سلسلة أوراق عمل
معهد التخطيط القومي

An Integrated Model for Strategic Environment Impact Assessment of Urban Transportation in Metropolitan Areas: A Case Study on Greater Cairo Region

Eng. Asmaa Hamdy

ورقة عمل رقم (13 - 2025)
أبريل 2025

WWW.INP.EDU.EG

سلسلة أوراق عمل

An Integrated Model for Strategic Environment Impact Assessment of Urban Transportation in Metropolitan Areas: A Case Study on Greater Cairo Region

م. أسماء حمدي
مدرس التخطيط البيئي المساعد - مركز التخطيط والتنمية البيئية - معهد التخطيط القومي

Asmaahamdy@inp.edu.eg

ورقة عمل رقم 13- 2025

تم النشر لأول مرة في عام 2025 بواسطة معهد التخطيط القومي.

سلسلة أوراق عمل معهد التخطيط القومي: تستهدف هذه السلسلة عرض بعض النتائج الأولية للبحوث التي يجريها معهد التخطيط القومي بقصد مناقشتها من جانب المعنيين من داخل المعهد وخارجه تمهيداً لتطوير هذه النتائج والإرتقاء بمستوى البحث العلمي بالمعهد، وإعادة نشر الورقة في وعاء نشر محكم محلياً أو إقليمياً أو دولياً.

WWW.INP.EDU.EG

جمهورية مصر العربية - طريق صلاح سالم - مدينة نصر - القاهرة - مكتب بريد رقم 11765

A.R.E SALAH SALEM ST. NASR CITY, CAIRO P.O.BOX: 11765

An Integrated Model for Strategic Environment Impact Assessment of Urban Transportation in Metropolitan Areas: A Case Study on Greater Cairo Region

نموذج متكامل لتقييم الأثر البيئي الاستراتيجي للنقل الحضري بالمدن الكبرى: دراسة حالة على منطقة القاهرة الكبرى

م. أسماء حمدي
مدرس التخطيط البيئي المساعد- مركز التخطيط والتنمية البيئية
معهد التخطيط القومي
Asmaahamdy@inp.edu.eg

Abstract

Air pollution poses a significant threat to human health and the environment, with major pollutants including gases, odors, and particulate matter (dust, mist, and smoke). High concentrations of these pollutants in urban areas severely impact residents, animals, and plants. The World Health Organization (WHO) attributes seven million annual deaths globally to poor air quality, citing risks such as stroke, heart disease, lung cancer, and respiratory illnesses like asthma. Reports from the World Bank, Climate Watch, and Egypt's 2020 State of the Environment Report indicate that transportation is a major contributor to air pollution in the Greater Cairo Region (GCR), where pollution levels often exceed international standards.

Due to limited and incomplete environmental data for the GCR, this paper aims to assess the environmental impact of various transportation policies through the development of a mathematical model. Utilizing an open-source software platform, the model integrates land use, activity-based travel data, traffic simulation, and emission modeling to enhance air quality planning in metropolitan areas. To address data gaps and improve coverage, the study also incorporates integrated environmental datasets derived from Landsat-8 imagery and GIS techniques. Remote sensing, a crucial data acquisition method, is employed to analyze and interpret satellite images and maps for land use, cultivated land, and urban distribution.

The paper concludes that the developed open-source software platform and mathematical model can effectively support environmental impact assessments, track implementation progress, monitor air pollutants, and identify heavily polluted zones, ultimately aiding in informed decision-making.

Key words: Air pollution - Mathematical modeling - open-source software platform - Traffic simulation model- Emissions model -Metropolitan areas.

الملخص:

يُشكل تلوث الهواء تهديدًا كبيرًا لصحة الإنسان والبيئة، حيث تشمل الملوثات الرئيسية الغازات والروائح والجسيمات العالقة (الغبار والضباب والدخان). تؤثر التركيزات العالية من هذه الملوثات في المناطق الحضرية بشدة على السكان والحيوانات والنباتات. تُعزي منظمة الصحة العالمية (WHO) سبعة ملايين حالة وفاة سنويًا على مستوى العالم إلى سوء جودة الهواء، مشيرةً إلى مخاطر مثل السكتة الدماغية وأمراض القلب وسرطان الرئة وأمراض الجهاز التنفسي مثل الربو. تشير تقارير البنك الدولي ومنظمة مراقبة المناخ وتقرير حالة البيئة في مصر لعام 2020 إلى أن النقل يُساهم بشكل كبير في تلوث الهواء في منطقة القاهرة الكبرى، حيث غالبًا ما تتجاوز مستويات التلوث المعايير الدولية. ونظرًا لمحدودية البيانات البيئية وعدم اكتمالها لمنطقة القاهرة الكبرى، تهدف هذه الورقة إلى تقييم الأثر البيئي لسياسات النقل المختلفة من خلال تطوير نموذج رياضي. باستخدام منصة برمجية مفتوحة المصدر، يدمج النموذج استخدام الأراضي وبيانات السفر القائمة على النشاط ومحاكاة حركة المرور ونمذجة الانبعاثات لتعزيز تخطيط جودة الهواء في المناطق الحضرية. لمعالجة فجوات البيانات وتحسين التغطية، تتضمن الدراسة أيضًا مجموعات بيانات بيئية متكاملة مستمدة من صور لاندسات-8 وتقنيات نظم المعلومات الجغرافية. ويُستخدم الاستشعار عن بُعد، وهو أسلوب أساسي لجمع البيانات، لتحليل وتفسير صور وخرائط الأقمار الصناعية المتعلقة باستخدام الأراضي والأراضي المزروعة والتوزيع الحضري. وتخلص الورقة إلى أن منصة البرمجيات مفتوحة المصدر والنموذج الرياضي المُطورين يمكنهما دعم تقييمات الأثر البيئي بفعالية، وتتبع تقدم التنفيذ، ورصد ملوثات الهواء، وتحديد المناطق شديدة التلوث، مما يُسهم في نهاية المطاف في اتخاذ قرارات مستنيرة.

الكلمات المفتاحية: تلوث الهواء – النمذجة الرياضية – منصة برمجيات مفتوحة المصدر – نموذج محاكاة حركة المرور – نموذج الانبعاثات – المناطق الحضرية.

1. Introduction

Transportation, while essential for urban development and the economy, significantly contributes to air and noise pollution, and climate change, particularly in Greater Cairo. Strategic Environmental Impact Assessment (SEIA) is crucial for mitigating these effects, and mathematical models are increasingly used for this purpose [1]. This paper presents a mathematical model for SEIA of Greater Cairo's transportation sector, using an open-source platform that integrates land use, travel data, traffic simulation (using tools like VISSIM, SUMO, Trans Modeler, PARAMICS) emissions modeling (MOVES, EMFAC, PROMETHEUS, CAL3P, IVE), spatial modeling, GIS, remote sensing, and other data.

This integrated approach supports air quality planning. The model uses a system dynamics approach, considering interactions between traffic demand, vehicle emissions, and air quality. It combines traffic and air quality models to estimate traffic volume, predict vehicle emissions, and assess air quality impacts [2]. The paper also discusses using these models to identify mitigation measures. This helps decision-makers make informed transportation planning and investment choices, minimizing environmental impacts. Specifically, it aids in early impact identification, cumulative impact assessment, comparison of transportation options, identification of hazardous areas, future impact prediction, and mitigation measure development.

