides invaluable insights into the spatial distribution of air pollutants at the Alexandria Port and their impact on health and environment. By doing so, it not only underscores the urgency to tackle pollution in port cities but also equips policy-makers and stakeholders with evidence-based interventions for improved air quality management. The suggested strategies, if adopted, could significantly enhance environmental sustainability at the Alexandria Port, setting a precedent for other port cities to follow.

It is recommended that further studies be conducted to investigate the specific sources of pollution identified during the sampling rounds. Additionally, the implementation of emission control technologies and measures should be prioritized in areas with consistently high pollutant levels.
The information gathered from this project can guide policymakers, environmental agencies, and stakeholders in developing effective strategies to mitigate air pollution, improve air quality, and safeguard public health. Continued monitoring and collaboration among all relevant parties are crucial for achieving long-term improvements in air quality and sustainable development.
In conclusion, this study underscores the need for concerted efforts to mitigate the environmental impact of port operations. With strategic interventions and a commitment to environmental sustainability, we can transform port cities like Alexandria into healthier, more eco-friendly urban spaces.

1.1.Introduction:

The warming of the globe is caused by greenhouse gases that trap heat. Nearly all of the 150-year rise in greenhouse gases in the atmosphere results from human activity. Burning fossil fuels for electricity, heat, and transportation accounts for the majority of greenhouse gas emissions caused by human activity. Greenhouse Gas Emissions and Sinks; for example, the US Environmental Protection Agency (US EPA) keeps track of all domestic emissions. The total national emissions and removals of greenhouse gases resulting from human activity in the United States have estimated that the main contributors to greenhouse gas emissions are the transportation industry is the primary producer of emissions. Burning fossil fuels for vehicles, trucks, ships, trains, and aeroplanes are the primary source of transportation-related greenhouse gas emissions. Electricity generation, the second-largest contributor to greenhouse gas emissions, is electric power. In the industrial sector, greenhouse gas emissions are caused mainly by burning fossil fuels for energy and some chemical processes required to make items from raw materials. These buildings' greenhouse gas emissions are caused by using things that contain greenhouse gases, burning fossil fuels for heating, and managing trash. Rice production, agricultural soils, and livestock like cows all contribute to this sector's emissions of greenhouse gases.
Land areas can either be a sink (absorbing CO2 from the atmosphere) or a source of greenhouse gas emissions. Since 1990, managed forests and other lands have been net CO2 sinks in the United States, meaning they have absorbed more CO2 from the atmosphere than they have released [1]

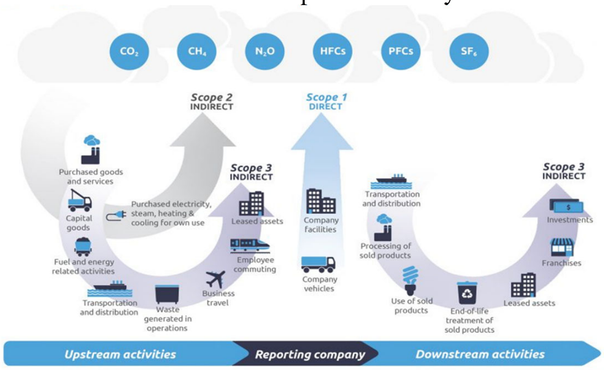

Fig.1 Overview of GHG Protocol scopes and emissions across the value chain Source: (https://ghgprotocol.org/sites/default/files/ghgp/standards_supporting/Diagram%20of%20scopes%20and%20emissions%20across%20the%20value%20chain.pdf)

GHG Protocol scopes as per (Fig. 1) used by US EPA are:
Scope 1 emissions include all emissions created from resources that your business owns or controls. Scope 1 emissions are made directly within the perimeter of your business's facilities, either from on-site operations or company-owned machinery. This may involve on-site fuel burning, business vehicle emissions, or emission leaks from running a refrigeration system.
Scope 1 emissions can be divided into four groups:
1. stationary combustion – emissions from machinery that heats a space by burning carbon-based fuels. This covers emissions from appliances like dryers, boilers, furnaces, and ovens.
2. mobile combustion - the exhaust from company-owned conventional internal combustion engine vehicles.
3. Fugitives emissions, which unintentionally leak or escape from pressured machinery like compressors, storage tanks, or pipes.
4. Process emissions: These are emissions that are a consequence or result of chemical processes, such as CO2 emissions from the production of cement or steel.
Since Scope 1 emissions are directly within your control, they can be significantly decreased by putting energy-saving measures, such as smart lighting and thermostats, heat recovery systems, or other energy-saving strategies. Companies must disclose their Scope 1 emissions under the National Greenhouse and Energy Reporting (NGER) 2007.
Indirect GHG emissions, or scope two emissions, are those produced when purchased energy is created. The energy can heat and cool your business, distribute process steam, or generate electricity. The

electricity you use at your facility, whether to turn on the lights or regulate the temperature inside, is produced somewhere. When you buy this power from a utility or other third-party generator, that generator's emissions go toward your Scope 2 emissions. For instance, your company's Scope 2 emissions would include the emissions from a natural gas plant that produces energy for your operation. Naturally, the Scope 1 emissions from the natural gas plant would be your Scope 2 emissions. Consider alternate choices that make power from clean energy sources reduce Scope 2 emissions.

Additionally, investigate ways to increase the energy efficiency of your own business. By doing this will be able to use less energy overall, cutting down on the quantity of power you need to import. Scope 2 emissions must be recorded under the NGER scheme, much like Scope 1 emissions.

The upstream and downstream activity effects on your business's goods and services are examined in scope 3 emissions. Scope 3 emissions are GHG emissions produced across the supply chain of your business but come from sources that are not under your management or your ownership. This may include emissions from raw material extraction and production, final applications for manufactured goods, handling of end-of-life products, or even fuel emissions from staff commuting.

Scope 3 emissions can be the hardest to manage because they come from a more significant economic perspective. They can also be the biggest source of overall GHG emissions. For instance, Kraft Foods discovered that 90% of all GHG emissions were from Scope 3 emissions when assessed throughout its entire supply chain. The Scope 3 emissions comprise 15 different activity kinds, according to the Greenhouse Gas Protocol. Addressing these emissions calls for open communication among participants in the supply chain and a comprehensive comprehension of the entire product life-cycle of manufactured items. The best solutions can involve using more recycled materials in your products, using less packaging material, or rewarding employees who commute or take fewer business trips. Although Scope 3 emissions are not reported under the NGER scheme, knowing about them is essential to measuring and developing a strategy to reduce your company's emissions in the larger economy. Your ability to properly grasp your exposure to dangers in a decarbonising world depends on understanding your scope 3 emissions [1].

Since 1970, the transportation sector's greenhouse gas (GHG) emissions have doubled, growing more quickly than any other energy end-use sector to reach 7.0 Gt CO2eq in 2010 [2]. The majority of this increase—about 80%—has come from automobiles. In 2010 [3]. The final energy consumption for transportation reached 28% of all end-use energy, with 40% of the energy going toward urban transport [4]. The global transportation sector, which includes car makers, transportation service providers, and infrastructure builders, engages in research and development (R&D) operations to become more carbon and energy efficient. Given the inevitable rise in demand, the slow turnover and sunk costs of stock (especially aeroplanes, trains, and huge ships), and infrastructure, reducing transportation emissions will be challenging. Despite the lack of success, new technology, stricter policy execution, and behavioural changes may all contribute to the shift needed to reduce GHG emissions [5].

The remaining greenhouse gas emissions from the transportation industry are produced by various forms of transportation, such as railways, pipelines, commercial aeroplanes, ships, and boats.

Methane (CH4) and nitrous oxide (N2O) are released in relatively tiny quantities during fuel burning. The Transportation industry also accounts for a modest proportion of hydrofluorocarbon (HFC) emissions. Portable air conditioners and refrigerated transportation are to blame for these emissions [1].

Transportation emissions also contribute to climate impacts. Transportation greenhouse gas (GHG) emissions have increased in recent years and were responsible for 28% of the US GHG emissions in 2018. 83% of transportation GHG emissions in 2018 came from vehicles, and 70% of vehicle GHG emissions came from Light-Duty Vehicles (LDVs). LDV energy efficiency has increased in recent years, and GHG emission factors per mile (EF) decreased, but their overall climate impacts have increased. Increased market penetration of larger LDVs and increased vehicle miles travelled (VMT) have contributed to this overall increase [6].

Without transportation, the world as we know it today would not be possible. We gain from transportation daily since it has so many positive economic and social effects. However, they all have some detrimental effects, manifested as various concerns, such as air quality degradation followed by climate change, accidents, traffic jams, health problems, etc. These adverse effects have been more prominent in recent decades, increasing demand for mitigation. Maritime transportation is not an exception, even if it is still seen as the method of transportation with the fewest adverse effects while offering affordable and effective transportation and encouraging manufacturing and global trade. However, as seaborne trade expands, adverse effects also increase, making marine shipping a contentious topic. The damaging atmospheric emissions, oil spills, and trash disposal are only a few of the adverse effects of maritime transportation. Because ships' bunkers burn heavy oil with high sulphur content, many sulphur oxides, nitrogen oxides, carbon dioxide, particulate matter, volatile organic compounds, etc., are produced. The kind and age of the vessel, the sailing area, the wind, and other meteorological factors all affect how much emissions are produced. In the worst situations, ship pollutants can travel thousands of kilometres inland, damaging nature, people's health, and constructed infrastructure field [7].

Maritime transport of goods is a relatively clean form of transportation per kilogram of material, and it is currently gaining relative weight concerning air and road transport. This form of transportation has also been increasing (and will most likely continue to do so in the future) due to the globalisation of manufacturing processes and the increase of global-scale trade. However, marine transport emissions contribute significantly to global air pollution. Around 15% of global anthropogenic NOx and 85% of global SOx emissions are attributable to oceangoing ships [9].

According to Endresen et al. (2003), over 70% of ship emissions occur within 400 km of land, which means that ships can potentially worsen the air quality in coastal communities dramatically. Not all vessels constantly turn off their main engines, but emissions are also produced when vessels are at berth. The relative importance of shipping emissions to all anthropogenic emissions has increased due to significant European efforts to reduce other emission sources (industrial, power generation, etc.). Energy intensity improvements could only counteract the rise in ship emissions under new, stringent laws to combat climate change (and air pollution). Major ports suffer from ship emissions, and smaller and more regional ones [8]. Despite this, shipping is one of the least regulated anthropogenic sources of emissions and makes a considerable contribution to the global transportation industry [10]. There is a need for worldwide limits on ship emissions, similar to those in place in Europe, where overall SOx emissions have decreased by 54% in the EU over the first ten years of the twenty-first century, and land-based sulphur emissions have been successfully reduced since the 1980s [11]. Investigating the current effects of ship emissions on primary and secondary aerosol levels in the ambient air is necessary for this context, as well as how the predicted future growth of ship traffic and the geographical expansion of waterways and ports, possibly in conjunction with international regulations, will affect the atmospheric composition [12].

Because shipping emissions affect ecosystems, the climate, and human health, assessing them globally and regionally is essential. A thorough understanding of these emissions' effects on the climate and their contribution to atmospheric pollution is required to establish and execute appropriate regulations to minimise their environmental effects. EEA contains a thorough discussion of these effects (2013). This evaluation makes it clear that immediate action is needed to cut emissions from the maritime transport industry. Although diverse strategies are employed in many nations to reduce shipping emissions, efforts to address these emissions have not yet succeeded in achieving the objectives of preserving human health. In order to get a quantitative picture of these effects, the current work's goal is to analyse previous research that addresses the effect of shipping emissions on air quality in European coastal locations [8]).

The maritime industry's role is increasingly important to the global transportation of goods and people. In reality, vessels carry more than 80% of global trade volume and more than 70% of global trade value handled by seaports worldwide. Global warming crisis, carbon dioxide emissions from maritime transport are estimated to be about 1 billion tonnes per year, with around 2.5 per cent of total global greenhouse gas emissions from the fuel combustion industry [13].

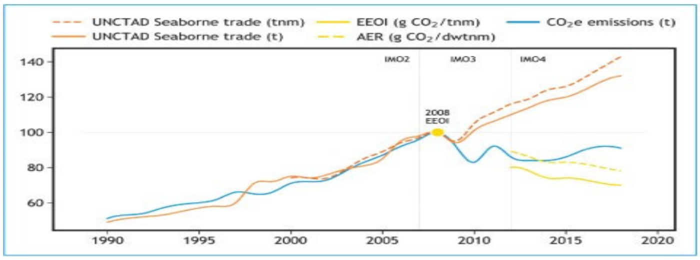

Fig. 2 International shipping emissions and trades metrics index in 2008 for the period 1990-2018 according to the voyage-based allocation of international emissions& [14]

Ships emit NOx, SOx, PM, and other emissions when arriving or departing from ports while mooring at wharves [15]. Such emissions significantly impact ports' environment and long-term sustainability, especially those near waterways [16].

Shipping emissions may rise 50 to 250 % by 2050, depending on potential economic growth and energy developments [15] This increase is incompatible with the need to reduce global emissions to hold the global average temperature rise [13].

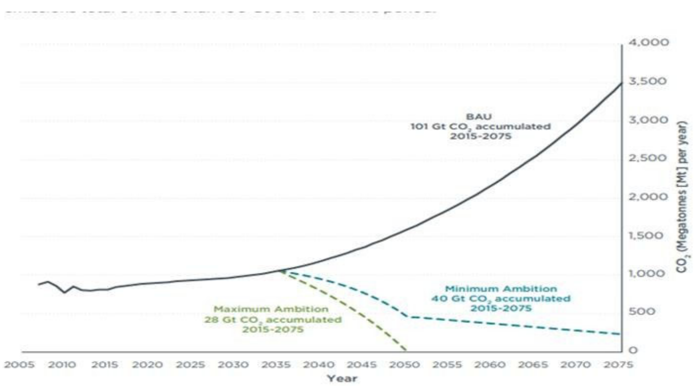

Fig. 3 CO2 emissions from international shipping under IMO`S initial GHG strategy (blue and green) vs BAU (black), with cumulative emissions 2015 Source: [16].

The international maritime organisation (IMO) is constantly concerned about ship emissions, especially the reduction of sulphur (SOx), nitrogen (NOx), carbon dioxide (CO2), particulate matter (PM), and other substances [19]. In 2011, shipping emissions in worldwide ports accounted for 18 million tons of CO2, 0.4 million tons of NOx, 0.2 million tons of SOx, and 0.03 million tons of PM10. According to several studies, ship emissions can impact the air quality and exposure of coastal populations in Europe, Asia, or North America in areas with significant levels of ship activity, which are frequently found close to urban and industrial centres [17]

According to a more recent study, despite implementing low-Sulfur rules, low-Sulfur marine fuels will still be responsible for 250,000 yearly deaths in 2020 because of rising sea shipping [18]. Numerous emission control and energy efficiency measures are available to reduce emissions and increase energy efficiency effectively; the range of available is quite extensive, including engine and boiler technologies, after-treatment technologies, fuel options, alternative power resources, operational efficiencies, and cargo vapour recovery Ports are a source ofcontamination in the atmosphere that significantly impacts the air quality of port cities[19].

