Biodiversity, Urban Quality Life and Air Quality Indices for Hotspot Detection of Transformation Opportunities in Cities: A Case Study in Barcelona

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Abstract: Half of the world's population lives in cities, where usually there are few little green space and there are also high levels of air pollution. Moreover, the traditional urbanization of cities contributes to climate change, promotes the loss of global biodiversity and induces serious health problems for citizens. Both climate change and the loss of biodiversity affect negatively to the ecosystems and therefore human health, as they are responsible for providing clean air, food, fresh water, medicines, renewable resources... This deterioration increases significantly the risk of human-borne infectious diseases such as coronavirus or HIV. The ability we have to re-naturalize anthropogenic spaces and learn to generate spaces for coexistence will be key for the future of our society. The research presented in this paper aims to do a step forward to achieve that ability by working in three schools of the city of Barcelona and their surroundings. Among other actions, in this project, a diagnosis of neighborhood has been carried out. The diagnosis includes the identification and quantification of relevant indicators regarding neighborhood's biodiversity and also the quality of daily life and the analysis of pollutants (NO_2 and PM_{10}) near the schools during the 2021-2022 school year. All these information has been merged in a single geographic data base and relevant hotspots where to act have been identified. The information has been shared with city council and citizens.

1 INTRODUCTION

In 2020, and as a way to provide response to the crisis situation caused by covid-19, Barcelona City Council promoted the Scientific Research Awards for Urban Challenges in the City of Barcelona 2020. This paper presents the main scientific outcomes from one of the projects awarded on that call: the project "Rethinking school environments". The proposal aroused from the need to provide solutions to the current environmental and urban planning situation in which Barcelona finds itself. This is a multidisciplinary project joining biology, urban planning, and air quality, among others, to perform a deep review of the city to make it healthier, more pleasant, sustainable, and a space for all urban biodiversity to live together. As a specific objective, the idea was to learn about school environments in order to renaturalize human spaces and learn to generate spaces for coexistence, at all levels and for all existing species. The aim was to provide tools that allow to redesign cities with a mixture of uses in which a change in mobility is possible, improve air quality, improve urban biodiversity and fight the climate emergency. This is how we will achieve healthier, more sustainable, and more pleasant cities. Studies carried out by (Benedict W Wheeler et al., 2021; Ojala and Campbell, 2020) have shown that the aspects of the city analyzed in the development of this work directly affect the life and health of the population, especially the most vulnerable groups.

Our proposal relies on the creation of new indices, and its join analysis to detect hotspots where to act first in order to improve citizens quality of life from a multidisciplinary perspective. To do that, the use of GIS tools is of foremost importance. In this paper

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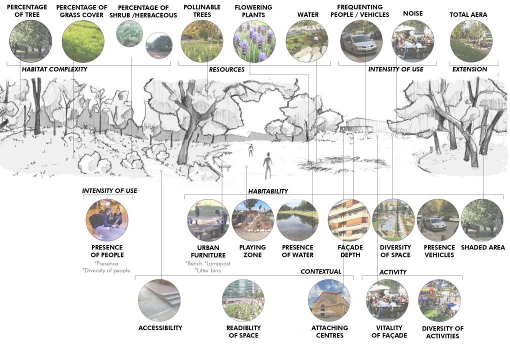


Figure 1: Graphical representation of the items analysed for the biodiversity squares, at the top, and for the people's quality of daily life squares, at the bottom.

we present the methodology proposed, as well as the analysis done in three neighborhoods of Barcelona.

2 METHODOLOGY

In this project we have defined several indices that allow showing citizenship the quality of life in the surroundings of schools. The indices have been designed to be easy to understand. Separate but analogous indices are created for biodiversity, urban quality life and air pollution. The joint analysis of them is what provide information on the areas where actions should take place.