Results show transportation's significant contribution to Greater Cairo's air pollution and demonstrate how different policies (e.g., public transport investment, road pricing) can significantly improve air quality. The paper is structured as follows: (Section 2: Literature Review; Section 3: Material and Method, then Applied Study; Section 4: Results and Interpretation; and finally, Section 5: Conclusion, Recommendation, and Future Studies). The addition of remote sensing methodologies to this work represents an original development introduced by the researcher, with the aim of deepening the understanding of the distribution of environmental pollution and enhancing the effectiveness of planning recommendations within the framework of the strategic environmental assessment of the transportation sector.[1]

---

[1] This research is partly based on Asmaa Hamdy Mostafa Ali's PhD dissertation, "Mathematical Model to Support the Strategic Environmental Impact Assessment of the Transportation and Road Sector Applying on Case Study (Greater Cairo)" (PhD diss., 2025), and developed by incorporating remote sensing techniques to more accurately identify areas most vulnerable to pollution.

2. Literature review

We review the relevant literature on air quality assessment for transportation, traffic simulation models, emission models and models about air quality assessment for transportation. Here are some research papers that show that Mathematical models can be used to assess the environmental impact of the transportation sector in a number of ways.

2.1 The Use of Strategic Environmental Impact Assessment (SEIA) in the Transportation Sector:

Strategic environmental impact assessment (SEIA) is a process for assessing the environmental impacts of policies, plans, and programs. It can be used to identify potential environmental impacts early in the planning process, consider alternatives, and develop mitigation measures.

The International Transport Forum [3] published a report in 2003 entitled "Strategic Environmental Assessment in the Transport Sector". The report provides an overview of the use of SEIA in the transport sector, and identifies the key benefits and challenges of using SEIA. The report finds that SEIA has the potential to be a valuable tool for improving the environmental performance of transport projects. However, the report also notes that more research is needed to understand how to implement SEIA effectively in the transport sector.

The ITF has continued to work on SEIA in the transport sector since the publication of this report. In 2018, the ITF published a handbook on SEIA in the transport sector. The handbook provides practical guidance on how to implement SEIA in the transport sector.

The use of remote sensing technology, geographic information systems, and spatial modeling in an environmental impact assessment of a transportation sector can improve the accuracy and efficiency of EIAs in a number of ways. Remote sensing can be used to collect data on the environmental conditions of the project area, such as land use, vegetation, and water bodies. GIS can be used to integrate this data with other data, such as traffic data and demographic data, to create a comprehensive picture of the environmental impacts of the sector. Spatial modeling can be used to predict the potential impacts of the sector, such as changes in air quality and noise levels [4].

SEIA has the potential to be a valuable tool for improving the environmental performance of the transportation sector, but more research is needed to understand how to implement SEIA effectively [5].

2.2 The use of mathematical models to assess the environmental impact of the transportation sector.

Mathematical models can be used to assess the environmental impact of the transportation sector in a number of ways. It can be used to estimate the amount of traffic that a sector will generate, Predict the emissions of pollutants from vehicles, assess the impact of the sector on air quality, noise levels, and other environmental factors and Identify mitigation measures that can be taken to reduce the environmental impact of the sector.

A case study of the application of mathematical models in the strategic environmental impact assessment of transportation projects in Greater Cairo was conducted by a team of researchers from the Egyptian National Institute of Transport (ENIT) and the Japan International Cooperation Agency [6]. The study used a variety of mathematical models to assess the environmental impact of a proposed new metro line in Greater Cairo. The models were used to estimate the amount of traffic that the new metro line would generate, predict the emissions of pollutants from vehicles using the line, and assess the impact of the line on air quality, noise levels, and other environmental factors. The study found that the new metro line would have a significant positive impact on air quality and noise levels in Greater Cairo. The study also found that the line would reduce traffic congestion and emissions of pollutants from vehicles.

The application of mathematical models in the strategic environmental impact assessment of the transportation sector can be a valuable tool for decision-makers. The models can be used to assess the environmental impact of the sector in a comprehensive and quantitative way. This information can be used to make informed decisions about the design, construction, and operation of the transportation sector [7].

Mathematical models can be used to assess the environmental impact of the transportation sector in a number of ways. **Here are some of the most common ways**:

- Traffic simulation models are used to estimate the amount of traffic that a transportation sector will generate. These models can take into account factors such as the location of the project, the type of transportation infrastructure, and the existing traffic patterns [8].

- Emissions models are used to predict the emissions of pollutants from vehicles using a transportation project. These models can take into account factors such as the type of vehicles, the fuel they use, and the driving conditions.
- Air quality models are used to assess the impact of a transportation project on air quality. These models can take into account factors such as the emissions from vehicles, the meteorology, and the terrain.
- Mitigation measures are used to reduce the environmental impact of the transportation sector. Mathematical models can be used to identify and evaluate mitigation measures, such as traffic calming measures, vehicle emission control technologies, and noise barriers.

Here are some examples of how mathematical models have been used to assess the environmental impact of transportation sector:

- A study by the US Environmental Protection Agency (EPA) used a traffic simulation model to estimate the impact of a new highway on air quality in the Los Angeles area. The study found that the highway would increase air pollution levels in the area [9].
- A study by the University of California, Berkeley used an emissions model to estimate the impact of a new bus rapid transit system on air quality in the San Francisco Bay Area. The study found that the bus rapid transit system would reduce air pollution levels in the area.

The use of mathematical models is becoming increasingly common, as they can provide a valuable tool for decision-making about transportation projects.

From literature review Simulation results show that mobility depends on travel time, the fulfilment ratio of public transport supply and demand, the effectiveness of public transport transfer distance and transfer time, as well as the access time. Traffic congestion is influenced by internal factors and external events.

As the above studies show, the body of studies regarding air pollution tried to address the problem from economic or chemical perspectives. A few of them utilized a modeling approach in their works and among them just small numbers took sustainable development into account, noticing the fact that air pollution is a rapidly growing environmental issue in metropolitan areas especially in greater Cairo. By investigating previous works regarding the air pollution in greater Cairo, there can be seen some research gaps that have been left intact, or not investigated thoroughly. Among them, there is a lack in determining a comprehensive set of factors and policies that could intervene in the air pollution problem.

Also, there is a shortage of introducing policies that could potentially mitigate the air pollution. In addition to that, it is unclear whether the factors and variables contributing to the air pollution in the study area could possibly interrelate with each other. Hence, one of the novelties of this study is to utilize a modeling approach in the air pollution problem in greater Cairo for the first time as one of the most polluted megacities with a sustainable development perspective. However, this study does not go through the chemical and technical facets of air pollution associated with metropolitan areas. By applying a platform for simulation models (traffic, emission and air quality) and modeling in this study, as one of the most reliable methods in complex problems, major variables affecting the air pollution in greater Cairo are going to be identified.

3. Materials and Methods

3.1 Data Used:

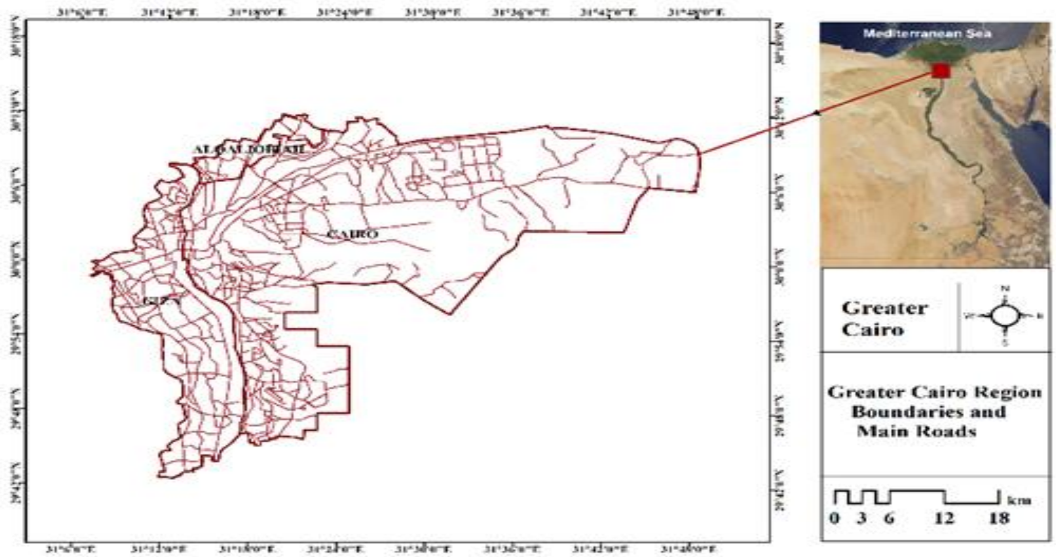
The data used in a mathematical model of strategic environmental impact assessment (SEIA) for the transport and road sector in the Greater Cairo region can be divided into two categories:

Quantitative data: This data includes information on the number of vehicles, the amount of traffic, the types of vehicles, the road network, and the environmental impacts of the transport sector. This data can be collected from a variety of sources, such as government agencies, transportation companies, and environmental organizations.

