Air Quality System in Smart City: Systematic Literature Review

Mouna Rhaiem[1], Mariam Chaabane[1] and Ismail Bouassida Rodriguez[1]

[1]*ReDCAD, ENIS, University of Sfax, Tunisia*

Abstract

Smart cities are becoming the go-to alternative when it comes to city planning or enhancement. Infrastructure, governance, security, transportation, economy, and healthcare are all now regulated by the advanced technologies of this modern age following multiple patterns and parameters. According to the United Nations Environment Program report [1], pollution is a global problem, and air pollution in a city is the major environmental risk factor in our health. Smart cities, oriented service applications, are becoming the go-to alternative when it comes to city planning or enhancement. Infrastructure, governance, security, transportation, economy, and healthcare are all now regulated by the advanced technologies of this modern age following multiple patterns and parameters. One of the main challenges threatening the outcome of smart cities is pollution, further quickened by the non-ending emissions and the acceleration of the global warming process. This highlights the importance of air quality in a smart city. So, in this work we analyze some works from various countries that address the air quality (AQ) in a smart city, the criteria used to evaluate the air quality in a smart city, and the categorization of air quality based on those criteria. Novel aspects of this work are the purpose of the categorization of the air quality in a smart city. This work is used to simplify the population the choice of the right place in a smart city according to their needs, with air quality being the main criteria.

Keywords

Modeling, Air Quality, Smart city, System of system,

1. Introduction

the "Smart City" is a city that collects and uses data generated by its inhabitants and its infrastructure, to improve the quality of life. It integrates services based on information and communication technologies (ICT), which provide added value serving the city, via equipment (such as sensors, actuators, etc.)[2]. These devices communicate with each other through a network that optimizes the data transmission[3].

Thus, the "Smart City" offers urban services that make the city smarter and more economical. The idea of the intelligence of a city is, therefore, to set up facilities in the city that use new technologies in order to improve the quality, performance, and interactivity of urban services while minimizing costs in money and time [4, 5].

One of the most important challenges in a smart city is the air quality system, So, this last can detect all the dangers gazes in a smart city can facilitate for people to choose the best place to live, and can encourage the government to make the best decision to decrease the source of this gazes.

For decades, one of the most common ideas in literature is the precarious air quality in the industrial zones and the healthy one in the green zones. However, in our day and time, green places are no longer an exception to this rule, unfortunately. One of the fundamental elements

Tunisian Algerian Conference on Applied Computing (TACC 2022), December 13 - 14, Constantine, Algeria

mouna.rh1111@gmail.com; mariam.chaabane@redcad.org; bouassida@redcad.org

of a healthy life is clean fresh air but there are many factors affecting its cleanness. Air pollution is a major problem in many cities globally, that's why we should know more about it and know the criteria that are responsible for improving or deteriorating the air quality. On the other hand, a very important evolution of cities is the emergence of "smart", especially smart technology, so smart can offer the users use, control, and interaction, with using the Internet. Essentially, a smart city is a city that provides services and solves city problems using advanced technology. The smart city features things like improving transportation and accessibility, ameliorating social services, promoting sustainability, and giving a voice to its citizens. We will be focusing in this paper on the categorization of air quality based on the criteria deduced from previous studies, and the main concept that we need to focus on is the purpose of the categorization of air quality as a service among the system of systems in a smart city.

2. Background

A systematic literature review is a core scientific activity that provides scientists to create a summary of current evidence. According to Barbara A. Kitchenham et al [6] that the main technologies underpinning (EBSE)[1] is a rigorous procedure for searching research literature called a systematic literature review (SLR). SLRs are secondary studies (i.e. studies that are based on analyzing previous research) used to find, critically evaluate, and aggregate all relevant research papers (referred to as primary studies) on a specific research question or research topic.

One of the principal tools used to support an evidence-based paradigm in other fields, according to Budgen and Brereton [7]is the generation of systematic literature reviews, used to aggregate the experiences gained from a range of different studies in order to answer a specific research question.