2.1 Biodiversity

The study of biodiversity in the city distinguish between two types of infrastructure: (1) Squares; and (2) Streets. They are considered separately since the squares usually have an area large enough for the species to stay there for a certain period of time (Beninde et al., 2015; Ian MacGregor-Fors, 2011). Streets, on the other hand, are usually passage areas for species, although sometimes they can also be staying areas, especially for vegetation. We evaluate each neighborhood using relevant indicators for biodiversity: 11 indicators in squares and 9 in streets, see Figures 1 and 2. All indicators are then used to create an index ranging from 0 (poor quality) to 100 (optimal quality) obtained by properly weighting all indicators.

Once the indices are computed, and in order to test for differences between the studied districts, two linear models are used, one for the biodiversity squares index and one for the streets index, with districts (i.e. different urban designs) as the independent variable.

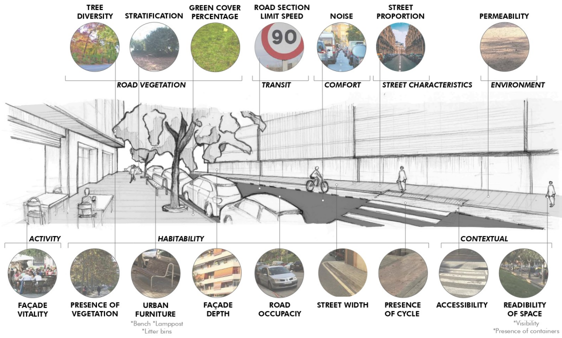


Figure 2: Graphical representation of the items analysed for the biodiversity of the streets, at the top, and for the people's quality of daily life streets, at the bottom.

2.2 Urban Life

Analogously to the study of biodiversity, we propose two types of indices for the quality of urban life: (1) Squares and (2) Streets. We evaluate the people's quality of daily life (i.e. spaces with equity for all individuals and groups) by using 15 indicators in squares and 11 in streets (Figures 1 and 2). Again, all indicators are used to create an index ranging from 0 to 100 obtained by weighting all indicators, and two linear models are used to test for differences between the three studied districts.

2.3 Air Quality

To estimate the amount of pollutants in the air two types of technologies are proposed: (1) Official air quality measurement stations; (2) Sentinel-5 Precursor satellite data.

2.3.1 Official Air Quality Measurement Stations

To generate the first air quality indicator, data from an entire academic year are needed. Two pollutants are considered here: nitrogen dioxide (NO_2) and particulate matter 10 micrometers or less in diameter (PM_{10}). The official air quality reference stations has been selected according to two criteria: (1) the closest to the schools; (2) with similar environments.

Based on the reference values defined by the WHO global air quality guidelines of 2021 (WHO, 2021), the air quality indices rely on the 24-hour average calculated for each of the pollutants and their annual mean. Table 1 shows the WHO reference values for these contaminants.

On a first step, the annual average concentration of pollutants in each station should be calculated to compare the resulting value with the reference values defined in the WHO guideline. Later on, graphs has to

Table 1: Reference values defined in the 2021 WHO guide for NO_2 and PM_{10} pollutants.

Pollutant	Averaging time	AQG level	Threshold
PM_{10} $\mu g/m^3$	Annual 24-hour	15 45	70
NO_2 $\mu g/m^3$	Annual 24-hour	10 25	40

be generated with the calculated averages of the concentration of the pollutants during 24 hours. This information allows to compare with the maximum limit defined by the WHO during 24 hours. The indices ranges from 0 to 100 according to: optimal air quality for values below the limit value defined by the WHO guidelines (100) to poor air quality for higher values that represent more health risk (0).

2.3.2 Sentinel-5 Precursor Satellite

Sentinel-5 Precursor (S5p) is a satellite system that provides information and services on air quality, climate and the ozone layer of our atmosphere. The Sentinel-5p satellite, from the Copernicus Sentinel-5 Percursor mission, offers a spatial resolution of 7x7 km^2 and in Spain we have a new image every day at approximately 12 noon. Through the Sentinel Hub plugin installed in the QGIS program, an analysis of the NO_2 concentration on each day of the academic year was carried out in a simple way. The first step is to configure Sentinel Hub according to the data objective to be displayed in QGIS. The plugin transforms any layer defined in Sentinel Hub configuration into a QGIS layer, (Sentinel Hub, 2019). Once the processed satellite images are directly accessed and with the color representation previously defined in the configuration, the plugin enables a quick exploration, customization and image download.

