The Impact of Industrial Air Pollution on the Urban Environment of Setif

Modeling and Mapping of Total Suspended Particles

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Abstract-Setif is one of the urban agglomerations most exposed to the problem of air pollution, which mostly arises from the industrial zone located on its immediate outskirts, as is the case with a large number of Algerian cities. Due to its size and the nature of its activities, Setif is a significant source of industrial pollution. Numerous experts agree that the majority of present air pollution analysis techniques are limited to predicting the dispersion of pollutants. However, restricting oneself to these usually rigid aspects impedes the proper management of this sort of urban nuisance harming the city and its surroundings. Consequently, the aim of this study is to propose an approach for assessing the danger of air pollution that can be simply applied to any terrain. This technique includes three primary stages. Initially, ARIA Impact software is used to develop a model of the Total Suspended Particles (TSP). Using the Analytic Hierarchy Process technique, the many human, material, and environmental issues are then plotted on a map. The last step is to build synthesis maps by crossing the theme maps developed in the first two steps. Consequently, the anticipated outcome of this study is that the industrial zone of Setif will serve as the basis for a methodological exercise generated from a real-world situation. The examination of the current case study will illustrate the reliability of dispersion models in the evaluation of industrial pollution provided that certain essential aspects are recognized and handled effectively.

Keywords-air pollution; industrial zone; modeling; mapping; Setif

I. Introduction

Setif, the capital of the Algerian highlands, is a mostly agricultural city that has prospered from a substantial industrial infrastructure, including a 282-hectare industrial zone. Due to its size and the nature of activities conducted there, the industrial zone of Setif generates all types of nuisance and pollution, especially atmospheric pollution due to the emission of pollutants and noxious gases, which are likely to harm the environment and the local population. Many contaminants are released into the atmosphere. Even though their concentrations are very low (usually measured in $\mu g/m^3$), they pose a threat to human health [1].

Pollutant dispersion in the atmosphere is a significant concern for the scientific community and many researches concentrate on the modeling of the dispersion of industrial air pollution. Authors in [2] have experimented with the dispersion of pollutants from a chimney using two measurement techniques: laser tomography, which enables the visualization of the evolution of a feather over a long distance, and PIV, which aims to determine the speed and vorticity fields. Authors in [3] proposed an air dispersion model to monitor and compute the fluctuation of the concentration of a pollutant at various distances from the source using a real-world numerical example. In the same vein, the author of [4] created a technique dubbed Flow'Air-3D based on an operational computer code that enables the near-real-time monitoring of pollutants on an industrial site. The latter has deduced that atmospheric dispersion modeling is an intriguing analytical method since it permits the monitoring of an industrial site and the mapping of concentrations in the area around the site. Further, authors in [5] have dealt with the modeling of atmospheric dispersion phenomena and the study of air flows at the boundary layer. Fuzzy logic was used to quantify the uncertainties associated with ammonia leakage at an industrial facility. Dealing with the issue of industrial emissions in metropolitan areas, researchers in [6] addressed the requirement to anticipate the concentration of air pollutants such as negative ozone and volatile organic compounds based on a model of Artificial Neural Networks (ANNs). Authors in [7] performed a random investigation of

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PM10 and PM2.5 (Particulate Matter with maximum diameter of 10 and 2.5μm respectively) in various metropolitan locations to examine the presence of other air pollutants, which is the focus of the current study. Notably, the current research focused on dust particles resulting from the open burning of solid waste and traffic patterns, which have a substantial impact on air quality. Authors in [8] centered on a novel method given in the form of an econometric model for the estimation of pollutant emissions created by civil aviation and affecting airports and the urban fabric around this neuralgic structure. Author in [9] undertook a methodological review that sought to comprehend the biogeochemical cycles that regulate the amounts of various air contaminants. According to him, numerical modeling is a scientific method of enveloping that involves solving mathematical equations reflecting the biogeochemical cycles and their dynamics. This strategy depends heavily on the computational capabilities of computers.

In this regard, the current paper will concentrate on one of these components of air pollution by, to begin with, modeling the dispersion of pollutants created by the electrochemical complex that comprises a substantial portion of the Setif industrial zone. Moreover, digital mapping to geographically locate the influence of this pollution on the urban environment of Setif is implemented. The novelty of this work consists in the use of cartography to simulate the amount of pollution in the city of Setif and its effect on the urban environment.

