INJECTING RESIDENTIAL INDUSTRIAL NEIGHBOURHOODS AND PLOTTING BUILT-UP AREAS EXPOSED TO INDUSTRIAL AIR POLLUTANTS IN THE ARAB REPUBLIC OF EGYPT

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ABSTRACT

The aim of this study is to develop a strategy for predicting the highest quality areas, in terms of their non-exposure to industrial air emissions. This is achieved through listing the built-up areas next to the industrial zones concerned. Illustrating the parameters of air pollution emissions from industrial activities in the region by the air modeling technique, and integrating data and information obtained using geographical signature programs in order to obtain an informational map that can be used in analyzing the data for the future planning of housing in close proximity to industrial areas. This study was conducted on an area of 49 km^2, Abu Qir Bay, east ofp the city of Alexandria, Egypt. The study showed that the safe areas of exposure to nitrogen oxides represent 8% of the study sample area (49 km^2). 3.5% represents the largest safe area located in the north-west of the industrial zone, 1.6% of the safe areas is located in the southern industrial zone towards the prevailing wind, and, finally, the ratio of built-up areas facing industrial emissions was revealed at 2.5% of the entire study area in the southern industrial zone. It is concluded that, by using the simulated gaseous emissions of industrial facilities and integrating it with geo-analytical maps of the built-up satellite-explored areas, a strategy for predicting the safe areas could be applied. The study recommends that residential urban planning decisions in industrial zones should be obtained through periodically monitoring the emissions. The researcher recommends the use of the results of this study as a guide, using (RS) satellites to detect and map built-up areas near industrial facilities, air-modelling techniques to predict the hazardous zones of the industry, and (GIS) to layer the information digitally, in order to take precise future urban planning decisions.
Keywords: residential industrial complex, hazard distances, NOx emission rates, petrochemical industries buffer zones, planning residential industrial neighborhoods, remote sensing built-up regions, NDVI reclassification, fertilizers industry, air modelling, industrial safe zones.

1 INTRODUCTION

The country's economic future is highly dependent on industrial investment. Large industrial areas represent a magnetic urban pole attracting urbanization, which presents a risk of exposure to emissions from energy extraction, and steam generation for manufacturing. The general strategies for industrial investment, in the Arab Republic of Egypt, have raised industrial growth rates to 10.7% in 2018. More than 30 million m^2 of land have been provided for the establishment of various industries since 2016. Half of the industrial settlements, are in the Greater Cairo Governorate area, reaching around 28,000 settlements.

According to the Egyptian law on Protection of the Environment No. 4/1994, issued by Prime Ministerial Decree No. 338 of 1995, the competent administrative authority (depending on the kind of the establishment) granting the license to an industrial firm, shall assess the environmental impact of the establishment for which the license is requested [1].

The industries in the region rely on fossil fuels that consume more than 60% of the total energy input. The major problem in this research is the lack of previous studies within the fields of, residential industrial neighborhood planning, and detection of the most exposed

built up areas to industrial gaseous emissions. Whereas the share of industrial pollution in the region, is not very well documented [2].

The consumption of fossil fuels in some industries usually reaches large proportions. It is shown in pulp and paper industry by 81%, chemicals 42%, oil refining 23% [3]. It sometimes represents 85% of production costs for some industries, for example fertilizer industry. However, data published in 2007, by the Organization for Economic Co-operation and Development (OECD), shows that global emissions of greenhouse gases will increase by 50% by the year 2050 [4], mainly as a result of increased demand for energy, and the economic growth in large countries with emerging economies. Although natural gas is one of the cleanest fuels [5], the concentration of air pollutants resulting from its burning process, are dangerous if they exceed global standards. These emissions mainly consist of CO_2, NO_X, small amounts of SO_2, and CO [6]. Nitrogen oxides account for 3.3% of total pollutants from manufacturing, and CO_2 accounts for 17.7% of the total industrial pollutants. NO_X emissions could be reduced by 80%, by using modern manufacturing technology, but the cost of units to reduce the emissions is very high.