Qualitative data: This data includes information on the public's views on the transport and road sector, the legal and regulatory requirements for environmental impact assessments, and the social and economic impacts of the transport sector. This data can be collected through surveys, interviews, and focus groups.

3.2 Study area: Greater Cairo Region

The selected study area for this research is the Greater Cairo Region (GCR), Egypt, which includes three sectors. The main sector is the metropolitan Cairo city on the eastern bank of the Nile River, parts of Giza City on the eastern bank of the Nile, and Qalyoubia, north of Cairo. The study area is located at 30˚00'N and 31˚20'E, in the middle and southern part, i.e. apex, of the Nile Delta Region, covering an area of 845,137 hectares (Figure 1).



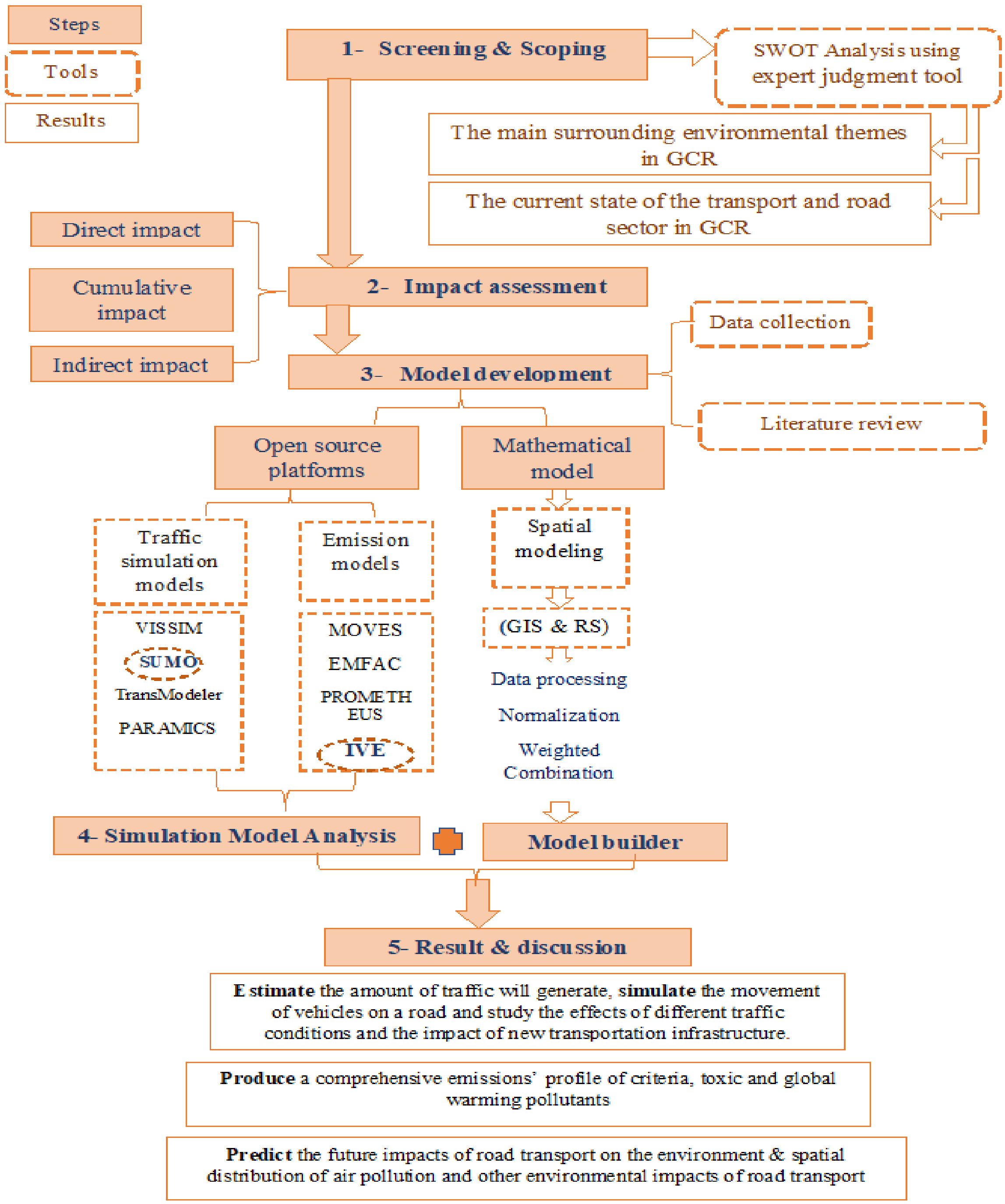
Source: **http://glovis.usgs.gov/2023**

Fig (1): Greater Cairo Region (GCR), Egypt.

The Greater Cairo Region (GCR) is a rapidly growing city with a unique location and climatic conditions. It is home to a diverse range of historical heritages and represents about 23% of the total population of Egypt. The GCR has grown more than thirty fold in the last century and a half, and is facing a number of challenges, including traffic congestion, pollution, and inadequate housing. However, the city is also a major economic engine for Egypt and is playing an increasingly important role in the global economy.

4. Methodology and data analysis

The paper reviews existing literature on air quality assessment, traffic simulation, and emission models, highlighting the importance of SEIA and the use of mathematical models in transportation planning. It emphasizes the need for a comprehensive understanding of contributing factors and mitigation policies, which this study aims to address. The methodology as shown in figure 2 involves data collection (quantitative and qualitative), defining the study area (Greater Cairo Region), and model development. A SWOT analysis identifies key environmental themes and the current state of the transportation sector, including traffic congestion, poor air quality, and inefficient public transport. Impact assessment identifies direct, indirect, and cumulative environmental impacts [10].



Source: Researcher

Figure 2: Methodology of applied study

4.1 <u>Screening and scoping</u>: Description and assessment of the surrounding environment using the stakeholder questions (SWOT analysis – risk assessment – cost benefit analysis)

SWOT analysis enables to **identify the main surrounding environmental t**hemes (water quality, air quality, pollution,…etc) in the city

Table (1): SWOT Analysis [10*]*

Weaknesses	Strengthens
• Lack of coordination between different government agencies. • Limited financial resources. • The transportation sector is fragmented, with a number of different government agencies responsible for different aspects of transportation planning and management. • There is a lack of data and information on the environmental impacts of transportation projects.	• The distinct ground formation (topography - tendencies) that allows for the settlement of a wide range of uses without limitations or. Barriers. • The study area has geological characteristics that allow for the settlement of all activities and uses. • The soil's suitability for the urban development process due to the absence of determinants or barriers to the development
RISK	**OPPORTUNITIES**
• Rapid population growth. • Increasing urbanization. • Climate change. • Political instability. • Traffic congestion • The increasing demand for transportation. • Air pollution. • Noise pollution. • Economic productivity: Traffic congestion and air pollution can lead to decreased economic productivity.	• The development of new technologies for reducing the environmental impacts of transportation. • Increased investment in renewable energy. • New technologies for environmental monitoring and remediation. • Growing public awareness of environmental issues. • The increasing use of public transportation and non-motorized transport. • The growing international cooperation on environmental issues related to transportation.

