Physical Agents Quality Index (PAQI): application in a University Campus

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Abstract. Among the most common techniques and methodologies for the analysis of the exposure to polluting agents, the definition of environmental indexes represents a very useful tool able to describe the status of the environment quantitatively and qualitatively. In this perspective a general Physical Agents Quality Index (PAQI) describing the status of an environment in terms of presence of different physical pollutants was developed by authors in a previous work. In this paper the PAQI concept is extended from a punctual idea to a spatial analysis and a practical application in order to evaluate the potentiality of the index on a visual map is discussed. In particular, the PAQI visual map of the Campus of the University of Salerno (Italy) was redacted. The results are presented and lay down the basis for further improvements in the visual mapping and also in the calibration of the calculation of the index.

1. Introduction

The air or environmental pollution is usually quantified by means of Quality Indexes (QI). The monitoring of the pollutant concentration in a specific period allows to determine the dose of pollutant and, consequently, the computation of the QI. The challenging field of QI is to provide sufficient evidence of the problems involved in assigning values to a particular aspect of an environment such as noise, PM₁₀, CO, or more in general physical, chemical, biological pollution [1]. Indeed, QI are intended to reflect the state of any aspect or component of the environment and must respond to changes in the component it is scaling, in such a manner that it accurately reflects the magnitude of those changes, and usually are necessary to assign quantitative values to subjective aspects such as public health [2,3]. However, since the pollutants are different from each other, their effects on the human health are generally evaluated by means of specific indexes.

In order to classify the impact of the pollutants, the QI are usually identified into ranges to which a descriptor can be associated [4]. In this way, it is possible to easy inform about the environmental conditions and their variations. The estimation of the Quality Indexes is not a standard procedure since it depends on the pollutant national threshold values and quality standards adopted in the interested country. In addition, when several indexes are condensed in a single complex index, it is necessary to evaluate all the variables, the method for the calculations and the descriptor classes. Commonly, the indexes used for environmental pollutants consider all the variables separately. Nevertheless, in some studies few indexes are aggregated [5-8]. As example, mixing physical, chemical and biological pollutants, the Health Quality Index has been proposed in [5]. In [8] the development of a quality index, aggregating all the physical pollutants, as an indicator describing the overall grade of physical pollution of an environment is presented, according to the procedure proposed in [5]. This index, namely the Physical Agents Quality Index (PAQI), could be applied for the description of an outdoor and indoor environment, as well. Maps of outdoor PAQI can be used to support the strategical urban
decisions, for instance identifying healthy areas where new residential zones could be developed or addressing deteriorated areas that need improvement of activities therein.

For indoor conditions, a peculiar application is devoted to occupational health. The exposure of workers to all physical agents is usually regulated by national legislations. In Italy, for instance, the Legislative Decree 81/08 [9] defines, in section VIII, the physical agents to be controlled and fixes the thresholds values for ‘danger’ and for ‘attention’. The Italian legislation recognizes the risk coming from exposure to noise, vibrations, ionizing and non-ionizing radiation, electromagnetic fields and, also, microclimatic conditions in the workplace. Moreover, it also defines and indicates standard techniques and methods for measuring pollutants [10]. The general idea of the PAQI index model is based on this framework but it can be easily extended to any national regulation, thanks to its modular and flexible structure.

In this paper, the PAQI concept is extended from a punctual idea to a spatial analysis. The possibility to create interpolation maps of PAQI is pursued in the case study of the Campus of the University of Salerno, located in the municipality of Fisciano, Italy. These maps will highlight potential hazardous areas and can be used to draw the quality of an outdoor environment, according to a defined classification.

2. Materials and methods

The main scope of the PAQI is to summarize in a single value the relation and the global potential impact of different physical agents, in a given site. The information packed in the PAQI can give a clear indication of the comprehensive quality of the environment, from the physical pollutant point of view.

2.1. PAQI definition

After selecting the relevant physical variables and the related descriptor, a sub-index is designed for each agent. The subindexes are usually designed as dimensionless ratios, with a critical value of the descriptor at the denominator. This implies that when the subindex is getting greater than 1, critical values are overcome and, consequently, the risk is increasing. A complete description of several subindexes can be found in [8], in which the physical indicators are transformed in dimensionless subindexes \( q_i \) considering the ratio between the environmental descriptors \( Q_i \), and their reference value \( Q_{ref} \). The evaluation of the value of \( Q_{ref} \) requires a careful analysis since it conditions the sign of the physical indicators that can be positive or negative.