Energy efficiency is increasing, more people have access to electricity, and renewable energy is making significant progress in the electricity industry. However, more emphasis is needed on improving 3 billion people's access to clean and safe cooking fuels and technology, increasing renewable energy outside the power industry, and expanding electricity in Sub-Saharan Africa. A global dashboard called the Energy Progress Report monitors energy access, efficiency, and renewable energy advancements. It assesses each nation's development on these three pillars and gives an overview of our progress toward achieving the 2030 Sustainable Development Goals [20].

Urban areas' local air quality, population exposure, and human health include asthma, lung cancer, cardiovascular illnesses, and heart attacks. Mainly ship emissions have been linked to such illnesses [21] For instance, a rise in hospitalisations for cardiovascular events has been linked to PM emissions from maritime vessel operations. According to estimates, the effects of ship emissions on human health result in about 60,000 annual deaths worldwide, with particularly severe effects in coastal locations, particularly along European, East Asian, and South Asian coastlines [22], can all be significantly impacted by ship emissions in harbours. According to specific research, local shipping emissions significantly (50–80%) impact NO2 exposure in the harbour areas of three Baltic Sea port cities. While the average exposure in the nearest urban areas ranged from 3 to 14%. As a result, the effects of shipping pollutants were more pronounced downwind and near harbour regions [23].

The proportion of shipping emissions to particulate matter pollution can range from 5 to 20% in some coastal locations.

United Nations defined sustainable development in 1992. Still, the concept of "green ports" has only recently gained traction as it is recognised that seaports need to reduceemissions from potential activities in the port sector and the broader logistics area [24]. So, tracking and regulating shipping pollution is vital for port management [15].

The ports' position in the transportation chain can influence global transportation systems' social and environmental performance. While many ports comply with existing environmental standards in their city, region, or country, they have often used their capacity to address social and environmental externalities [25] As mentioned in [15], the growth of maritime traffic and the effect of vessels and port operations on the environment are rising. Port and vessel emissions are studied at both a global and a local level for the concern of a green environment [15].

Alexandria is Egypt's second-largest city and the county's main seaport. The city is located on the Mediterranean Sea's northern coast and is so densely populated that most people live in multi-storey flat-style buildings [26]. The number of private vehicles on Alexandria's streets is steadily increasing. As a result, traffic congestion increases, causing detrimental effects on the city's air quality [26]. Concerns over air quality are essential for both occupational and environmental health. Numerous airborne influences have a detrimental impact on human health in this regard. Many air pollution sources can be found in coastal areas and port cities.

Aviation and shipping were excluded from the Kyoto Protocol's legally binding emissions objectives, which were introduced in 1997 and enacted in 2005. [27]. Emissions can be broadly separated into local air pollution, principally sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), and greenhouse gas (GHG) emissions that cause climate change (PM). Shipping generated 2.8% of the world's GHG emissions between 2007 and 2012, twice as much as air travel [28]. According to the World Health Organization (WHO), air pollution seriously threatens human health and is responsible for three million annual fatalities [29]. This risk is significantly increased by shipping, particularly in coastal areas. According to [30], worldwide shipping accounts for 15% of NOx and 5-8% of SOx emissions, significantly impacting the environment and human health [25].
This report was done based on the port emission toolkit, which strongly suggests that a series of planning steps be followed before starting the assessment. The recommended steps are illustrated in Fig. 4 [31].

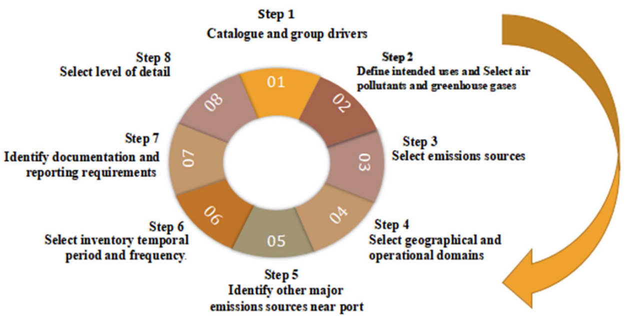

Fig. 4 Planning steps for a port emissions assessment. Source: Retrieved from [31].

1.2.Importance of the study:

Only a few researches on global shipping emissions provide estimates of Port emissions or ship emissions in ports, especially air quality within the Alexandria Port limits. The ongoing research will be preliminary research that measures the air quality, analyses and represents accurate data for the port of Alexandria in Egypt and the surrounding area 5 kilometres from the port. Researchers should either emphasise the development of new approaches or adopt better policies in future studies on reducing shipping emissions, especially for Port emissions and the relationship with cities of remote areas.

1.2.1. Research problem (problem statement):

Greenhouse gases and other emissions from ships and other maritime trade activities have had significant environmental consequences, especially in coastal areas [24]. The growing emphasis on port environmental impacts is wider than the existing port, ship, and hinterland transportation operations. Port expansion and construction should ensure long-term sustainable development [32]. So, tracking and regulating shipping pollution is vital to port management tasks [15]. As a result, the port's mission is to combine corporate social responsibility port strategy and comply with national and local environmental regulations [24]. As a result, the main research problem to quantify the risks may be found according to the port operations of Alexandria's main port in the port area and surrounding habitat areas' air quality.

1.2.2. Research aim and objectives:

1.2.3. Research aim

This research aimed to quantify the concentrations of Sox, Nox, CO2 and airborne particulate matter for Alexandria port and the surrounding areas in the range of 5 km to evaluate Sox, Nox, CO2 and PM's concentration for six months inside and to surround the main city port and how far the port operations and shipping traffic affect the surrounding resident habitat. This research aims to fill the gap in research related to the Alexandria main port emissions that affect the surrounding area.

1.2.4. Research objectives

To explain air quality parameters, causes and sources, Explain the effect of these particulate matters, Sox, Nox, and Co2 of Alexandria port, on the city air quality, especially the port surroundings.
Measure Alexandria port's contribution to air quality for the port and surrounding area.
• To Measure the contribution of particulate matter, NOx, and Sox, Co2 inside the port and outside the port limit region using previous benchmark studies and recommendations to reduce PM and improve air quality by verifying the sampling position outside the Alexandria port, understanding the wind patterns in the west of Alexandria to validate the most vulnerable region.
Ground-breaking research to provide a benchmark for the Egyptian ports to achieve significant air emission reduction, Transfer and apply the framework of green port management from developed to developing countries and achieve UN SDGs and the Egyptian 2030 agenda.

1.3. Research methodology:

According to the port emission toolkit, which is strongly suggested that a series of planning steps be followed before starting the actual assessment. The recommended steps are illustrated in Figure 2.1 and further discussed in the following sections.

As a result, this research focuses on analysing port SOX, NOX, PM, and CO2 emissions and their relevance to maritime climate action toward the port activities sector, inexpensive and clean energy, sustainable cities and communities, well-being, decent work and life on land. The research will be conducted as follow: Identify the sampling locations within a range of five kilometres on the map around and inside the case studied port (Alexandria port) to ensure consistency and validity of results comparison for the measured samples for Nox, Sox, Co2, and PM emissions, especially PM10 and PM2.5 emissions, due to shipping and port activities.

Using chosen probability sample for 10 sample points inside Alexandria port represent all jetty areas and 10 sample point for the surrounding habitat area to measure how far the port operation affect the air quality for the surrounding region forsix months by using a series 500 device to measure Sox, Nox, and PM concentration. The sampling and measurement will be conducted twice monthly during the first six months of the total thesis period.

The research is bottom to top technique and mixed method between quantitative and qualitative data. Primary quantitative processing data was extracted through primary research using collected data samples over six months inside and outside the port limit. The data from previous studies on air quality and particular matters inside ports will be considered a benchmark for recommending the solutions and goals for the green port. Moreover, the need for technical assistance on emissions and energy efficiency was highlighted in partnership with the IMO to assist port operators and developers in their planning as part of their operational management and investmentin future projects. This practical advice was developed as part of the GEF-UNDP- IMO GloMEEP project. Within GloMEEP, three emissions toolkits (one for ships and one for ports) have been developed to help governments understand the nature of emissions from ships at sea and in ports and devise strategies to reduce them. Additional studies on emissions detection, control, and the potential use of alternative fuels have been conducted in addition to these toolkits.

Furthermore, a series of workshops was held in several port locations. These helped raise awareness, train participants on conducting emissions inventories and develop emission reduction strategies in the port area. [33] The GloMEEP project output port emission toolkit guide 01 will be used to assess the studied port emissions.

Measuring tool prosperities:

Series 500 – Portable Air Quality Monitor (Fig. 5)

A portable device that accurately monitors typical outdoor contaminants in real time can assist in short-term fixed monitoring, personal exposure monitoring, and large-area air quality surveys, among other things. Interchangeable sensor heads may measure up to 30 distinct pollutants. Sensors are placed in a replaceable cartridge ("head") that connects to the monitor base. Users canmeasure as many gases as possible because the head can be removed and replaced in seconds. Active fan sampling is used in sensor heads to guarantee that a representative sample is taken, which improves measurement accuracy [34].

Particulate matter sensor:

Laser Particle Counter (LPC) in the portable monitor range because of its compact size and portability. Like all portable sensors, the PM sensor uses active fan sampling and comes factory calibrated.

Carbon dioxide sensor:

A Non-Dispersive Infrared (NDIR) sensor in the portable monitor range measures carbon dioxide. Like all others in the portable monitor family, the sensor uses active fan sampling and is factory calibrated.

Nitrogen Dioxide sensor:

The nitrogen dioxide in the portable monitor range is measured using an electrochemical sensor. The sensor uses active fan sampling and is factory calibrated, just like the rest of the portable monitor family. The NO2 sensor is equipped with an ozone filtering layer for improved performance.

Sulphur Dioxide

Electrochemical (GSE) sensor: Like all sensors in the portable monitor range, the sensor benefits from active fan sampling and comes factory calibrated. [34].

Fig. 3 Series 500 – Portable Air Quality Monitor   Source: https://www.aeroqual.com/products/s-series-portable-air-monitors/series-500-portable-air-pollution-monitor

2. Area of study (scope of the study):

Using chosen probability sample for 10 sample points inside Alexandria port representing all jetty area and 10 sample point for the surrounding habitat area to measure how far the port operation affect the air quality for the surrounding region forsix months by using a series 500 device to measure Sox, Nox, and PM concentration. The sampling and measurement will be conducted twice monthly during the first six months of the total Thesis period. Egypt is one of the founding members of the Arab League and has its headquarters; it is also one of the founding members of the United Nations since 1945. As well as a member of the African Union and many international federations and organizations like (IMO) "The International Maritime Organization". The most important sea corridors in the world are located in Egypt, Suez Canal in Addition to 15 major sea and commercial ports, Alexandria, Damietta, El-Suez-Suez, West and east Port Said and Red Sea ports.
The emission types from the ports in general and from the port of Alexandria in particular, according to the Air Quality Index, as shown in the table, are:

Table 1 Port-related emissions source categories by energy type [31].

Source type	Emissions source category	Energy types
Mobile	Seagoing vessels	fuel oil, diesel, natural gas (NG), methanol
	Domestic vessels	fuel oil, diesel, NG
	Cargo handling equipment	diesel, NG, propane, gasoline, methanol, electricity
	Heavy-duty vehicles	diesel, NG, electricity
	Locomotive	diesel, NG, electricity
	Light-duty vehicles	diesel, NG, propane, gasoline, electricity
Stationary	Electrical grid	coal, NG, diesel, renewable
	Power plant	coal, NG, diesel, renewable
	Industrial facilities	electricity, renewable, diesel
	Manufacturing facilities	electricity, renewable, diesel
	Administrative offices	electricity, renewable, diesel

2.1.1. *ALEXANDRIA PORT*

Alexandria is Egypt's second-largest city and the main seaport. According to (ALEXANDRIA PORT AUTHORITY, 2022), The Alexandria Maritime Port handles roughly 60% of Egypt's foreign trade and is the busiest in the Arab Republic of Egypt regarding trade volume. Between the Mediterranean Sea and Lake Mariout, Alexandria is located on the western bank of the Nile.

2.1.2. *The geographical location of the port Berths*

	Longitude	**Latitude**
East of Alexandria	East "34.5252 '52 °29	North "36.9492 '11 °31

2.1.3. *Nature characteristics:*

1. Weather Wind North westerly ranging between 2-3 on Beaufort in summer and between 3-4 on Beaufort in winter
2. The average water density is 1.30 g / cm3
3. Winter rain season
4. Tide height is 0.46 above the average mean

2.1.4. *Port Berths*

There are 75 berths in the port other than Maritime Services berths.
The locations chosen from the port of Alexandria to take samples for our research are:

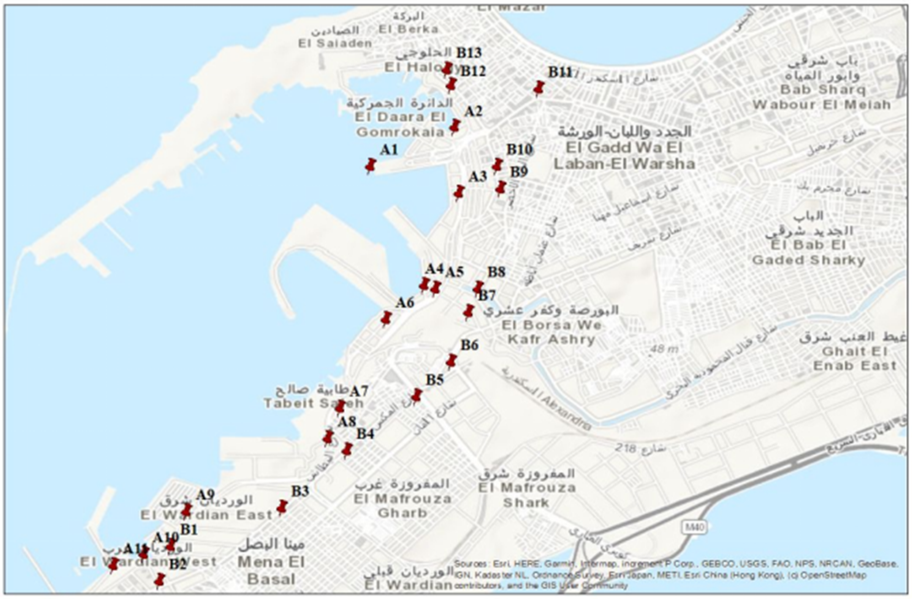

Fig. 6 This map shows the selected places in and out of the port of Alexandria to collect samples. Source: (Author)