The Geographic Information System (GIS) is a computer-based information system for capturing, storing, inspecting, and submitting models of terrestrial sites. GIS can show many types of data on a single map. In this research, GIS is used to match pollution maps, generated by pollutant dispersion modelling platforms, to different built-up areas that are in proximity to plant emissions. Remote sensing methods based on the use of image data, which are obtained by cameras, scanners, or radar from Landsat satellite imagery, are used to detect areas built in the research environment. To monitor long-term land coverage, and land use change, Landsat data is crucial. Remotely sensed data has become increasingly available in digital form, allowing for their computer-assisted interpretation and processing. In 2013, Landsat 8 was launched with two sensors; the Operational Land Imager (OLI), and the Thermal Infrared Sensor (TIRS). Images consist of nine spectral bands with a spatial resolution of 30 m for bands 1 to 7 and 9 [7].

Lo found that a computer-assisted method of analysis of Landsat data, permits the extraction of more detailed urban land-use information, but at an accuracy of only 69% [8]. The aim of this paper is to develop a strategy to assist urban planners, and architects, to plan residential complexes near industrial regions, and to forecast the most industrial emission areas, in order to locate new construction sites. Therefore, by using spatial information, the decision-making process is transformed to a more clear, visualized proposal.

1.1 Research location

The study area covers about 49 km^2 in the city of Alexandria, Northern Egypt. A city that experienced a 2.8% urban expansion from 1999 up until 2013 [9]. Coordinates of the study area are as follows: latitude 31°14'57.86'N, longitude 30°3'58.20"E, bordered by the Mediterranean Sea from North (see Fig. 1). The research sample includes different industrial activities, where fertilizer factories occupy half the area of the industrial complex, which is 4 km^2. Abu Qir Fertilizers Company is the largest in the industrial complex of fertilizer production, spanning 825 m^2. Alexandria Fertilizer Company, constructed in the year 1990, on an area of 121.836 m^2 [10], and a paper production company, Rackta, on an area of 900 m^2.

Figure 1: Research location.

2 RESEARCH METHODOLOGY

The study focused on tracking the parameters of NO_X pollutants in the selected industrial area, as a model for implementing the proposed strategy. In addition, applying the methodology of gathering information on other industrial emissions in future studies to guide the decisions, and development of future urban planning projects in industrial contexts. The dominant industrial activity in the study area is the fertilizers industry, where 97% of nitrogen fertilizers are derived from ammonia [11]. The methodology is based on the following:

- Follow-up of high-concentration emission source of air pollutants, using gaseous dispersion tracking programs.
- Compile and analyze data and compare it to some similar local and global standards.
- Apply the developed strategy, to determine the quantity and quality of non-exposed regions in the research, with gas dispersion techniques and integrating them with the geo-analytical maps of the built-up, satellite-explored areas.

2.1 Gaseous dispersion

Pollutant dispersion modelling is created by feeding the industrial utilities-design standards (if available) in to the Aermod platform, Which is the EPA's preferred regulatory tool for modelling pollutant dispersion, developed by the Organizational Models Improvement Committee of the American Meteorological Society (AMS)/Environmental protection agency (EPA) [12]. It records the movement of emitted gases, identifies and measures the concentration of pollutants, acquiring the sources of emissions from industrial units, and introduces emission coefficients for deduction of flue gas.

2.1.1 Pollutants emission rates

Approximate emission rates of air pollutants are estimated by applying emission factors based on production quantities, and the ratios for standard industrial natural gas consumption. The emission factor for nitrogen oxides in ammonia plants is estimated at 2.7 + 23% g/kg of ammonia [13], whereas the emission factor calculated by the material balance reaches 4.38, 5.95 g/kg Nh_3 [14]. Estimating the NO_X emission rates for industrial large wall fired boilers, generated by using the standard percentages of natural gas burnt in ammonia plants, and applying the AP-42 Compilation of Air Emissions Factors [15]. In most of ammonia plants, an average of 65% to 75% of the natural gas is used as chemical feedstock, while 25% to 35% is used as fuel for the radiant heat section burnt in primary reformer for generating heat

and steam production [16]. The percentage of fuel consumed in boilers, can be calculated by Using the global standards of the best available techniques in ammonia production. Whereas, Natural gas used in a typical ammonia plant, using the steam reforming process, ranges between 26.6 to 33.6 MMBtu/ton, which is approximately 19–21 MMBtu/ton of ammonia used as feedstock. 6.8–8.5 MMBtu/ton is fuel in the primary reformer, and most of the remaining fuel, 0.5–4.0 MMBtu/ton, powers auxiliary boilers, which generates 7.4% of the total consumption of natural gas in the fertilizer industry. While the standard fuel consumption for industrial boilers reaches 80% of natural gas used for steam generation in pulp production facilities [17], Natural gas use can account for up to 85% of operating costs for ammonia industries. Ammonia is manufactured by steam reforming process in the primary reformer and the temperatures of the process reaches more than 900°C [18].

