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Development of a methodology for the evaluation of environmental equity at urban level with high spatial resolution. Case study in Valencia (Spain)

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ABSTRACT

Detecting vulnerable areas or areas with less favourable conditions than the rest of the city is essential for public administrations to achieve sustainable development. This paper describes the development of a methodology to obtain the most vulnerable neighbourhoods at an urban scale based on a series of geo-referenced economic, social and environmental variables. In addition, a network of NO_2 passive sensors has been deployed to introduce air quality as an environmental variable in the developed methodology. This allows us to identify the neighbourhoods with the worst air quality to determine the areas in the city where vulnerable groups and poor air quality conditions coincide. Finally, results are analysed to see if there is a direct relationship between vulnerable neighbourhoods and neighbourhoods with poorer air quality.

Then, the developed methodology has been applied in Valencia (Spain) as a case study. Thus, the methodology developed has been allowed to identify the most vulnerable neighbourhoods based on facilities, demography and socioeconomic variables. This would allow public decision-makers to use available resources to reduce vulnerability efficiency. Finally, cross-referencing vulnerability and air quality results give the location of vulnerable neighbourhoods with the worst air quality, allowing the identification of environmental inequities at an urban level with high spatial resolution. In the pilot case of Valencia, it is concluded that there is no direct relationship between vulnerable neighbourhoods and neighbourhoods with high NO_2 levels, although 14.28% meet both conditions.

1. Introduction

Air pollution is a significant health concern in Europe ("Air quality in Europe 2022, 2022). In 2020, there were 238.000 premature deaths in the EU due to exposure to concentrations of fine particulate matter above the 2021 World Health Organization guideline level ("Air quality in Europe 2022, 2022). People who live in urban areas are particularly exposed to air pollutants (Niemenmaa et al., 2018).

The main air pollutants are particulate matter with a diameter of 2.5 μm or less (PM2.5), particulate matter with a diameter of 10 μm or less (PM10), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO) (Weltgesundheitsorganisation and World Health Organization, 2021). The European Green Deal has proposed a revision of the EU Directive's pollutant limit values to align them more closely with the WHO recommendations ("Exceedance of air quality standards), as the latter is much stricter than the current EU Directive ("Exceedance of air quality standards).

NO2 and PM2.5 are identified as the predominant outdoor air pollutants among the various contaminants in European cities (Costa et al.). Exposure to high concentrations of NO_2 in the air is associated with respiratory diseases such as inflammation of the airways, increased bronchial reactivity and decreased defences leading to increased susceptibility to respiratory infections (Great Britain. Committee on the Medical Effects of Air Pollutants et al., 2011). Adverse health effects were detected when the annual average NO2 concentrations exceeded the limits outlined in the EU Directive (Great Britain. Committee on the Medical Effects of Air Pollutants et al., 2011), which is 40 $\mu g/m^3$ (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION).

Lorenzo (Lorenzo-Sáez et al., 2021a) demonstrated the variability of air quality levels throughout a city by deploying a network of passive dosimetry sensors Palmes Tubes (PALMES et al., 1976), which also

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indicates differences between neighbourhoods.

On the other hand, the United Nations Department of Economic and Social Affairs defined vulnerability as a state of high exposure to certain risks and uncertainties, combined with a reduced ability to protect or defend oneself against those risks and uncertainties and cope with their negative consequences (United Nations, 2003). Vulnerability exists at all levels and dimensions of society and forms an integral part of the human condition, affecting individuals and society as a whole (United Nations, 2003).

Some authors analyse the concept of urban vulnerability related to other negative impacts, such as floods in Santiago de Chile (Müller et al., 2011) and Brazilian cities (Rasch, 2016). A project in China assessed urban vulnerability and its spatial differentiation by studying 10 sub-indexes involving 36 specific parameters from four aspects: i. Resources; ii. eco-environmental systems; iii. economics and iv. social development (Fang et al.).

Equity is another term that has increasingly concerned policymakers, academics, and activists (Kruize et al., 2007). To ensure inclusion and fill important gaps, scientific evidence is needed on the health effects of the living environment (Northridge et al., 2003). Environmental equity is defined as “the distribution of amenities and disadvantages across individuals and groups” (Zimmerman). This term was studied in the Rijnmond region, where it was concluded that the situation of environmental equity seemed to be regulated by a combination of market dynamics and political regulations (Kruize et al., 2007).

The National Collaborating Centre for Environmental Health in Canada defines environmental equity as the circumstance in which no group or community is disadvantaged in the face of hazardous environmental exposures such as pollution (Rosenkrantz, 2022). This concept is closely linked to environmental justice, which represents the fair treatment of all people regardless of factors such as income, race or origin so that they are protected from adverse hazards to human health, such as pollution, and have equitable access to a healthy, sustainable and resilient environment in which to live, work and grow (United States Environmental Protection Agency).

Some research analyses the relationship between socio-economic inequality and exposure to air pollution (Hajat et al., 2015) and the relationship between ultrafine particle concentrations and socio-demographic indicators (Thayer et al., 2022), but nowadays, no research evaluates environmental equity considering high-resolution air quality monitoring and vulnerability by neighbourhoods, introducing socio-economic, demographic and infrastructure variables into vulnerability. This analysis makes it possible to identify the causes of poor environmental equity and the areas which each neighbourhood could be improved.

Thus, a methodology to evaluate environmental equity at an urban level with high spatial resolution is developed. This evaluation is carried out by analysing the relationship between high spatial resolution quantification of air quality through passive dosimetry sensors of NO_2, with three primary axes that define urban vulnerability: a) equipment vulnerability refers to the physical supports that welcome the lives of citizens (transport, schools, hospitals, etc.); b) socio-demographic vulnerability refers to vulnerable social groups, to demographic dynamics that condition the development of the population in a territory and c) socio-economic vulnerability refers to the population’s economic capacity and wealth distribution. The methodology developed aims to help decision-makers identify inequalities and solve them efficiently to improve citizens’ quality of life.

2. Material and methods

2.1. Case study

The city council of Valencia (Spain) has signed a collaboration agreement with the Joint Research Centre of the European Commission and Polytechnic University of Valencia (UPV), designating Valencia as a City Lab under the auspices of the Community of Practice on CITIES (Joint Research Centre and The Community of Practice on Cities Newsletters, 2020). The objectives of this collaboration agreement are to develop and test methodologies to collect, share and analyse a set of social, economic and environmental indicators in the city of Valencia to have a better understanding of the complex and dynamic realities at the city level.

Therefore, the city of Valencia (Spain) has been selected as a case study to apply the developed methodology.

Valencia is a city located in the autonomous community of Valencian, east of Spain. Nowadays, it is the third biggest city in Spain and the 24th most populated municipality in the European Union, with 792,492 residents (Instituto Nacional de Estadística, 2021). Valencia is divided into 19 districts subdivided into 88 neighbourhoods (Lorenzo-Sáez et al., 2021b) (Fig. 1). Table 2 shows the neighbourhoods that belong to each district.

2.2. Data

Datasets and sources per dataset needed to calculate the variables that affect each vulnerability can be seen in Table 2. These are mainly obtained from the open data portal (Valencia City Councila) and the statistical office (Valencia City Councilb). All data were collected for the 2021 year.