3. Methods

3.1. Research questions

The review focuses on four research questions:

- How did the literature address the air quality in a smart city?
- What are the criteria used to evaluate the air quality in a smart city?
- How can we categorize the air quality in the smart city based on these criteria?
- What is the purpose of the categorization of the air quality in a smart city?

3.2. Search Process

The search process combines the key concepts of our search questions in order to retrieve accurate results. The selected sources are shown in table 1:

It is an organized structure of keywords which are: "modeling" and "air quality" and "smart city" and "system of systems", used to search a database. Then, we added synonyms, variations,

[1]Evidence-Based Software Engineering

Table 1
Literature sources

Source	Type of source	Search URL
IEEE Xplore Digital Library	reviewed paper	ieeexplore.ieee.org
ACM Digital library	reviewed paper	dl.acm.org
Springer	reviewed paper	springer.com

and related terms for each keyword. A Boolean operator (AND and OR) allows us to try different combinations of search terms. The final search string is (modeling OR model OR design) AND (air quality OR air-quality) AND (smart city OR smart cities) AND (system of systems OR system-of-systems OR systems of systems OR systems-of-systems).

3.3. Inclusion and exclusion criteria

A set of exclusion/inclusion criteria was applied, after obtaining the search results from the different sources:

3.3.1. Inclusion Criteria

- Publications that are related to the research questions
- Publications that match one of the search items
- Publications that are published after or on the 01.01.2010
- Publications that have the best practices examples
- Publications that are related to higher education institutions/universities

3.3.2. Exclusion Criteria

- Publications that do not match one of the search items
- Publications that do not have best practices examples
- Publications that are published before or on the 31.12.2009
- Publications, that are not related to higher education institutions/universities
- Publications that are not related to the research questions

3.4. Data collection

The different studies retrieved from the search process were stored in different libraries. The data extracted from each study were:

- The publication year.
- Information about answers to the research questions.

4. Search Results

4.1. search results by resources

The search results are summarized in table 2 including each resource and the corresponding number of papers.

Table 2
Search results by Resource

Resources	Number of papers
Springer	74
IEEE Xplore Digital Library	135
ACM Digital library	389
Hyper Articles en Ligne (HAL)	4
Total	**602**

4.2. Filtered search results

The filtered search results are summarized in table 4 from 602 references. We could not find one reference. We excluded 7 papers that were duplicated 521 were excluded by reading the title and the abstract. We obtained 73 papers for introduction reading. we obtained 66 papers for reading.

Table 3
Filtered search results

Irrelevant and duplicates	7
Incomplete and not related to RQ, excluded by reading the title and abstract	521
File not found	1
Total for Introduction reading	73
Not related to RQ, excluded by reading Introduction	7
Total for reading	**66**

4.3. Filtered search results by resources

After filtering irrelevant, duplicate, and incomplete papers, a total of 66 papers were selected for the reviewing process. Table3 presents the filtered search results by resources.

Table 4
Filtered search results by resources

Resources	Number of papers
Springer	2
IEEE Xplore Digital Library	44
ACM Digital library	20
Hyper Articles en Ligne (HAL)	0

5. Finding

The review process of the different selected papers was done by how this researcher answering for the four research questions defined previously.

5.1. Air quality in a smart city as addressed by the literature

Air pollution is a vital health problem in a city. According to the World Health Organization (WHO)[2], ambient outdoor air pollution was estimated to cause 4.2 million premature deaths in 2016, which are mainly due to the exposure to small particulate matter PM2.5[3] etc.
Urban air pollution is a major problem in many cities globally. According to Min et al [8] among air pollutants, Particulate Matter (PM) is of major concern since it can penetrate into the respiratory system of people. In particular, PM 2.5 and PM 10 consist of particulates with a diameter smaller than 2.5 and 10 micrometers respectively.
Most of the papers take air quality as the main segment in their research, and they agree that there are many places on our planet that are considered unsafe. The more we know about the subject, the greater we can improve it. Therefore, it is crucial to further study the air quality variables in order to classify cities according to the degree of safety and well-being of citizens.