2.1.2 Plant inventory and locations of NO_X pollutant

By tracking the emission points of air pollutants from different industries, guided by typical emission levels in natural gas-based steam repair plants [18], the industrial units emitting NO_X pollutant have been mapped on a digital map for the study location (as illustrated in Fig. 2). The standard height of stacks in primary reformers for ammonia processing, ranges from 35 m to 50 m, whereas flow gas standard speeds from chimneys reaches 185,000 NM^3. The internal diameter of the stacks ranges up to 2 m. Gas discharge temperature in the combustion nozzles reaches 120°C [19], and in industrial boilers, the combustion gas temperature reaches 150°C to 180°C [20]. The amount of ammonia produced in the region of study is about 8 million tons per year for Abukir Fertilizers Company, and about 1925 tons per day at Alexandria Fertilizer Company [21]. The total consumption of industrial natural gas in the study area for the ammonia plants of AFC is approximately 700 million m^s per year [22], as for Rackta company the consumption reaches 36 million m^3 per year [23].
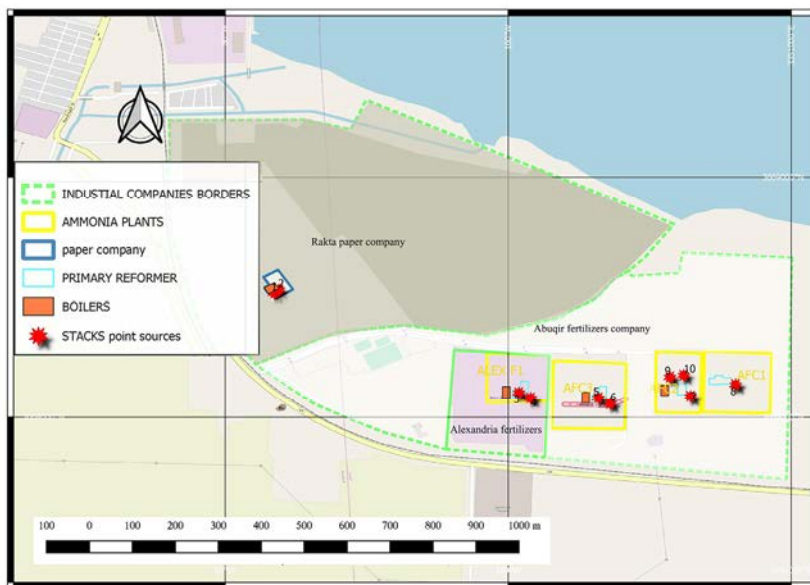

Figure 2:   Locations of boilers and primary reformers in the study zone of Abukir industrial area (latitude 31°14'57.86"N, longitude 30° 3'58.20"E).

2.2 Built-up zones

A Landsat 8 image from the 8th of August 2018, on path 177, row 38, was used in this research. The data was provided as level L1T data captured under clear atmospheric conditions (cloud coverage = 0.01%) in the dry season. The image is in UTM projection (zone 36 N) and was retrieved from the United States Geological Survey (USGS), Earth Explorer website. Spectral indices are a good approach to differentiate land cover types [24]. The normal deviation of vegetation index NDVI of satellite imagery of sanitary plants is used in different formulas to generate studies for the separation of vegetation regions on digital geographical maps [25]. Previously, Matthias and Martin applied spectral NDVI to map an uncertain region in an urban area of Germany [26]. An appropriate threshold of values from the output of the equation, can be used for mapping built-up and non-built-up areas. As NDVI can be used to characterize the evolution and expansion of built-up land [27].