When assembling the different subindexes, that have similar scales, in the single index PAQI, different quantities are put together, thus a weighting procedure is necessary. The weights \( p_i \) carry information about the relative importance between the subindexes and can be fixed, in general, by means of different approaches like the experts’ involvement, epidemiological studies, statistical or other decision theory tools [5, 11].

The final formula of the PAQI is the weighted sum of the subindexes:

\[
PAQI = \sum p_i q_i
\]

The first step in the determination of the PAQI is the identification of the descriptors, representative of the quality level of a certain environment. In this paper, the environmental physical agents on which the attention is focused are acoustic noise, ionizing radiation and microclimate, being considered as representative of the major hazardous physical agents for the Campus of Fisciano users, whose subindexes are reported in Table1. In this application, the weights have been chosen equal for each subindex, i.e. \( p = 0.25 \).

The other physical agents (i.e. vibrations, electromagnetic noise,…) are neglected in this application but can be easily implemented in future studies by adding more subindexes and calculating the relative weights as more detailed in [8].
Table 1. PAQI sub-indexes considered for the application in the Campus of Fisciano [8].

| Pollutant sub-index | Acoustic noise | Radon | Temperature | Humidity |
|---------------------|---------------|-------|-------------|----------|
| $q_i$               | $L_{eq}$      | $D$   | $\frac{T-T_{ref}}{T_{ref}}$ | $RH$     |
| $L_{eq}^{ref}$      | $D_{ref}$     |       |             | $RH_{ref}$ |

In the following subsections, the selected agents’ measurements and parameters will be briefly summarized.

2.1.1. Acoustic noise

Acoustic pressure levels represent one of the central problems that must be taken into consideration in the definition of a global quality index. The selected descriptor is the equivalent A-weighted noise level $L_{eq}$, measured in dBA, as in [5] and in [6]. In order to develop PAQI interpolation maps of the Campus, a database of widespread measurements of the $L_{eq}$ collected in the Campus has been used. These sound levels have been recorded using smartphones of volunteers, with the NoiseCapture free and open-source Android application [12] during two “NoiseCapture Parties” organized by the Applied Physics Laboratory (LAFIN) at the Department of Civil Engineering of the University of Salerno. The NoiseCapture approach consists of computing each second of the equivalent A-weighted sound levels along a path and then sharing data with the community. All data are aggregated in cells with the shape of a regular hexagon, to produce mean noise indicators in each one [13].

The corresponding sub-index $q_i$ has been determined considering two different reference values depending on the characteristics of the considered environment. In fact, according to the Italian code [14], the $L_{eq}^{ref}$ is taken equal to 50 dBA in Campus areas as study rooms, libraries and offices while the $L_{eq}^{ref}$ is equal to 65 dBA with reference to the environments characterized by intense human activity as the canteen, the car parks and all the areas intended for the development of sports and recreational activities.

2.1.2. Natural radiation

Radon (222Rn) is an inert radioactive gas produced by the decay of uranium naturally present in rocks and soils throughout the earth’s crust. As a gas, radon easily escapes from soil into the outdoor air where if diluted is of no further concern. But, in some rare case or if it reaches confined spaces radon can accumulate to harmful levels. For this reason, since the soil is generally the principal source of Radon maps of the radon potential are redacted to assess the potential risk of an area.

The assessment of the radiological risk related to the inhalation of radon and its progeny is expressed by the following expression [15]:

$$D = C_{Rn} \times F \times O \times DCF$$ (2)

where $F$ is the equilibrium factor, $O$ is the global average occupancy factor, $DCF$ is the dose conversion factor, $C_{Rn}$ is the arithmetic mean of radon concentration. The radon sub-index will consider the dose $D$, with respect to the reference value ($D_{ref}$) which is calculated by replacing $C_{Rn}$ with the threshold value established by the national legislation ($C_{Rn, ref}$). In particular, the equilibrium factor for outdoor varies in the range 0.6-0.8. The global average occupancy factor depending by the time spent in the ambient under investigation, has been calculating considering that students spent on average about 1 hour per die in the outdoor environment when moving to and from the bus terminal, lunching and relaxing in the open air, etc. Indeed, the university campus of Fisciano is a very lively outdoor place where students enjoy studying, having break and lunch and hanging out thanks also to the typical sunny weather of the south of Italy. The DCF is a fixed values equal to 9 nSvh⁻¹Bq⁻¹m³. The average outdoor concentration $C_{Rn}$ have been calculating, by assuming that generally Radon in the outdoor air, exhalating from the soil, dilute in the atmosphere until 100 times compared to the concentration measured in the soil gas. This widespread simplified assumption is very practical since measurements in the soil gas are generally easily available by means of measurements campaign or
Radon maps [16] which are mandatory developed in many countries. In this application, for example, results come from the redaction of a map of the potential radon from soil realized by researcher of the university of Salerno by means of the monitoring of the soil gas concentration in the campus area [17].