On the other hand, the air quality has been monitored during the year 2021, by monitoring NO_2 concentration obtained from the deployment of 648 passive dosimetry sensors (PALMES et al., 1976) network distributed throughout the study area, carrying out four sampling periods (14-day campaigns) per year (one per season following the methodology of (Lorenzo-Sáez et al., 2021a)) following the criteria of macroimplementation and microimplementation described by EU directive 2008/50/EC (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION).

2.3. Vulnerability calculation

The developed methodology calculates the relative vulnerability of the neighbourhoods of the studied area. Thus, this methodology identifies the most and least vulnerable neighbourhoods of the city compared to the others.

Four types of vulnerability are calculated by neighbourhood: equipment, demographic, socioeconomic, and global vulnerability.

The vulnerability calculation is divided into two steps.

1. Normalization of variables.

Each variable has a different origin and, in some cases, different units. To compare and consider them all regardless of their units, the variables have been normalized. Each variable is coded by values from 1 to 5, with the value 1 being the worst situation and 5 the best. To code them, the percentiles corresponding to 10%, 36.66%, 63.33% and 90% of the distribution of each variable concerning the entire study area are calculated (Fig. 2).

$$\text{VARIABLE VALUE} \leq p0.1 \rightarrow \text{CODING} = 1$$

$$p0.1 < \text{VARIABLE VALUE} \leq p0.3666 \rightarrow \text{CODING} = 2$$

$$p0.3666 < \text{VARIABLE VALUE} \leq p0.6333 \rightarrow \text{CODING} = 3$$

$$p0.6333 < \text{VARIABLE VALUE} \leq p0.9 \rightarrow \text{CODING} = 4$$

$$\text{VARIABLE VALUE} > p0.9 \rightarrow \text{CODING} = 5$$

2. Vulnerability indices calculation.

The vulnerability indices of equipment, demography and socio-

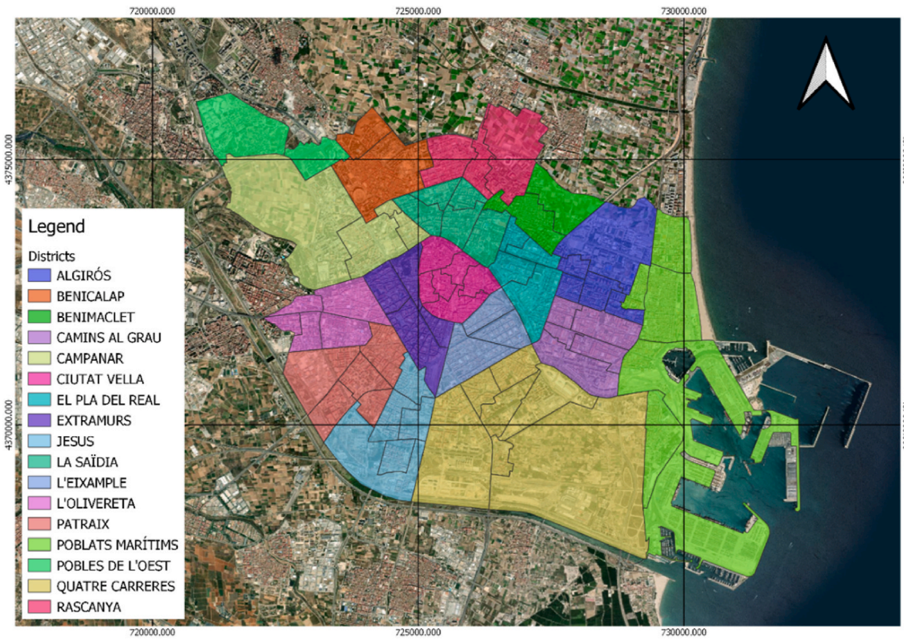

Fig. 1. Map of the districts of Valencia.

economics are calculated for each neighbourhood by taking an arithmetic mean of all variables belonging to each type of vulnerability (Table 1). In the case of equipment vulnerability, the variables are measured as the number of facilities in each neighbourhood. To obtain a first visualisation of the distribution of facilities in the city, five heat maps are calculated, one for each variable. The heat maps were made using the "heat map" tool of the QGIS software (QGIS User Guide). Thus, the fewer facilities a neighbourhood has, the more vulnerable it will be.

On the other hand, the global vulnerability index is calculated as the arithmetic mean of the three types of vulnerability described (equipment, demography and socio-economic).

Finally, the vulnerability level could be: a) high vulnerability: vulnerability index is in the 10% percentile (p0.1); b) Medium vulnerability: the vulnerability index is between the 10% percentile and the 20% percentile (p.0.2); and c) No Vulnerability: vulnerability index is above the 20% percentile (>p0.2) (Table 3).

2.4. Air quality calculation

Air quality has been monitored by deploying a passive dosimetry sensors network across the studied area following the EU Directive 2008/50/EC (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION) criteria of microimplementation and macro-implementation (Fig. 3). A total of 648 sensors have been deployed.

Table 4 shows the number of sensors located in each monitored neighbourhood. In accordance with Annexes III and V of the EU Directive, the setup of monitoring locations must adhere to specific criteria regarding macroimplementation, microimplementation and minimum number of monitoring points required to safeguard human health (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION). An attempt has been made to monitor the different representative environments of the city.

The sensors used are Palmes tube (PALMES et al., 1976), which has an open downside that allows the entrance of ambient air towards the topside. The pollutant gas is transported to the upper part of the tube by molecular diffusion and absorbed by a surface placed on the top part. This effect causes a linear concentration gradient from the air value to the absorbent surface (Lorenzo-Sáez et al., 2021a). Its operation can be seen in Fig. 4 (Lorenzo-Sáez et al., 2021a).

The limit annual average value for nitrogen dioxide (NO_2) concentration for health protection is 40 μg/m^{3,} set by the European Union Directive (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION) as well as by the World Health Organization (Weltgesundheitsorganisation and World Health Organization, 2021).

Passive sensors are deployed during the first 15 days in February, May, August and November. Thus, the average value obtained represents the annual average, reducing meteorological biases. The location of each sensor has been chosen considering the criteria described by the EU Directive and maintaining the type of monitored environment between locations (constant distance between sensor location and the nearest pollution source, usually traffic, avoiding pacified areas, tunnels, unventilated areas, etc.).

The average NO_2 values per neighbourhood are calculated based on every sensor located in the neighbourhood. Five classes are defined based on percentile calculation to normalize them. Thus, 10%, 36.66%, 63.33%, 63.33% and 90% percentiles of the distribution of NO_2 values are calculated to highlight areas with better and worse air quality levels. An inverse distance weighted (IDW) or distance interpolation is performed from the spatial layer representing the location of the dosimetry sensor.

Then, the five classes obtained from the percentile calculation of the NO_2 data are coded, with values from 1 to 5, with neighbourhoods with value 1 having the highest NO_2 level and neighbourhoods with value 5 having the lowest NO_2 level. In the study case of Valencia, the coding of the NO_2 data can be seen in Fig. 5.

Finally, each neighbourhood is associated with the corresponding code based on the NO2 concentration obtained (Fig. 5) to normalize the air quality level by neighbourhood.

2.5. Environmental equity calculation

Based on the results of the vulnerability and air quality by neighbourhood, whether or not there is a relationship between them is analysed.