Table 2 explains each sample point located on the map. **Source: (Author)**

Site Symbol	LAT	LONG	Description
1A	31 11 36 N	029 52 34 E	ALEXANDRIA PORT BERTH NUMBER 16

2A	31 11 46 N	029 52 56 E	ALEXANDRIA PORT BERTH NUMBER 1&2
3A	31 11 28.7N	029 52 57 E	CUSTOMER ADMINSTRATION BERTH NUMBER 26
4A	31 11 05 N	029 52 48 E	BERTH NUMBER 27&28
5A	31 11 04 N	029 52 51 E	CONTAINER BRIDGE
6A	31 10 56 N	029 52 38 E	SCRAP TERMINAL
7A	31 10 33 N	029 52 26 E	CONTAINER TERMINAL NEAR SHIP YEARD
8A	31 10 25 N	029 52 23 E	SHIPYARD WALL OUTSIDE
9A	31 10 06 N	029 51 46 E	CHINEASE CONTAINER TERMINAL
10A	31 09 55 N	029 51 35 E	WOOD BERTH
11A	31 09 52 N	029 51 27 E	BULK BERTH AND SILO TERMINAL AREA
1B	31 09 57 N	029 51 42 E	PORT GATE NUMBER 56 NEAR MOBIL GAS STATION
2B	31 09 48 N	029 51 39 E	SHIPYARD OUTSIDE PORT GATE
3B	31 10 07 N	029 52 11 E	EL KASHAAB FIRE STATION & SHAMLAA STATION
4B	31 10 22 N	029 52 28 E	SHIPYARD SCHOOL GATE
5B	31 10 36 N	029 52 46 E	GATE 27 BRIDGE OUTSIDE PORT
6B	31 10 45 N	029 52 55 E	EL MAFROOZA STATION, NEAR QABARI POST STATION
7B	31 10 50 N	029 52 20 E	KAFR ASHERI, NEAR ZOUAIL SCHOOL AND PORT GATE 22
8B	31 11 04 N	029 53 02 E	PORT GATE 22, SOAQ EL GOMAA
9B	31 11 30 N	029 53 08 E	NEAR PORT TRAINING INSTITUTE GATE
10B	31 11 36 N	029 53 07	BETWEEN PORT GATE 10 AND 14
11B	31 11 56 N	029 53 18 E	NASR STEET NEAR AMOUN HOTEL
12B	31 11 57 N	029 52 55 E	NEAR GATE NUMBER 6 AND GOMROK POLICE STATION
13B	31 12 01 N	029 52 54 E	NEAR TO GATE NUMBER 1

2.1.5. Description of locations:

The numbering and the measurement's beginning were done gradually, starting from Alexandria port gate 1 and gradually moving to the west until Alexandria Port Gate 54. The numbering was done with (**A)** symbol for the locations inside the port and (**B)** for the locations outside the port's walls so that the measurement starts outside the port’s wall from the beginning of Gate 54 and the direction is opposite to Alexandria port gate 1 from the outside.

2.1.5.1. The reasons for choosing each location:

The selection of locations inside the port was the main goal of it that achieve all the different activities by considering the distances between the sites so that the activities are completely inside the port and have sample points. The places outside were chosen to be parallel to the sites of samples inside the port, especially in places where it is difficult for us to take samples inside the port, due to the presence of obstacles, for example, some military areas where it is forbidden to photograph or take samples or proximity to them, such as the naval shipyard of the Ministry of Defence and the Egyptian ship repair company.

Inside the port:

A1: This symbol expresses the tourist berth of Alexandria Port. This pier is considered the quietest and least polluted area, and this berth stands on which the ship AIDA 4 of the Arab Academy for Science, Technology and Maritime Transport is located. Opposite this berth is the floating dock dry lock of the Egyptian Company for Ship Repair.

Therefore, this site is considered a privileged site, as it also monitors the pollution arising from the maintenance work of ships given the prevailing wind direction in the area, as well as the difficulty of entering the basin or taking samples in this area because it is considered a military area and in some times the pier is also used by RORO ships ship In the absence of passenger ships, so that the berth is wholly filled with cars, and this is the most sought-after site for the presence of an AIDA4 vessel on it.

A2: This site is close to Alexandria port gate1 and is used to berth bunker barges and tugs for ship fuel supply. This berth is quiet, largely unused, and close to the new in-port parking garage and the general cargo vessels berth.

A3: Berth 26 This berth is located near Gate 10, and opposite it is the service building of banks and logistics services inside the port, and the berth is located on it most of the time, RORO ship ships for cars.

A4: The birth of various ships, especially timber ships and containers, has a yard of containers in front of it.

A5: Container Bridge The site was chosen over the bridge of the container berth due to its proximity to the military berth, and it was impossible to take measurements from the berth. Therefore, the bridge was used as the nearest berth site with consideration of the wind and to indicate the container berth and the military berth.

A6: scrape terminal the scrap and metal berth are one of the busiest berths filled with loading and unloading equipment.

A7: The container yard near the shipyard due to the presence of the loading and unloading operations of the container yard and container berths.

A8: shipyard the wall of the naval shipyard, which is considered a military area for the repair of warships only, is forbidden to be in its vicinity, and therefore samples are taken from outside the wall.

A9: The container yard of the Chinese Container Company due to the presence of Container gantry cranes and container terminal.

A10: wood berth Due to the presence of a large number of cranes for wooden ships and the proximity of the berth to the Alexandria port control tower for monitoring the movement of ships in the port of Alexandria.

A11: grain berth the berth that contains the silos for storing wheat, which receives all grain ships, is close to the ship control building, and it is also close to the waterway that connects the barges that take wood and sail from seawater to Nile River.

Outside Alexandria port

B1: Alexandria port gate 56 from the outside, near the Mobil gas station, a residential area from the outside and parallel to the site A11 A 10 inside the port

B2: Near the gate of the SHIPYARD from the outside, as well as a public road and a crowded residential area

B3: residential area

Parallel to the shipyard wall and the Chinese container yard, and a crowded residential area adjacent to the port

B4: The gate of the shipyard technical school and parallel to the military from the inside

B5: Near Gate 27, considered one of the main entrances to the port, and near the crowded Friday market in Alexandria.

B6: Sorted A dense residential area with many government interests for the area's people and a remarkable central bus station for Alexandria's west regions.

B 7: Residential area adjacent to the harbour wall

B8: Gate 22 near the Friday market and the location of workshops and shops selling used furniture and household appliances, and near Gate 22, the main gate for the passports department and the issuance of entry permits to the port and work permits.

B9: Adjacent to the harbour wall and near the gate of the Ports Institute.

B10: The area between Gate 14 and Gate 10 is an area for workshops and Mobil cranes and a garage for some loading and unloading equipment for companies and private agencies outside the port.

B11: Al-Nasr Street in front of the square and the Kazyon supermarket, considered one of the most vital areas in Alexandria regarding the number of sellers, sales, and purchases.

B12: In front of the customs department and door 6 of the port, which is considered the gate for investors and owners of agencies, and in front of it is an administrative building.

B13: Near gate 1 in the port, which is considered the main gate to enter the Safety Authority, for the issuance of maritime certificates and seaman passports, which is the competent maritime authority for Egypt, as well as the building of the Export Development Authority and the Quarantine Building.

2.2.1. Research significance and original contribution:

Ports emit air pollutants, oil pollution, excessive noise, health concerns, and environmental hazards, all of which affect the long-term development of ports in a country.

The policy is a vital, if not life-threatening, concern for the port's stakeholders. Only a few researches on global shipping emissions provide estimates of Port emissions or ship emissions in ports, especially the air quality within Alexandria. The research will be at hand preliminary research that measures the air quality, analyses and represents accurate data for the port of Alexandria in Egypt and the surrounding area within a 5 km radius of the port.

2.2.2. Conceptual framework:

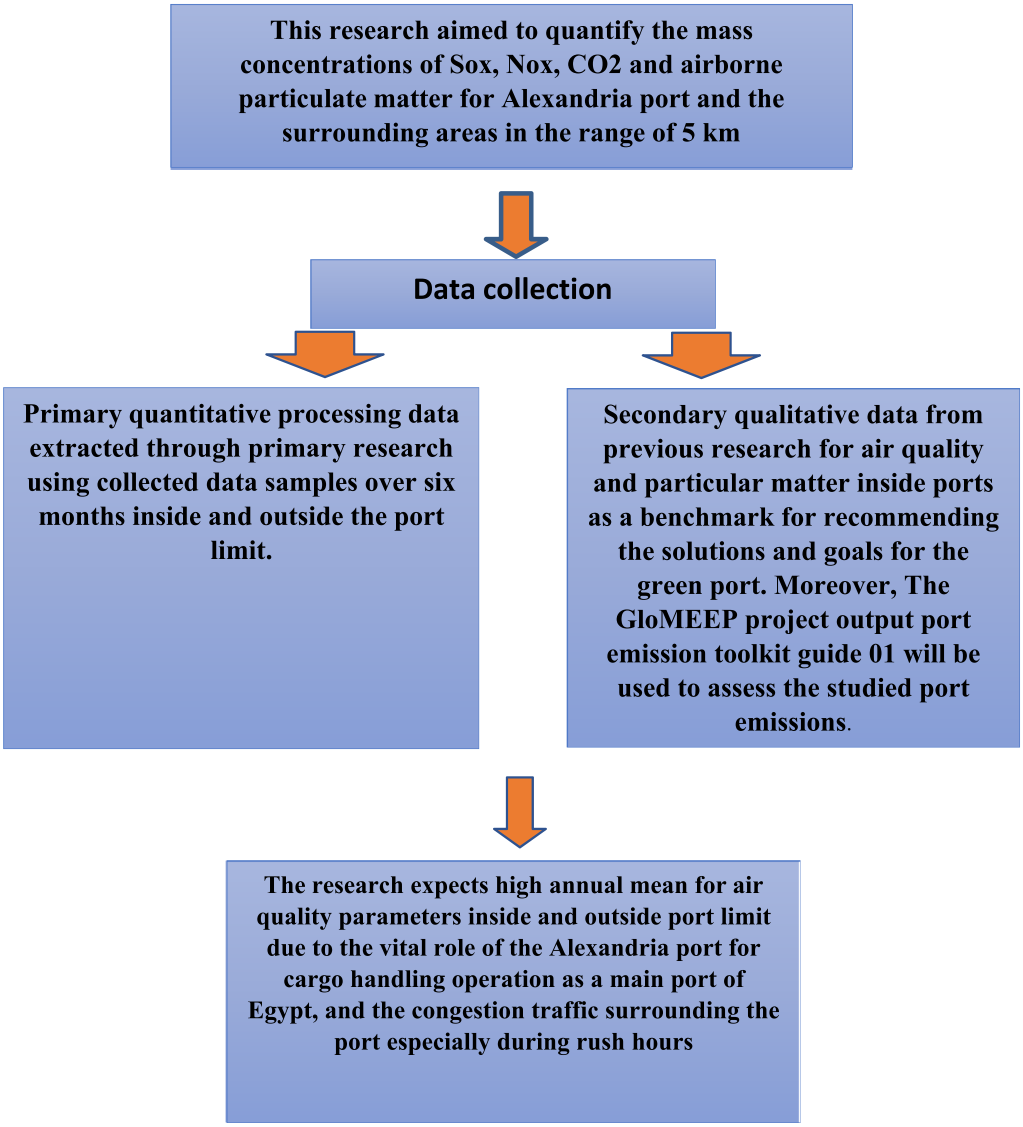

Fig. 7 Research conceptual framework. Source: (Author)

3. Literature review

Approximately 40% of the EU population lives within 50 kilometres of the sea, so air emissions from ships mainly concern coastal communities. Ships emit substances, including sulphur oxides (SOX), nitrogen oxides (NOX) and particulate matter (PM), which can affect human health. These emissions can be significant in areas of heavy maritime traffic. In 2018, the maritime transport sector produced 24% of all NOx emissions, 24% of all SOx emissions and 9% of all PM2.5 emissions (particle matter emissions with a diameter of less than 2.5µm) as a proportion of national EU emissions from all economic sectors:

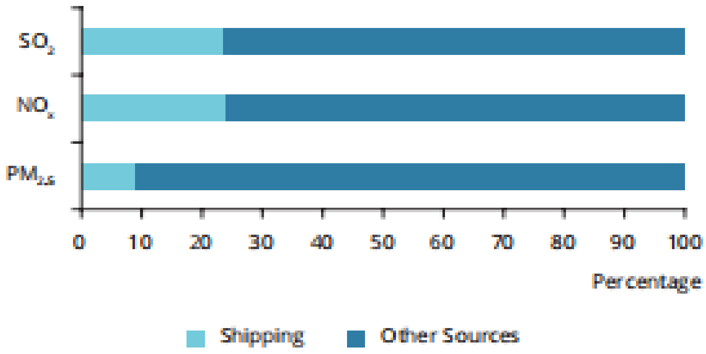

Fig. 8 SO2, PM from all sectors

Shipping air pollution rose when compared to different modes of transportation.While shipping's CO2 emissions are represented by 20% compared to road transport, NOx and PM emissions are nearly equal, and its SOx emissions are 160% to 270% of road transport. Heavy fuel oil, especially residual oil, is used to power the engines of ocean-going vessels. Ships emit significant amounts of oxysulphides (SOx), nitric oxides (NOx), and particulate matter (PM) into the atmosphere [35]. High levels of SOx and NOx in the air can cause breathing diseases and raise ocean acidity [35].

Introducing particulates or harmful substances into the Earth's atmosphere is not a part of the natural composition of air; the spread of disease, death, destruction, or disturbance of the natural environment is known as air pollution. Researchers increase the concern about studying green ports, including ways to evaluate. Their green efficiency is because of the current global trend to reduce energy consumption [37]. Some port authorities are starting to provide rewards for environmentally friendly vessels. The World Port Climate Initiative (WPCI), for example, is a group of 55 ports from around the world thatwork together to implement various environmental activities, such as offering discounts to vessels that score above a certain threshold on the Environmental Ship Index (ESI) [24]. In 2008, the International Association of Ports and Harbours (IAPH) directed its Port Environment Committee to develop a strategy to assist ports in combating climate change in partnership with regional ports. Consequently, the C40 World Ports Climate Declaration, which outlines measures to eliminate CO2 emissions from hinterland transportation, was adopted in 2008 [37].

The ports of Rotterdam and Antwerp were among the first to participate in theEnvironmental Ship Index, along with Amsterdam's port authorities, Le Havre, Hamburg, and Bremen, and in collaboration with the International Association ofPorts and Harbours (IAPH) (ESI). Each ship is given a score from 0 to 100 based onthe data entered, such as fuel consumption and emissions (0 points implies compliance with rules, 100 points when zero-emissions and carbon management). The ports themselves choose incentives for participating ships [32]. Since 1 July 2011, seagoing vessels with a score of 31 or higher have earned a 10% discounton Antwerp tonnage dues.