Initially, a first filtering should be carried out on the data in order to discard the images that do not have data in the study area. Next, the resulting data set should be analyzed by week (Monday to Sunday), with the aim of identifying patterns in the data. The first pattern we need to identify is whether all the schools had the same levels of contamination or if the one located furthest from the urban center had different levels of contamination. The second pattern to identify is if the days with the highest concentration of NO_2 occur on workdays and the days with the lowest concentrations are on weekends or holidays.

2.4 Joint Analysis

Once all the indicators are computed, for every street or square we can analyze separately each indicator and also we can do it jointly. The joint analysis of the three indicators will allow us to have a better understanding of the situation (comfort, biodiversity and air quality). The analysis of all streets and squares of a neighborhood will allow us to detect hotspots to improve inside of a neighborhood. And the comparison of the neighborhoods as a whole, will allow us to determine which neighborhood of the city need more attention.

3 STUDY AREA AND DATA

3.1 Study Area

The project focus on three neighborhoods of Barcelona. The selection of the three public schools was carried out through the *Consorci Escoles + Sostenibles*, which is part of a network made up of organizations committed to environmental, social and economic sustainability that collectively build a responsible city with people and the environment, (Ajuntament de Barcelona, 2022). With the aim of analyzing the school environment taking into account different types of urbanization and areas with different urban fabrics. The selected schools were, *Ferrer i Guàrdia* (Nou Barris district - close to the Collserola wood), *Diputació* (Eixample district - dense with wide streets and lot of cars) and *Patronat Domènech* (Gracia district - pedestrian area with narrow streets).

The cartographic data base used in the delimitation of the territory of Barcelona was downloaded from the Open Data BCN portal.

3.2 Biodiversity and Quality of Urban Life Data

The data for these indices has been obtained from the Open Data BCN portal. Fieldwork to check the quality of the data base was performed in July 2021. The Barcelona territory layer has been our base layer for the insertion of the data to be analyzed. In the QGIS program, an initial edition was made to the territory layer, with the objective of sectioning each street section into a polygon, see Figures 4 and 5, information treated as urban connectors in the analyzes. Each street section of the study area was associated with data such as tree cover, presence of businesses, and elements of interest for wildlife, among others, see Figures 1 and 2. An example of the analysis performed in the GIS program to generate all the indexes is the calculation of the percentage of trees per street section generated from the tree cover data. It is important to note that the processing and analysis of the data in the QGIS program has been carried out jointly with the WMS resources of the geoservices offered in the GeoportalBCN.

3.3 Air Quality Data

The air quality analysis has been carried out for the 2021-2022 Barcelona's school year. From September/2021 to June/2022 and in this study every day of this period was analysed, both for the data obtained from the surface reference stations and for the satellite data.

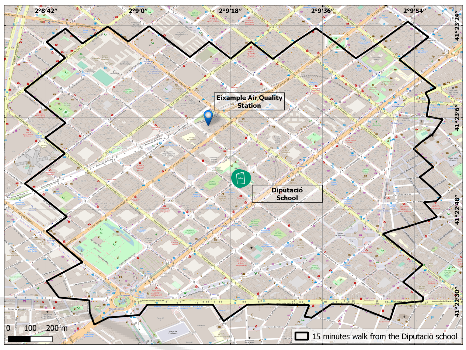
3.3.1 Surface Reference Station

The *Generalitat de Catalunya* monitors the air quality of the territory based on the data collected by the Air Pollution Monitoring and Forecasting Network (XVPCA). The data collected by the stations are available on the Open Data Portal of Catalonia, with hourly frequency, (Generalitat de Catalunya, 2014). To define the air quality around the *Diputació, Patronat Domènech* and *Ferrer i Guàrdia* schools, daily data on NO_2 and PM_{10} pollutants have been used for the 2021-2022 academic year from the Eixample, Gracia and Parc Vall Hebron stations, respectively. See Figures 3b, 3a, 3c. The Parc Vall Hebron station is not close to Nou Barris district, however, this is the closest station that meets the second requirement of having an environment similar to the school zones studied.