The vulnerability index varies between values 1 and 5, with neighbourhoods with 1 being very vulnerable and neighbourhoods with a value of 5 being not vulnerable. Then, the air quality levels are normalized in a codification from 1 to 5, with neighbourhoods with value 1 having the highest NO_2 level and neighbourhoods with value 5 having the lowest NO_2 level.

Table 1
Districts and neighbourhoods of Valencia.

District code	District	Neighbourhood
1	CIUTAT VELLA	EL CARME
		LA SEU
		LA XEREA
		EL MERCAT
		EL PILAR
		SANT FRANCESC
2	L'EIXAMPLE	EL PLA DEL REMEI
		LA GRAN VIA
		RUSSAFA
3	EXTRAMURS	EL BOTANIC
		LA PETXINA
		ARRANCAPINS
		LA ROQUETA
4	CAMPANAR	EL CALVARI
		LES TENDETES
		CAMPANAR
		SANT PAU
5	LA SAÏDIA	TORMOS
		SANT ANTONI
		MARXALENES
		MORVEDRE
		TRINITAT
6	EL PLA DEL REAL	JAUME ROIG
		CIUTAT UNIVERSITARIA
		EXPOSICIO
		MESTALLA
7	L'OLIVERETA	TRES FORQUES
		NOU MOLES
		SOTERNES
		LA LLUM
		LA FONTSANTA
8	PATRAIX	PATRAIX
		SAFRANAR
		SANT ISIDRE
		FAVARA
		VARA DE QUART
9	JESUS	LA RAIOSA
		L'HORT DE SENABRE
		LA CREU COBERTA
		CAMI REAL
		SANT MARCEL.LI
10	QUATRE CARRERES	MONT-OLIVET
		CIUTAT DE LES ARTS I DE LES CIENCIES
		EN CORTS
		NA ROVELLA
		MALILLA
		LA FONTETA S.LLUIS
		LA PUNTA
11	POBLATS MARÍTIMS	BETERO
		CABANYAL-CANYAMELAR
		NATZARET
		EL GRAU
		LA MALVA-ROSA
12	CAMINS AL GRAU	ALBORS
		AIORA
		CAMI FONDO
		PENYA-ROJA
		LA CREU DEL GRAU
13	ALGIRÓS	LA VEGA BAIXA
		L'ILLA PERDUDA
		L'AMISTAT
		LA CARRASCA
		CIUTAT JARDI
14	BENIMACLET	BENIMACLET
		CAMI DE VERA
15	RASCANYA	TORREFIEL
		SANT LLORENS
		ELS ORRIOLS
16	BENICALAP	BENICALAP
		CIUTAT FALLERA
18	POBLES DE L'OEST	BENIMAMET
		BENIFERRI

Table 2
Dataset used to calculate the variables of each vulnerability and its source.

Vulnerability	Variables	Links
Equipment	Health: hospitals, clinics and health centres	https://valencia.opendatasoft.com/explore/dataset/hospitales/table/
	Public transport: EMT, Metrovalencia and Valenbisi	https://valencia.opendatasoft.com/explore/dataset/transporte-barrios/table/
	Schools: private, concerted and public	https://valencia.opendatasoft.com/explore/dataset/centros-educativos-en-valencia/table/
	Social resources: senior centres, social service centres and youth centres	https://valencia.opendatasoft.com/explore/dataset/recursos-socials-sociales/table/
	Public services: libraries, sports centres and police stations	https://valencia.opendatasoft.com/explore/dataset/equipamients-municipals-equipamientos-municipales/table/
Demographic	Population density	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Population variation in the last five years	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Dependent population	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Non-EU population	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Population over 80 years old	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Population over 65 living alone	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
	Population under 19	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=2
Socio-economic	Academic level	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=9
	Cars over 16 CV	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=6
	Average age of passenger cars	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=6
	Passenger cars over 15 years old	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=6
	Cadastral value	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=4
	Average constructed surface	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=4
	Average age of buildings	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=4
	Unemployment on record	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=7
	Personal income tax (IRPF)	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=6
	Tax on Economic Activities (IAE)	https://www.valencia.es/cas/estadistica/anuario-estadistica?capitulo=6

Thus, to obtain the environmental equity of neighbourhoods, they are classified with three values: neighbourhoods with value 1 will be those with medium or high vulnerability and exceed the NO_2 limit level, neighbourhoods with value 2 will be those with medium or high vulnerability or neighbourhoods exceeding the NO_2 limit level, and

Code	Name	Public transport	
		Facilities	Coding
11	LA SEU	5	1
12	LA XEREA	9	2
13	EL CARME	9	2
14	EL PILAR	4	1
15	EL MERCAT	6	1
16	SANT FRANCESC	34	4
21	RUSSAFA	37	5
22	EL PLA DEL REMEI	21	4
23	LA GRAN VIA	24	4
31	EL BOTANIC	10	2
32	LA ROQUETA	11	2
33	LA PETXINA	17	3
34	ARRANCAPINS	33	4
41	CAMPANAR	42	5
42	LES TENDETES	8	2
43	EL CALVARI	5	1
44	SANT PAU	35	4
51	MARXALENES	20	4
52	MORVEDRE	16	3
53	TRINITAT	15	3
54	TORMOS	8	2
55	SANT ANTONI	7	2
61	EXPOSICIO	15	3
62	MESTALLA	36	5
63	JAUME ROIG	8	2

Percentile	Position	Value
10%	7	6
36.66%	25.662	11
63.33%	44.331	18
90%	63	35

Fig. 2. Example of codification of the variable "Public Transport" to normalize them based on percentiles.

Table 3
Vulnerability levels based on vulnerability index calculation.

Percentile of code per type of vulnerability	Level of Vulnerability
Vulnerability index ≤ p0.1	High vulnerability
Vulnerability index between p0.1 and p0.2	Medium vulnerability
Vulnerability index > p0.2	No vulnerability

Each vulnerability index has been represented on a map using QGIS software. A colour has been selected, in this case blue. The intensity of the colour in each neighbourhood increases or decreases according to the value of the calculated vulnerability index.

neighbourhoods with value 3 are those that do not meet any of the above conditions (Table 5).

3. Results and discussion

3.1. Analysis of vulnerability

a) Equipment vulnerability

The equipment vulnerability shows that the central and northeastern areas have the most vulnerable neighbourhoods. Neighbourhoods with high equipment vulnerability in the case study of Valencia City are Camí de Vera, El Calvari, Jaume Roig, La Vega Baixa, Beteró, Camí Fondo, La Seu, El Mercat and La Roqueta (Fig. 7). This is due to the poor performance of public transport, social resources and public services (Valencia City Councila) in this city area, as shown in Fig. 6. In particular, the lack