II. PRESENTATION OF THE CASE STUDY

A. The Industrial Zone of Setif

According to the 2022 annual report compiled by the Establishment for the Management of Industrial Zones, among Algeria's 113 industrial zones, the Setif zone, situated 2km south of the city of Setif, is now one of the most prominent. Its significance is determined by the quantity and caliber of businesses situated there. There are now 202 firms in the zone, of which 32 are state- and 170 are private-owned, occupying 68 and 144 hectares respectively. The industrial zone is bounded to the east by the Wilaya road number 112 heading to Batna, to the west by the Constantine-Alger portion of the railway, to the south by the agglomeration known as Ain Trik, and to the north by the zone of Setif adjacent to the activity zone [10] (Figures 1, 2).

B. Operating Companies in the Industrial Zone

The first industrial units were established in the industrial zone of Setif between 1970 and 1982 [10]. These units are quite diverse in terms of their type of activity. Hence, production, realization, storage, distribution, and service provision units dispersed can be distinguished by sector. As seen in Figure 3, the enterprises operate in various plastics-related, electrochemical, electrical, building and construction material, food processing, and service sectors. The nature of the operations conducted there can be considered to be light industrial, not requiring a great deal of raw materials and labor, and using little space, water, and energy (Figure 1).

Fig. 1. Location of the the industrial zone in relation to the city of Setif (screenshot from Google Earth, © CNES/Airbus, Landsat/Copernicus, Maxar Technologies).

Fig. 2. General overview of the industrial zone of Setif.

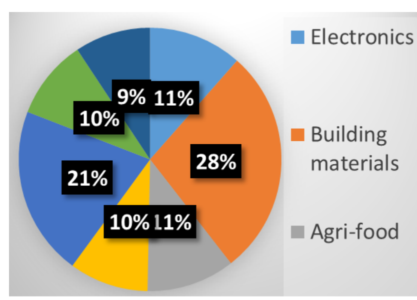

Fig. 3. Distribution of industrial compagnies in the area of Setif by sector of activity (data source: Industrial Zone Management Establishment).

C. The Industrial Zone as a Source of Air Pollution

According to the field study carried out and the data acquired by the director of the environment of Setif, the most polluting industrial units in terms of atmospheric pollution are mainly: the brickyard (EL AFAK: construction materials and ceramics), the national electrochemical products (NCEP) with its three components: lead refining, electrolytes, batteries and accumulators, and to a lesser degree the plastic processing units such as: KPLAST, SOFIPLAST, ALMOULES and CALPLAST (Figure 4).

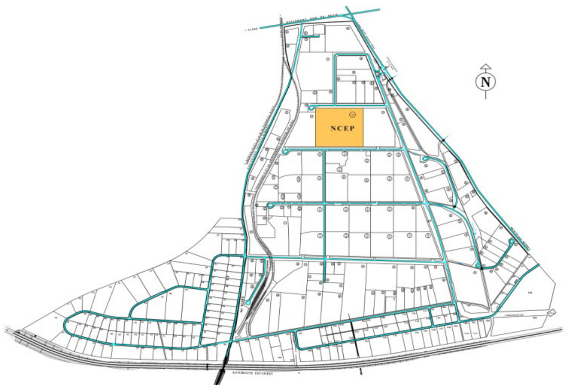

Fig. 4. Location of the the NCEP complex (source: Industrial Zone Management Establishment treated by the authors, 2022).

Fig. 5. Chimney of the NCEP complex - lead refining unit.

For the complex NCEP, the sulfuric vapors emitted from its chimney release acids. At the same time, lead dust is primarily a result of the massive exploitation of lead, which is essential for this electrochemical industry. However, it is important to note the existence of a system for the treatment of atmospheric rejects at the level of this complex (Figure 5).

The data presented below confirm that the values of gas concentrations (NO_x, total hydrocarbons) are below the standards recommended by various international organizations such as the World Health Organization (WHO) and the USA Environmental Protection Agency (EPA), with the exception of total dust loaded with lead (in suspension), which recorded a dust concentration of 406.72g/m^3 exceeding the standard set by EPA (Figure 6) and WHO (Figure 7).

These aggressive air pollutants deteriorate the hues, alter the look of the structures, giving them an unattractive appearance, and cause physical degradation in all circumstances. Lead emissions are a significant cause of environmental pollution. Once deposited on soil, plants, and surface waterways, lead may enter the food chain. According to [11], lead particles may be carried great distances in the atmosphere, sometimes up to hundreds of kilometers from their source, before being deposited by precipitation. As lead is neither biodegradable nor degradable, the body takes around 20 years to clear it. The neurological effects of lead poisoning in childhood may last a person's whole life [11].