A reclassification process of Ndvi value is used to segregate the built up regions on the open GIS platform QGIS, which is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data [28], NDVI is calculated in Landsat 8 after the formula (band 5-Band 4)/(band 5 + band 4). For most satellites, NDVI, are calculated from eqn (1):

$$NDVI = (Pnir-\rho d) / (Pnir + \rho d), \tag{1}$$

where Pnir reflects the wavelength range near infrared and ρd is the reflection of the red wavelength range. While the bands used are band 4 with the wavelength ranges of 0.636–0.673 μm and the range 5 for the wavelength 0.851–0.879 [29].

2.3 Pollution maps and built-up spatial relation

Environmental impact assessment (EIA) process is the systematic examination of consequences of a proposed project, aiming to prevent, reduce or mitigate negative impacts on the environment, natural resources, health and social elements as well as capitalize on positive impacts of the project [30].

The Egyptian EIA system was designed with the support of the Danish International Development Agency (DANIDA), where it is summarized in the annex along with the corresponding features of the World Bank's Environmental Assessment policy OP 4.01 and the European Union's EIA Council Directive 97/11/EC [31].

The results of pollutant contours are generated on the Aermod platform with EU standards. They are then exported to shape file extensions, to be projected on the generated built-up regions on the QGIS platform. The results are stored in a digital geographical map, that can be visualized and analyzed. The main aim for the study is to spatially analyze the built-up regions exposed to industrial gaseous emissions.

Global standard limits of the EU air quality levels are regulated by the COUNCIL DIRECTIVE 1999/30/EC of 22 April 1999, for exposure of 1 hour to nitrogen oxides pollutants the concentrations should not exceed 200 $\mu g/m^3$ [32]. Whereas, the legislation as reported by the Egyptian Environmental Affairs Agency (EEAA), based on support from Danish International Development Assistance (DANIDA), and a national network of air contamination in the Republic of Egypt, has reached the maximum allowable exposure standard to NO_X at 400 $\mu g /m^3$ (shown in Table 1), As The EEAA has the power to set criteria and conditions, monitor compliance and to take procedures against violators of these criteria and conditions. The EEAA must be notified of any expansions or renewals to the existing facility or any work, which might result in an adverse impact on the environment.

Table 1: Global standards of NO$_X$ pollutant emissions. *(Source: Ke, W.K, 2006.)*

Direct exposure period (µg /m^3)	NO$_X$ concentrations (µg/m^3)		
	Egyptian air quality standards (Law 4/1994)	Application (world bank general environment guidelines, PPAH)	Eu standards for air quality (directive 1999/30/EC)
1 hour period	400	-	200
24 hour period	150	150	125
Annual period			40
At the facility fence		300	

3 RESULTS AND DISCUSSION

3.1 NO$_X$ pollutant contours

Nitrogen oxide emission rates, for primary reformers, in ammonia plants, ranged from the application of nitrogen oxides emission factor, to (37 g/s) and (41 g/s). The emission factors for boilers in fertilizer plants were estimated at (10.5 g/s), (28.5 g/s) (AFC3). The emission rates for boilers at Rakta Paper Manufacturing (14 g/s) were calculated based on standard fuel consumption rates (see Table 2), as the EEAA and EPAP [33], funding the projects to convert the company boilers systems to work on natural gas instead of using mazut fuel. Calculations were also applied using the material equilibrium emission factor for the second case, resulting in nitrogen oxides emission rates for primary reformers ranging from 68 g/s to 75 g/s.

Table 2: Emission rate of NO$_X$ estimated in the industrial study area.

Emission rates (g/s)	Industrial complex plants				
	Abukir Fertilizers Company			Alexandria Fertilizers	Rackta paper Boilers 4 and 5
	AFC1	AFC2	AFC3	ALEX FERT	
Case 1: (Normal ranges in Primary reformers)	36.94	33.59	40.30	40.30	-
Case 2: (Material balance standards for Primary reformers)	68	62	74.37	74.37	-
Boilers	-	10.5	28.5	28.5	14.04