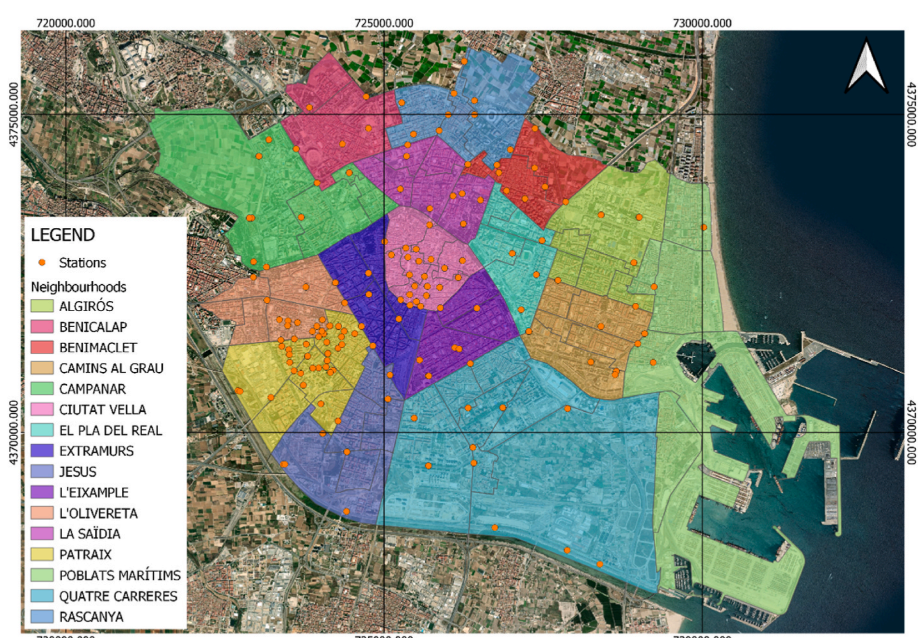

Fig. 3. Geolocation of passive dosimetry sensors deployed during 2021 across the study area of Valencia.

Table 4
Number of sensors in monitored neighbourhoods.

Neighbourhood code	Neighbourhood	Number of stations
11	LA SEU	16
12	LA XEREA	24
13	EL CARME	8
14	EL PILAR	4
15	EL MERCAT	36
16	SANT FRANCESC	115
21	RUSSAFA	56
22	EL PLA DEL REMEI	8
23	LA GRAN VIA	8
31	EL BOTANIC	12
32	LA ROQUETA	24
33	LA PETXINA	20
34	ARRANCAPINS	32
41	CAMPANAR	16
43	EL CALVARI	8
44	SANT PAU	56
51	MARXALENES	5
52	MORVEDRE	8
53	TRINITAT	40
54	TORMOS	12
61	EXPOSICIO	8
62	MESTALLA	16
64	CIUTAT UNIVERSITARIA	12
71	NOU MOLES	16
72	SOTERNES	8
73	TRES FORQUES	76
74	LA FONTSANTA	12
81	PATRAIX	68
83	VARA DE QUART	46
84	SAFRANAR	64
85	FAVARA	16
91	LA RAIOSA	20
94	SANT MARCEL.LI	12
95	CAMI REAL	27
101	MONT-OLIVET	8
103	MALILLA	24
104	LA FONTETA S.LLUIS	24
105	NA ROVELLA	24
106	LA PUNTA	11
111	EL GRAU	20
113	LA MALVA-ROSA	4
114	BETERO	12
121	AIORA	13
125	PENYA-ROJA	44
131	L'ILLA PERDUDA	12
133	L'AMISTAT	8
135	LA CARRASCA	48
141	BENIMACLET	40
142	CAMI DE VERA	28
151	ELS ORRIOLS	15
152	TORREFIEL	8
153	SANT LLORENS	20
161	BENICALAP	28
162	CIUTAT FALLERA	4

of public rail transport in the southeast and police stations and libraries in the east, north and south of the city played a major role in the equipment vulnerability (Fig. 6).

b) Demographic vulnerability

The demographic vulnerability results show that the most vulnerable neighbourhoods are located in the central area of the city (Fig. 8). The variables population density, population change over 5 years and population over 65 living alone have had a high weight in this result (Valencia City Councilb).

The average population density is 225 inhabitants per hectare, with the most vulnerable neighbourhoods exceeding this value with data above 300 inhabitants per hectare. With regard to the population over 65 years of age, 9 of the 11 vulnerable neighbourhoods have values above the city average, which is 619.

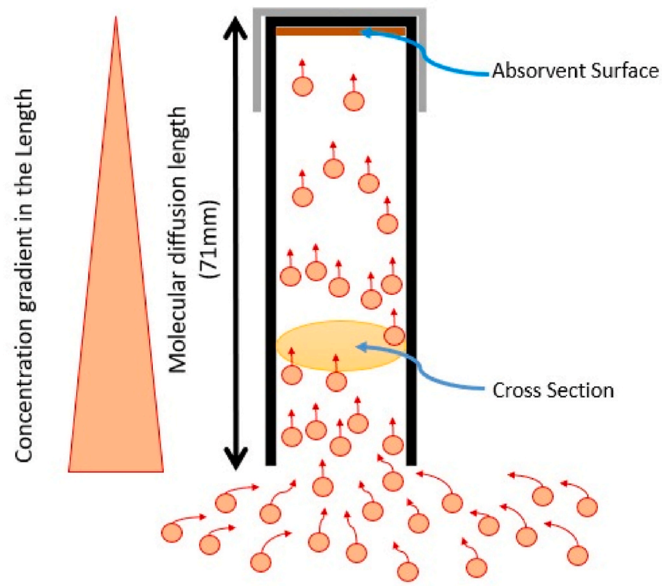

Fig. 4. Molecular diffusion law inside a passive dosimetry sensor.

< = 23.5 → CODE = 5

23.5 – 33.11 → CODE = 4

33.11 – 40 → CODE = 3

40 – 49.79 → CODE = 2

> 49.79 → CODE = 1

Fig. 5. Codification of air quality based on percentiles.

Table 5
Environmental equity values.

Environmental equity	Vulnerability	Conditional	Air quality
1	Medium-high	And	Exceed the NO_2 limit level
2	Medium-high	Or	Exceed the NO_2 limit level
3	Low	And	Low NO_2 level

Neighbourhoods with high demographic vulnerability in the case study of Valencia City are Morvedre, Benimaclet, Jaume Roig, La Petxina, Patraix, La Raiosa, Russafa, En Corts, Mont-Olivet, Na Rovella and Aiora.