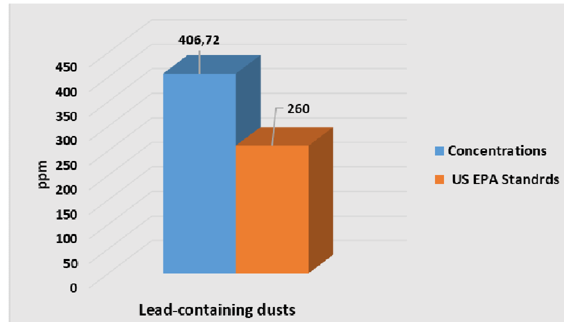

Fig. 6. Atmospheric discharges (lead-containing dusts) from NCEP.

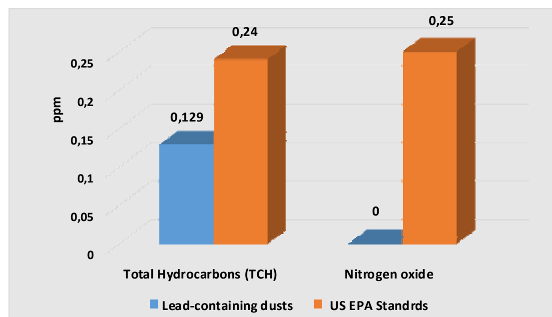

Fig. 7. Atmospheric discharges (hydrocarbons and NO_x) from NCEP.

III. MATERIALS AND METHODS

As stated above, this research entails 3 main phases. Using the ARIA Impact, the TSP emerging from the electrochemical complex as the primary source of air pollution is primarily estimated. Then, using many thematic maps of the city of Setif, different human, material, and environmental stakes susceptible to this form of industrial nuisance are detected. Lastly, a cross-reference of the digital maps created during the previous 2 stages will be used to illustrate the magnitude of the air pollution and its influence on the urban environment of Setif.

A. Phase One: Modeling the TSP Using the ARIA Impact Software

The modeling aims to anticipate the concentrations of different pollutants around the industrial site of the electrochemical complex NCEP and their mode of dispersion over the whole city of Setif. The pollutants modeled will be the Total Suspended Particles (TSP) rejected by the lead refining plant. ARIA Impact enables the development of meteorological data and the determination of the influence of emissions from a single or many points, lines, or surface sources. Using climatic data characteristic to the location, it is possible to simulate many years of operation. At the end of this simulation, themed maps (Figures 11-13) were created to illustrate the scope of the air pollution caused by the Setif industrial zone.

1) Materials Required for Modeling

The use of ARIA Impact software requires the following hardware:

- A baro-thermo-hygrometer (BTHR918) was used to measure the ambient temperature, atmospheric pressure, and relative humidity. This device allows controlling these climatic elements: air temperature (accuracy of 0.1°C), relative humidity (accuracy of 1% RH), and atmospheric pressure (accuracy of 0.3mb).
- A High Volume Sampler (HVS): The Portable Tripod High Volume Air Sampler GT2001 from Andersen is a compact unit that consists mainly of a protective housing, an electric motor, a high flow fan (1.1-1.7m^3/min), a support capable of holding a 20cm×25cm filter, and a flow selector/flow time indicator. The TSP drawn in enters through the space between the cover and the support structure of the filter holder. The air velocity required for effective TSP collection is between 20 and 35cm/s. The shape of the collector roof allows the intake air to be well distributed on the surface of a G810 binderless glass fiber filter where the suspended dust is trapped. The TSP sampler is certified by the U.S. EPA.
- Portable gas analyzers: PHYWE portable gas analyzers are used to measure the concentration of CO_2, CO, NO, and total hydrocarbons. Their use requires a preliminary calibration thanks to appropriate gas bottles. The analyzers are connected to gas probes that are automatically recognized by the portable analyzers. These probes integrate a measuring cell with an infrared transmitter and receiver.

2) General Conditions for Modeling

As previously indicated, the modeling will anticipate the concentrations of different pollutants in the vicinity of the electrochemical complex at the level of the Setif industrial zone in order to compare them with the applicable international criteria. The contaminants modeled are mostly TSP. Notably, other pollutants such as benzene, arsenic, polycyclic aromatic hydrocarbons, and butadiene are excluded from this modeling because they do not pose a risk due to the fact that the melting process (rotary kiln) permits sufficiently high temperatures to achieve their nearly complete combustion. Those modeling periods for which criteria have been defined are used. The followed standards are stated in Tables I and II:

TABLE I. AIR QUALITY STANDARDS

Time Interval	TSP
24 hours	260μg/m^3
1 year	70μg/m^3

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial risks, 2022

TABLE II. PARTICLES AND LEAD DEPOSITION GUIDELINES

Pollutant Interval	Particles
1 year	350mg/m^2.day

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial Risks, 2022

3) Input Data Required for Modeling

The software used for the modeling requires hourly meteorological data as well as topographical data of the modeled area. The hourly meteorological data for the Setif region are summarized in Table III. The physical data are summarized and reported in Table IV.