3.2 Mapping built-up areas using the NDVI index

The NDVI values in Fig. 3,were calculated from eqn (1), where high threshold ranges represent healthy vegetation (NDVI values > 0.24, represented in dark green), while lower threshold and negative values represent water surfaces. In order to determine the optimum value, to segregate built-up from non-built-up areas, a test was conducted on the number of built-up pixels by selecting values of 0 to 0.24. The output is illustrated in Fig. 4, where the pixels in red show built-up areas, and the dark and green tones represent other land covers. Fig. 5(a) shows hand digitized vector areas, tracing the built-up zones on QGIS open GIS platform, on a google map background for the study area, where a boundary of 7 km height

by 7 km width has been chosen as a limit for the tracing process surrounding a 4 km² industrial complex. Fig. 5(b) illustrates the extracted vector layers for built-up areas on QGIS open platform by reclassifying NDVI values. Using the tracing method for built-up areas on QGIS platform, resulted in an area of 7644390.3433 m² (7.644 km²). Near values extracted from the automated reclassification method of NDVI index for Landsat 8 images, results in the mapping of a built-up area 7648902.763 m² (7.648 km²) (Fig. 5(a) and 5(b)), which identify that the method of extraction is clear and practical.
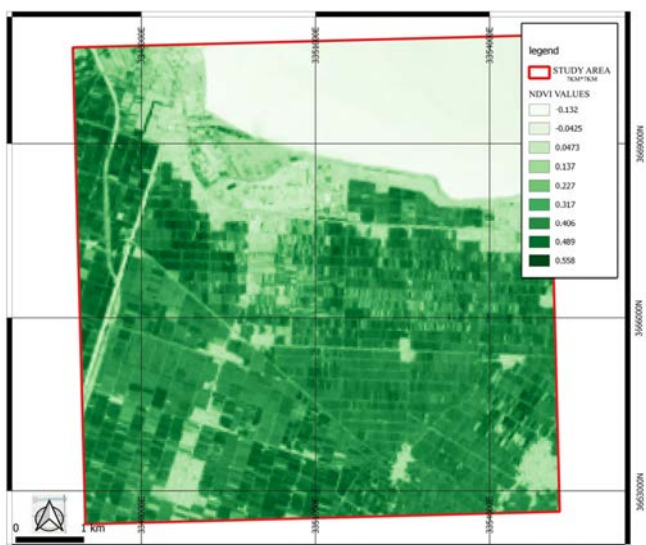
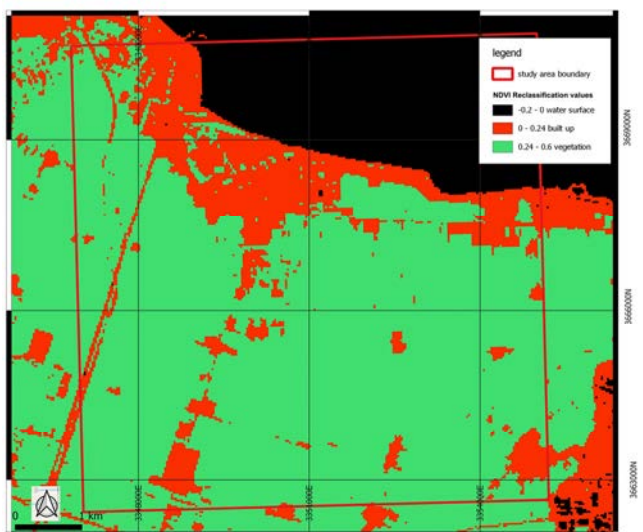Figure 3: NDVI index, extracted from Landsat 8 image, 8 August 2018.