<u>From Table 1 we can identify:</u>

Some of the main surrounding environmental themes in Greater Cairo: (Air pollution - Water pollution - Solid waste management - Land use – Deforestation - Climate change).

The current state of the transport and road sector in the Greater Cairo region is characterized by the following [10]:

- **High traffic congestion**: Traffic congestion is a major problem in the Greater Cairo region. The average speed of traffic in the city is only 15 kilometers per hour, and the average commute time is over two hours.
- **Poor air quality**: Air quality in the Greater Cairo region is poor, due to the high levels of traffic congestion. The city has been ranked as one of the most polluted cities in the world.
- **High rates of traffic accidents**: Traffic accidents are a major problem in the Greater Cairo region. There are over 10,000 traffic accidents each year, and over 3,000 people are killed.
- **Inefficient public transportation**: Public transportation in the Greater Cairo region is inefficient and overcrowded. The metro system is the most popular form of public transportation, but it is still unable to meet the demand.

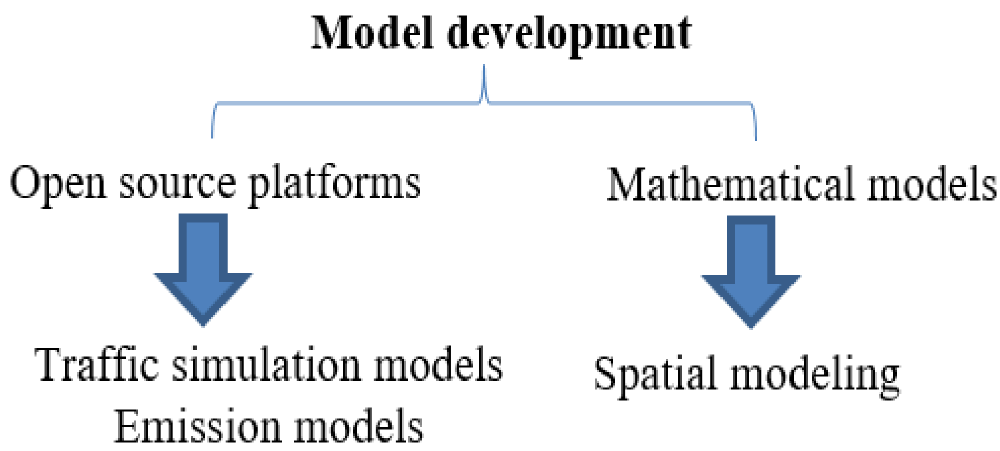
- **Lack of investment in infrastructure**: The government has not invested enough in the transport and road sector in the Greater Cairo region. This has led to the deterioration of the road network and the aging of the public transportation system.

4.2 Impact assessment:

The next step is to assess the environmental impacts of the transportation sector. This includes identifying the direct, indirect, and cumulative impacts, as well as the positive and negative impacts. Identifying the environmental impact of the plan's components on environmental elements using a checklist tool and literature review show that Greater Cairo is one of the most polluted cities in the world. The main sources of air pollution in the city are traffic emissions, industrial emissions, and dust from construction sites. Air pollution in Greater Cairo has been linked to a number of health problems, including respiratory diseases, heart disease, and cancer.

4.3 Model development:

Here are some of the open source platforms and mathematical models as shown in figure (3) that are commonly used in the strategic environmental impact assessment of the transportation sector then get output data from it to be input data and value of parameter for system dynamics.



Source: Researcher

Fig (3): model development methodology

4.3.1 Traffic simulation models:

Traffic simulation is a widely used method applied in the research on traffic modelling, planning and development of traffic networks and systems. From the literature study, a variety of traffic simulation models were found in experiments and applications with aims to imagine real traffic operations to present a real traffic situation into a dynamic model. The traffic simulation models can be categorized into three namely, microscopic modelling, macroscopic modelling and mesoscopic modelling Selecting the right model according to study aims is an important step towards traffic problem resolution [11].

There are three main types of traffic simulation models [12]**:**

- **Microscopic models**: model the behavior of individual vehicles. These models are very detailed and can be used to study the interactions between vehicles and the road network.
- **Macroscopic models**: model the traffic flow as a fluid. These models are less detailed than microscopic models, but they are faster and can be used to study larger road networks.
- **Mesoscopic models**: are a hybrid of microscopic and macroscopic models. They model the behavior of groups of vehicles and can be used to study the interactions between vehicles and the road network at a more aggregated level.

Here are some of the most popular traffic simulation software in table (2):

Table (2): the most popular traffic simulation software

Feature	VISSIM	SUMO	Trans Modeler	PARAMICS
Type	Microscopic	Microscopic	Macroscopic	Macroscopic
Open-source	No	Yes	No	No
Free academic version	Yes	Yes	Yes	Yes
Suitable for	Transportation planning, traffic engineering, traffic safety	Research, education	Transportation planning, traffic engineering	Transportation planning, traffic engineering
Pros	Detailed simulation of individual vehicles, Easy to use	Flexible, Open-source, Large user community	Fast, Scalable, Can be used to simulate large road networks	Accurate, Can be used to simulate traffic dynamics
Cons	Expensive, Can be difficult to learn	Can be computationally intensive, Not as detailed as VISSIM	Not as flexible as SUMO	Not as widely used as other models
Capabilities	Detailed simulation of individual vehicles, including their movements, interactions, and emissions.	Flexible and open-source model that can be used for a variety of applications.	Fast and scalable model that can be used to simulate large road networks.	Accurate model that can be used to simulate traffic dynamics.
Data requirements	Road network, traffic demand, vehicle characteristics, traffic rules	Road network, traffic demand, vehicle characteristics, traffic rules	Road network, traffic demand	Road network, traffic demand, vehicle characteristics
Level of detail	High	High	Low	Medium

In the case of greater Cairo, the Traffic simulation model (SUMO) is an open-source microscopic traffic simulation model that is well-suited for large and complex road networks like study areas. SUMO is a powerful tool that can be used to create traffic simulation models of a variety of regions and networks. The output from a SUMO simulation can be used to assess the impact of transportation infrastructure projects, develop traffic management strategies, and analyze the impact of transportation policies.

we can analyze the output data of a traffic simulation model of GCR using SUMO as shown in figure (4) to:

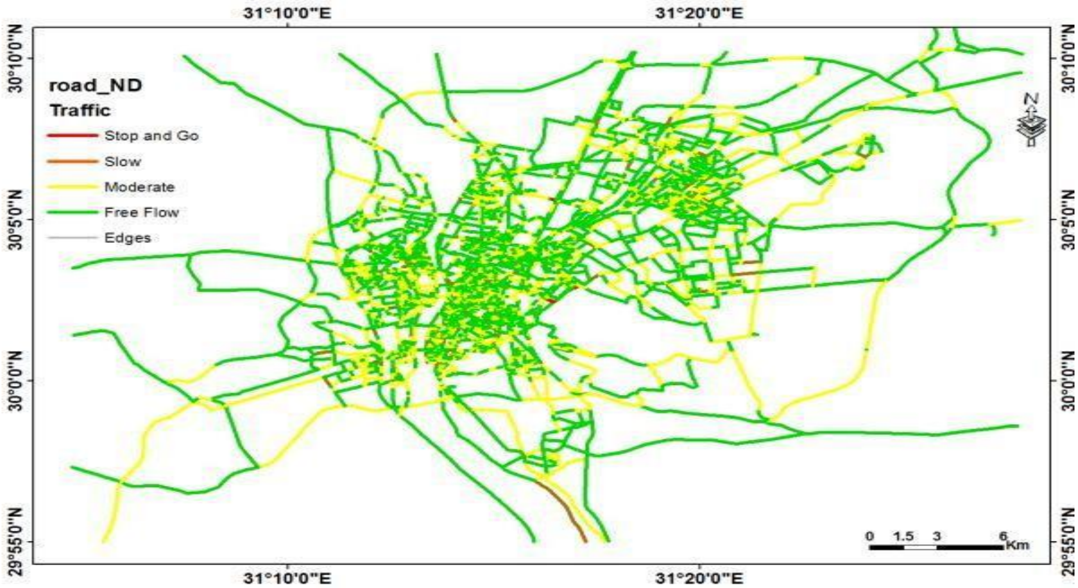


Fig (4): output data of a traffic simulation model of GCR using SUMO

Identify the most congested roads and intersections. You can use the travel time data to identify the roads and intersections that are most congested. Once you have identified the most congested areas, you can focus your efforts on developing strategies to improve traffic flow in those areas.