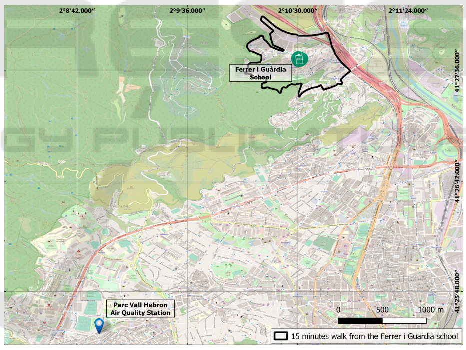
3.3.2 Satellite Data

In this study, an analysis of 302 Sentinel-5p images was performed, all corresponding to the 2021-2022 academic year. The first data filtering was done to discard the images that had no information in the study area, 206 images were discarded. The objective of defining patterns in the data was carried out based on the analysis of 96 images of the study area, which would allow us to compare the results obtained with the air quality data measured on the surface with the patterns found based on satellite data. It is very important to note that the data from the surface stations are measured at a height close to the pollutant emission source. Whereas, the satellite data is from the entire air column, from the surface to the troposphere and there is a dispersion time of the air in the column. Thus, the values to create the indices from one sensor and the other will never be the same.

(a) Gracia Air Quality Station.



(b) Eixample Air Quality Station.

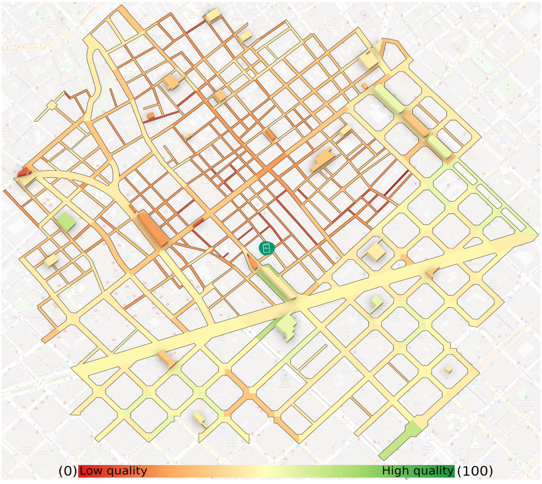


(c) Parc Vall Hebron Air Quality Station.

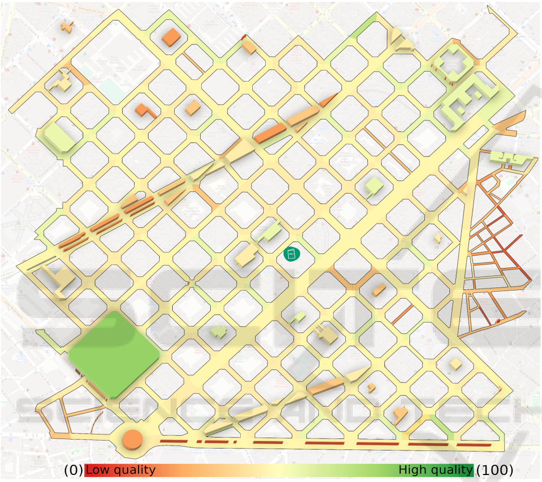
Figure 3: Air Quality Stations.