2.1.3. Microclimate
The microclimate is usually described by parameters like temperature and humidity even though wind speed could also be taken into consideration. As both low and high temperatures negatively affect the human health, the definition of a sub-index describing the temperature effects is different from the simple ratio adopted in the previous subindexes. Consequently, it is useful to define a reference range, for example from 10°C to 25 °C, rather than a single comfort value. Thus, a penalty factor should be introduced for deviations from the preferred value, both positive and negative. To overcome this problem, in [5] the authors adopted the difference between the measured temperature and a comfort reference one, under square root. The reference temperature value $T_{ref}$ is fixed equal to 18°C since it is considered as an optimal value rather than a limit one. As for the other subindexes, the definition of the sub-index related to humidity is obtained by means the ratio of the measured value and the reference one. In the case study herein reported, the reference value of the humidity $R_{Href}$ is set equal to 85% since higher values create thermal discomfort in human perception [18]. Values of temperature and relative humidity have been fixed respectively at 21°Celsius and 60%, according to the values recorded during the noise level measurements.

3. Case study and results
The proposed index has been evaluated calculating the interested subindexes in 20 points widespread in the Fisciano Campus of the University of Salerno (Figure 1).

![Figure 1. Case study cartography and values of the PAQI in red, estimated in each measurement point in black.](image)

These sites have been identified on the basis of different human activities and environmental characteristics of the area (see table 2 reporting a brief description of the nearby area) as well as to mostly cover the entire area of the Campus. Data comes from different campaign of measurements performed: one campaign of three days for the measurement of natural radioactivity in the campus area and a one-day campaign for the measurement of sound pressure levels. The non-simultaneity of the measurements is, of course, not a problem since the radon potential of a soil depends on its geological features and do not vary sensibly over the time. Following the procedures and the choices proposed in the previous sections, the four subindexes and, subsequently, the PAQI values have been determined, reported in Table 2 and illustrated in Figure 1.

The spatial distribution of the index has been developed by means of the ARCMAP GIS software [19] and, interpolating the measured data by means of the Inverse Distance Weighting (IDW) method, the
PAQI unknown values has been simulated and overlapped on the cartography of the Fisciano Campus. In particular, the IDW method allows the determination of values of unknown points calculating a weighted average of the values available at the known scattered set of points.

### Table 2. Measured values of the investigated physical agents and determined PAQI

| # Point | Description                                      | $L_{eq}$ [dBA] | $C_{in,soil}$ [Bq/m$^3$] | $T$ [$^\circ$C] | $H$ [%] | PAQI |
|---------|--------------------------------------------------|----------------|--------------------------|----------------|---------|------|
| 1       | student residence                                | 55             | 619879                   | 21             | 60      | 0.92 |
| 2       | multilevel car park                              | 63             | 104068                   | 21             | 60      | 0.59 |
| 3       | masseria                                         | 66             | 266085                   | 21             | 60      | 0.70 |
| 4       | transit area buildings E and F                    | 58             | 451359                   | 21             | 60      | 0.85 |
| 5       | bus terminal                                     | 63             | 193749                   | 21             | 60      | 0.64 |
| 6       | square                                           | 66             | 294664                   | 21             | 60      | 0.80 |
| 7       | botanical garden                                  | 55             | 44938                    | 21             | 60      | 0.58 |
| 8       | engineering laboratories                         | 59             | 256230                   | 21             | 60      | 0.82 |
| 9       | canteen                                          | 58             | 294664                   | 21             | 60      | 0.69 |
| 10      | environmental laboratories                        | 65.7           | 166549                   | 21             | 60      | 0.73 |
| 11      | library parking                                  | 60             | 294664                   | 21             | 60      | 0.70 |
| 12      | square to access to the library                   | 58             | 463185                   | 21             | 60      | 0.86 |
| 13      | square in front of the E2 building                | 54.3           | 294664                   | 21             | 60      | 0.74 |
| 14      | printing centre                                  | 63             | 403069                   | 21             | 60      | 0.78 |
| 15      | theatre                                          | 53             | 294368                   | 21             | 60      | 0.47 |
| 16      | rectorate                                        | 52             | 449388                   | 21             | 60      | 0.82 |
| 17      | parking                                          | 65             | 294664                   | 21             | 60      | 0.72 |
| 18      | M2 building                                      | 62             | 186259                   | 21             | 60      | 0.71 |
| 19      | tennis courts                                    | 66             | 12161                    | 21             | 60      | 0.44 |
| 20      | swimming pool                                    | 59.2           | 226665                   | 21             | 60      | 0.47 |