5.2. The criteria used to evaluate the air quality in a smart city

Many cities have built air quality systems monitoring stations to inform people about urban air quality.
According to Suciu et al [9] air quality systems integrate various air quality sensors (VOCs[4], air temperature, and relative humidity.
In initial implementation according to [10][11], [16], each sensor board has five environmental

[2]https://www.who.int/fr

[3]Particulate matter 2.5 (PM2.5), refers to tiny particles or droplets in the air that are two and one-half microns or less in width

[4]Volatile Organic Compound: a type of compound (a chemical that combines two or more elements) containing carbon that changes easily into a gas and that can be harmful to people's health or to the environment

sensors including air pressure, such as CO2[5], NO2[6], CO[7], O2, formaldehyde, and UVI[8], RSPM[9], SO2[10], SPM[11], TVOC[12], illuminance , photochemical oxides, the weather condition (i.e. air pressure, humidity, cloud condition, wind, rain), metahne, isobutene, ethanol, hydrogen, NO3[13], N2O5, HNO3, HONO, PNA[14], H2O2[15], ALD2Acetaldehyde, PANPeroxyacetylnitrat, PACDPeroxyacetic acid, FACDFormic acid, AACDAcetic Acid,CRES Cresol, MGLY Methylglyoxal, ISOP, ISPD Products of isoprene rxns, SULF H2SO4 Sulfuric acid, UMHP Methanediol, TERP, NH3 (gases34), monsoon, other basic chemical substances, Hydrocarbon (CxHx), gas density, soil moisture, and MQ5 Gas, CO3, chlorofluorocarbons, methane, sulfur dioxide, and CFC. PSO4, PNH4, PNO3, POA, PEC, SOAA, SOAB, FPRM, CPRM.
Based on those studies, many criteria evaluating the air quality can be acquired, and with these criteria, we can design a thorough categorization of smart cities using air quality systems as the main parameter.

5.3. Categorization of the air quality in a smart city based on the previously mentioned criteria

Du et al [12] propose different classifications of categories including one of them suggesting five categories(good, moderate, unhealthy, very unhealthy, hazardous).
The work of Mehta et al [13] offers five categories as we can see in all of the air quality systems (good, satisfactory, moderate, poor, very poor, and severe), or (very low, low, moderate, high, very high).
Further, Do et al [14] propose three categories with this description (good, moderate, poor) or this description Max concentration, Min concentration, and Mean concentration. As well, Gore et al [11] takes colors and values as a categorization, with values:[0..50], [51..100], [101..150], [151..200], [201..300] and [301..500] with colors: green, yellow, orange, red, purple, and maroon.
The work of Aiello [15] is based on a simple circular marker: the marker is filled with a value ranging from a minimum value (blue) to the maximum value(red), where blue stands as 0 PM10 pollution and red stands as 30 PM10 pollutions, the maker based on both colors and values.
Ivanov et al used a scale from 0 (very low) to 100 (very high)[16], the scale was based on category and values at the same time.

The categorization of air quality was addressed by multiple papers on which various groups were suggested based on. These classifications are accessible and comprehensible for the majority of the citizens, making it an efficient way to appreciate the state of a smart city.