4 RESULTS

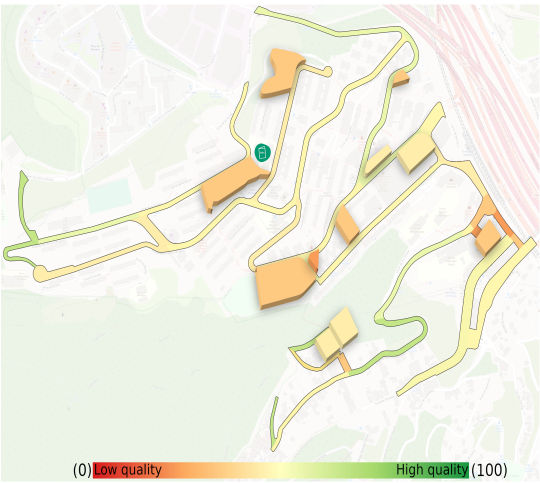
This section presents the calculated indices of biodiversity and quality of urban life. Based on these values, in the QGIS program, the edited layer of the Barcelona territory was used to generate a graphical representation of these indices, (Figures 4 and 5). For the air quality index, the calculated averages are presented, the values measured at each station by means of a graph (Figures 6, 7 and 8), and finally, a map of the NO_2 concentration measured by the Sentinel-5p satellite (Figure 9).



(a) Gracia.

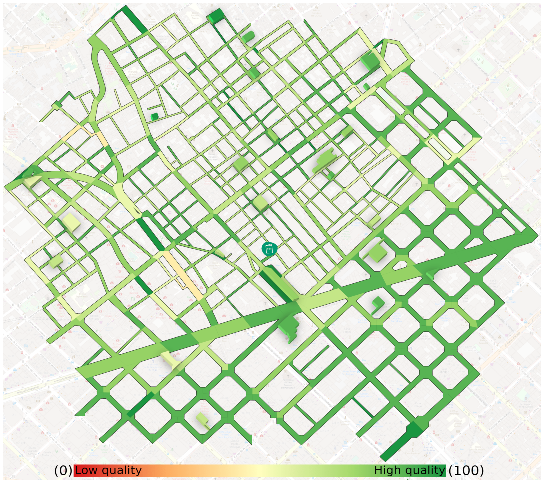


(b) Eixample.

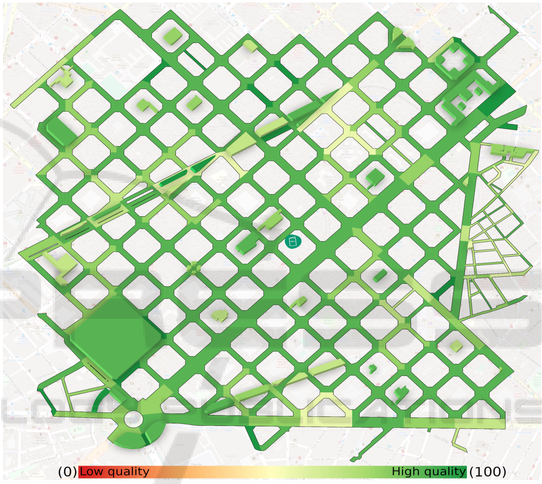


(c) Nou Barris.

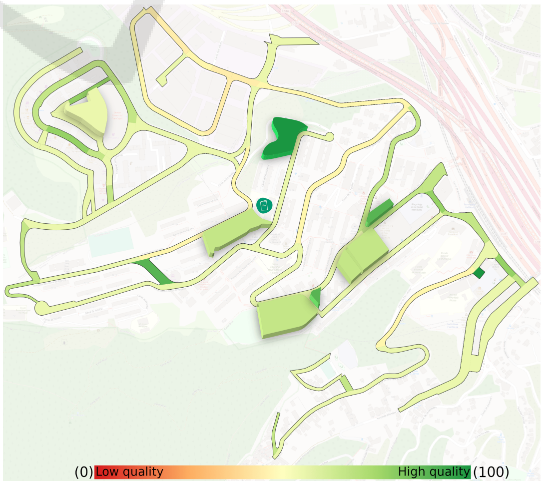
Figure 4: Biodiversity quality of squares and streets in three districts of Barcelona.



(a) Gracia.



(b) Eixample.