In figure 2a has been reported a PAQI map of the Campus where 9 subclasses of the index have been introduced automatically, showing how the index degrades over the distance. Then, results of the interpolation phase have been elaborated and the classes rearranged in order to convert the numerical information in terms of level of risk.
In particular, according to the classification reported in Table 3, where $P_{\text{tot}}$ is the sum of the weights, in our case equal to 1, a map of the overall quality of the environment related to the presence of physical agents has been drawn and reported in Figure 2b.

![Figure 2. Campus of Fisciano, Italy: a) Interpolation map of the PAQI; b) map of the environmental quality according to PAQI](image)

| Class | Colour | Status          | Range                     |
|-------|--------|-----------------|---------------------------|
| VI    | Dark red | Very highly unsafe | $PAQI \geq 1.5 \cdot P_{\text{tot}}$ |
| V     | Red    | Highly unsafe    | $1.25 \cdot P_{\text{tot}} \leq PAQI < 1.5 \cdot P_{\text{tot}}$ |
| IV    | Orange | Unsafe           | $P_{\text{tot}} \leq PAQI < 1.25 \cdot P_{\text{tot}}$ |
| III   | Yellow | Alert            | $0.75 \cdot P_{\text{tot}} \leq PAQI < P_{\text{tot}}$ |
| II    | Green  | Moderate safe    | $0.5 \cdot P_{\text{tot}} \leq PAQI < 0.75 \cdot P_{\text{tot}}$ |
| I     | Light green | Safe          | $PAQI < 0.5 \cdot P_{\text{tot}}$ |

This map gives a quick and qualitative overview of the safety and health quality of an environment, clearly and rapidly highlighting the points with greater presence of physical agents affecting the environment. In this application, the areas in orange belong to the alert level of risk which means that some pollutant overcome reference levels. They correspond to the canteen (point 1, $PAQI = 0.92$), the area below big conditioning machines (points 4, 6 and 12, $PAQI \geq 0.8$) and the rectorate square (point 16, $PAQI = 0.82$) where, in fact, acoustic noise is the pollutant affecting widely the area. On the contrary, points 19 and 20, that are located close to the park and to some sport facilities, report the lowest values of $PAQI$ and influence the surrounding area, consequently classified as safe. According to the measured and simulated data, and according to the choice of equal weights in this preliminary application carried out in order to assess the potentiality of a map, no dangerous zones ($PAQI \geq 1$), are highlighted in the map. Thus, microclimate, natural radioactivity and acoustic noise do not affect the...
campus area up to harmful levels for human health, but some area in orange should be taken under control, of course, in order to avoid the overcoming of reference levels.

4. Conclusions
In this paper an application of the PAQI index developed in [8] has been presented in order to evaluate the potentiality of a map describing the overall environmental quality of an area related to the presence of physical agents.

Of course, this kind of map could be a useful tool not only in urban planning. If based on real time measurements it could give additional information to authorities for the developing, adopting, implementing and evaluating environmental policy, and also easily evidence to the general public the quality of the environment they live.

Further development regarding the implementation of the map will focus on the adding of information on the number of subindexes greater than 1, with indication of the specific physical agent overcoming the threshold. Moreover, a map of the impact could be easily redacted by integrating the number of people exposed, for instance with circles whose diameter is the density of population and the filling colour is the PAQI classification. Other further applications will focus on the optimization of the general formula by defining a general method for the definition of the values of the weights coherently with the severity of the effects on human health. Indeed, since it was not the aim of this study to calibrate the methodology but to test the applicability on map it has been adopted the same weight to all the physical hazards. So, for example, since noise and radon are well recognized hazard for human health, they could be weighted differently to microclimate parameters which impact mostly on the human wellbeing without fatal consequences.

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