[5] gaz carbon dioxide
[6] nitrogen dioxide gas
[7] Carbon monoxide
[8] Ultra Violet Index
[9] Respirable suspended particulate matter
[10] Sulfur dioxide
[11] Suspended Particulate Matter
[12] Total Volatile Organic compounds
[13] Nitrogen oxide pollution
[14] Peroxynitric acid
[15] Hydrogen peroxide

5.4. Purpose of the categorization of the air quality in smart city

For smart cities, there is a need to monitor environmental conditions[17] to identify pollution sources and mitigate them. Thus, a network of low-cost air quality monitoring sensor nodes can be deployed to monitor air quality and weather parameters. Thus, through the detection of pollution sources, the city can take corrective action and improve its environmental health. By installing disaster detection systems, such as flood and precipitation monitoring solutions in your environment, citizens can be alerted in advance of a catastrophic event. A holistic view can be obtained, allowing authorities to make data-driven infrastructure planning and policy decisions.
All papers preview the air quality both indoors and outdoors in a normal city and smart city and talk about the criteria that contribute to the classification of the air quality.
The researches address the purpose of the categorization of the air quality in the smart city to provide timely information to both government and the public. This data can be used to make better decisions, whether it's about planning for transportation or knowing the most optimal route to walk to work.

6. Discussion

Studies have shown multiple criteria used to evaluate the air quality system in a smart city such as dangerous gases, particulate matter, humidity, temperature, etc. An adequate categorization of air quality based on these criteria was detailed, for example: (good, moderate, poor),(good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, hazardous), in order to determine the purpose of this categorization especially before building the smart city.
However, we acknowledge that there are considerable discussions on the purpose of the categorization of air quality in a smart city. It was limited to assessing the hazard levels or the degree of comfort, without including details about both subjects. As a matter of fact, an analysis of the age, medical record, and profession of the citizens should be taken into consideration to ensure an adapted air quality system for their needs. In addition, the areas with the highest air quality index should include more green areas and more restrictions on gas emissions.

7. Threats to Validity

We identified two main threats to the validity of this SLR, when we talk about the time period, we used studies that are published in 2010 and after, so there are some studies in 2010, and we know after a decade, many indications change after a long period of time.
Further, in this SLR we used some studies consisting of a small number of papers and we know that the number of papers in a study affects greatly the results.

8. Conclusion

In conclusion, indoor and outdoor air pollution is known to cause plenty of health problems, that's why we must take into consideration the importance of research assessing air quality

systems in a smart city.
The installation of an air quality monitoring system controls the presence of pollutants, resulting in better environmental conditions for humans. It also has an impact on our health and reduces the risk of health problems by maintaining a moderate or as-needed environment.
This paper focuses on the air quality in a smart city, precisely on the criteria used to evaluate the air quality in a smart city and the categorization of the air quality system in a smart city based on the aforementioned criteria.
Future investigations are necessary to validate the suggestions that can be drawn from this study, specifically to describe clearly and in a detailed manner the purpose of the categorization of air quality systems in a smart city, and most importantly before the construction of the smart city.

Acknowledgment

This work was partially supported by the LABEX-TA project MeFoGL:
"Méthodes Formelles pour le Génie Logiciel"

Glossary

AQ Air Quality. 1

EBSE Evidence-Based Software Engineering. 2

ICT Information and Communication Technologies. 1

SLR Systematic Literature Review. 2

References

[1] United Nations Environment Programme , Actions on Air Quality: A Global Summary of Policies and Programmes to Reduce Air Pollution. Nairobi, Technical Report, United Nations, 2021.

[2] N. Khabou, I. Bouassida Rodriguez, Threshold-based context analysis approach for ubiquitous systems, Concurrency and Computation: Practice and Experience 27 (2015) 1378–1390.

[3] S. Marzouk, A. J. Maalej, I. Bouassida Rodriguez, M. Jmaiel, Periodic checkpointing for strong mobility of orchestrated web services, in: Services-I, 2009 World Conference on , International Workshop on Self Healing Web Services (SHWS 2009), IEEE, 2009, pp. 203–210.

[4] M. Chaabane, I. B. Rodriguez, K. Drira, M. Jmaiel, Mining approach for software architectures' description discovery, in: 2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA), 2017, pp. 879–886. doi:10.1109/AICCSA.2017.169.

[5] A. Gassara, I. Bouassida Rodriguez, M. Jmaiel, Towards a multi-scale modeling for architectural deployment based on bigraphs, in: European Conference on Software Architecture, Springer Berlin Heidelberg, 2013, pp. 122–129.