c) Socioeconomic vulnerability

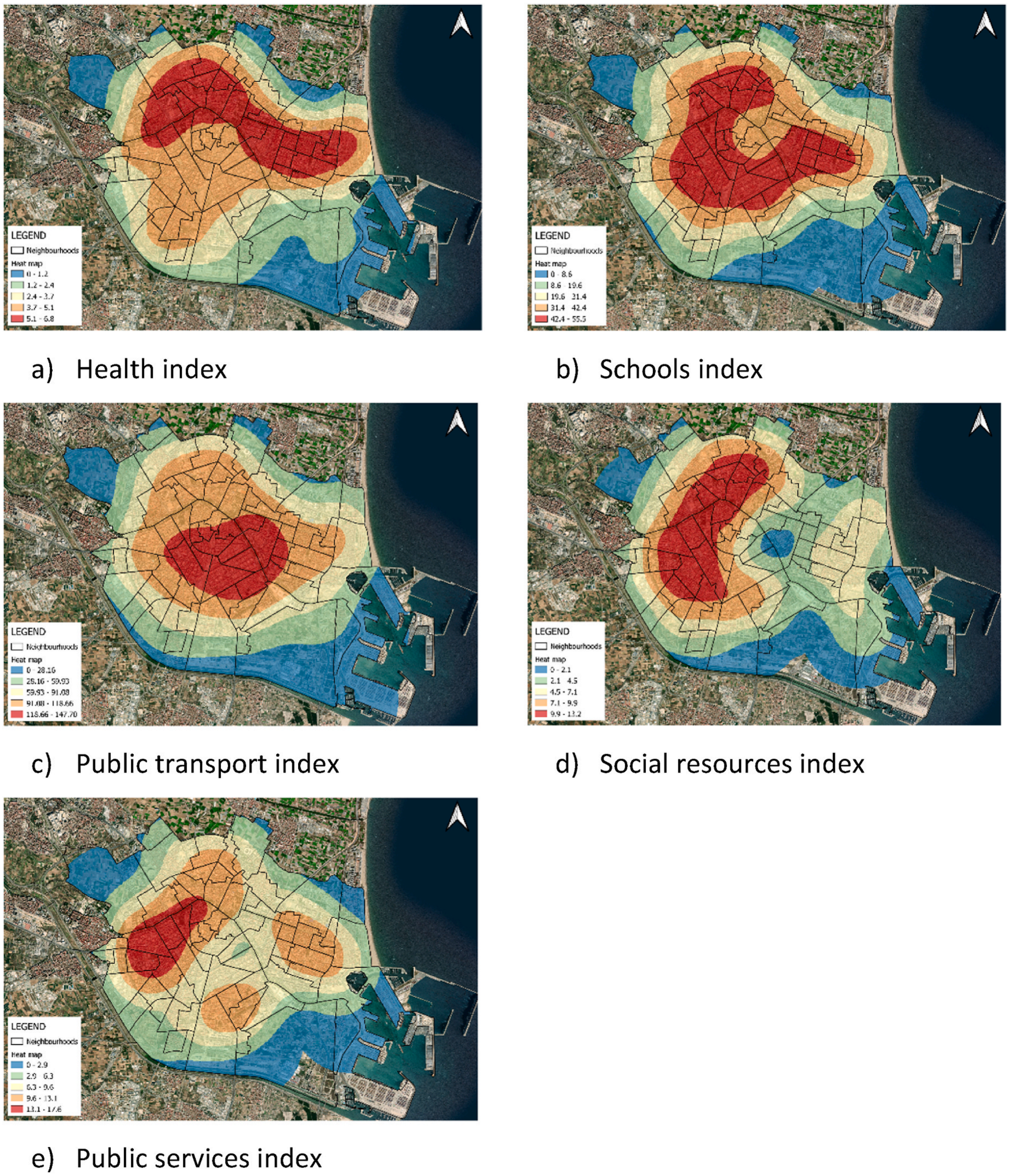

Fig. 6. Distribution of individual variables that affect equipment vulnerability in the case study.

Socioeconomic vulnerability results show that the most vulnerable neighbourhoods are located on the outskirts of the city, scattered to the north and south of the city (Fig. 9). Socioeconomic vulnerability is highly influenced by the variables academic level, the average age of private cars, personal income tax and IAE (Valencia City Councilb).

The academic level of a neighbourhood is measured by the number of inhabitants who can neither read nor write and the number of inhabitants who have less than a school-leaving qualification. On average, 14.34% of the inhabitants of a neighbourhood have a low academic level; neighbourhoods classified as socio-economically vulnerable have percentages higher than 23%. These neighbourhoods also exceed the average age of private cars, which is 13 years. Regarding personal income tax, these neighbourhoods have values of approximately 23,000€ while the average variable value is 35,723.76€.

Neighbourhoods with high socioeconomic vulnerability in the case study of Valencia City are Ciutat Fallera, Orriols, El Calvari, La Fontsana, Tres Forques, Na Rovella and Natzaret.

d) Global vulnerability

The global vulnerability results show that vulnerable neighbourhoods are located around the city, with the most vulnerable neighbourhoods situated north, south and west of the city centre (Fig. 10).

Regarding the neighbourhoods with high vulnerability, Morvedre, Mont-Olivet and En Corts are in this group due to their high vulnerability in demographics. Ciutat Fallera and Orriols stand out as the most

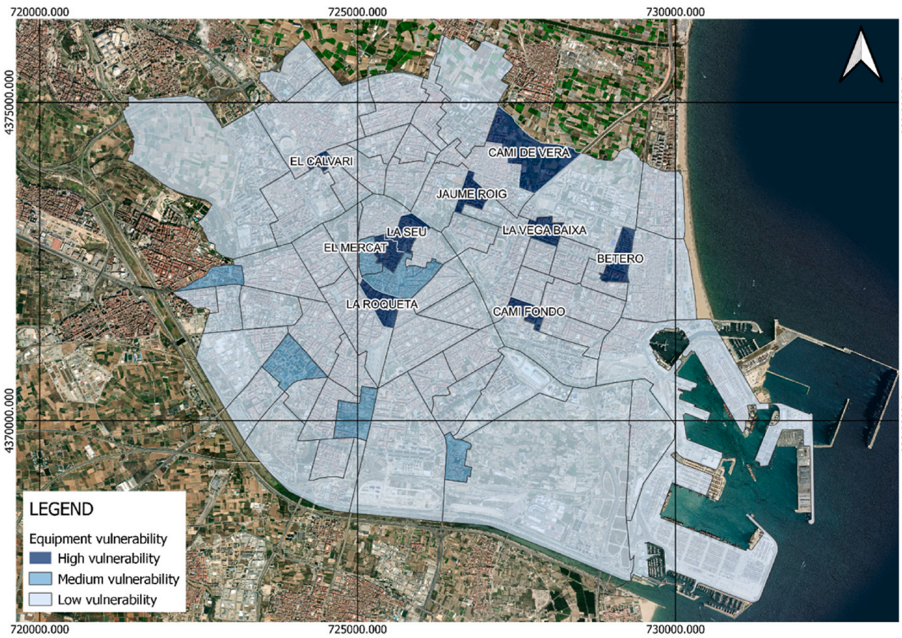

Fig. 7. Equipment vulnerability map.

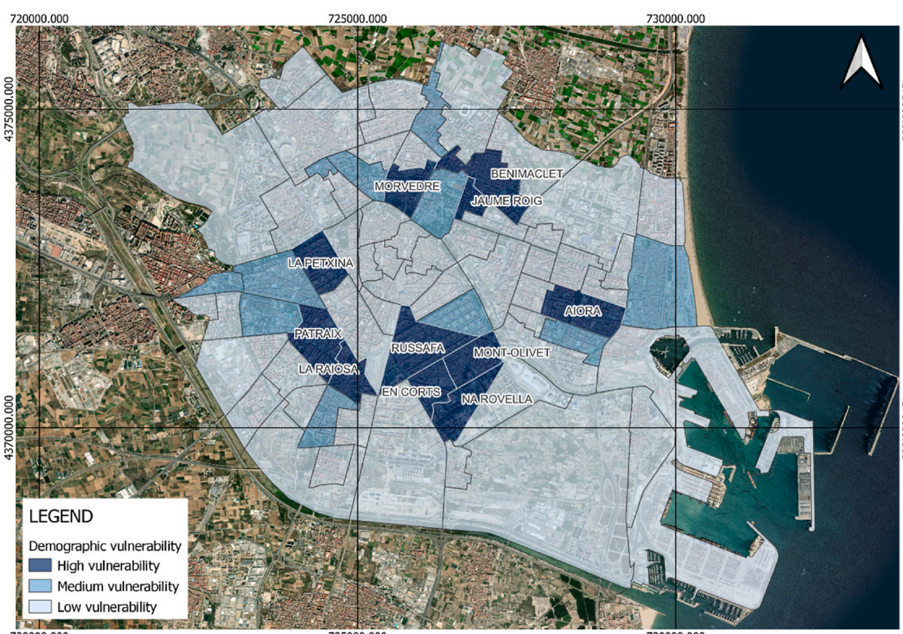

Fig. 8. Demographic vulnerability map.

vulnerable neighbourhoods in terms of socioeconomics, and the latter has also been classified with a medium level of vulnerability in terms of demographics. Soternes is classified as a neighbourhood with a high level of global vulnerability due to its unfavourable results in terms of facilities and demographics. Finally, the most vulnerable neighbourhood in the city of Valencia is El Calvari, with a score of 1.9 on a range of 1–5 due to its high vulnerability in facilities and socioeconomics and its medium vulnerability in demographics.