Analyze the impact of different traffic signals and lane markings. You can use the simulation model to compare the impact of different traffic signals and lane markings on traffic flow. This information can be used to improve the traffic signal timing and lane markings in GCR.

Estimate the emissions from the transportation sector. You can use the emissions data to estimate the total emissions from the transportation sector in GCR. This information can be used to develop strategies to reduce emissions from the transportation sector.

Overall, the output data of a traffic simulation model of GCR using SUMO can be used to analyze a variety of metrics related to traffic flow and emissions as shown in table 3. This information can be used to develop strategies to improve traffic flow and reduce emissions in GCR.

Table (3): Analysis of output data of a traffic simulation model of GCR using SUMO

Variable	Description
Vehicle travel times	• High, especially during peak hours. Average vehicle travel time is around 30 minutes per kilometer. Travel times can be much longer during peak hours.
Vehicle speeds	• Relatively low, especially during peak hours. Average vehicle speed is around 20 kilometers per hour. Vehicle speeds can be much lower during peak hours.
Vehicle queues	• Common sight, especially during peak hours. Found at intersections, toll booths, and other locations on the road network. Length of vehicle queues can vary depending on the time of day, day of the week, and time of year.
Fuel consumption	• High due to the high volume of traffic and the low vehicle speeds. Average fuel consumption per vehicle is around 10 liters per kilometer. Fuel consumption can be much higher for vehicles that travel in congested traffic.
Emissions	• Major source of air pollution in GCR. Main pollutants emitted by vehicles in GCR are nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), and levels of PM2.5 and other pollutants often exceeding safe limits.
Traffic flow patterns	• Complex and vary depending on the time of day, day of the week, and time of year. Traffic flow is typically heaviest during peak hours, when people are commuting to and from work or school. Traffic flow is also typically heavier on weekdays than on weekends.
Congestion levels	• High, especially during peak hours. Found on all types of roads in GCR, including highways, main roads, and local roads. Severity of congestion can vary depending on the location, time of day, and day of the week.
Impacts of transportation policies and infrastructure projects	• The public transportation system in greater Cairo is inefficient and overcrowded, leading to long wait times and unreliable service. • Transportation policies and infrastructure projects can have a significant impact on traffic flow and congestion in GCR.

The results of the SUMO simulation model show that traffic congestion is a major problem in Greater Cairo. The average travel time for vehicles in the city is over an hour, and the average speed is less than 20 kilometers per hour. The congestion is particularly severe in the city center and on the major highways.

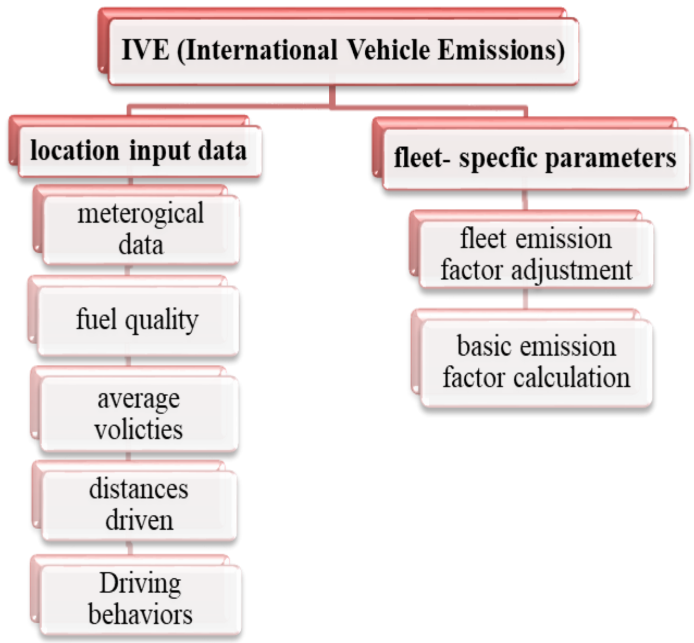
4.3.2 Emission models

These models are used to predict the emissions of pollutants from vehicles using the project as shown in table (4):

Table (4): Emission models

Type	MOVES	EMFAC	PROMETHEUS	IVE
Scope	Fleet of vehicles	Fleet of vehicles	Individual sources	Fleet of vehicles
Data requirements	Vehicle type, fuel type, emission control technology and driving cycle	Vehicle type, fuel type, emission control technology, driving cycle, geographic location	Emission factors, meteorological data and traffic data	Vehicle type, fuel type, emission control technology, driving cycle, geographic location, vehicle speed and vehicle acceleration
Spatial and temporal resolution	1 km, 1 hour	1 km, 1 hour	Varies by source	1 km, 1 hour
Level of detail	Moderate	High	High	Moderate
Availability of data	Widely available	Varies by state	Limited	Limited
Cost	Free	Varies by state	Varies by state	Free
Expertise required	Moderate	High	High	Moderate

In case of Greater Cairo, the Emission model IVE show in figure (5) is an emission model that is specifically designed for vehicles in developing countries like Egypt. It takes into account the factors that are unique to these countries, such as the use of old vehicles with outdated emission control technologies.



Source: Researcher

Fig (5): methodology of the Emission model of IVE

Location Page of the IVE model and Creating a Location File in an Excel Spreadsheet

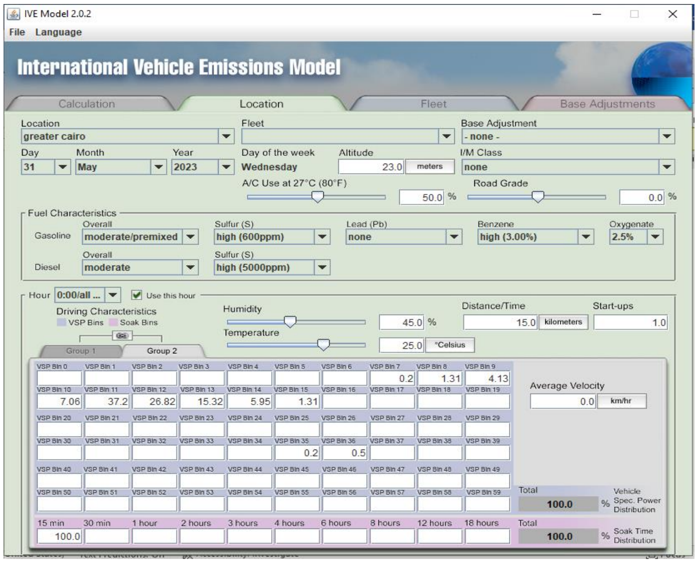
Section 1: Location-Specific Parameters:

Location-specific parameters included meteorological data, fuel quality, average velocities, distances driven, and driving behaviors. Data availability was a significant challenge for this study. Therefore, we used national reports and literature findings to derive the required parameters.

- **Meteorological data**

The city is at a latitude and longitude of 30.0444◦ N and 31.2357◦ E and an altitude of 23 m [13].