TABLE III. METEOROLOGICAL DATA DEPLOYED FOR MODELING

Parameter	Average
Temperature (°C)	36.5
Atmospheric pressure (mb)	600
Relative humidity (%)	21

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial Risks, 2022

TABLE IV. PHYSICAL DATA

Parameter	Unit	Concentration	EPA standard
Total suspended dusts	μg/m^3	406.72	260
CO_2	ppm	244	Greenhouse gases
Total hydrocarbons	ppm	0.129	0.24 for 3 hours
CO	ppm	0	35 for 1 hour
NO	ppm	0	0.25 for 1 hour for NO_x

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial Risks, 2022

4) Emission Sources

The emission stack for gases from the melting process taking place in the rotary kiln represents the emission source that is distinguished by the following characteristics:

- Emission factors corresponding to existing processes were applied for TSP pollutants.
- These emissions are stationary and point sources.
- The pollutants are discharged at the stack of the above-mentioned source.
- The gas cleaning efficiency retained in the present study is 75%.
- Emission parameters are calculated based on the consumption of an annual quantity of 9000 tons of scrap metal and are summarized in Table V.

TABLE V. EMISSION PARAMETERS

Sources of Release	Solder flux	
Chimney height (m)	15	
Chimney diameter (m)	1.2	
Output temperature (K)	328	
Output speed (m/s)	1.2	
Purification efficiency	75%	99%
Mass Flow Rate (g/s)		
Lead particles	4 10^{-3}	0.1
TSP	0.15	0.6

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial Risks, 2022

5) Limitations of Using the ARIA Impact Software

Some quantities are relatively easy to measure regularly (quantities of atmospheric or water discharges, volumes of industrial waste). However, others are much more difficult to measure, either because of their very nature (nature of the pollutants: gases, heavy metals) or because of their randomness or rarity (mechanism of diffusion of the pollutants according to their nature and the meteorological conditions). Generally, the likelihood of the phenomena will be determined using historical data and the consultant's observations.

B. Phase Two: Digital Mapping of Human,Material, and Environmental Issues

The spatialization of the stakes involves identifying, locating, and assessing the vulnerability of the three primary classes of stakes (human, environmental, and material) to the many types of pollution caused by the industrial zone of Setif. The approach entails a decomposition of the data collected initially by the statistical services of the municipality of Setif, followed by a recomposition according to the population density and the presence of material and environmental stakes on the space of the city in the form of homogeneous sets based on the Analytic Hierarchy Process (AHP) methodology [12]. This technique offers the benefits of being user-friendly, versatile, and adaptive.

1) Thematic Map of Human Issues

The current study will concentrate on the human stakes in 12 urban districts. These goals may be assigned vulnerability criteria to improve the use of basic residential density. Therefore, the population density given as the number of people per hectare are taken into account, as indicated in Table VI. The statistics are given by the municipality's statistical services. The thematic map of the human stakes distributed on the urban sectors of the city of Setif is illustrated in Figure 8.

TABLE VI. URBAN DISTRICTS CONSTITUTING THE CITY OF SETIF

Number	District	2018 Population	Surface area (hectares)
01	Saal Bouzid	45784	288.90
02	Belkhired Hassen	28973	527.37
03	05 Juillet 1962	38518	165.50
04	08 Mai 1945	60464	236.05
05	Tlidjene Abderahmane	24445	326.50
06	El Hassi	16281	1409.38
07	Laid Edhahoui	70829	2607.66
08	Cheikh El Aifa	79600	2484.67
09	Ferhat Abbes	71941	583.03
10	M. lemine Debaghine	50872	2742.32
11	1er Novembre 54	67599	506.34
12	Ain Trick	21350	1215.78

Source: authors assisted by the Consulting Firm of Expertise in Environment and Industrial Risks, 2022

2) Thematic Map of Material and Economic Issues

The material issues can be classified into 5 major classes, divided into more detailed targets as shown in Figure 9.

- Residential buildings: Collective housing, residential subdivision (individual housing).
- Buildings with economic activities: Banks, etc.
- Buildings with various activities: Administration, worship (mosques), education (schools, universities), health (hospitals, clinics, health centers), heritage, entertainment (youth centers, cinemas, amusement parks, etc.), cemetery.
- Transport infrastructure: urban roads, public transport, pedestrian areas.
- Energy networks: electricity and gas.