3.2. *Air quality monitoring*

The spatial distribution of the air quality monitoring through NO_2 passive sensors can be seen in Fig. 11. The average daily NO_2 concentration value monitored by the deployment of the 648 sensors of passive dosimetry is 38.06 μg/m^3. The areas where the worst air quality levels have been recorded correspond to the main entrances and exits in the city. Sensors located in these areas had an average NO_2 of 59.88 μg/m^3 in 2021, higher than the average of all recorded values and thelimit value of 40 μg/m^3 set by the European Union Directive (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION).The maximum NO_2 value monitored corresponds to one of the sensors located at one of the entrances to the city, with 84.75 μg/m^3.

The World Health Organisation sets targets for reducing nitrogen dioxide in long-term exposures, proposing that levels be reduced by up to 10 μg per cubic metre. These intermediate targets are set at 40, 30 and 20 μg/m3, thus aiming for a progressive decrease in the levels of nitrogen dioxide (Weltgesundheitsorganisation and World Health Organization, 2021).

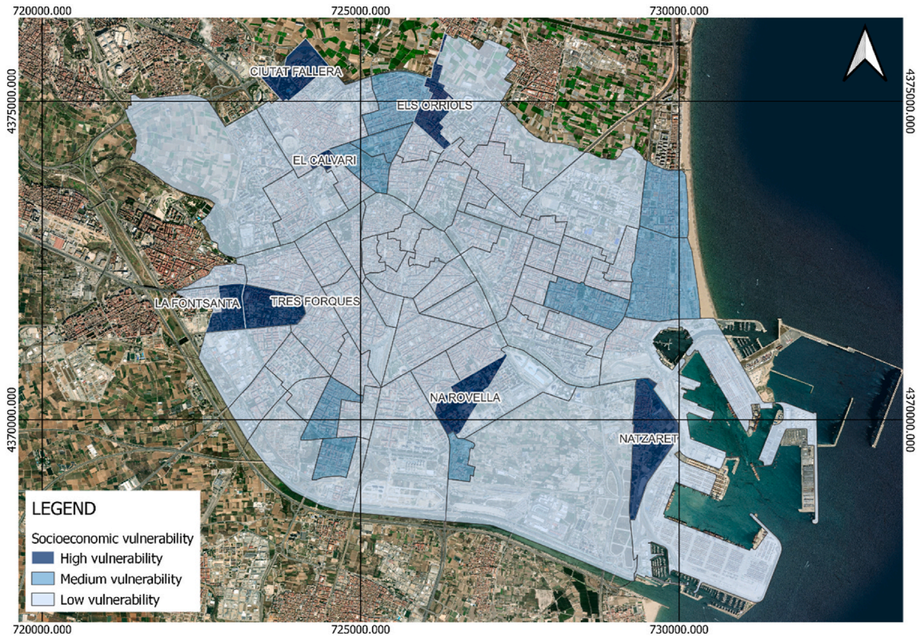

Fig. 9. Socioeconomic vulnerability map.

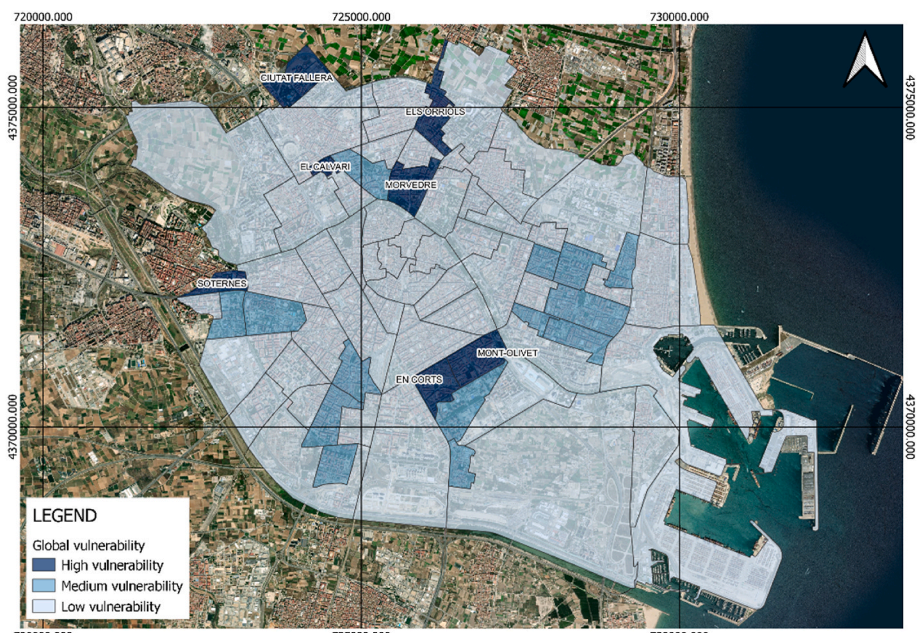

Fig. 10. Global vulnerability map.

Low NO_2 values have been monitored in pacified areas near orchards and parks. The mean recorded at stations located in these pacified areas is 17.62 μg/m^3. The lowest NO_2 value is 7.85 μg/m^3, recorded at a Monitoring Network station located in the northeast of the city, close to an orchard area.

The average air quality results per neighbourhood can be seen in Fig. 12. The poor air quality continues to coincide with the neighbourhoods where the main entrances and exits of the city are located, as well as the neighbourhoods near the centre. Specifically, the neighbourhoods with worse results are Ciutat fallera, Torrefiel, La Roqueta, Arrancapins, Vara de Quart, Sant Isidre and La Fonteta de San Lluis. Fig. 13 shows the neighbourhoods exceeding the EU Directive limit value (red line) (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION) and in yellow, those neighbourhoods that are classified as having poorer air quality.