Saturday, May 2023, was chosen to simulate a standard workday in Greater Cairo for the base case scenario, with an average temperature of 25 ◦C and average relative humidity of 45% [14].



Source: IVE software interface

Fig (6): Location-Specific Parameters

- **fuel quality**

Lead content in gasoline was set to zero, sulfur and benzene at 600 ppm and 3%, respectively, and oxygenate at 2.5%, while diesel sulfur content was at 5000 ppm [15] [16] [17].

Section 2: Fleet-Specific Parameter:

The fleet-specific parameters of vehicles in Greater Cairo in 2023 are as follows:

- **Vehicle type**: The type of vehicle, such as car, bus, truck, or motorcycle.
- **Fuel type**: The type of fuel used by the vehicle, such as gasoline, diesel, or natural gas.
- **Age**: The age of the vehicle. Older vehicles typically emit more pollutants than newer vehicles.
- **Engine size**: The size of the engine, which affects the amount of power the vehicle has. Vehicles with more power tend to emit more pollutants.
- **Weight**: The weight of the vehicle. Heavier vehicles tend to emit more pollutants than lighter vehicles.
- **Driving behavior**: The way the vehicle is driven, such as the amount of acceleration and braking. Driving aggressively can lead to higher emissions.

The fleet-specific parameters of vehicles in Greater Cairo are important for understanding the sources of air pollution in the city. By understanding the types of vehicles that are on the road and their emissions characteristics, policymakers can develop strategies to reduce air pollution and improve public health.

The following table 5 shows the fleet-specific parameters of vehicles in Greater Cairo in 2023, according to the study "Emissions Control Scenarios for Transport in Greater Cairo":

Table (5): Fleet-Specific Parameter [18] [19]

Vehicle type	Fuel type	Remaining	(Distance traveled by a vehicle throughout its lifetime	Engine size	Weight	Driving behavior
Cars	96% petrol	13% natural gas	42% traveled 80K km and 161K km	1,500 kg	200 kg	Normal
Buses	71% Diesel	2% natural gas.	60% more than 161K km.	10,000 kg	10,000 kg	Normal
Taxis	47% Gasoline	16% natural gas	60% more than 161K km	1,000 kg	1,000 kg	Normal
Trucks	85% Diesel	--	70% more than 161K km.	15,000 kg	15,000 kg	Normal
Motorcycles	96% petrol	--	70% more than 50 km	200 kg	200 kg	Normal

4.3.3 spatial modeling

Spatial modeling are mathematical models that are used to monitor air pollutants and identify most polluted zones using integrated environmental datasets, GIS and remote sensing techniques. This will help to understand the causes of air pollution, develop and evaluate strategies for reducing air pollution, predict the impact of different emission control measures on air quality and identify areas where air quality monitoring is needed in GCR.

A- <u>Building GIS Database for Decision Making and model builder:</u>

In ArcGIS software, geo processing tools can be used to perform spatial analysis and manage all GIS data. Model Builder was used to create, edit, and manage geo processing models that automate those tools. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. Also, Model Builder can be thought of as a visual programming language for building workflows [20].

B- The factors and criteria for measuring and monitoring impacts from transportation sectors

Factors assigned on literature review and expert knowledge as shown in table (6).

Table (6) Data sources and derived factors which have been applied as inputs for the multi-criteria analysis process.

Factors & data	Derived factors	Data Sources
Population	Total population and density	Central Agency for Public Mobilization and Statistics (CAPMAS). Landsat 8. (https://www.capmas.gov.eg. Accessed on 5/5/2023
Greenhouse gasses	(CO_2, CH_4 and N_2O) Emissions & concentrations	Stallete image, sensor: sentinel 5P, spatial resolution 7000m https://www.usgs.gov/core-science-systems/ngp/3dep Egyptian Ministry of Environment (https://www.eeaa.gov.eg)
Other air pollutants	(NO_2, PM 2.5, PM 5 and PM10).	Egyptian Ministry of Environment https://www.eeaa.gov.eg
Surface urban heat island and heat waves	Air temperature, Land surface temperature, Water temperature	
Traffic volume	counting the number of vehicles that pass a particular point over a period of time	Egyptian Ministry of Transportation
Fuel type	Vehicles that use gasoline or diesel fuel & natural gas or electricity.	https://www.capmas.gov.eg. Ministry of Petroleum and Mineral Resources International Energy Agency
Weather conditions	levels of air pollution are typically higher on hot, sunny days than they are on cold, cloudy days.	Egyptian Meteorological Authority (EMA)
Traffic congestion		Egyptian Ministry of Transportation
Land use		Landsat 8 ETM Images. sensor: Landsat TM,ETMT, OLI

The location of monitoring stations		Egyptian Ministry of Environment. https://www.eeaa.gov.eg
Roads network.		https://www.usgs.gov/core-science-systems/ngp/3dep
Shuttle Radar Topography Mission (SRTM) Data	Digital Elevation Model (DEM), slope, aspect and stream network	sensor: ASTER GDEM (http://www.gdem.aster.ersdac.or.jp provided by the US Geological Survey and retrieved from "https://www.usgs.gov/core-science-systems/ngp/3dep. (Accessed on 13 February 2023)
Road network & infrastructure		Landsat 8 ETM Images. sensor: Landsat TM,ETMT, OLI
Traffic congestion, stops, trips		Landsat 8 ETM Images. sensor: Landsat TM,ETMT, OLI
Services		https://www.eeaa.gov.eg https://www.capmas.gov.eg.

A- Normalization

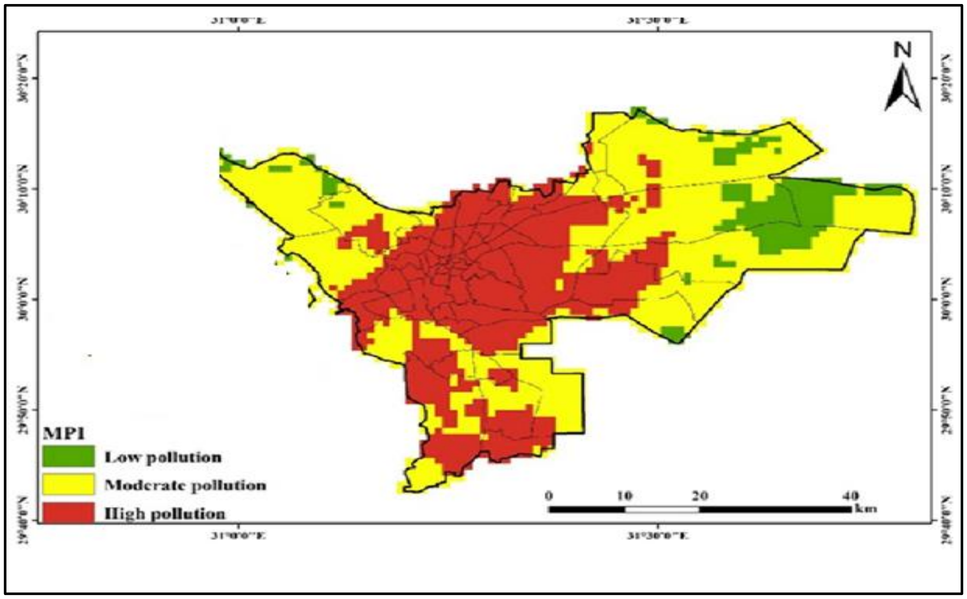
Factors attributes have different measuring scales. In order to perform analysis, standardization has to be performed through transformation of attributes into a common suitability index. For each factor, the attributes were rated in reference to a common scale. Thus for each sub routine, the criteria attributes were transformed from the original values to a common suitability scale ranging from (1) to (9).The higher value being more favorable and vice versa. A value of zero was given to unsuitable pixels.