Some major ports in the United States are taking independent action. For example, the Port of Long Beach introduced a voluntary program called the "Green flag incentive" that provided discounts for port dues on incoming ships that reduced their speed in the port area, which is one of the key strategies available to ports to minimise vessel pollution (Du et al., 2018). The Antwerp Port Authority guarantees this discount for at least three years, maintaining continuity for shipping companies who invest in enhancing their ships' ESI scores [32].

Rotterdam's port is one of 30 major European ports implementing discounted green fees to use their facilities. It created Green Award discounts for ships based on theirenvironmental performance to encourage them to minimise pollutant emissions; ships with a valid Green Award certificate could receive a 10 to 20% discount on port fees [24]. [38], in 2014, had identified a range of potential port measures (divided into pricing, tracking and measuring, market access control, and environmental quality regulation) and then adapted them to the ports' functional activities (shipping traffic, cargo handling and storage operations, intermodal connection, industrial activities, and port expansion). Although the port's activities contribute to a range of externalities, including emissions (both local and GHG) and congestion, very few of these papers have addressed the landside's environmental performance [37]. [37], listed several green priorities within the port, divided into those motivated by the landlord, regulators, operators, and community actors, such as monitoring emissions, providing waste reception facilities, and balancing energy consumption. [38] had identified a range of potential port measures (divided into pricing, tracking and measuring, market access control, and environmental quality regulation) and then adapted them to the ports'functional activities (shipping traffic, cargo handling and storage operations,intermodal connection, industrial activities, and port expansion). Green efficiency is described as the efficiency of a port's operation, considering economic and environmental benefits (Xing et al., 2018). As the world's second-largest economy, China is home to seven of the top ten container ports, which handle 30 per cent of the world's containers annually. However, China is the world's largest emitter, accounting for 23% of global GHG emissions in 2015.

The port's role in organising hinterland logistics activities has evolved from a critical aspect of sustaining competitiveness to another. Over the last decade, academic research continually concentrated on reducing pollution from shipping and ports. The key issues concern reducing emissions from ships at sea (which accounted for 2.8per cent of global GHG emissions in 2007–2012, or twice the amount emitted by air aviation) [37]. As a result, a green port strategy can achieveeconomic and environmental goals, especially for long sustainability. At the same time, ports must emphasise port development while focusing on emission reduction and more environmentally friendly practices [24]. Green port environmental issues can be divided into three categories, according to [24] a) shipping emissions, b) port activity, and c) transportation in the hinterland in 2018.

Pollutants in ports can have a significant impact on both public health (causing lung cancer, allergies, and asthma, for example) and ecosystems (e.g., acid rain and smog) [38]. Ports can only operate and develop if they realise and embrace environmental factors due to rapid urbanisation of the coast, growing global trade, stakeholder emancipation, and continual loss of natural resources.

Rotterdam port

Rotterdam has a strategy to become the world's most sustainable port by 2030. To foster a circular economy and support port growth, the port operates an innovation hub where numerous industries are integrated with the city [39]. Furthermore, the Rotterdam Climate Initiative program intends to cut CO2 emissions by half by 2025 by including all stakeholders, including the Rotterdam Region, Government, Organizations, Businesses, and Citizens. For example, the port of Rotterdam uses reward and penalty programs, such as a 10% surcharge on berthing costs for barge operators who use fuel oil with a Sulphur Ship-caused marine oil spills and non-compliance with the modal change agreement are punishable by the Port of Rotterdam. Seagoing vessels calling at the port with a score of 31 on the Environmental Ship Index (ESI) receive a 10% discount on berthing fees[38]. The port also uses the Automatic Identification System (AIS) to track ship emissions by monitoringfuel oil usage.

Rotterdam has adopted the International Organization for Standardization (ISO) 14001 in its Environmental Management System (EMS). The port authorities inRotterdam have four adopted IMO regulations under the International Convention for the Prevention of Pollution from Ships MARPOL

Annex VI relating to port operations.

The Green Award Foundation was created in 1994 to initiate market incentives to promote excellent shipping. The Green Award programme was established after being developed with the Port of Rotterdam. It is intended to incentivise large boats to improve safety and environmental protection by certifying exceptionally clean and safe ships. This will be accomplished via the use of a certification system. Ships that have been given a Green Award certificate are eligible for some financial and otherwise rewards. The Green Award certification programme is available to oil tankers, chemical tankers, and dry bulk carriers with a DWT of 20,000 tonnes or more and higher, as well as LNG and container carriers and boats used for inland navigation. The Bureau Green Award administers the Green Award process, the administrative body of the Green Award Foundation, an independent, not-for-profit organisation [40].

Antwerp port

In 2012, the Port of Antwerp published the first report on port energy efficiency. The port supervises and tests the design and construction of ecological ports for port growth and expansion (Port of Antwerp, 2010). Antwerp, on the one hand, applies penalties for ship-caused maritime oil leaks and, on the other hand, offers a 10% discount on berthing fees to ships that reach the ESI [38]. In addition, the port of Antwerp regulates GHG emissions from ships, the entire port area, and the supply chain and rewards shipping businesses that conduct energy audits.

More rules are required for port extensions controlling marine pollution damage by coastal development projects, in addition to the IMO MARPOL Annex VI and the IMO INTERVENTION Convention Protocol, as adopted by the Antwerp Port. Furthermore, the Antwerp port administration has implemented stricter sulphur fuel restrictions regulations for freight and vehicle operations [41].

Shanghai port

Shanghai is home to the world's largest container port. Wusongkou, Waigaoqiao, and Yangshan are three of the largest port container zones. Yangshan Port, in particular, ishome to the world's largest automated container terminal. In 2015, the Shanghai city government developed a green port strategy for the port's long-term development. Six shore power facilitations with a total capacity of 12 berths had been built by 2017. Additionally, under this plan, LNG-powered trucks would replace container trucks, and renewable energy will account for 75% of the energy utilised at container facilities [38].

Busan port

Based on adopting the air pollution regulations proposed in the MARPOL Annex VI in 1997, the International Maritime Organization (IMO) has increased the emissions regulations for the major air pollutants emitted by ships. These include Sulphur Oxides (SOx), Nitrous Oxides (NOx), and Particulate Matter (PM) [42]. Due to vessels that have been centred on the Marine Environment Protection Committee (MEPC) since 2016, IMO has also established the goal of a reduction of fifty per cent (50%) in emissions of greenhouse gases (GHG) and air pollutants by the year 2050. IMO has implemented several mandatory measures, including the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). IMO gave its approval in 2019 to the mandatory fuel oil Data Collection System (DCS) for international sailing vessels that are over 5000 Gross Tonnage (GT). This created a quantitative monitoring system for ship emissions and a more effective IMO GHG reduction strategy. The port authorities of each country have instituted a "green port policy" or an "eco-port policy" in the ports from where these ships set sail to control the emissions of air pollutants produced by ships, port unloading equipment, and port vehicles [43].

In 2011, Busan Port, the largest port in Korea and the world's sixth-largest container port developed and implemented an all-encompassing strategy to construct a green port. However, the Busan Port green port policy focuses on CO2 reduction initiatives and does not address air pollution. The port's effect on improving air quality needs to be improved due to a lack of legal grounds for forced regulation by the port authority and a lack of finances to carry out the initiatives that have been planned.

Because of this, the Busan Port Authority (BPA) has been establishing policies based on incentives rather than rules to motivate ships to limit the air pollution they produce voluntarily. As a result, as direct emission reduction measures for ships that contributed the most air pollutant emissions in Busan Port as of 2019 (94.79% of the total emissions), the Environmental Ship Index (ESI) rewards scheme and a Vessel Speed Reduction (VSR) program were both implemented in 2014 and 2019, respectively. Both of these programs are referred to as "Vessel Speed Reduction." Despite this, participation in the VSR program was just 35.6% in the year 2020[44].

3.1. Previous studies:

The average ambient NO_2 concentrations associated with shipping levels range between 12 μg/m^3 and 107 μg/m^3, depending on the measurement period, with the highest values in Scotland, Spain and China. In some studies, the air pollution levels were lower around the harbour when compared with the surrounding urban area. For instance, the case study of Aberdeen showed lower concentrations of NO_2 around the harbour than those registered in the city centre [45]. The study's authors identified the probable highest cause and source of emissions as the top of the ferry hoppers and the oil service vessels. This is enough to spread the hot emissions effectively, not detected locally at a ground level but affecting the neighbour urban area [45].

Similarly, in Gothenburg, during summertime, the average concentrations measured at an averaged distance of 800 m from the ships of NO_2, in line with the ship's plume, indicate an average concentration of NO_2 12 ug/m^3 above the urban background levels, while for SO_2this value was 4.5 for background levels 11.3 and 1.6 ug/m^3, respectively [46]. The relatively low values of SO_2 may be due to the efforts of the EU and IMO to restrict ship emissions. 45 % of the harbours reviewed were located under emission control areas, mainly across the coast of Europe, the United States of America and the European North Sea. The SO_2 concentrations measured in the different case studies range from 0.83 to 47.2 μg/m^3, considering the distinct sampling periods for different cases. All studies carried out in European countries reported a low SO_2 concentration in conjunction with the impact of the EU directive 2005/33/EC, which regulates the SO_2 ship emissions in EU harbours from January 2010 [47].

The concentration of SO_2 decreased significantly from 2009 to 2010 in EU harbours: 41 % in Barcelona, 72% in Palma de Mallorca, 97% in Savona and 85 % in Civitavecchia [48]. Moreover, there is also evidence in other European harbours that this strategy contributed to lower SO_2 concentrations, namely in Calais, France [49], Brindisi, Italy [50]; [51] and Bari, Italy [50], [47]. show evidence of a noticeable improvement in air quality in Yangshan Harbour due to the control measures of ship emissions employed in the Yangtze River Delta region [47].

Some studies also showed that low-sulphur fuels could reduce the shipping contribution to $PM_{2.5}$ concentration in harbour areas, but with limited effects on metals and PAHs concentrations [53]. Hong Kong harbour is subject to IMO regulation and a voluntary low sulphur program. The study focuses on Brindisi and indicates the impact on SO_2 concentrations of manoeuvring during the ship's arrival and departure. On the other hand, the hoteling phase had limited effects on SO_2 concentration, probably due to the mandatory use of low-Sulphur content fuels in European harbours, together with the differences between the auxiliary and main motor emissions, as well as the different engine loads [50].

No reduction was detected in the non-EU harbour of Tunis and Shanghai [48], [54] Some of these studies have also revealed that ship emissions contribute more to fine particles, especially ultrafine particles, than coarse aerosols [55]. Primary particles emitted by ships are predominantly in the sub-micron size fraction may support these results [56]. Ship emissions have been identified as contributors to an increase in particle concentrations and are thus dominated by ultrafine particles [57p[58] show that on the coast of China, the $PM_{2.5}$ concentration at Xiamen Harbour differed by less than 20 % from values reported in other harbours such as Shanghai 62.6 μg/m^3 [54]. Besides that, the $PM_{2.5}$ concentration at this harbour was more than twice the concentration found in other harbours such as Busan, Korea [59]. Italy [60]. and Barcelona, Spain [61]. In Shanghai, [54]. Xiamen [62] and Yangshan [47] studies point out that ship traffic has a non-negligible impact on primary particles in the harbour and surrounding land areas. Despite being the most studied pollutants in the literature, PM, NO_2, and SO_2 are not the only pollutants affecting air quality over harbour areas. Various other compounds can be found at significant concentrations around harbours [47]. For instance, Vanadium (V) and nickel (Ni), as well as BC (black carbon) and polycyclic aromatic hydrocarbons, are typically emitted by shipping activities, and they are hazardous to human health. As an example, the urban area of the harbour of Venice (Sacca San Biagio) has registered annual average values of 30.7ng/m^3 in 2009 and 6.3 ng/m^3 in 2012 for gas and particulate PAHs together [53]. In comparison, the monitored air quality levels of the city showed values of 5.4 ng/m3 and 2.6 ng/m^3 in 2009 and 2012, respectively. The same effect was observed in Brindisi by applying the same double-sampling method [51]. Air from the harbour/industrial sector was richer in PAHs (5.34 ng/m^3) than air sampled from all directions (3.89 mg/m^3). This result is like the findings in other harbour cities such as Venice [52]. In the particular case of Europe, the high number of available studies addressing marine Transport emissions and their related air quality denotes the relevance of this issue in the Europe [63].

4. Results

As a result, this research focuses on analysing port SOX, NOX, PM, and CO2 emissions and their relevance to maritime climate action toward the port activities sector, inexpensive and clean energy, sustainable cities and communities, well-being, decent work and life on land. The research will be conducted as follow: Identify the sampling locations within a range of five kilometres on the map around and inside the case studied port (Alexandria port) to ensure consistency and validity of results comparison for the measured samples for Nox, Sox, Co2, and PM emissions, especially PM10 and PM2.5 emissions, due to shipping and port activities.