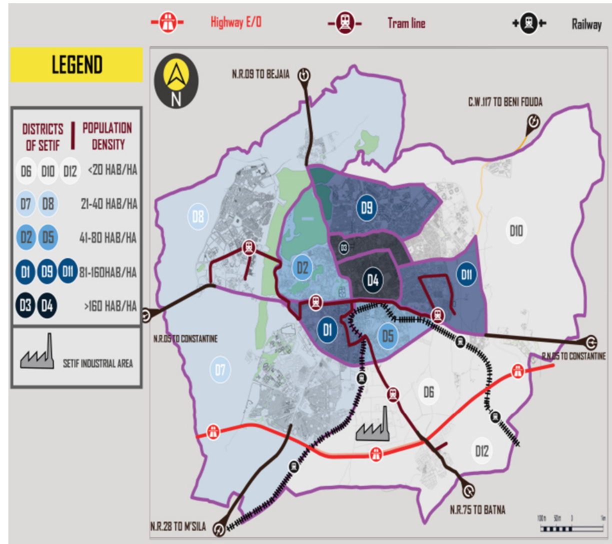

Fig. 8. The produced map of human issues present in the city of Setif.

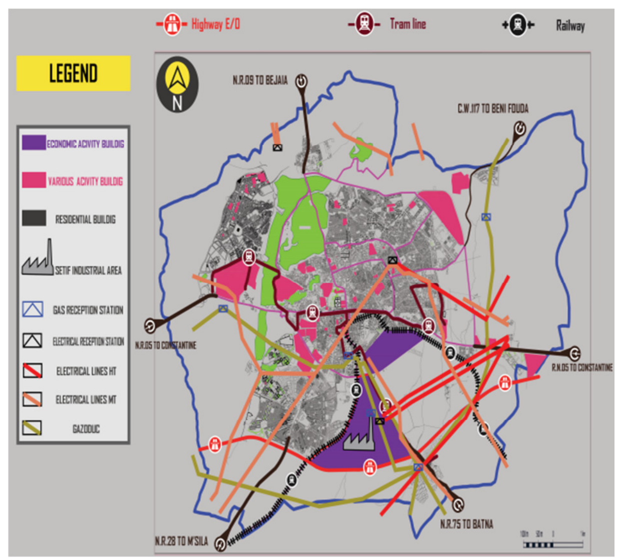

Fig. 9. The produced map of material and economic issues present in the city of Setif.

3) Thematic Map of Environmental Issues

Finally, grouping the environmental issues resulted in 8 major groups which are:

- Developed green space.
- Agricultural space.
- Protected natural areas: classified wooded areas, sensitive natural areas.
- Aligned trees.

- Potable water catchment areas.
- Water resources: Main watercourses, secondary watercourses.
- Remarkable natural heritage.

It should be noted that the environmental and material criteria were compiled using the database developed by the Center of Studies and Realizations in Urbanism of Setif as part of the study of the Inter-municipal Master Plan for Urban Development and Planning of Setif.

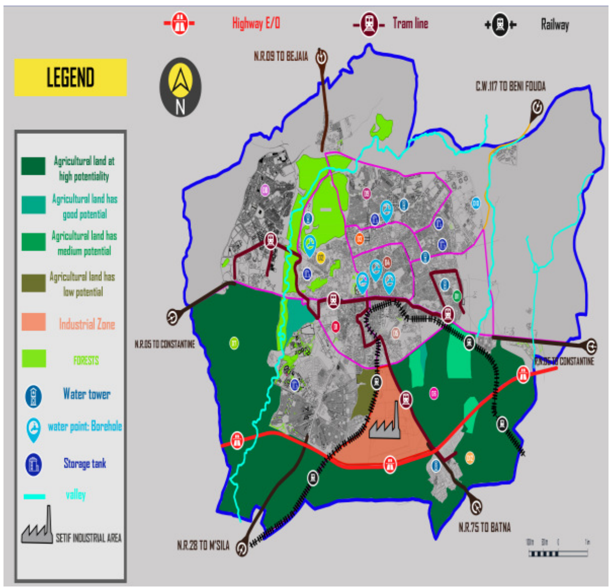

Fig. 10. The produced map of environmental issues in the city of Setif.

C. *PHASE Three: Cross-Referencing of Thematic Maps and Location of Urban Sectors Exposed to the Problem of Air Pollution of Industrial Origin*

During the last step of this digital mapping technique, the urban vulnerability of the city of Setif will be highlighted via theme synthesis maps, from which the urban regions most vulnerable to the pollution issue, will be spatialized with great accuracy. This technique will continue by superimposing and intersecting theme maps: those of the atmospheric pollutant modeling performed in the first phase and the thematic map of human, material, and environmental concerns from the second phase. Thus, with the technology of digital mapping, particularly that of the superposition of vectorial layers, a thematic map of synthesis will be created, depicting the urban sectors sensitive to the air pollution emerging from the Setif industrial zone.