3.3. Environmental equity

The application of the methodology developed to evaluate environmental equity with high spatial resolution can be seen in Fig. 14, which is applied to the pilot city, Valencia. This methodology allows to identify the neighbourhoods with less environmental equity compared with the whole city. Thus, Fig. 14 shows that neighbourhoods with the worst environmental equity are located around the entrances and exits of the city because of its poor air quality. Five of the seven neighbourhoods with high vulnerability have been identified with bad environmental equity. In the same way, 42.8% of neighbourhoods with medium environmental equity coincide with neighbourhoods with NO_2 levels

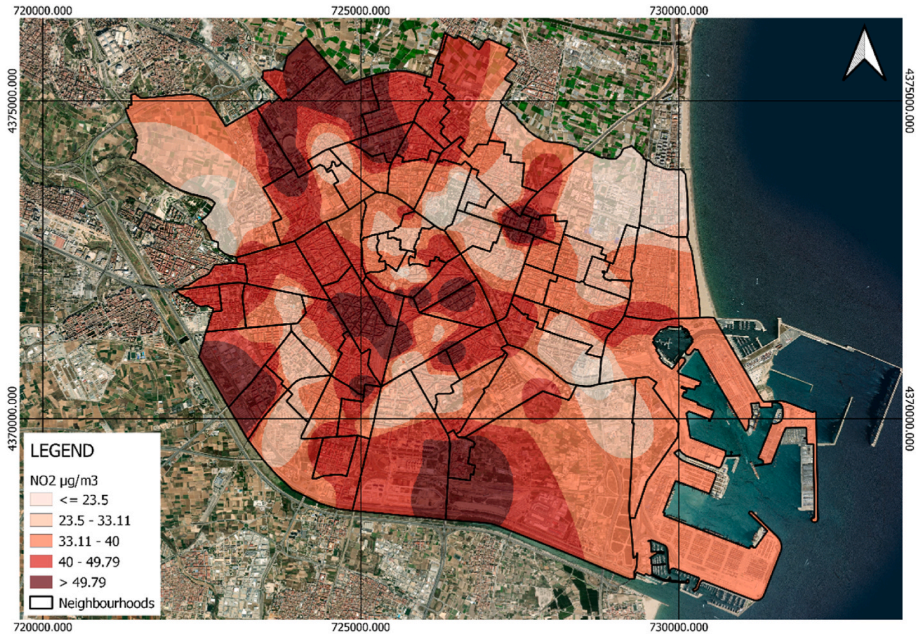

Fig. 11. NO_2 map of Valencia.

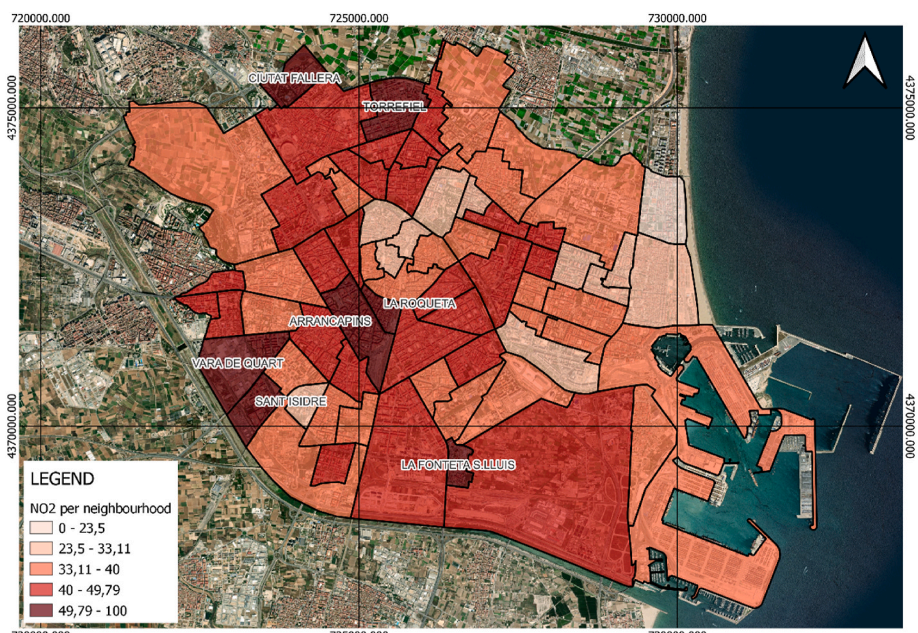

Fig. 12. Air quality by neighbourhoods.

between 40 and 49.79 µg/m^3.

The neighbourhoods with poor environmental equity are Ciutat fallera, Els Orriols, Morvedre, Mont-Olivet, Soternes, Marxalenes, La Fontsanta, La Raiosa, La Fonteta de Sant Lluis, L'Amistat and Sant Marcel·li. The first five neighbourhoods have been classified as high vulnerability, and the other six as medium vulnerability. All of them exceed 40 µg/m^3 of NO_2.

Finally, the relationship between the normalized air quality values and global vulnerability by neighbourhood can be seen in Fig. 15, which shows no direct relationship between vulnerable neighbourhoods and neighbourhoods with poor air quality. Some examples are El Calvari, classified as highly vulnerable but with a NO_2 value of 37.86 µg/m^3, or Torrefiel, with low vulnerability but a NO_2 value of 51.06 µg/m^3, exceeding the EU Directive limit value.

This methodology makes it possible to calculate and represent the environmental equity of the study area's neighbourhoods and analyse the connection between vulnerable neighbourhoods and neighbourhoods with poorer air quality. It is concluded that there is no direct relationship between the two factors.

4. Conclusions

The methodology developed makes it possible to identify 10% of the city's most vulnerable neighbourhoods and the variables to which they are vulnerable. In addition, the deployment of a passive dosimetry sensors network to monitor NO_2 has allowed to identify the neighbourhoods with higher NO_2 levels, indicating poorer air quality and, therefore, a risk to the health of citizens. Finally, environmental equity

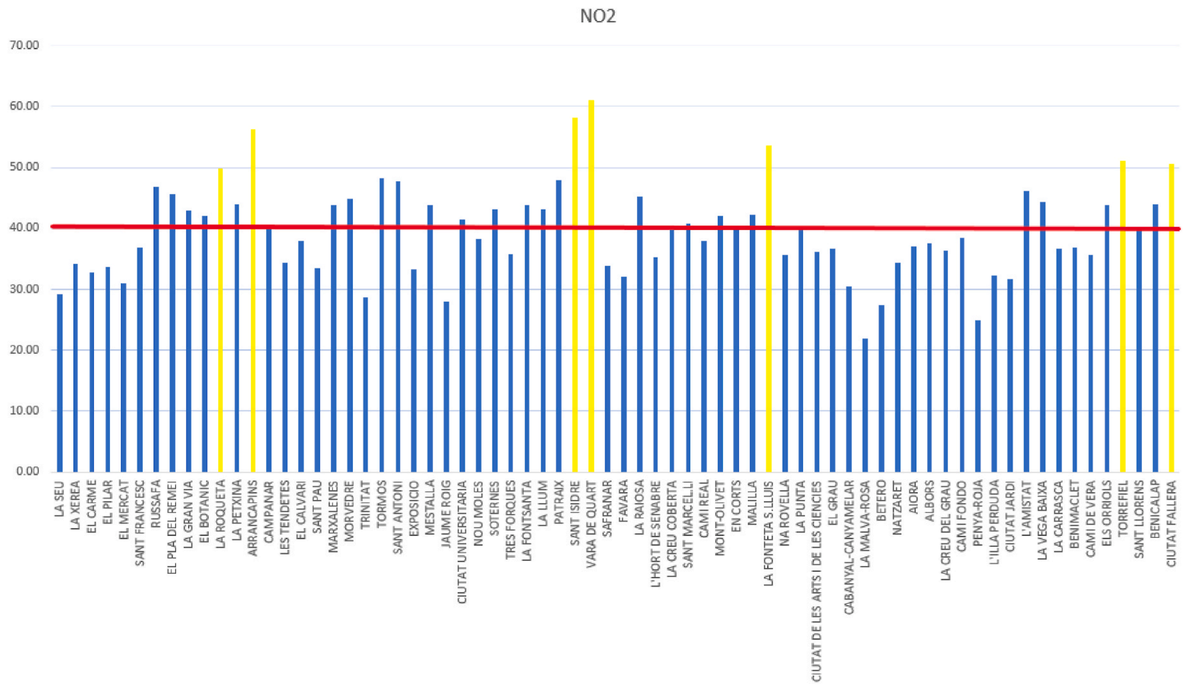

Fig. 13. NO2 values per neighbourhood. The red line indicates the EU Directive limit established at 40 μg/m^3. Yellow bars indicate neighbourhoods with poorer air quality.