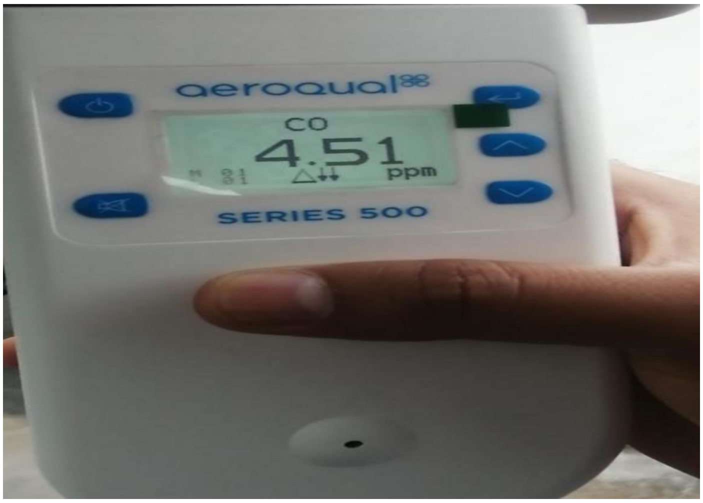

Fig. 9 Random photo while sampling CO   Source:(Author)

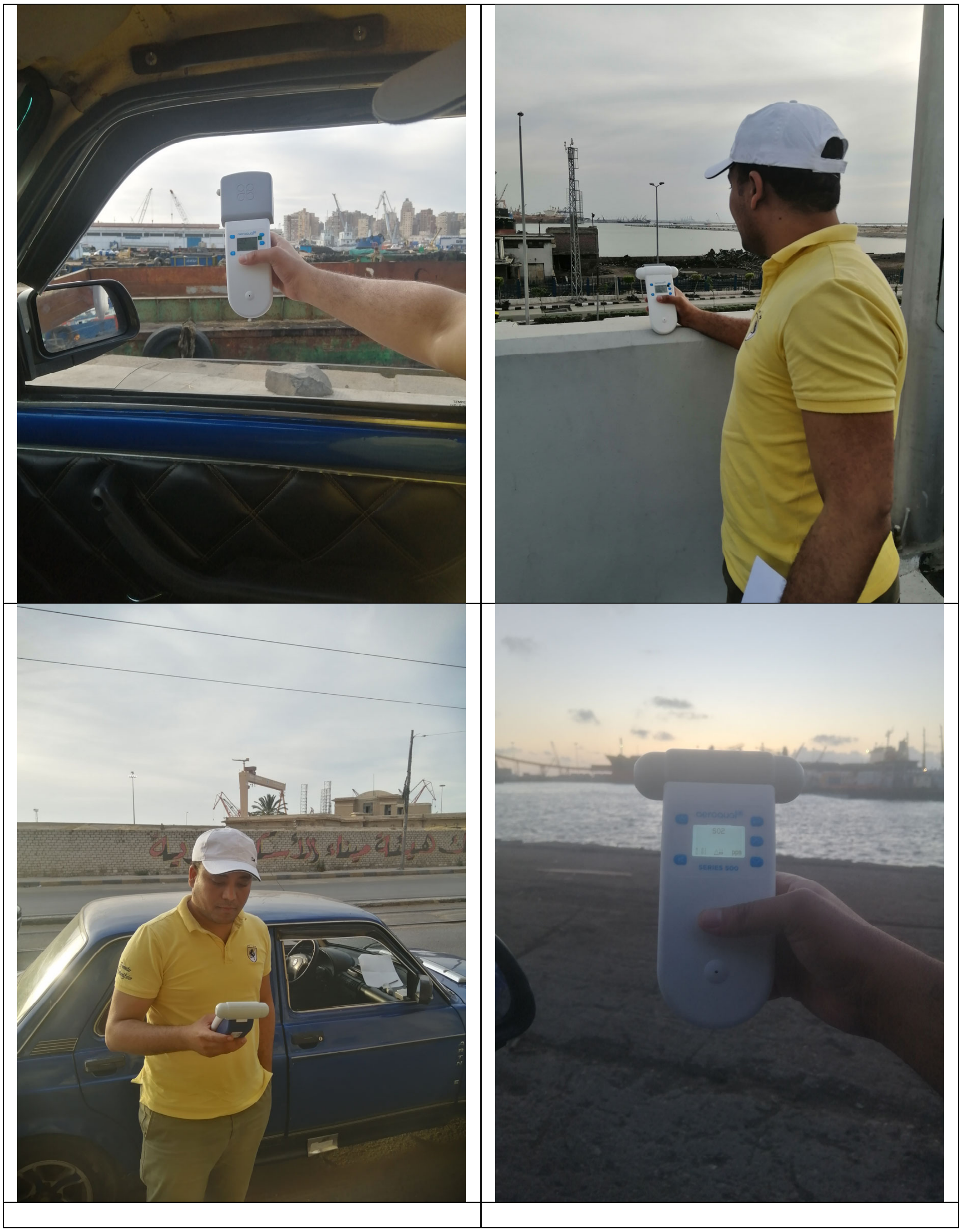

Fig. 10 Random photos of the Author while sampling outside Alexandria port
Source:(Author)

4.1. Data collected: Note: All the results are in Part Per Million (PPM)

First Sampling Visit:

Table 4 showcases the first round of sampling results for the emission of various pollutants at different sites in Alexandria Port during the week of May 7-13, 2022. High CO2 emissions, a potent greenhouse gas, are recorded across all sites, pointing towards activities contributing to global warming. Sites A4, A6-A11, and B1-B13 display concerning CO levels, suggesting incomplete combustion processes. Anomalously high NH3 emissions are seen at A6, A7, and A9, hinting at significant ammonia-releasing processes. While Cl2, H2S, and SO2 levels remain low, providing some relief, the VOC emissions vary from 1.2 to 22.2 across sites, raising air quality concerns due to their role in ground-level ozone formation. Lastly, the PM2.5 and PM10 values are generally low, although constant monitoring is warranted for maintaining health standards, particularly for locations like A9 with a slightly higher PM2.5 level.

Table 4 The first sampling round results **Source:(Author)**

May (7-13) 2022										
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	465	0	0	0	0	0.088	0	0	22.2	0.001	0.001
A2	482	0	0	0.01	0	0.067	0	0	18.2	0	0.001
A3	453	0	0	0.01	0	0.07	0	0.022	3.4	0	0.001
A4	540	0	1.43	0.01	0	0.062	0	0	3.2	0.001	0.001
A5	528	0	0	0.01	0	0.078	0	0.023	1.2	0.001	0.001
A6	555	0	1.91	0	17.2	0.095	0	0	4.6	0.002	0.001
A7	602	0	3.11	0.01	136.2	0.076	0	0	3.2	0.001	0.001
A8	490	0	3.67	0	13.2	0.065	0.31	0	3.2	0.002	0.001
A9	527	0	3.54	1.01	138.2	0.091	0	0	1.8	0.012	0.001
A10	548	0	2.43	0	0	0.068	0.61	0	6.4	0.001	0.001
A11	521	0	4.43	0	0	0.087	0	0	1.2	0.002	0.003
B1	488	0	7.54	0	0	0.061	0	0.012	2.2	0.001	0.001
B2	587	0	6.75	0.01	0.3	0.078	0	0.018	1,6	0.001	0.001
B3	586	0	1.21	0.02	0.2	0.082	0	0	1.9	0.001	0.001
B4	612	0	3.65	0.01	0.5	0.088	0	0	1.6	0.002	0.001
B5	643	0	6.43	0.02	0.3	0.078	0.47	0.022	2	0.005	0.005
B6	650	0	3.65	0.03	0.2	0.095	0.44	0	1.6	0.003	0.002
B7	675	0	7.65	0.03	0.2	0.089	0.39	0.008	1.8	0.003	0.003
B8	590	0	6.87	0	0.1	0.084	0.3	0	2.8	0.002	0.001
B9	688	0	7.21	0.04	0	0.078	0	0.014	2.8	0.001	0.001
B10	623	0	8.43	0	0.2	0.105	0	0	2.6	0.001	0.003
B11	641	0	3.78	0.01	0.4	0.093	0.55	0.013	1.8	0.002	0.004
B12	560	0	8.54	0.04	0.8	0.11	0.5	0	5.3	0.001	0.001
B13	580	0	4.43	0.02	0.6	0.108	0.3	0	4.3	0.002	0.001

Second Sampling Visit:

The second round of sampling results (Table 5) in May 2022 reveals several key insights about air pollution at different sites. The CO2 emissions remain high across all sites, reinforcing the need for actions to reduce greenhouse gas emissions. Carbon monoxide (CO) levels are higher at A4, A6-A11, and B1-B13, which implies incomplete combustion processes at these sites. NH3 emissions are slightly higher at sites A6, A7, A8, and A9, possibly due to ammonia-related industrial activities. While Cl2, H2S, and SO2 levels are generally low, site A9 presents an exception with a SO2 value of 0.23. VOC emissions have significantly increased at A1 and A2 compared to the first round, raising concerns about potential health and environmental impacts. PM2.5 and PM10 levels have generally increased since the first round, with sites A5, A6, A7, B1, and B2 showing the highest values, requiring continuous monitoring to ensure air quality standards.

Table 5 The 2nd sampling round results **Source:(Author)**

May (21-27) 2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	452	0	0	0	0	0.075	0	0.026	46.3	0.001	0.006
A2	545	0	0	0.04	0	0.068	0	0	24.7	0.002	0.004
A3	580	0	0	0	0	0.096	0	0	5.9	0.002	0.004
A4	519	0	2.54	0.01	0	0.065	0	0.024	7.8	0.003	0.006
A5	499	0	0	0.01	0	0.082	0	0	6.9	0.006	0.012
A6	586	0	2.29	0	16.2	0.076	0.03	0	5.1	0.008	0.014
A7	546	0	3.67	0.01	15.1	0.086	0.04	0	4.3	0.012	0.013
A8	541	0	4.67	0	13.2	0.064	0.09	0.054	2.8	0.006	0.005
A9	565	0	4.51	0	14.1	0.054	0.23	0	3.2	0.008	0.008
A10	532	0	4.76	0	0	0.076	0.24	0	4.2	0.012	0.002
A11	515	0	6.65	0	0	0.065	0.09	0.016	1.3	0.001	0.003
B1	590	0	8.54	0.03	0	0.076	0.04	0.023	2.6	0.013	0.023
B2	570	0	7.43	0.02	0.8	0.072	0	0.019	2.4	0.015	0.019
B3	569	0	2.21	0.05	0.8	0.086	0.02	0	2.5	0.002	0.004
B4	630	0	3.43	0.06	0.5	0.082	0.06	0	3.1	0.001	0.003
B5	605	0	5.43	0.01	0.7	0.042	0.03	0	2.9	0.002	0.002
B6	623	0	3.75	0.01	0	0.074	0.31	0	2.7	0.001	0.004
B7	665	0	9.87	0	0	0.079	0.38	0.012	2.9	0.008	0.004
B8	642	0	7.76	0	0	0.065	0.09	0	3.7	0.004	0.002
B9	618	0	7.64	0	0	0.076	0.05	0	2.4	0.001	0.001
B10	550	0	10.51	0	0.2	0.063	0.14	0	3.8	0.002	0.001
B11	548	0	4.65	0.01	0.2	0.069	0.12	0.023	3.6	0.012	0.013
B12	487	0	7.64	0	0.4	0.053	0.07	0	2.2	0.002	0.008
B13	567	0	6.72	0	0.6	0.058	0.03	0	2.6	0.001	0.004

Third Sampling Visit:

The third sampling round (Table 6) from June 2022 provides continued insights into the air quality at various sites. CO2 levels continue to be elevated across all sites, while CO levels have generally increased, with B9, B10, and B11 showing notably high readings. NH3 levels remain low across all sites. The NO2 values at A2 and A11 seem to be an order of magnitude higher than other sites, which could be a data error or an indication of a sudden increase in nitrogen dioxide emissions at these sites. SO2 levels also appear to have risen, particularly at sites B1-B13. Volatile organic compounds (VOC) emissions have drastically increased, especially at B1, B4, A10, A11, B2, B6, B7, B8 and B9, raising potential concerns over environmental and health impacts. The PM2.5 and PM10 particulate levels remain relatively stable, but some sites such as A7, A9, B2, B3, B5, B6, B7, B9, B10, and B11 showed increased values, which warrants further monitoring and analysis.

Table 6 The 3rd sampling round results **Source:(Author)**

June (4-10) 2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	531	0	0	0.02	0	0.065	0.021	0	24.5	0.002	0.001
A2	487	0	0	0.04	0	0.66	0.04	0	25.7	0.001	0.001
A3	498	0	1.02	0.03	0	0.076	0.02	0	19.8	0.002	0.004
A4	503	0	1.6	0.12	0	0.062	0.02	0	12.5	0.001	0.002
A5	465	0	1.87	0.14	0	0.078	0.04	0	12.6	0.002	0.006
A6	563	0	2.75	0.16	0	0.064	0.08	0	17.5	0.001	0,.002
A7	576	0	2.83	0.08	0	0.077	0.12	0	8.2	0.006	0.008
A8	523	0	4.74	0.09	0	0.071	0.07	0	32.3	0.004	0.002
A9	576	0	3.43	0.15	0	0.068	0.12	0	13.9	0.006	0.012
A10	505	0	2.5	0.17	0	0.078	0.06	0	42.7	0.002	0.008
A11	623	0	2.04	0.25	0	0.77	0.12	0	47.8	0.006	0.012
B1	612	0	4.85	0.09	0	0.073	0.18	0	74.6	0.004	0.006
B2	490	0	7.05	0.14	0	0.079	0.22	0	42.7	0.006	0.012
B3	588	0	5.43	0.21	0	0.082	0.16	0	14.7	0.002	0.009
B4	605	0	6.21	0.24	0	0.074	0.24	0	56.8	0.004	0.004
B5	622	0	8.75	0.37	0	0.074	0.43	0	34.6	0.001	0.014
B6	643	0	2.43	0.22	0	0.086	0.23	0	42.5	0.003	0.006
B7	608	0	3.54	0.12	0	0.077	0.32	0	42.5	0.002	0.006
B8	499	0	6.54	0.34	0	0.089	0.12	0	44.1	0.001	0.003
B9	623	0	14.54	0.23	0	0.068	0.48	0	39.7	0.003	0.12
B10	612	0	12.43	0.38	0	0.078	0.53	0	15.6	0.001	0.018
B11	580	0	12.08	0.41	0	0.083	0.42	0	28.6	0.002	0.011
B12	643	0	6.87	0.18	0	0.076	0.64	0	18.6	0.001	0.006
B13	550	0	6.54	0.12	0	0.062	0.23	0	9.83	0.001	0.001

Fourth Sampling Visit:

The fourth sampling round (Table 7), conducted in June 2022, exhibits a persistent trend in CO2 concentrations with slight decreases in some locations, while there are increased readings of CO across most sites. Site A11 and sites B1-B13 demonstrate a considerable increase in CO emissions. H2S levels have also increased in some locations, with A4 and A11 showing notably high levels. NO2 levels have generally remained stable, while SO2 levels are elevated across all sites, particularly in B5 and B11-B13. VOC concentrations vary significantly across the sites, with A11, B1, B3, and B4 showing especially high levels. PM2.5 and PM10 particulate concentrations have slightly increased, with A11 showing a remarkable increase. This could suggest a potential rise in fine particulate matter, which may have health implications.