[6] B. A. Kitchenham, D. Budgen, O. Pearl Brereton, Using mapping studies as the basis for further research – a participant-observer case study, Information and Software Technology 53 (2011) 638–651. URL: https://www.sciencedirect.com/science/article/pii/S0950584910002272. doi:https://doi.org/10.1016/j.infsof.2010.12.011, special Section: Best papers from the APSEC.

[7] D. Budgen, P. Brereton, Performing systematic literature reviews in software engineering, in: Proceedings of the 28th International Conference on Software Engineering, ICSE '06, Association for Computing Machinery, New York, NY, USA, 2006, p. 1051–1052. URL: https://doi.org/10.1145/1134285.1134500. doi:10.1145/1134285.1134500.

Annex: Most relevant papers obtained from the SLR

[8] K. T. Min, P. Lundrigan, and N. Patwari, "Iasa - indoor air quality sensing and automation: Demo abstract," in *Proceedings of the 16th ACM/IEEE International Conference on Information Processing in Sensor Networks*, ser. IPSN '17. New York, NY, USA: Association for Computing Machinery, 2017, p. 277–278. [Online]. Available: https://doi.org/10.1145/3055031.3055043

[9] G. Suciu, M. Balanescu, C. Nadrag, A. Birdici, C. M. Balaceanu, M. A. Dobrea, A. Pasat, and R.-I. Ciobanu, "Iot system for air pollutants assessment in underground infrastructures," in *Proceedings of the 6th Conference on the Engineering of Computer Based Systems*, 2019, pp. 1–7.

[10] R. Tse and G. Pau, "Enabling street-level pollution and exposure measures: a human-centric approach," in *Proceedings of the 6th ACM International Workshop on Pervasive Wireless Healthcare*, 2016, pp. 1–4.

[11] R. W. Gore and D. S. Deshpande, "Voting method for aqi prediction and monitoring air pollution using real-time data," in *2020 International Conference on Smart Innovations in Design, Environment, Management, Planning and Computing (ICSIDEMPC)*. IEEE, 2020, pp. 196–199.

[12] X. Du and A. S. Varde, "Mining pm2. 5 and traffic conditions for air quality," in *2016 7th International Conference on Information and Communication Systems (ICICS)*. IEEE, 2016, pp. 33–38.

[13] Y. Mehta, M. M. Pai, S. Mallissery, and S. Singh, "Cloud enabled air quality detection, analysis and prediction-a smart city application for smart health," in *2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC)*. IEEE, 2016, pp. 1–7.

[14] T. H. Do, E. Tsiligianni, X. Qin, J. Hofman, V. P. La Manna, W. Philips, and N. Deligiannis, "Graph-deep-learning-based inference of fine-grained air quality from mobile iot sensors," *IEEE Internet of Things Journal*, vol. 7, no. 9, pp. 8943–8955, 2020.

[15] G. Aiello, A. Camillo, M. Del Coco, E. Giangreco, M. Pinnella, S. Pino, and D. Storelli, "A context agnostic air quality service to exploit data in the ioe era," in *2019 4th International Conference on Smart and Sustainable Technologies (SpliTech)*. IEEE, 2019, pp. 1–8.

[16] V. Ivanov and I. Georgieva, "Air quality index evaluations for sofia city," in *IEEE EUROCON 2017-17th International Conference on Smart Technologies*. IEEE, 2017, pp. 920–925.

[17] M. Wu, J. Huang, N. Liu, R. Ma, Y. Wang, and L. Zhang, "A hybrid air pollution reconstruction by adaptive interpolation method," in *Proceedings of the 16th ACM Conference on Embedded Networked Sensor Systems*, ser. SenSys '18. New York, NY, USA: Association for Computing Machinery, 2018, p. 408–409. [Online]. Available: https://doi.org/10.1145/3274783.3275207