B- Weighted Combination

A specific weight should then be assigned among all criteria factors in each alternative, since they have different priorities due to the goals and objectives. The Analytical Hierarchy Process (AHP) method is advantageous in determining weights by comparing each factor with other corresponding ones, thus yielding a relative weight, which is better than an absolute weight without any comparison [21]. The criterion weights estimate the perceived importance of individual criterion relative to the other criteria. In the pairwise comparison method, the pairwise comparison matrix is developed by the decision maker depending on the evaluation of the relative importance of any criteria using a scale, which ranges from (1) to (9), where (1) is the least suitable and (9) most suitable [22].

C- Model builder and the map:

The GIS overlay process is used to combine the factors and develop a model then identify the location of most air pollution areas in GCR as shown in figure (7) to identify most areas that have pollution.



Source: Arcmap GIS10.2 software

fig (7): Impacts of road transport on the environment

5. Results and interpretation:

This paper presents a mathematical model for strategic environmental impact assessment (SEIA) of the transportation sector in Greater Cairo. The model is based on a system dynamics approach and takes into account the interactions between different components of the transportation system, such as traffic demand, vehicle emissions, and air quality. The model was developed using an open-source software platform that integrates land use and activity-based travel data with traffic simulation, emissions, and air quality modeling software. This platform provides a new capacity for integrated land use, transportation, and emissions modeling to support air quality planning in metropolitan areas.

The mathematical model and open-source software platform presented in this paper can be used to support decision-making on transportation policies in Greater Cairo. The model can be used to assess the environmental impacts of different policies, identify the most effective policies, and track the progress of implementation. it would help them to make informed decisions about transportation planning and investment that would minimize the environmental impacts of transportation identify the potential environmental impacts of transportation projects at an early stage, assess the cumulative impacts of multiple transportation projects, compare the environmental impacts of different transportation options and identify the most hazardous areas to predict the future impacts of transportation on the environment and identify mitigation measures to reduce the environmental impacts of transportation.

The (IVE) modeling tool can produce a comprehensive emissions' profile of criteria and Toxics, toxic and global warming pollutants as in table 7 shows the maximum concentration of different emission types in Greater Cairo. CO2 has the highest maximum concentration, at 400 ppm. CO has the second highest maximum concentration, at 100 ppm. NOx has the third highest maximum concentration, at 200 ppb. CH4, VOCs, PM10, Sox, Voce Vap, Toxic pollutants, and N2O all have maximum concentrations of 100 ppb or less.

Table 7: the maximum concentration of different emission types in Greater Cairo 2023.

Emission Type	Percentage	Value (tonnes)	Maximum Concentration (µmol/m²)
CO2	93.70%	34,000	400
CO	4.10%	1,400	100
NOx	1.10%	400	200
CH4	0.40%	130	1.8
VOCs	0.40%	130	100
PM10	0.20%	70	100
Sox	0.10%	30	80
Voce Vap	0.10%	30	100
Toxic pollutants	<0.1%	<10	10
N2O	<0.1%	<10	0.3

Source: Researcher depend on data from IVE software

Air quality models was used to help understand the causes of air pollution, develop and evaluate strategies for reducing air pollution, predict the impact of different emission control measures on air quality and identify areas where air quality monitoring is needed in Greater Cairo. The model found that vehicle emissions are a major contributor to air pollution in the city. The model predicts the future impacts of road transport on the environment as shows above in figure (7).

6. Conclusion, Recommendation and Future Studies:

6.1 Conclusion

Air pollution, primarily from gases, odors, and particulate matter, poses a significant threat to human health and the environment, causing millions of deaths annually worldwide. In Greater Cairo, transportation is a major contributor, with pollution levels exceeding international standards. This paper develops a mathematical model to assess the environmental impact of various transportation policies in the region.

The model utilizes an open-source platform, integrating land use, travel data, traffic simulation (using software like VISSIM, SUMO, Trans Modeler, PARAMICS), and emission modeling (MOVES, EMFAC, PROMETHEUS, IVE). It incorporates spatial modeling, GIS, and remote sensing to enhance data coverage and analysis. The paper concludes that the developed platform and model can effectively support environmental impact assessments, track progress, monitor pollutants, and identify pollution hotspots, ultimately aiding in informed decision-making for a more sustainable transportation system in Greater Cairo.

6.2 Recommendation:

This study presents a valuable framework for assessing the environmental impact of transportation policies in Greater Cairo using a mathematical model and open-source platform. Based on the findings, the following recommendations and future research directions are suggested:

- **Data Enhancement:** A crucial recommendation is to improve the availability and quality of environmental data for the GCR. This includes more comprehensive and regularly updated data on traffic volume, vehicle types, emissions, meteorology, and air quality. Investing in monitoring stations and data collection infrastructure is essential. Specifically, gather more granular data on driving behavior (e.g., acceleration, braking patterns) to refine emission estimates.
- **Policy Evaluation and Implementation:** The developed model should be used to evaluate a wider range of transportation policies, including public transport improvements (e.g., bus rapid transit, metro expansion), traffic management strategies (e.g., congestion pricing, parking restrictions), promotion of non-motorized transport (e.g., cycling infrastructure), and incentives for electric

vehicle adoption. The model can also be used to track the effectiveness of implemented policies and make adjustments as needed.

- **Mitigation Strategy Development:** The model should be applied to develop specific mitigation strategies for air pollution in the GCR. This could involve identifying optimal combinations of policies, targeting pollution hotspots, and considering the social and economic impacts of different interventions. Explore the potential of integrating green infrastructure (e.g., urban green spaces) into transportation planning to mitigate air pollution.
- **Stakeholder Engagement:** Engage with stakeholders, including government agencies, transportation planners, and the public, to ensure that the model is used effectively in decision-making. Disseminate the model's findings and promote transparency in the policy-making process.
- **Capacity Building:** Invest in capacity building to train local experts in using and maintaining the model. This will ensure the long-term sustainability of the project and promote its wider application in Egypt.

6.3 Future Studies:

This study provides a solid foundation for understanding the environmental impacts of transportation policies in Greater Cairo. However, there are several areas where future research can expand and refine these findings:

- **Model Refinement:** The model can be further refined by incorporating additional factors, such as noise pollution, land use changes, and the impact of climate change on transportation. Explore the use of machine learning techniques to improve the accuracy of traffic simulation and emission models.
- **Health Impact Assessment:** Conduct a health impact assessment to quantify the health benefits of different transportation policies. This will provide a stronger justification for investing in sustainable transportation solutions.
- **Economic Analysis:** Conduct a cost-benefit analysis of different transportation policies, considering both the environmental and economic impacts. This will help decision-makers prioritize investments and maximize the overall benefits.
- **Spatial Disaggregation:** Develop a spatially disaggregated model to analyze air pollution at a finer scale. This will help identify pollution hotspots and target interventions more effectively.
- **Long-Term Projections:** Use the model to project the long-term impacts of transportation policies on air quality and public health. This will help inform long-term planning and investment decisions.

- **Integration with Other Models:** Explore integrating the transportation model with other environmental models, such as air quality dispersion models, to provide a more holistic assessment of environmental impacts.
- **Comparative Studies:** Conduct comparative studies with other megacities facing similar transportation challenges to identify best practices and lessons learned.

By addressing these recommendations and pursuing these future research directions, the developed model can become a powerful tool for promoting sustainable transportation and improving air quality in Greater Cairo. This will contribute to a healthier environment and a better quality of life for residents of the region. Future research should focus on refining SEA methodologies, incorporating advanced predictive analytics, and exploring the economic feasibility of sustainable transport initiatives. By strengthening institutional frameworks and fostering international cooperation, cities can achieve a balanced approach to transportation planning that supports economic growth while preserving environmental integrity.