IV. RESULTS AND DISCUSSION

A. *Modeling (Phase I)*

The amount of exposure can be determined by comparing the values of the maximum concentrations of the modeled contaminants to the appropriate environmental criteria. Each contaminant will be treated individually. Dust generated from the combustion of boilers and furnaces is less than 1μm in size. Remember that for the modeling of air pollutants emitted from the chimney of the electrochemical complex, TSP with 75% purification efficiency were deployed. The maximum daily concentration and yearly mean concentration of TSP are projected to be 15.54 and 0.272g/m^3 respectively (Figures 11 and 12). The predicted yearly average deposition is 0.74mg/m^2.day (Figure 13).

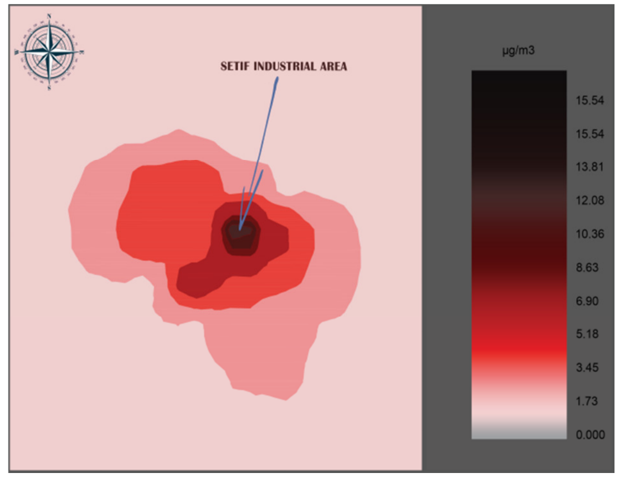

Fig. 11. Daily maximum concentrations of total particles related to the refining operations around the NCEP site (μg/m^3).

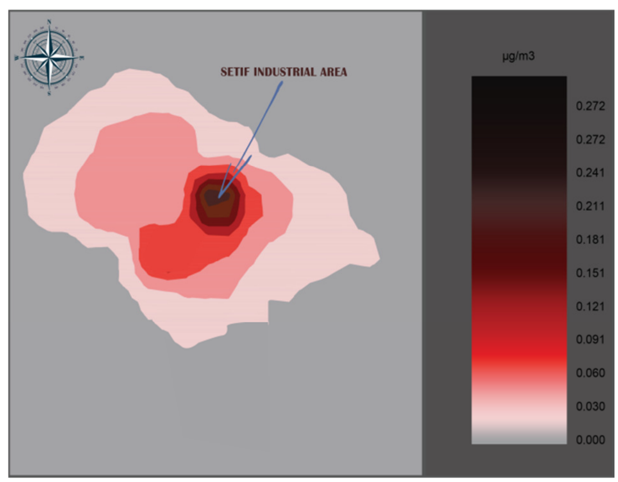

Fig. 12. Annual average concentrations of total dust related to refining operations around the NCEP site (μg/m^3).

B. *Digital Mapping (Phases II and III)*

The susceptibility map to industrial air pollution was developed by superimposing multiple thematic maps relevant to the topic, namely the air pollution maps derived by the modeling of the TSP (Figures 11-13) and those of the pervasive concerns at the municipal level (Figures 8-10). Cross-referencing these maps resulted in the following conclusions.

As shown by the maps of theme synthesis (Figures 14-16), the urban sectors most sensitive to the issue of industrial air pollution are those with a large population density in the vicinity of the industrial zone of Setif. Thus, the urban fabrics most exposed to this type of environmental risk would be the entire southern portion of the city, including the city center and its surrounding historical suburbs, such as Tlidjène neighborhood, Beau Marché street, Bounechada street, Faubourg de la Gare, and Ain Sfiha. These sectors are marked as D2, D5, and D6 in Figure 14. On the other hand, the neighborhood of Ain Trik, which represents urban sector D12 in Figure 14, is clearly the area that continues to experience industrial air pollution at the most alarming rate. This is mostly due to the impacts of the prevailing winds (northerly winds) as the primary vector for the dispersion of gaseous pollutants on the one hand and the high population density on the other. As for the area of Setif, whose susceptibility is categorized as average, it encompasses a significant amount of the city, including the old districts Yahiaoui, Belair, Cheminots, Langare, Maaboud, the amusement park, the hospital, the financial city, and the administrative city. The unseen, but severe long-term impacts of air pollution on human health and the built environment threaten these tangible and of economic interests districts.