Figure 4: Reclassifying NDVI values to generate built-up regions.
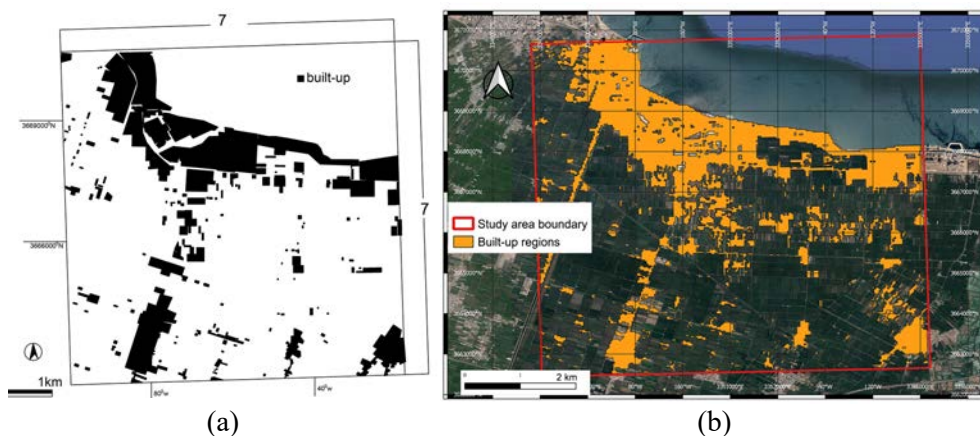
Figure 5:   Built-up areas for the study zone. (a) Hand digitized tracing method; and (b) Built-up vector layer extracted by reclassifying NDVI values.

3.3 Pollution maps and built-up spatial relation

Feeding the gaseous dispersion model with the plant inventory design standards, and the emission rates of nitrogen oxides in the area under study derived from (Table 2), resulted in mapping the concentration contours of nitrogen oxides pollutant (shown in Fig. 6(a) and 6(b)). Fig. 6(a) illustrates the contours of the concentrations of NO_X pollutants that exceed EU standards, and Fig. 6(b) spot the concentrations of NO_X contours following the legislated EEAA standards. (Fig. 6(c) and 6(d)) shows the safe areas that are not exposed to industrial emitted NO_X pollutant, following EU standards, and the Environmental Affairs Agency of the Arab Republic of Egypt regulations.

'The Main Features and the capability to simulate turbulent flows of plume dispersion in unprecedented detail is Hard to Predict', making the results of evaluating and site selection validation a great challenge [34]. The different international standards for determining the concentration of nitrogen oxides emissions from the industry, and the variation of the emission coefficient of that pollutant, creates more than one perception for the forecasting strategy. The results identified trends in the transmission of nitrogen oxides (NO_X) plumes shows the plumes moving 6.39 km south-east, 6.91 km south, and some of the effects are shown traveling towards the west, 6 km from the center of the industrial complex. These results are generated by plotting the pollution maps of the AERMOD program on QGIS platform (as shown in Fig. 6(a) and 6(b)). Following EU standards, the safe area represents 9.2% of the total studied habitable land around an industrial facility, while in EEAA regulations; an area of 86.2% represents the safe area in (Fig. 6(c) and 6(d)). Whereas the strategy detected (0.846 km^2) of safe areas following the EU regulations, under the direction of the prevailing wind (Fig. 6(c)).