(c) Nou Barris.

Figure 5: Urban Life quality of squares and streets in three districts of Barcelona.

4.1 Biodiversity

Regarding the biodiversity square index, a mean of 38.16 for the three neighborhoods was obtained (SD: 11.45, range: 13-72) (see Table 2 for extended details and Figure 4). Using the analysis of variance (Girden, 1992), surprisingly, no significant differences were found between the three districts studied (Gracia's Estimate ± SE, p: -6.03 ± 2.96, 0.045; Nou Barris -4.18 ± 3.62, 0.69; ANOVA p= 0.10; N = 78). In the case of streets, a mean of 38.52 for the three neighborhoods was obtained (SD: 12.09, range: 6-69) (see Table 3 and Figure 4). As expected, significant differences were found between districts (Gracia's Estimate ± SE, p: 9.65 ± 4.98, 0.053; Nou Barris 64.03 ± 7.51, < 0.0001; ANOVA $p < 0.0001$; N= 1,196).

Table 2: Biodiversity indices for squares.

	Gracia	Eixample	Nou Barris
Items analysed	19	60	13
Min index val	13	13	29
Max index val	63	72	47
Mean index val	35.26	39.17	37.6

Table 3: Biodiversity indices for streets.

	Gracia	Eixample	Nou Barris
Items analysed	590	589	75
Min index val	6	7	26
Max index val	63	67	69
Mean index val	30.46	45.50	45.50

4.2 Quality of Urban Life

Regarding the quality of people's daily life indices, a mean of 78.7 for the three neighborhoods was obtained (SD: 11.83, range: 51-99) (see Table 4 for extended details and Figure 5) in the case of squares and a mean of 75.08 (SD: 9.91, range: 36-94) (see Table 5 for extended details and Figure 5) in the case of streets. The obtained results were higher in both cases than the results obtained for the biodiversity squares and streets indices. Surprisingly, no significant differences were found for the quality of people's daily life squares (Gracia's Estimate ± SE, p: 3.40 ± 3.41, 0.32; Nou Barris -0.40 ± 4.20, 0.92; ANOVA p= 0.58; N= 82), while significant differences were found for the streets (Gracia's Estimate ± SE, p: -6.57 ± 0.50, < 0.0001; Nou Barris -19.98 ± 1.04, < 0.0001; ANOVA $p < 0.0001$; N= 1254).

Table 4: Urban life indices for squares.

	Gracia	Eixample	Nou Barris
Items analysed	17	52	13
Min index val	57	55	60
Max index val	91	97	97
Mean index val	78.47	75.73	75.70

Table 5: Urban life indices for streets.

	Gracia	Eixample	Nou Barris
Items analysed	590	589	75
Min index val	49	47	40
Max index val	100	98	92
Mean index val	78.53	84.13	62.05

4.3 Air Quality

According to the analyzes carried out, the environments of the three schools have poor air quality. This indicator was defined based on surface and satellite air quality data.

4.3.1 Official Air Quality Measurement Stations

Firstly, it has been verified that during the week, the day with the highest concentration of polluting gases is predominantly a workdays, while the days with the lowest concentrations take place on weekends or holidays. Second, the time series for the three study areas have been generated from the calculation of the daily average of pollution and compared with the maximum daily proposed levels defined by the WHO in the 2021 guide, presented in Table 1. Annual mean is also computed (Table 6) and can be compared against reference values (Table 1). The values are clearly above the ideal ones.