Future research should focus on refining the mathematical model by incorporating additional variables such as socio-economic impacts and technological advancements in sustainable mobility. Additionally, expanding the study to include comparative analyses with other metropolitan regions can provide deeper insights into global best practices for urban transport planning. By leveraging smart policies and strategic investments, cities can transition towards a more sustainable, efficient, and equitable transportation future. This research provides a foundation for policymakers to develop long-term, data-driven urban mobility strategies that balance economic growth, environmental protection, and social equity.

Reference:

1. Abd-Elaty et al., (2021). Management of saltwater intrusion in coastal aquifers using different well systems: A case study of the Nile Delta aquifer in Egypt. Hydrogeology Journal, 29(5), 1767–1783.
2. Abou-Senna et al., (2013). Using a traffic simulation model (VISSIM) with an emissions model (MOVES) to predict emissions from vehicles on a limited-access highway. Journal of the Air & Waste Management Association, 63(7), 819–831.
3. Ali et al., (2025). Mathematical model to support the strategic environmental impact assessment of the transportation and road sector applying on case study (Greater Cairo) (Doctoral dissertation, Cairo University).
4. Armanuos et al., (2023). Groundwater in the Nile Delta Aquifer, Egypt: Assessment, modelling and management with climate change in the core. In Groundwater in Arid and Semi-Arid Areas (pp. 233–287).
5. CAPMAS. (2020). Statistical Yearbook: Transport and communication. Cairo, Egypt: Central Agency for Public Mobilization and Statistics.
6. Chandio et al., (2013). GIS-based land suitability analysis of sustainable hillside development. In the Fourth International Symposium on Infrastructure Engineering in Developing Countries (IEDC).
7. Darwish, K. S. (2023). Assessment of the Nile Delta's coastline dynamics: A remote sensing and GIS-based computational approach. In Hazard Modeling and Assessment of the Nile Delta Coast (pp. 101–128).
8. Darwish, K. S. (2023). Geospatial assessment and mapping of coastal erosion vulnerability along the Nile Delta coast: A remote sensing and GIS approach. In Hazard Modeling and Assessment of the Nile Delta Coast (pp. 181–218).
9. El Banna, M. M. (2007). Erosion and accretion rates and their associated sediment characters along Ras El Bar coast, northeast Nile Delta, Egypt. Environmental Geology, 53(1), 41–49.
10. El-Ganzori et al., (2012). Towards a climate change adaptation strategy for the water sector in Egypt. UNESCO Cairo Office.
11. El-Nahry, A. H., & Doluschitz, R. (2010). Climate change and its impacts on the coastal zone of the Nile Delta, Egypt. Environmental Earth Sciences, 59(7), 1497–1506.
12. Elshinnawy, I. A., & Almaliki, A. H. (2021). Vulnerability assessment for sea level rise impacts on coastal systems of Gamasa Ras El Bar area, Nile Delta, Egypt. Sustainability, 13(24).

13. Fouda et al., (2021). Report on the baseline situation for IMAP common indicator 15. Egypt.
14. Glasson et al., (2019). Introduction to environmental impact assessment (4th ed.). Routledge.
15. González, A. (2012). GIS in environmental assessment: A review of current issues and future needs. Environmental Assessment Policy and Management.
16. Hegazy, E. H. A., & Mohamed, N. (2014). Resource-based zoning map for sustainable industrial development in North Sinai using remote sensing and multicriteria analysis. International Journal of Sustainable Development and Planning, 9(4).
17. Hemida et al., (2023). A systematic review of coastal vulnerability assessment methods in the Egyptian context: The case study. HBRC Journal, 19(1), 161–181.
18. Hereher, M. E. (2010). Vulnerability of the Nile Delta to sea level rise: An assessment using remote sensing. Geomatics, Natural Hazards and Risk, 1(4), 315–321.
19. Hereher, M. E. (2013). Coastal vulnerability assessment for Egypt's Mediterranean coast. Geomatics, Natural Hazards and Risk, 6(4), 342–355.
20. Hobbs, B. F. (1980). A comparison of weighting methods in power plant siting. Decision Sciences, 11(4), 725–737.
21. Howari et al., (2007). Application of GIS and remote sensing techniques in identification, assessment, and development of groundwater resources. Applied Geomatics, 1(3–4), 113–125.
22. Hussein, M. M. A., & Mohamed, E. E. E. (2016). Temperature trend over Nile Delta, Egypt in the 20th century. Advances in Research, 7(2), 1–14.
23. Information and Decision Support Center. (2021). Vehicles in Egypt—Figures and Facts. Cairo, Egypt.
24. International Transport Forum (ITF). (2003). Strategic environmental assessment in the transport sector. OECD Publishing.
25. IPCC. (2023). Sixth Assessment Report.
26. Japan International Cooperation Agency (JICA). (2002). Transportation master plan and feasibility study of urban transport projects in Greater Cairo Region in the Arab Republic of Egypt: Phase I final report (Volume III: Transport master plan).
27. Kassem et al., (2019). Climate change adaptation in the Delta Nile region of Egypt: Implications for agricultural extension. Sustainability, 11(3).

28. Kumar et al., (2020). A review on impact of climate change on water resources in a river basin. International Research Journal of Engineering & Applied Sciences (IRJEAS), 8(3).
29. Ladi et al., (2022). Assessing environmental impacts of the transportation sector by integrating DPSIR framework and X-Matrix. Case Studies on Transport Policy, 10(1), 434–443.
30. Lin, X., & Zhang, Y. (2013). Multi-criteria GIS-based procedure for coffee shop location decision (Bachelor's thesis, Hogskolan I Gavle).
31. Malczewski, J. (2006). GIS-based multi-criteria decision analysis: A survey of the literature. International Journal of Geographical Information Science, 20(7), 703–726.
32. May, A. D. (1990). Traffic flow fundamentals. Prentice Hall Englewood Cliffs.
33. Mourad, K. A., Nordin, L., & Andersson-Sköld, Y. (2022). Assessing flooding and possible adaptation measures using remote sensing data and hydrological modeling in Sweden. Climate Risk Management, 38.
34. Neira et al., (2023). Climate change and human health in the Eastern Mediterranean and Middle East: Literature review, research priorities, and policy suggestions. Environmental Research, 216.
35. Phillips, J. (2012). The application of a mathematical model of sustainability to the results of an environmental impact assessment of the Russeifa landfill, Jordan. International Journal of Environment and Pollution, 49(Published online).
36. Pichugina, O. (2020). Mathematical modeling of transport logistics problems. In the 2nd International Conference on System Analysis & Intelligent Computing (SAIC) (Kyiv, Ukraine).
37. Searle, S., & Malins, C. (2016). Case study: The Egyptian Refining Company Project in Cairo. The International Council on Clean Transportation.
38. Shanthikumar, R. S. J. G. (1983). A unifying view of hybrid simulation/analytic models and modeling. Operations Research, 31(6), 1030–1052.
39. Shehata et al., (2018). Monitoring and modelling of variables affecting isomerate octane number: An industrial isomerization process. Egyptian Journal of Petroleum, 27, 945–953.
40. Youssef, M., & El-Abyad, A. (2015). Fuel quality roadmap for Arab States. Centre for Environment and Development in the Arab Region and Europe (CEDARE).

Websites:

1. "https://nilebasin.org/goals/climate-change-adaptation," [Online].
2. "https://www.delta.com/us/en/delta-vacations/africa-and-middle-east-vacations/cairo-vacation-packages," [Online].
3. "https://www.ipcc.ch/," [Online].
4. "https://www.fao.org/climate-change/en," [Online].
5. "https://www.worldwatercouncil.org/en," [Online].
6. "https://link.springer.com/book/10.1007/978-3-319-56124-0," [Online].
7. "https://link.springer.com/book/10.1007/978-3-319-56124-0," [Online].
8. "https://www.ramsar.org/," [Online].
9. Weather.com. *Climate in Cairo, Egypt*. Retrieved May 31, 2023, from https://www.timeanddate.com/weather/egypt/cairo/climate