The spatial analysis done on QGIS platform on extracted built-up zones, spotted a condensed region of built up areas, found to lie in the north-west of the industrial complex. (see Fig. 6(e)), where the projection method of the NO_X pollutant contours, layered on the vector built-up layer, resulted in the extraction and identification of areas that are highly exposed to industrial emitted pollutants (see Fig. 6(f)).
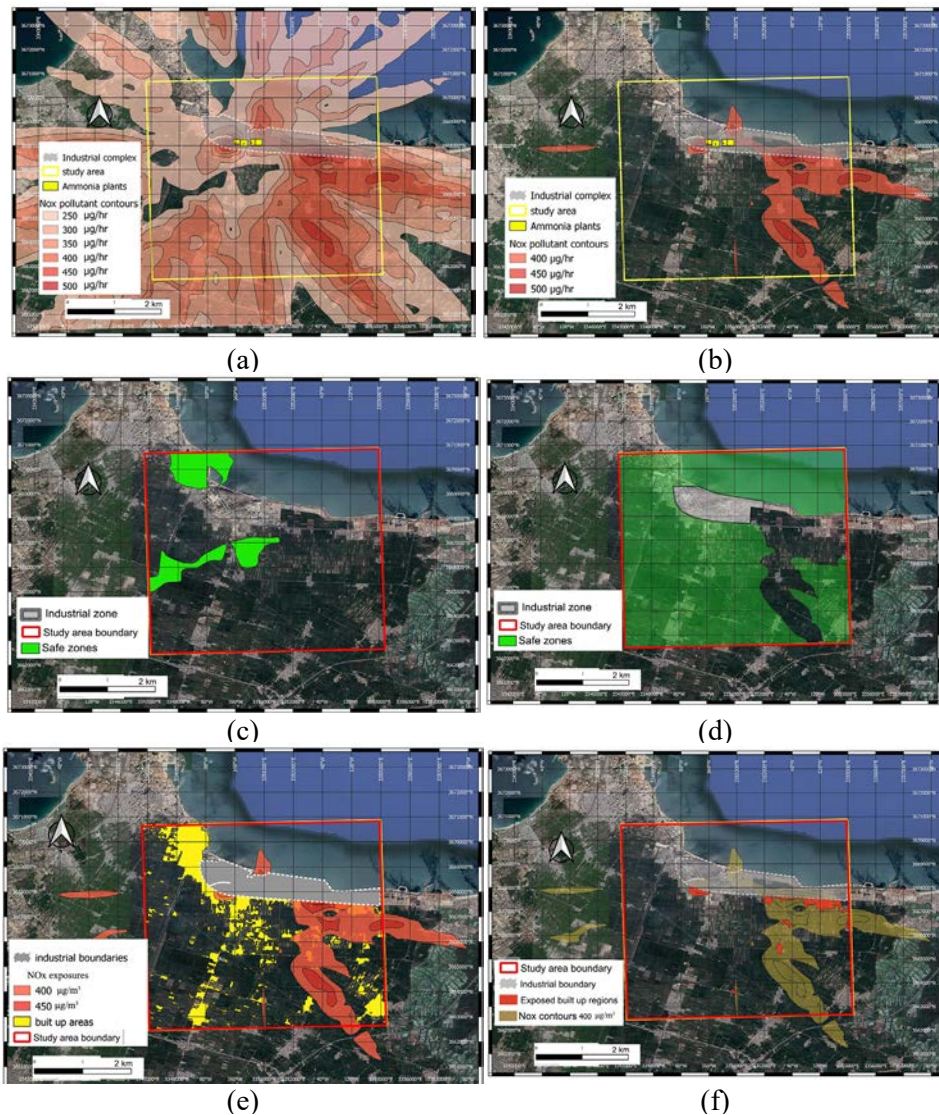
Figure 6: Spatial analysis of NO_X pollutant map and built up regions on a total area of 49 km². (a) EU regulations (above 200 μg /m³ for 1 hour exposure); (b) EEAA NO_X concentrations contours (400 μg /m³ for 1 hour exposure); (c) Standard EU safe regions (area of 4.162 km²); (d) EEAA Safe regions (area of 38.81 km²); (e) Built-up regions (yellow) and NO_X pollution projection contours; and (f) Highly exposed built-up regions (0.918 km²).

4 CONCLUSIONS AND RECOMMENDATIONS

Use of dispersion modeling to track regionally transmitted pollution, added semi-accurate numerical data for air pollution in the perimeter of the studied industrial complex. The identification of the built-up areas, using satellite imagery reclassification method, gave

accurate analytical results of the areas where population activity is concentrated, thus aiding in the creation of a rapid digital cartographic image for those regions.

The study suggests that the application of air modeling simulation and satellite detection process could be used to provide a reliable method of urban decision making in industrial zones. The air modeling techniques used in this paper demonstrated that "It is necessary to consider the safe distance when planning and placing residential plants with industrial spaces in 7 km from a petrochemical industrial complex".

The possibility of using the NDVI index for vegetation cover can provide maps of the built areas, however, the accuracy of the method is quite limited by the moderate resolution of the data, which means that the contemporaneous tracking of the pollutants extension in the present-day monitoring network, could lead to better results. Further testing of the source, and an increase in the number of observation stations are required to enable the monitoring of pollutant concentrations in the air, in areas adjacent to industrial complexes.

The study recommends the transfer of residential complexes that fall under the contaminated concentrated spots. We also recommend that the methodology followed, should guide the study, and link it to the strategic plan for industrial investment in the region. Given that emission rates inventories are characterized by large uncertainties, using satellite-dispersion modeling method offers a much more cost-effective approach to relocate residential complexes falling under the polluted concentrated spots.

CONFLICT OF INTEREST

ACKNOWLEDGEMENT

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