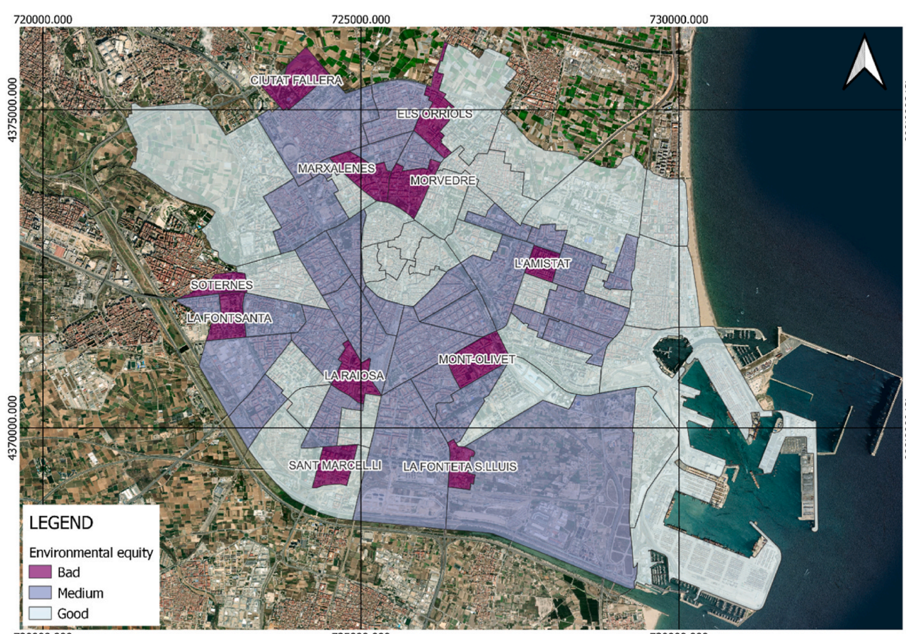

Fig. 14. Environmental equity map.

relating to the air quality levels and vulnerability per neighbourhood has been evaluated.

Developed methodology has been applied to the Valencia case study. Results show that the neighbourhoods with high equipment vulnerability are those located in the centre and northeast of the city, in some cases because a large part of the neighbourhood is garden and has no facilities. Regarding demographics, the most vulnerable neighbourhoods are around the city centre and some in the east due, among other reasons, to the ageing population living in these neighbourhoods. There are few dispersed neighbourhoods with high socioeconomic vulnerability, classified in this way because of their unfavourable results on some variables such as academic level and personal income tax, compared to the rest of the city's neighbourhoods.

Regarding air quality, a network of 648 passive dosimetry sensors has been deployed throughout the study area to monitor NO_2 concentration in the air. The average daily NO_2 monitored of the city has been 38.06 μg/m^3, very close to the European Union Directive limit value and WHO recommendation of 40 μg/m^3. Nevertheless, 45.7% of the neighbourhoods exceed this limit, and 8.57% exceed 50 μg/m^3. The neighbourhoods where high NO_2 values have been recorded coincide with the city's entrances and exits.

Finally, it is concluded that there is no direct relationship between

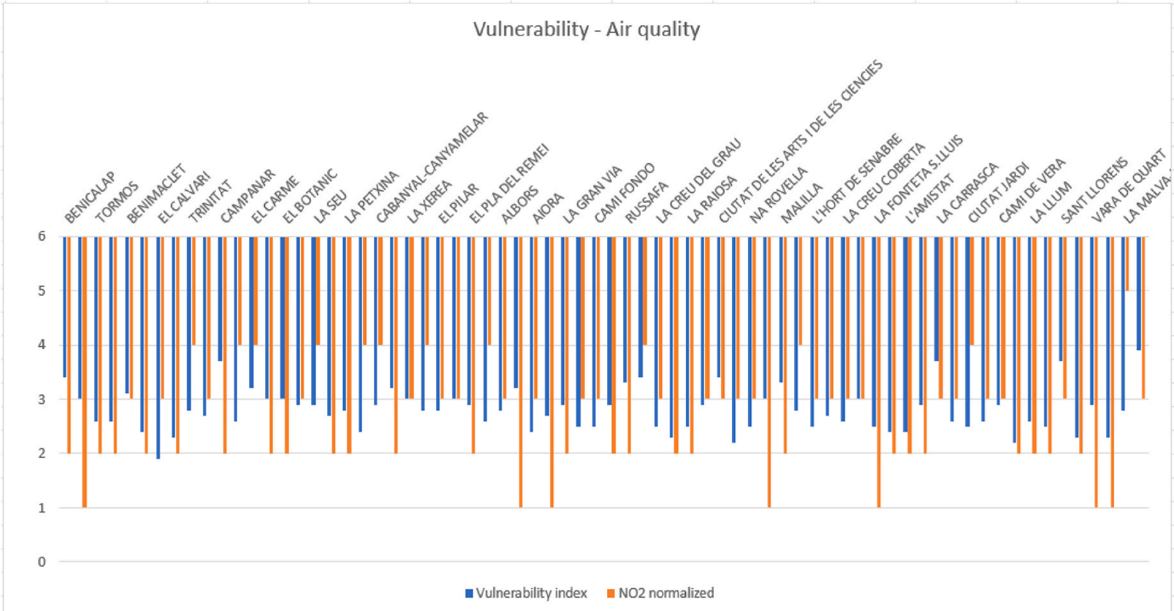

Fig. 15. Vulnerability and air quality relationship.

neighbourhoods with high vulnerability and neighbourhoods with poorer air quality. Nevertheless, 14.28% of total neighbourhoods meet both conditions.

The developed methodology has great potential for application in other urban areas and can be useful for policy makers, especially in view of the forthcoming changes in EU air quality directives. It allows to identify the areas with less environmental equity with high spatial resolution, as well as the variables responsible for that low environmental equity. This allows to improve efficiently the different variables that affect it, as well as focusing efforts on improving air quality in areas with the worst values, developing targeted mitigation strategies, promoting equitable environmental solutions and ensuring compliance with evolving EU regulations, making it a crucial tool for informed policy decisions.

CRediT authorship contribution statement

Clara Bosch-Checa: Methodology, Writing – original draft, Writing – review & editing. **Maria Joaquina Porres de la Haza:** Conceptualization, Supervision. **Eloina Coll-Aliaga:** Investigation, Validation. **Victoria Lerma-Arce:** Data curation, Formal analysis. **Edgar Lorenzo-Sáez:** Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data links are specified in the original research article

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