Table 7 The 4th sampling round results **Source:(Author)**

June (18-24)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM10
A1	452	0	0	0.01	0	0.073	0.02	0	35.3	0.001	0.002
A2	489	0	0	0.07	0	0.064	0.06	0	23.6	0.001	0.001
A3	465	0	0	0.04	0	0.071	0.04	0	16.8	0.002	0.003
A4	487	0	1.21	0.28	0	0.066	0.03	0	9.9	0.004	0.004
A5	477	0	2.54	0.23	0	0.062	0.08	0	13.4	0.003	0.004
A6	507	0	3.32	0.08	0	0.076	0.12	0	12.8	0.002	0.008
A7	560	0	3.12	0.13	0	0.073	0.08	0	9.7	0.004	0.012
A8	532	0	2.43	0.11	0	0.079	0.11	0	37.8	0.001	0.004
A9	542	0	2.67	0.25	0	0.078	0.14	0	21.7	0.003	0.002
A10	563	0	2.54	0.14	0	0.084	0.12	0	34.6	0.006	0.011
A11	605	0	1.86	0.32	0	0.076	0.17	0	56.7	0.018	0.055
B1	598	0	4.65	0.21	0	0.067	0.24	0	65.3	0.006	0.016
B2	522	0	6.65	0.15	0	0.085	0.29	0	43.8	0.008	0.022
B3	578	0	5.2	0.11	0	0.088	0.15	0	67.6	0.002	0.005
B4	597	0	5.43	0.12	0	0.065	0.34	0	44.2	0.001	0.002
B5	643	0	7.75	0.16	0	0.061	0.53	0	23.8	0.001	0.006
B6	612	0	3.21	0.28	0	0.08	0.12	0	16.9	0.001	0.004
B7	580	0	4.79	0.18	0	0.067	0.43	0	23.7	0.001	0.002
B8	541	0	8.67	0.23	0	0.085	0.57	0	27.1	0.002	0.003
B9	540	0	12.21	0.13	0	0.076	0.47	0	30.5	0.002	0.008
B10	523	0	10.7	0.22	0	0.077	0.67	0	11.8	0.005	0.006
B11	608	0	13.7	0.36	0	0.082	0.59	0	29.4	0.004	0.013
B12	575	0	8.9	0.24	0	0.074	0.77	0	32.8	0.001	0.002
B13	590	0	7.85	0.17	0	0.066	0.65	0	17.8	0.001	0.001

Fifth Sampling Visit:
The fifth sampling round (Table 8) in July 2022 revealed several important shifts in environmental conditions. Sites A2-A10 saw a dramatic increase in CO readings, with A6 and A7 reporting the highest numbers. The CO2 levels slightly fluctuated across sites, with the highest concentration observed at site B8. H2S levels were relatively stable, although sites A5, A6, A10, and B8 showed higher readings compared to the rest. Slight NH3 levels were reported at A1 and A5, indicating a new development. NO2 and SO2 levels remained relatively consistent with previous readings. In terms of VOC, sites A10, A11, B1, and B4 still showed high levels. PM2.5 and PM10 particles presented slightly increased concentrations with site A9 indicating a remarkably high PM2.5 reading. These changes in emissions and particulates could indicate varying industrial activities across these sites and warrant further analysis.

Table 8 The 5th sampling round results **Source:(Author)**

July (2-8)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	532	0	0	0.02	0.004	0.064	0.02	0	24.6	0.001	0.006
A2	570	0	10.3	0.04	0	0.66	0.06	0	25.7	0	0.004
A3	490	0	8.43	0.05	0	0.076	0.04	0	19.7	0.001	0.005
A4	516	0	6.54	0.12	0	0.062	0.03	0	12.5	0.001	0.007
A5	588	0	10.4	0.24	0.003	0.078	0.07	0	12.6	0.001	0.012
A6	601	0	18.77	0.21	0	0.064	0.12	0	17.8	0.002	0.014
A7	565	0	19.4	0.15	0	0.077	0.08	0	8.2	0.001	0.013
A8	597	0	16.32	0.18	0	0.073	0.12	0	32	0.002	0.005
A9	546	0	13.43	0.08	0	0.068	0.13	0	13.9	0.012	0.008
A10	564	0	14.65	0.28	0	0.078	0.12	0	42.7	0.001	0.001
A11	497	0	8.43	0.32	0	0.77	0.17	0	47.8	0.002	0.003
B1	480	0	6.87	0.07	0	0.073	0.24	0	74.6	0.001	0.023
B2	610	0	13.54	0.08	0.0005	0.079	0.29	0	42.7	0.001	0.019
B3	615	0	12.43	0.12	0	0.082	0.15	0	14.8	0.001	0.004
B4	634	0	11.45	0.04	0	0.074	0.34	0	56.8	0.002	0.003
B5	637	0	14.86	0.22	0	0.074	0.53	0	34.6	0.005	0.002
B6	630	0	9.75	0.14	0	0.086	0.12	0	41.9	0.003	0.004
B7	656	0	9.54	0.11	0	0.077	0.43	0	42.5	0.003	0.004
B8	675	0	4.43	0.31	0	0.089	0.56	0	44.2	0.002	0.002
B9	654	0	6.76	0.26	0	0.068	0.47	0	39.7	0.002	0
B10	603	0	9.43	0.19	0	0.078	0.67	0	15.6	0.001	0.001
B11	623	0	13.64	0.16	0	0.085	0.58	0	28.6	0.002	0.013
B12	590	0	12.75	0.07	0	0.076	0.77	0	18.6	0.001	0.008
B13	633	0	12.65	0.18	0	0.062	0.65	0	9.83	0.002	0.004

Sixth Sampling Visit:

In the 6th sampling round from July 16-22, 2022, site A6 stood out with a significant surge in CO2 levels, while site A8 reported a trace amount of Cl2. CO values remained high, particularly in sites A2-A10. A noticeable drop in H2S was observed in site A4. Minor amounts of NH3 were detected in sites A1, A3, and A5. NO2 levels saw significant reduction at sites A3 and A4. A noteworthy increase in VOC levels was detected at sites A9 and B1. PM2.5 and PM10 concentrations showed slight fluctuations, with PM2.5 in site B1 and A2 seeing an increase. These changes suggest shifting environmental conditions and likely altered industrial activities at these sites during this period.

Table 9 The 6th sampling round results **Source:(Author)**

July (16-22)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	532	0	0	0.02	0.004	0.064	0.01	0	24.6	0.001	0.006
A2	570	0	10.3	0.01	0	0.66	0.06	0	25.7	0.021	0.003
A3	490	0	8.43	0.04	0.006	0.006	0.04	0	19.7	0.001	0.005
A4	516	0	6.54	0.6	0	0.002	0.03	0	12.5	0.001	0.007
A5	588	0	10.4	0.19	0.003	0.078	0.07	0	12.6	0.001	0.012
A6	828	0	18.77	0.21	0	0.064	0.12	0	17.8	0.002	0.014
A7	565	0	19.4	0.15	0	0.077	0.04	0	8.2	0.001	0.013
A8	600	0.01	16.32	0.18	0	0.073	0.12	0	32	0.002	0.005
A9	589	0	13.43	0.08	0	0.068	0.13	0	183.4	0.012	0.008
A10	536	0	14.65	0.28	0	0.078	0.12	0	42.7	0.001	0.001
A11	516	0	8.43	0.32	0	0.77	0.17	0	47.8	0.002	0.003
B1	500	0	6.87	0.07	0	0.073	0.24	0	180	0.021	0.023
B2	650	0	13.54	0.08	0.0001	0.079	0.29	0	50	0.001	0.019
B3	615	0	12.43	0.12	0	0.082	0.15	0	14.8	0.001	0.004
B4	634	0	11.45	0.04	0	0.074	0.34	0	56.8	0.002	0.003
B5	637	0	14.86	0.22	0	0.074	0.53	0	34.6	0.005	0.002
B6	630	0	9.75	0.14	0	0.086	0.12	0	41.9	0.003	0.004
B7	656	0	9.54	0.11	0	0.077	0.43	0	42.5	0.003	0.004
B8	675	0	4.43	0.31	0	0.089	0.56	0	44.2	0.002	0.002
B9	654	0	6.76	0.26	0	0.068	0.47	0	39.7	0.005	0
B10	603	0	9.43	0.19	0	0.078	0.67	0	15.6	0.007	0.004
B11	623	0	13.64	0.16	0	0.085	0.58	0	28.6	0.012	0.006
B12	590	0	12.75	0.07	0	0.076	0.77	0	18.6	0.003	0.002
B13	633	0	12.65	0.18	0	0.062	0.65	0	9.83	0.009	0.003

Seventh Sampling Visit:

In the 7th sampling round from August 6-12, 2022, there is a striking elevation of CO at site A6, which also presents an unusually high VOC level. In general, CO2 levels in the sites are decreased compared to previous rounds, and NH3 shows only minor quantities at sites A10 and A11. A broad decrease in CO levels is evident across many of the sites except for A6, A7, A8, A9, and A11, and several B sites where moderate CO levels are noted. H2S shows a slight uptick at some sites, notably at A8. SO2 levels are relatively constant compared to the previous round, with a minor increase at several sites. PM2.5 and PM10 levels fluctuate, with PM10 seeing a notable increase at site B9. These observations suggest considerable changes in emission sources during this period.

Table 10 The 7th sampling round results **Source:(Author)**

August (6-12)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	452	0	0	0.02	0	0.065	0.021	0	24.5	0.002	0.001
A2	545	0	0	0.04	0	0.66	0.04	0	25.7	0.001	0.001
A3	580	0	0	0.03	0	0.077	0.02	0	19.8	0.003	0.002
A4	519	0	2.54	0.12	0	0.062	0.02	0	12.5	0.006	0.001
A5	499	0	0	0.14	0	0.08	0.04	0	12.6	0.002	0.006
A6	586	0	41.59	0.16	0	0.064	0.08	0	512.8	0.001	0,.002
A7	546	0	3.67	0.08	0	0.077	0.12	0	8.2	0.006	0.008
A8	541	0	4.67	0.35	0	0.071	0.07	0	32.3	0.004	0.002
A9	566	0	4.51	0.15	0	0.068	0.12	0	13.9	0.006	0.012
A10	532	0	0	0.17	0.001	0.078	0.06	0	42.7	0.002	0.008
A11	515	0	6.65	0.25	0.002	0.77	0.12	0	47.8	0.012	0.007
B1	500	0	4.36	0.09	0	0.073	0.18	0	74.6	0.004	0.006
B2	598	0	3.33	0.14	0	0.079	0.22	0	42.7	0.006	0.012
B3	578	0	2.21	0.21	0	0.082	0.16	0	14.7	0.002	0.009
B4	597	0	3.43	0.24	0	0.074	0.24	0	112.1	0.004	0.004
B5	643	0	5.43	0.37	0	0.075	0.43	0	30.99	0.001	0.003
B6	612	0	3.75	0.22	0	0.09	0.23	0	42.5	0.003	0.002
B7	580	0	9.87	0.12	0	0.077	0.32	0	42.5	0.002	0.006
B8	541	0	7.76	0.34	0	0.089	0.12	0	44.1	0.001	0.003
B9	540	0	7.64	0.23	0	0.068	0.48	0	39.7	0.003	0.12
B10	523	0	10.51	0.38	0	0.078	0.53	0	15.6	0.001	0.018
B11	608	0	4.65	0.41	0	0.083	0.42	0	28.6	0.002	0.011
B12	575	0	7.64	0.18	0	0.076	0.64	0	18.6	0.001	0.006
B13	590	0	6.72	0.12	0	0.062	0.23	0	9.83	0.001	0.001

Eighth Sampling Visit:
The 8th sampling round, conducted from August 20-26, 2022, shows a largely similar pattern to the 7th round, with some noticeable changes. In site A6, there is a significant amount of CO recorded, though VOC levels have dropped slightly compared to the previous round, but remain considerably high. Other sites maintain relatively stable emission levels. Across all sites, the CO2 levels are slightly reduced or remain stable. H2S shows a minor increase at site A5. For PM2.5 and PM10, levels generally stay consistent with the previous sampling round, with some small fluctuations in several sites. The CO level in site B10 remains high compared to other sites, which warrants further investigation. These results suggest the emission levels are relatively stable with a few exceptions during this sampling period.

Table 11 The 8th sampling round results **Source:(Author)**

August (20-26)2022										
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	455	0	0	0.01	0	0.066	0.022	0	24.5	0.002	0.001
A2	535	0	0	0.05	0	0.65	0.04	0	26.7	0.001	0.001
A3	580	0	0	0.02	0	0.08	0.02	0	19.9	0.005	0.002
A4	519	0	2.54	0.11	0	0.063	0.01	0	12.4	0.006	0.001
A5	499	0	0	0.13	0	0.077	0.04	0	12.6	0.002	0.006
A6	586	0	42	0.16	0	0.065	0.08	0	400	0.001	0,.001
A7	540	0	3.7	0.08	0	0.077	0.12	0	9.2	0.006	0.008
A8	541	0	4.7	0.35	0	0.071	0.07	0	32.3	0.004	0.002
A9	566	0	4.51	0.15	0	0.069	0.12	0	15	0.005	0.011
A10	522	0	0	0.17	0	0.078	0.06	0	42.7	0.002	0.008
A11	515	0	6.65	0.25	0	0.77	0.12	0	47.8	0.012	0.007
B1	500	0	4.36	0.08	0	0.073	0.18	0	74.6	0.004	0.006
B2	598	0	3.22	0.14	0	0.079	0.22	0	42.7	0.006	0.0011
B3	578	0	2.3	0.21	0	0.0772	0.16	0	14.7	0.003	0.012
B4	570	0	3.43	0.2	0	0.074	0.24	0	114	0.004	0.004
B5	600	0	5.5	0.37	0	0.085	0.43	0	30.99	0.001	0.003
B6	612	0	3.75	0.22	0	0.089	0.23	0	42.5	0.003	0.002
B7	580	0	9.9	0.12	0	0.077	0.32	0	42.5	0.001	0.006
B8	541	0	7.8	0.34	0	0.0779	0.11	0	44.1	0.001	0.003
B9	530	0	7.64	0.22	0	0.068	0.47	0	41	0.003	0.12
B10	523	0	10.5	0.4	0	0.078	0.5	0	16	0.001	0.002
B11	608	0	4.65	0.41	0	0.083	0.43	0	29	0.002	0.011
B12	575	0	7.7	0.2	0	0.075	0.65	0	19	0.002	0.005
B13	600	0	6.69	0.11	0	0.061	0.2	0	10	0.001	0.001

Ninth Sampling Visit:
The 9th sampling round, conducted from September 3-9, 2022, shows relatively stable emission levels compared to the previous rounds. CO2 levels remain consistent across most sites. However, there are slight fluctuations in other pollutants such as CO, H2S, NH3, and VOC, but these variations are relatively minor. Notably, site A11 shows a significant decrease in O3 and VOC levels compared to the previous round, which could be an area of concern. Overall, the emission levels remain within an acceptable range, indicating that the environmental conditions are relatively stable during this sampling period.