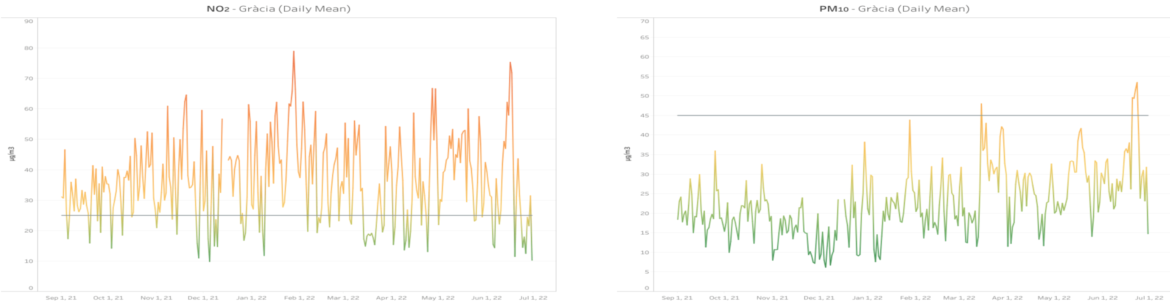
In the three neighborhoods during the 2021-2022 scholar course (Eixample and Gracia: almost all days; Nou Barris: half of the days) the NO_2 Daily thresholds (25 $\mu g/m^3$) have been exceed (see Figures 6a, 7a and 8a). The NO_2 annual means are also above WHO recommendations. Special attention to the Eixample station, which exceeds not only the recommended value but also the maximum threshold. Regarding PM_{10}, daily thresholds (45 $\mu g/m^3$) have been exceed in two neighborhoods during the 2021-2022 scholar course (Eixample: 10 days; Gracia: 1 day; Nou Barris: 0 days)(see Figures 6b, 7b and 8b).

Table 6: Average air quality in the 2021-2022 academic year.

Annual ($\mu g/m^3$)	Gracia	Eixample	Nou Barris
NO_2	36.35	45.15	24.32
PM_{10}	21.78	30.80	17.05

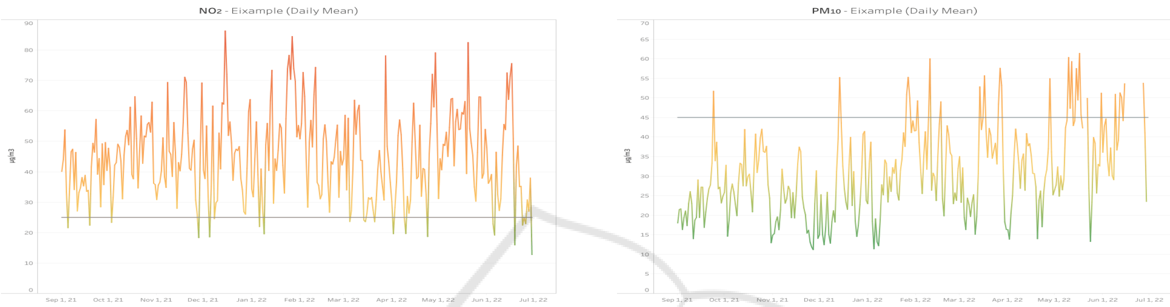
4.3.2 Sentinel-5 Percursor Satellite Data

Analyzing the Sentinel-5p satellite images of the entire study period, it has been possible to verify that the



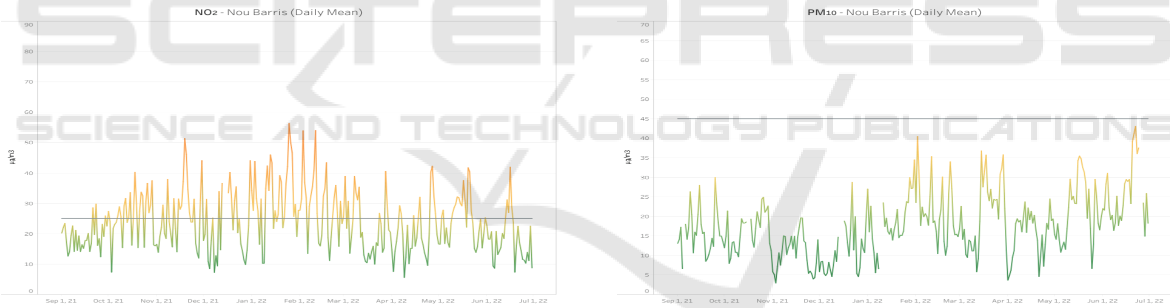
(a) NO_2. (b) PM_{10}.