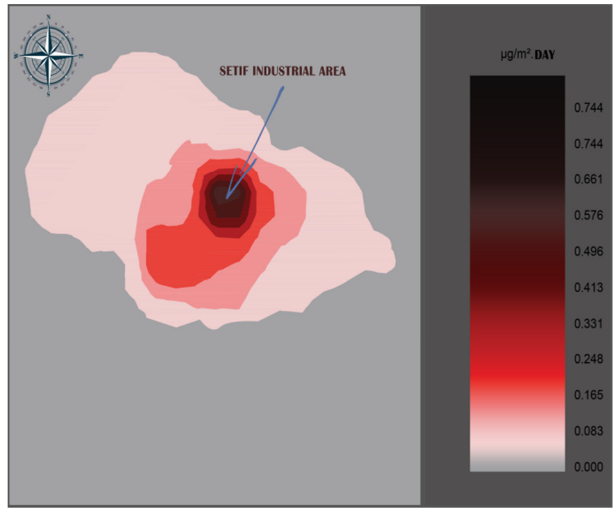

Fig. 13. Annual TSP from refining operations around the NCEP site (mg/m^2.day).

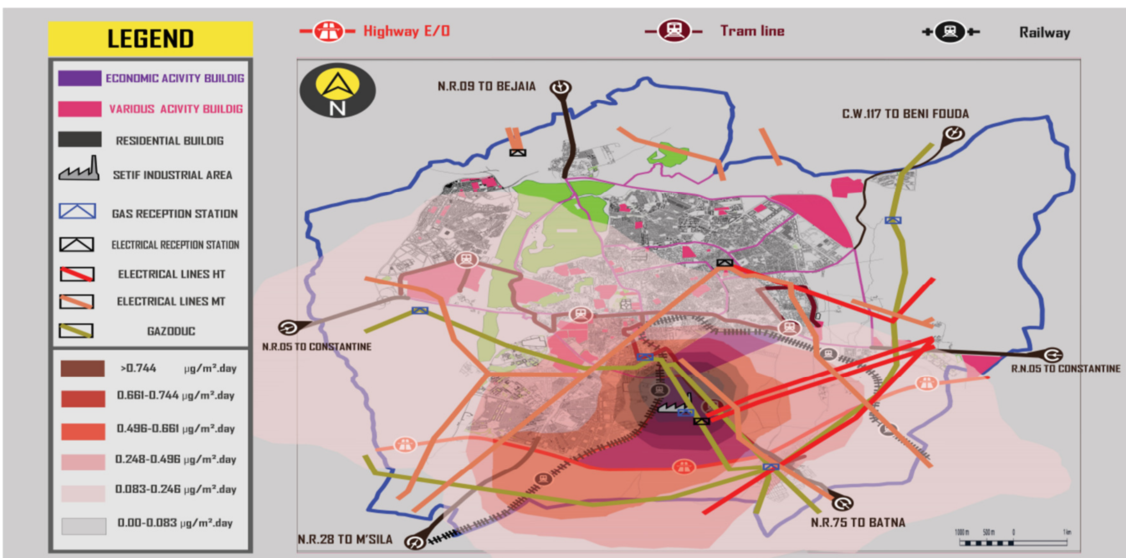

Fig. 14. Vulnerability of humans issues to industrial air pollution in the city of Setif.

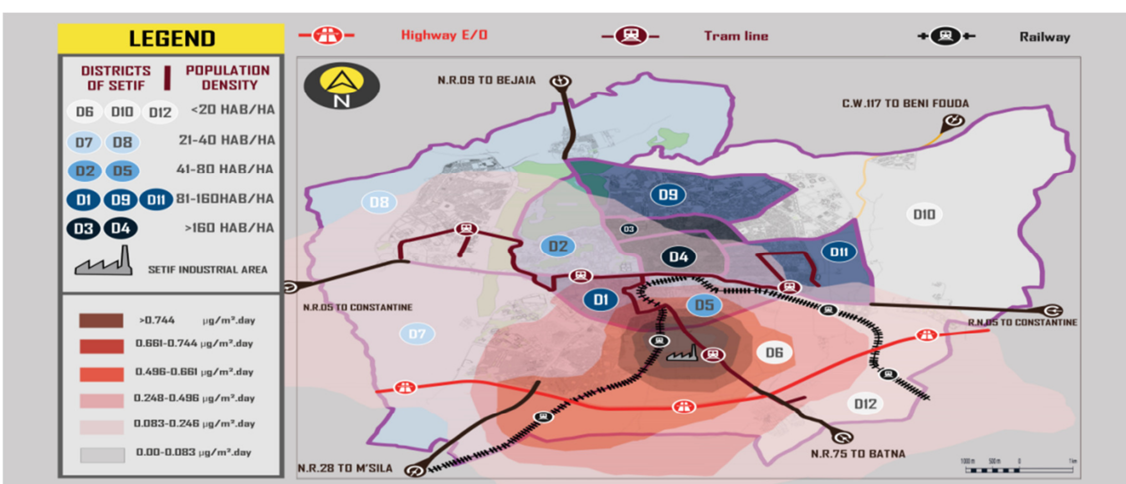

Fig. 15. Vulnerability of material and economic issues to industrial air pollution in the city of Setif.