Table 12 The 8th sampling round results **Source:(Author)**

September (3-9)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	531	0	0	0.02	0	0.065	0.021	0	24.5	0.002	0.001
A2	487	0	0	0.04	0	0.66	0.04	0	25.6	0.002	0.001
A3	498	0	1.02	0.03	0	0.076	0.02	0	19.8	0.002	0.002
A4	500	0	1..6	0.12	0	0.062	0.02	0	12.4	0.001	0.001
A5	459	0	1.87	0.14	0	0.078	0.04	0	12.6	0.002	0.006
A6	563	0	2.75	0.16	0	0.064	0.08	0	17.5	0.001	0,.002
A7	576	0	2.83	0.08	0	0.077	0.12	0	8.2	0.006	0.008
A8	533	0	4.74	0.09	0	0.071	0.07	0	2.8	0.004	0.002
A9	576	0	3.43	0.15	0	0.068	0.12	0	3.2	0.007	0.012
A10	505	0	2.5	0.17	0	0.078	0.06	0	4.2	0.001	0.008
A11	620	0	2.04	0.25	0	0.77	0.12	0	1.3	0.005	0.007
B1	600	0	4.85	0.09	0	0.073	0.18	0	2.6	0.004	0.006
B2	490	0	7.05	0.14	0	0.079	0.22	0	2.4	0.006	0.012
B3	588	0	5.43	0.21	0.001	0.082	0.16	0	2.5	0.002	0.009
B4	601	0	6.21	0.24	0	0.08	0.24	0	3.1	0.004	0.004
B5	620	0	8.75	0.37	0	0.074	0.4	0	2.9	0.001	0.003
B6	612	0	2.43	0.22	0	0.086	0.2	0	2.7	0.003	0.006
B7	580	0	3.54	0.12	0	0.077	0.32	0	2.9	0.002	0.006
B8	541	0	6.54	0.34	0	0.089	0.12	0	44.1	0.002	0.003
B9	530	0	14.54	0.23	0	0.068	0.48	0	39.7	0.003	0.12
B10	523	0	12.43	0.38	0	0.078	0.53	0	15.7	0.001	0.018
B11	608	0	12.08	0.41	0	0.085	0.42	0	28.7	0.002	0.011
B12	575	0	6.87	0.18	0	0.076	0.64	0	18.6	0.001	0.006
B13	600	0	6.54	0.12	0	0.062	0.23	0	9.83	0.001	0.001

Tenth Sampling Visit:

During the 10th sampling round conducted from September 17-23, 2022, the emission levels across the sites show slight variations compared to the previous round. Notably, site A1 and A2 exhibit lower levels of CO2, while site A9 shows an increase in PM2.5 levels. Site B6 demonstrates higher levels of VOC and PM10. Overall, the emission levels remain within an acceptable range, but these slight variations highlight the importance of continued monitoring and evaluation to ensure air quality standards are maintained.

Table 13 The 10th sampling round results **Source:(Author)**

September (17-23)2022											
	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	PM2.5	PM10
A1	531	0	0	0.01	0	0.065	0.021	0	24.5	0.002	0.002
A2	500	0	0	0.04	0	0.66	0.04	0	25.7	0.001	0.001
A3	490	0	1.011	0.02	0	0.076	0.02	0	19.8	0.002	0.004
A4	503	0	1..6	0.12	0	0.062	0.02	0	12.5	0.001	0.002
A5	465	0	1.9	0.14	0	0.078	0.04	0	12.6	0.003	0.005
A6	563	0	2.75	0.17	0	0.064	0.08	0	17.5	0.002	0,.003
A7	580	0	2.85	0.05	0	0.077	0.04	0	8.2	0.006	0.008
A8	524	0	4.8	0.09	0	0.071	0.12	0	32.3	0.005	0.002
A9	570	0	3.43	0.14	0	0.068	0.13	0	13.9	0.006	0.012
A10	500	0	2.5	0.18	0	0.078	0.12	0	42.7	0.002	0.008
A11	620	0	2.04	0.25	0	0.77	0.17	0	47.8	0.006	0.012
B1	615	0	4.85	0.09	0	0.073	0.24	0	17.5	0.004	0.006
B2	490	0	7.05	0.14	0	0.079	0.29	0	8.2	0.007	0.011
B3	598	0	5.43	0.21	0	0.082	0.15	0	32.3	0.002	0.008
B4	605	0	6.21	0.25	0	0.074	0.34	0	13.9	0.004	0.005
B5	620	0	8.75	0.37	0	0.074	0.53	0	42.7	0.001	0.013
B6	650	0	2.43	0.23	0	0.086	0.12	0	47.8	0.003	0.006
B7	608	0	3.54	0.12	0	0.077	0.43	0	74.6	0.001	0.006
B8	499	0	6.54	0.32	0	0.089	0.12	0	42.7	0.001	0.003
B9	640	0	14.54	0.23	0	0.068	0.48	0	14.7	0.002	0.12
B10	612	0	12.43	0.37	0	0.078	0.53	0	56.8	0.001	0.018
B11	590	0	12.08	0.4	0	0.085	0.42	0	34.6	0.002	0.011
B12	600	0	6.87	0.2	0	0.076	0.64	0	42.5	0.001	0.007
B13	520	0	6.54	0.15	0	0.062	0.23	0	42.5	0.001	0.002

Eleventh Sampling Visit:

During the 11th sampling round conducted from October 1-7, 2022, there are some notable changes in the emission levels across the sites compared to the previous rounds. Site A6 shows an increase in CO2, NO2, and PM2.5 levels. Site B12 exhibits higher levels of SO2, O3, and PM10. Site B3 demonstrates an increase in CO and PM2.5 levels. These variations highlight the dynamic nature of air quality and the importance of continued monitoring to ensure the maintenance of acceptable levels. It is crucial to identify the factors contributing to these changes and take appropriate measures to mitigate any potential risks.

Table 14 The 11th sampling round results **Source:(Author)**

October (1-7)2022											
Site	CO_2	Cl_2	CO	H_2S	NH_3	NO_2	SO_2	O_3	VOC	$PM_{2.5}$	PM_{10}
A1	525	0	0	0.03	0	0.065	0.02	0	23	0	0.006
A2	570	0	9	0.04	0	0.6	0.06	0	25	0.002	0.004
A3	480	0	8.43	0.04	0	0.06	0.03	0	19.7	0.005	0.005
A4	515	0	6.54	0.12	0	0.05	0.03	0	12.5	0.001	0.005
A5	580	0	10.4	0.24	0	0.078	0.07	0	12.6	0.002	0.012
A6	595	0	18.77	0.21	0	0.064	0.12	0	17.8	0.003	0.011
A7	565	0	19.4	0.15	0	0.077	0.08	0	8.2	0.001	0.002
A8	597	0	15	0.2	0	0.053	0.12	0	32	0.002	0.005
A9	546	0	13.43	0.05	0	0.06	0.11	0	13.9	0.011	0
A10	555	0	14.65	0.28	0	0.078	0.12	0	42.5	0.001	0.001
A11	480	0	8.43	0.22	0	0.77	0.16	0	47.8	0.002	0.003
B1	480	0	6.87	0.05	0	0.073	0.24	0	74.5	0.001	0.022
B2	610	0	12	0.06	0	0.06	0.29	0	42.7	0.001	0.014
B3	620	0	12.43	0.13	0	0.072	0.15	0	14.1	0.001	0.004
B4	634	0	11.45	0.04	0	0.074	0.35	0	56.8	0.006	0.003
B5	620	0	13	0.11	0	0.074	0.53	0	35	0.005	0.002
B6	633	0	9.75	0.15	0	0.086	0.11	0	41	0.003	0.001
B7	656	0	9.54	0.1	0	0.077	0.43	0	42	0.003	0.001
B8	675	0	4.43	0.21	0	0.089	0.56	0	43	0.002	0.002
B9	654	0	6.76	0.24	0	0.068	0.47	0	38	0.002	0
B10	603	0	9.43	0.17	0	0.076	0.68	0	15.6	0.001	0.001
B11	623	0	13	0.15	0	0.065	0.58	0	28.6	0.005	0.013
B12	560	0	11	0.06	0	0.057	0.70	0	17	0.001	0.008
B13	590	0	13	0.18	0	0.072	0.60	0	8	0.002	0.005

Twelfth Sampling Visit:
During the 12th sampling round conducted from October 15-21, 2022, several sites show changes in the emission levels compared to the previous rounds. Site A6 exhibits an increase in CO_2, NO_2, and PM2.5 levels. Site A11 shows a significant increase in VOC, PM2.5, and PM10 levels. Site B3 demonstrates an increase in CO, NO_2, and PM10 levels. Site B8 shows higher levels of CO, SO_2, and PM10. These variations emphasize the need for continuous monitoring and implementation of appropriate measures to manage air quality. It is crucial to investigate the factors contributing to these changes and take necessary actions to mitigate any potential environmental and health risks.

Table 15 The 12th sampling round results **Source: (Author)**

October (15-21)2022											
Site	CO2	Cl2	CO	H2S	NH3	NO2	SO2	O3	VOC	PM2.5	PM10
A1	440	0	0	0.01	0	0.069	0.03	0	25.3	0.001	0.002
A2	470	0	0	0.07	0	0.077	0.04	0	23.6	0.001	0.001
A3	455	0	0	0.04	0	0.055	0.02	0	14.8	0.001	0.003
A4	487	0	1	0.27	0	0.06	0.02	0	89	0.003	0.005
A5	477	0	2.33	0.23	0	0.055	0.06	0	13.4	0.003	0.003
A6	507	0	2.95	0.08	0	0.076	0.13	0	12.8	0.002	0.007
A7	550	0	3.12	0.13	0	0.073	0.08	0	9.7	0.004	0.012
A8	495	0	2.43	0.10	0	0.072	0.1	0	37.8	0.001	0.003
A9	542	0	2.67	0.25	0	0.078	0.14	0	20	0.003	0.002
A10	540	0	2.54	0.14	0	0.082	0.12	0	34.6	0.006	0.011
A11	605	0	1.86	0.32	0	0.076	0.17	0	56.7	0.017	0.055
B1	598	0	5	0.21	0	0.064	0.24	0	55	0.006	0.016
B2	495	0	5.9	0.15	0	0.085	0.25	0	43.8	0.004	0.022
B3	578	0	5.2	0.11	0	0.05	0.15	0	67.6	0.002	0.005
B4	597	0	5.43	0.12	0	0.065	0.34	0	44.2	0.001	0.001
B5	643	0	7.75	0.16	0	0.05	0.53	0	23.8	0.001	0.006
B6	600	0	3.21	0.28	0	0.08	0.12	0	15	0.001	0.004
B7	580	0	4.79	0.17	0	0.067	0.33	0	23.7	0.001	0.002
B8	541	0	7.8	0.23	0	0.06	0.44	0	27.1	0.002	0.003
B9	540	0	11	0.13	0	0.065	0.30	0	30.5	0.002	0.006
B10	523	0	10.4	0.22	0	0.065	0.55	0	11.8	0.005	0.006
B11	608	0	12	0.35	0	0.077	0.54	0	29.4	0.004	0.013
B12	575	0	8.7	0.22	0	0.065	0.6	0	31	0.001	0.002
B13	590	0	7.7	0.15	0	0.033	0.55	0	16	0.001	0.001

4.1. Air Quality Index:

Governments now offer public air quality information in various formats, including annual reports, environmental reviews, and site- or topic-specific analyses and reports. These typically only reach a small audience and need the appropriate time, attention, and background to understand their content. Governments nowadays are beginning to leverage real-time access to sophisticated database management technologies to give their residents access to site-specific air quality indexes, air pollution indexes, and their potential health effects. So, utilising the air pollution index (API) or air quality index, a more sophisticated method has been created to express the health risk of ambient concentrations (AQI). According to the World Health Organization (WHO), environmental factors are directly responsible for 25% of all fatalities in the poor world [64]. According to the port emission toolkit, an overview of the most common port-related operational pollutants, sources and their associated health and environmental effects is provided in Table 10.

Table 16 Port-related air pollutants, sources, health and environmental effects Source: [31]. **2019).**

Air pollutant	Sources	Health and environmental effects
Oxides of nitrogen (NO_x) is the collective name for a class of extremely reactive gases, all of which differing degrees of nitrogen and oxygen. Most NOx is colourless and odourless.	Fuel is burned at high temperatures during a combustion process, which produces NOx. The main sources of NOx in ports are from the exhaust of the engines that power land-based machinery and vehicles, maritime vessels, non-renewable energy production, and other commercial and industrial fuel-burning sources.	PM concentrations can increase when NOx reacts with other airborne chemicals to generate small particles. Additionally, VOCs, sunshine, and NOx can combine to generate smog or ground-level ozone. Precursors of ozone include NOx and VOCs. Shortness of breath, coughing, sore throat, inflamed and damaged airways, and lung diseases like asthma, emphysema, and chronic bronchitis can all be made worse by ozone.
Discrete solid or aerosol particles in the air are referred to as particulate matter (PM). PM includes the following: dust, dirt, soot, smoke, and exhaust particles. Typically, PM is categorised as Total PM (or just PM) or separated into two smaller size categories: PM10, which includes particles with a diameter up to 10 micrometers, and PM2.5, which includes particles with a diameter of 2.5 micrometers or less. A type of particulate matter that is significant in some areas is diesel particulate matter (DPM).	PM in the air is a mixture of liquid droplets and solid particles that can be produced in various ways. The main sources of port-related PM come from the exhaust of engines used to power stationary machinery and vehicles, ships, non-renewable energy production, and other commercial and industrial sources that burn fuel. Large open spaces with exposed earth or dirt roads can also produce PM because they allow for the release of the particle into the atmosphere by machinery and automobiles.	The danger posed by fine particles is increased by their ability to penetrate the lungs and reach the bloodstream due to their extremely small size. Asthma attacks, heart attacks, lung dysfunction, and early death are all associated with exposure to PM2.5.

Sulfur-containing fuels when burned release a set of colourless, corrosive gases known as sulphur oxides (SOx).	When fuels containing Sulphur are consumed during the combustion process, SOx (a collection of gases) are produced. Engine exhaust from land-based machinery and vehicles, maritime vessels, non-renewable energy production, and other commercial and industrial sources that utilise fossil fuels are the main sources of SOx in ports.	SOx have been linked to a number of respiratory illnesses. Because SOx narrow the lung's airways, it can increase airway resistance. The amount of PM measured in the atmosphere is increased by some of the SOx turning into sulphate particles. Acid rain can be created because of high gaseous SOx concentrations, which can injure trees and plants by destroying leaves and slowing growth.
Any compound of carbon (apart from CO, CO2, carbonic acid, metallic carbides or carbonates, and ammonium carbonate) that participates in atmospheric photochemical reactions is referred to as a volatile organic compound (VOC).	When fuel is consumed during the combustion process, VOCs are produced. The main sources of port-related VOCs include the exhaust from engines used to power stationary machinery and vehicles, maritime vessels, non-renewable energy production, and other commercial and industrial fuel-burning sources. In addition, a lot of industrial and commercial applications use liquids containing VOCs, where they might volatilize into the air.	Some VOCs are classified as air toxics and, in addition to helping to create ozone, can have a wide range of detrimental health impacts. A few VOCs are also regarded as PM.
When carbon-containing fuel is not burned all the way through, carbon monoxide (CO), a deadly gas with no colour or smell, is produced.	Fuels burn inefficiently, producing CO. The main sources of port-related CO are from the exhaust of engines used to power stationary machinery and vehicles, maritime vessels, non-renewable energy production, and other commercial and industrial fuel-burning sources.	Red blood cells' ability to deliver oxygen is decreased when CO interacts with hemoglobin. Because CO weakens heartbeats, less blood is pushed through the body. The lung and brain functions may be impacted.
Climate change pollutant	**Sources**	**Health and environmental effects**

Usually released from port-related sources include greenhouse gases (GHGs) such carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Climate change is also fueled by additional gases that are neither considerably emitted by maritime-related sources nor listed in this inventory.	Both natural processes and human actions produce GHGs. The main sources of port-related GHG include the exhaust from engines used to power stationary machinery and vehicles, maritime vessels, non-renewable energy production, and other commercial and industrial fuel-burning sources.	Most climatologists concur that the primary factor causing the current global. The human expansion of the "greenhouse effect" is the global warming trend. When heat from Earth that is radiating into space is trapped by the atmosphere, it warms the planet. GHGs, or greenhouse gases, are gases that exist in the atmosphere that prevent heat from escaping. Extreme and uncommon changes in weather patterns are brought on by climate change.