Figure 6: Graphs of NO_2 and PM_{10} at Gracia station during the period from September/2021 to June/2022.



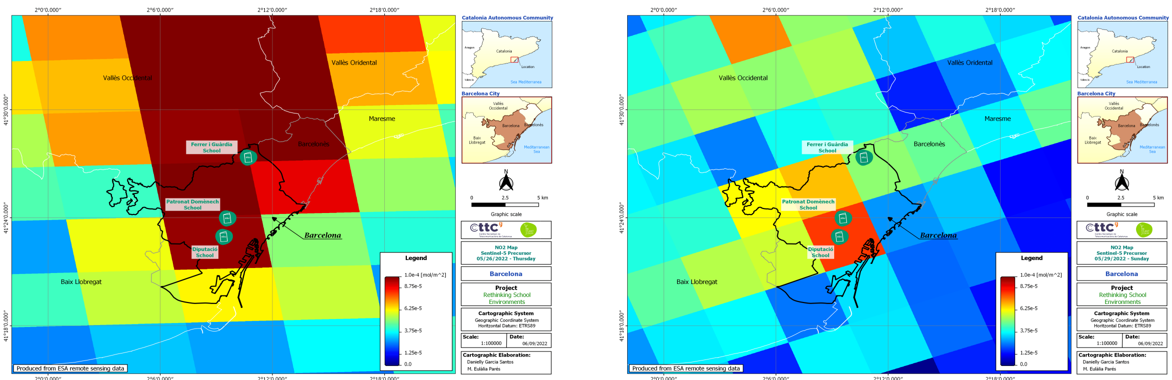
(a) NO_2. (b) PM_{10}.

Figure 7: Graphs of NO_2 and PM_{10} at Eixample station during the period from September/2021 to June/2022.



(a) NO_2. (b) PM_{10}.

Figure 8: Graphs of NO_2 and PM_{10} at Parc Vall Hebron station during the period from September/2021 to June/2022.



(a) Workday - Thursday. (b) Weekend - Sunday.

Figure 9: Comparison between two images from the S5p satellite, from a weekday and from a weekend of the same week.

same pattern is seen as with the data from the official surface stations. Separating the data as weekly sets (Monday to Sunday), predominantly, the day with the highest NO_2 concentration occurs on workdays and the days with the lowest concentrations occur on weekends or holidays. Figure 9 shows a comparison between two images from the S5p satellite, Figure 9a from a workday and Figure 9b from a weekend day of the same week. In the comparison presented in Figure 9, it is easy to see that, in the same week, the concentration of NO_2 changes significantly according to the activities carried out by the majority of the city's inhabitants.

4.4 Joint Discussion

This study highlights the poor quality of green infrastructure and air quality in three districts of Barcelona. This may be because squares and streets are designed for humans and vehicles rather than for biodiversity and health. In fact, considerably better results have been obtained for human daily quality of life than for biodiversity and health. Regarding street usages, the ones with more traffic (Eixample) are the ones polluted and with less biodiversity.

5 CONCLUSIONS

The proposed joint approach enable us to detect hotspots where transformations to enhance biodiversity, people's quality of daily life as a whole and health are needed. Regarding the biodiversity and urban life methodologies the indices generated are a promising tool, specially for urban planning in this sustainability context. Next steps on this area will be to compare the results with citizens perceptions and to improve indices calculations taking into account this issue. Regarding the air quality proposed methodology, it is important to note that the way we use Sentinel data is not the most suitable for a complete analysis of air quality data from satellites. However, when considering the processing time and the volume that these data can reach, it is a recommendable methodology for initial analysis, for more visual than quantitative representations and to easily and accurately filter the images that can be used in the study. Concerning the location of air measurement stations, this model does not allow to evaluate the air quality in different streets of a neighborhood, a useful assessment to determine, for example, how the implementation of a pedestrian street reduces the emission of pollutants in this Street.

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