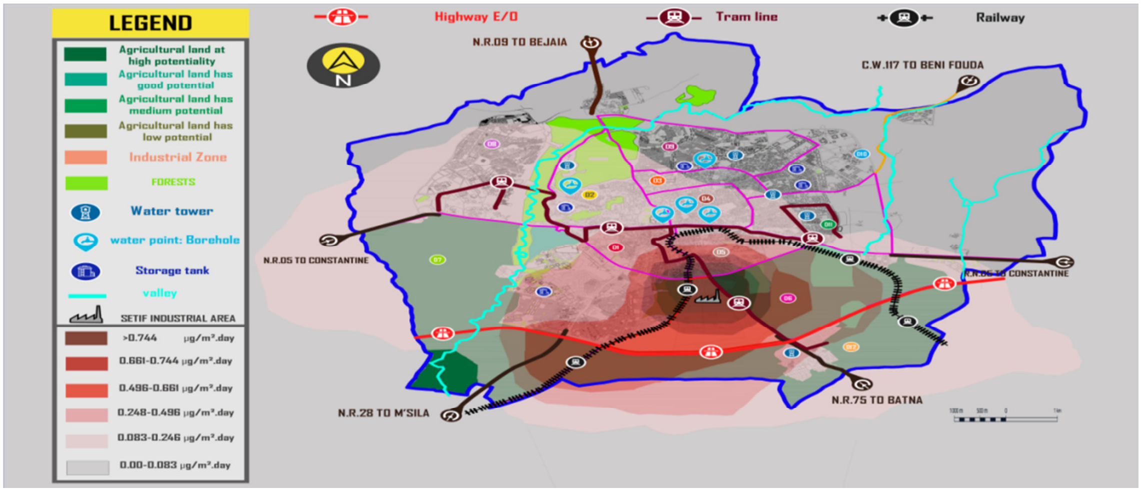

Fig. 16. Vulnerability of environmental issues to industrial air pollution in the city of Setif.

In the same context, the environmental stakes posed by the green spaces and agricultural land (all categories combined) located in the immediate vicinity of the industrial zone of Setif have been ranked as moderately vulnerable due to the fluorine pollution demonstrated by multiple plants and laboratories. Lastly, the industrial zone, with its urban areas marked as D9 and D10 and the remainder of the city marked as D7 and D8 in Figure 16 would be generally spared and hence be the least susceptible to these pollution issues.

V. Conclusion

The current study has confirmed that the Setif region creates several kinds of air pollution, originating mostly from the electrochemical complex NCEP through an excessive emission of carbon dioxide, sulfur dioxide, sulphuric vapors, and lead-laden dust. Lead dust and acid-releasing sulfuric vapors are primarily products of the electrochemical industry's vast exploitation of lead. These air pollutants provide a significant source of environmental pollution for all forms of city-wide problems.

The final thematic maps show that high-population-density urban areas around the Setif industrial zone are under risk. The most vulnerable urban fabric is the city core (formerly an intramural city) and its historical suburbs, with AinTrik having the most industrial air pollution. The industrial zone and the rest of the city have minimal vulnerability to environmental hazards.

This research's strategy is applicable to other Algerian cities. It allowed the exact definition of TSP and their effects on Setif. The current technique can replace previous methods which predict the dispersion of air contaminants without considering their spatial and geographical effect on urban areas. Thus, the focus is placed on the methodological aspect of the instrument and not the outcomes particular to the region under study. The recommended method uses basic data from local technical services and generally available, easy-to-use modeling software (Aria Impact). Digital mapping technologies were used to create clear and realistic thematic maps. The developed cartographic assistance aims to help decision makers decrease industrial air pollution in metropolitan areas. It is possible to reduce atmospheric pollutants by implementing ambitious initiatives to install manufacturing chimneys with electrostatic screens. In addition, the issue must be resolved drastically upstream by conducting significant and exhaustive impact assessments and standardizing the stack heights in proportion to the overall topography of the surrounding urban fabric. The most acceptable solution to preserve the urban environment of the cities is to use clean technologies with emissions that adhere to standard requirements.

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