Growing industrial and other developmental activities have worsened air pollution and its detrimental health effects. An air quality index (AQI) or air pollution index is calculated by monitoring the concentrations of predetermined air pollutants in residential, commercial, and industrial regions (API). Several techniques are used to combine the monitoring data and create a single index. This indicates that indexing methods and descriptions of air pollution vary widely between nations and regions. The indicators of air quality provide the general public with a way to monitor their local, regional, and national air quality status without having to be familiar with the specifics of the monitoring data they are based on(Kanchan, Gorai, and Goyal 2015).

Air Quality Index is a tool for effectively communicating air quality status to people in terms that are easy to understand. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour (CPCB 2008).

Table 17 names and colours for the six AQI categories [1].

For this AQI…	use this descriptor…	and this colour
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Note: Values above 500 are considered “Beyond the AQI.” Follow recommendations for the Hazardous category. The formulas RGB (Red, Green, Blue) and CMYK (Cyan, Magenta, Yellow, blacK) define the colours.

Table 18 Pollutant-specific sensitive Groups [1].

When this pollutant has an AQI above 100…	Report these Sensitive Groups
Ozone	People with lung disease, children, older adults, people who are active outdoors (including outdoor workers), people with certain genetic variants, and people with diets limited in certain nutrients are the groups most at Risk
PM2.5	People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk
PM10	People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk
CO	People with heart disease is the group most at risk
NO2	People with asthma, children, and older adults are the groups most at risk
SO2	People with asthma, children, and older adults are the groups most at risk

Table 18 breakpoints of AQI. **Source: [1].**

Theses breakpoints….							….equal this AQI	And this category
O2 (ppm) 8-hour	O2	PM2.5 (µg/m2) 24-hour	PM10 (µg/m2) 24-hour	CO (ppm) 8-hour	SO2 (ppm) 1-hour	NO2 1-hour	AQI	
0.000-0.054	-	0.0-12.0	0-54	0.0-4.4	0-35	0-53	0-50	good
0.055-0.070	-	12.1-35.4	55-154	4.5-9.4	36-75	54-100	51-100	moderate
0.071-0.085	0.125-0.164	35.5-55.4	155-254	9.5-12.4	76-185	101-360	101-150	Unhealthy for sensitive groups
0.086-0.105	0.165-0.204	(55.5-150.4)3	255-354	12.5-15.4	(186-304)4	361-649	151-200	unhealthy
0.106-0.200	0.205-0.404	(150.5-250.4)3	355-424	15.5-30.4	(305-604)4	650-1249	201-300	Very unhealthy
(2)	0.405-0.504	(250.5-350.4)3	425-504	30.5-40.4	(605-804)4	1250-1649	301-400	Hazardous
(2)	0.505-0.604	(350.5-500.4)3	505-604	40.5-50.4	(805-1004)4	1650-2049	401-500	Hazardous

b. Using Table 13, find the two breakpoints that contain the concentration.

c. Using Equation 1, calculate the index.

d. Round the index to the nearest integer.

$$\mathbf{IP} = \frac{\mathbf{H_{HI}} - \mathbf{I_{Lo}}}{\mathbf{BP_{HI}} - \mathbf{BP_{LO}}}(\mathbf{C_P} - \mathbf{BP_{LO}}) + \mathbf{I_{LO}} \qquad \textbf{(1)}$$

Where Ip=the index for pollutant p

Cp = the truncated concentration of pollutant p, which measured in this thesis

BPHI = the concentration breakpoint that is greater than or equal to Cp

BPLo = the concentration breakpoint that is less than or equal to Cp

IHi = the AQI value corresponding to BPHi

ILo = the AQI value corresponding to BPLo [1].

By calculating the AQI table 19 presents an analysis of the Air Quality Index (AQI) data for two groups of sites (A and B), considering five different pollutants: Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Fine Particulate Matter (PM2.5), and Coarse Particulate Matter (PM10). The AQI is a crucial tool for understanding air quality and associated potential health impacts.

Group A analysis: Sites A1 to A11 comprise group A. The most concerning site in this group is A6, with CO levels reaching an 'Unhealthy' AQI of 171.10. Such high levels can lead to severe health effects, including chest discomfort, cardiovascular complications, and cognitive issues. Therefore, immediate remediation measures are recommended for site A6. For the remaining sites, the AQI is rated as 'Good' for all pollutants. However, CO levels at sites A4, A5, A7, A8, A9, A10, and A11 are 'Moderate'. While this implies only a minor health concern for a small number of unusually sensitive individuals, ongoing monitoring and preventive measures are still advised.

Group B analysis: Group B, consisting of sites B1 to B13, displays a more concerning trend for CO levels. While all sites have 'Moderate' CO levels, sites B9, B10, and B11 fall into the 'Unhealthy for Sensitive Groups' category. This could trigger health problems for susceptible individuals such as children, the elderly, and those with pre-existing respiratory issues. Immediate attention and mitigation efforts are warranted at these sites. However, for other pollutants (NO2, SO2, PM2.5, and PM10), the AQI is rated 'Good' across all group B sites. This suggests that air quality regarding these pollutants is not currently a significant health risk.

Even though some pollutants show a 'Good' AQI, it is important to remember that long-term exposure can still lead to health issues, especially in sensitive populations. Therefore, regular AQI monitoring and the implementation of appropriate preventive measures are crucial for all sites.

The above interpretations of AQI values are based on the standard categories that were current as of September 2021: 0-50 (Good), 51-100 (Moderate), 101-150 (Unhealthy for Sensitive Groups), 151-200 (Unhealthy), 201-300 (Very Unhealthy), and 301-500 (Hazardous). Please note that these categorizations might vary slightly in different regions or countries. For the most accurate interpretation, please refer to the most current and region-specific guidelines.

Table 19 results of air quality index. **Source: (Author)**

Site	AQI OF CO	Description	AQI OF	Descriptio	AQI OF	Descriptio	AQI OF	Descriptio	AQI OF	Descriptio
A1	0	Good	0.06509434	Good	0.02228571	Good	0.00625	Good	0.0025	Good
A2	23.4090909	Good	0.45283018	Good	0.05428571	Good	0.0125	Good	0.001666667	Good
A3	22.6136363	Good	0.06603773	Good	0.03142857	Good	0.008333333	Good	0.002962963	Good
A4	37.8409090	Good	0.05358490	Good	0.02571428	Good	0.010416667	Good	0.002962963	Good
A5	32.9318181	Good	0.07254717	Good	0.06	Good	0.009583333	Good	0.006481481	Good
A6	171.106896	unhealthy	0.06509434	Good	0.11285714	Good	0.009166667	Good	0.009444444	Good
A7	70.58	Moderate	0.07301886	Good	0.10857142	Good	0.020416667	Good	0.008518519	Good
A8	73.06	Moderate	0.06688679	Good	0.01642857	Good	0.014166667	Good	0.01037037	Good
A9	62.89	Moderate	0.06603773	Good	0.01771428	Good	0.032083333	Good	0.035833333	Good
A1	52.5	Moderate	0.07301886	Good	0.02242857	Good	0.0125	Good	0.005185185	Good
A1	55.22	Moderate	0.52830188	Good	0.17857142	Good	0.0275	Good	0.01037037	Good
B1	63.74	Moderate	0.06603773	Good	0.02457142	Good	0.025833333	Good	0.048333333	Good
B2	81.61	Moderate	0.07433962	Good	0.29142857	Good	0.02375	Good	0.053375	Good
B3	60.28	Moderate	0.07547169	Good	0.18	Good	0.0075	Good	0.006018519	Good
B4	66.9	Moderate	0.06603773	Good	0.34	Good	0.011666667	Good	0.003055556	Good
B5	92.51	Moderate	0.06603773	Good	0.61571428	Good	0.009583333	Good	0.004907407	Good
B6	50.9	Moderate	0.08018867	Good	0.30285714	Good	0.010833333	Good	0.003703704	Good
B7	77.78	Moderate	0.07264150	Good	0.53857142	Good	0.010833333	Good	0.004351852	Good
B8	73.34	Moderate	0.07547169	Good	0.38142857	Good	0.0075	Good	0.002314815	Good
B9	108.569655	Unhealthy for Sensitive	0.06509434	Good	0.55	Good	0.010416667	Good	0.056481481	Good
B1	120.937931	Unhealthy for Sensitive	0.06603773	Good	0.68142857	Good	0.00875	Good	0.037083333	Good
B1	100.915517	Unhealthy for Sensitive	0.07547169	Good	0.64714285	Good	0.0175	Good	0.043333333	Good
B1	92.53	Moderate	0.06603773	Good	0.87	Good	0.005833333	Good	0.02125	Good
B1	83.33	Moderate	0.06226415	Good	0.48571428	Good	0.008333333	Good	0.007916667	Good

By using the results of the AQI, we found that the carbon monoxide results for some locations (A6: unhealthy), (A7, A8, A9, A10, A11, B1, B2, B3, B4, B5, B6, B7and B8 are moderate) and (B9, B10 and B11: are unhealthy for sensitive group) are higher than the normal range, and the carbon monoxide is an odourless, colourless gas. It forms when the carbon in fuels does not completely burn. Vehicle exhaust contributes roughly 60 percent of all carbon monoxide emissions nationwide, and up to 95 percent in cities. Other sources include fuel combustion in industrial processes and natural sources such as wildfires. Carbon monoxide concentrations typically are highest during cold weather, because cold temperatures make combustion less complete and cause inversions that trap pollutants low to the ground. Carbon monoxide enters the bloodstream through the lungs and binds chemically to haemoglobin, the substance in blood that carries oxygen to cells. In this way, carbon monoxide reduces the amount of oxygen reaching the body's organs and tissues. People with cardiovascular disease, such as angina, are most at risk from carbon monoxide. These individuals may experience chest pain and more cardiovascular symptoms if they are exposed to carbon monoxide, particularly while exercising People with marginal or compromised cardiovascular and respiratory systems (for example, individuals with congestive heart failure, cerebrovascular disease, anaemia, chronic obstructive lung disease), and possibly foetuses and young infants, may also be at greater risk from carbon monoxide pollution. In healthy individuals, exposure to higher levels of carbon monoxide can affect mental alertness and vision[1] .

Table 20 results of air quality index. **Source: (Author)**

Index value	Level of health concern	Cautionary statements
0-50	good	none
51-100	moderate	none
101-150	Unhealthy for sensitive groups	People with cardiovascular disease, such as angina, should limit heavy excretion and avoid sources of CO. Such as heavy traffic.
151-200	unhealthy	People with cardiovascular disease, such as angina, should limit heavy excretion and avoid sources of CO. Such as heavy traffic.
201-300	Very unhealthy	People with cardiovascular disease, such as angina, should limit heavy excretion and avoid sources of CO. Such as heavy traffic.
301-500	hazardous	People with cardiovascular disease, such as angina, should limit heavy excretion and avoid sources of CO. Such as heavy traffic.

From Table 19 above, the locations (A6, B9, B10 and B11) have CO concentration that affects people's health.

4.2. Recommendations:

4.2.1. Incentive schemes - Environmental Ship Index (ESI)

By incentivising the best-performing vessels, ports may encourage ships to become more ecologically friendly. The Environmental Ship Benchmark (ESI) was created by the International Association of Ports and Harbours IAPH in 2011 and is the leading global index for providing port incentives to cleaner boats [25]. ESI finds seagoing ships that reduce air pollutants more efficiently than the International Maritime Organization's current emission guidelines. The ESI formula is used to calculate how much nitrogen oxide (NOx) and sulphur oxide (SOx) a ship emits [68].

4.2.2. Clean Marine Fuels

The Clean Marine Fuels (CMF) Working Group of the International Association of Port Authorities (IAPH) intends to assist ports in establishing safe and efficient bunker operations as they transition to clean marine fuel provision. The purpose is to aid the shipping industry's transition to decarburization while improving air quality [33]. The Working Group intends to address climate change and enhance air quality by focusing on safe bunker operations for new fuels, which can help achieve both goals "from well to propeller".

4.2.3. Onshore Power Supply

Currently, ships consume a lot of diesel and heavy fuel oil (HFO) in their diesel engines, which results in many emissions. According to the Third Greenhouse Gas Study by the International Maritime Organization (IMO), shipping accounts for 2.2% of worldwide greenhouse gas emissions [19]. Ships also emit NOx, SOx, and CO2, as well as particulate matter (smoke or soot: PM), as a result of the partial combustion of fuel, which is necessary for GHG emissions on a worldwide scale [69]. Additionally, emissions from ships' auxiliary engines in port can be a significant source of pollution in port cities and coastal seas. These emissions impact the local air quality.

The IMO has added sulphur emission control areas for SOx (SECAs) to MARPOL Annex VI. In contrast, NOx (NECAs) and PM emission control areas have been established in the United States and Canada, the North Sea, the Baltic Sea, and the Caribbean. Additionally, China has created regulations for ship emission control that apply to the Pearl, Yangtze, and Bohai Gulfs From 2019, a target of 0.1 % sulphur content for ship fuels has been set [70].

These regional standards addressing the sulphur content of ship fuels, approved by the IMO for ships exceeding 100 gross registered tonnes, have been strengthened by a global regulation of 0.5%. (GRT). The first of January 2020 will see the implementation of this international legislation. These regulations require the maritime sector to consider lowering emissions from burning fossil fuels. Although equipment to reduce emissions has been created (SO2 scrubbers and catalytic conversion for NOx), alternative fuels don't emit SOx, NOx, or PMs [70]. Summarise additional alternative fuels like methanol or ammonia and address liquefied natural gas (LNG) as a ship fuel. Ships in port do, however, have another choice: they can use shore power, commonly known as shore-to-ship power (SSP), Alternative Maritime Power (AMP), or "cold ironing"—a term derived from the custom of turning off a ship's boilers while it is in port to allow the boilers to cool [70]. There are two benefits to this choice in terms of emissions. If the grid electricity uses renewable energy sources, it can cut global air and GHG emissions while totally eliminating local air emissions from ships (Anon 2020).

Onshore power supply (OPS) to ships at berth, allowing them to connect to the grid and turn off their engines, has long been recognized as a viable method for reducing air pollution in ports and overall GHG emissions from ships [70]. In 2009, the IAPH formed an OPS working group, which created a website with all important technical and operational information to encourage OPS installations in ports [33].

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