climate

MDPI

Article

Cloud-Based Decision Support System for Air Quality Management

Vasilis Evagelopoulos [1,*], Nikolaos D. Charisiou [2], Milton Logothetis [2], Georgios Evagelopoulos [3] and Christopher Logothetis [2]

[1] Department of Chemical Engineering, University of Western Macedonia, 50100 Kozani, Greece
[2] Purcon Ltd., 146 Mihalakopoulou Str., 11527 Athens, Greece; ncharisiou@uowm.gr (N.D.C.); info@purcon.gr (M.L.); clogothetis@gmail.com (C.L.)
[3] School of Electrical & Computer Engineering, Technical University of Crete, 73100 Chania, Greece; gevangelopoulos@isc.tuc.gr
* Correspondence: vevagelopoulos@uowm.gr

Abstract: Air quality is important for the protection of human health, the environment and our cultural heritage and it is an issue that will acquire increased significance in the future due to the adverse effects of climate change. Thus, it is important to not simply monitor air quality, but to make information immediately available to those responsible for monitoring the networks, to policy/decision makers, but also to the general population. Moreover, the development of information technologies over the last couple of decades has allowed the proliferation of real-time pollution monitoring. The work presented herein concerns the development of an effective way of monitoring environmental parameters using dedicated software. It offers a complete suite of applications that support environmental data collection management and reporting for air quality and associated meteorology. It combines modern technologies for the proper monitoring of air quality networks, which can consist of one or more measuring stations. Innovatively, it also focuses on how to effectively present the relevant information, utilizing modern technologies, such as cloud and mobile applications, to network engineers, policy/decision managers, and to the general public at large. It also has the capability of notifying appropriate personnel in the event of failures, overruns or abnormal values. The system, in its current configuration, handles information from six networks that include over 55 air pollution monitoring stations that are located throughout Greece. This practical application has shown that the system can achieve high data availability rates, even higher than 99% during the year.

Keywords: air pollution; monitoring; integrated information systems; web services; air quality management system

check for updates

Citation: Evagelopoulos, V.; Charisiou, N.D.; Logothetis, M.; Evagelopoulos, G.; Logothetis, C. Cloud-Based Decision Support System for Air Quality Management. *Climate* **2022**, *10*, 39. https://doi.org/10.3390/cli10030039

Academic Editor: Steven McNulty

Received: 17 February 2022
Accepted: 9 March 2022
Published: 10 March 2022

1. Introduction

The development of human societies and the accompanying growth in the consumption of natural resources, especially over the past couple of centuries, has given rise to a multitude of human-induced environmental problems. Chief amongst these is climate change, whose adverse effects are fast becoming the familiar horsemen of a planetary apocalypse, as so vividly made clear to world leaders at the recent cop26 summit.

Climate change also affects outdoor air quality (AQ), long recognized as one of the main factors leading to deteriorating human health, especially in urban or industrial areas. In fact, the World Health Organization (WHO) has estimated that air pollution is responsible for over seven (7) million premature deaths worldwide, per year [1]; in the EU, it is responsible for 400,000 premature deaths, and health-related external costs that are estimated in the hundreds of billions of euros [2]. The major air pollutants are particulate matter (PM), classified into PM2.5 (particles with a maximum diameter of 2.5 μm) and PM10 (particles with a maximum diameter of 10 μm) and gaseous pollutants such as SO_2

and NOx [2,3]. As is well understood, exposure to particulate matter can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias, affect the central nervous system and the reproductive system, and cause cancer [4–13].

Climate change will also worsen indoor air, as it will lead to an increase of outdoor airborne allergens (which can then infiltrate indoor spaces), dampness and humidity (which can lead to increases in mold, dust mites, bacteria, and other biological contaminants indoors), and higher indoor temperatures [14–16]. The current Covid-19 pandemic, which still forces people to spend increasing amounts of time indoors, as well as the likelihood that such pandemics may become more frequent in the future (as humans further push and shrink the limits of ecosystems), should focus the mind further.

Given the context provided above, the regulation and control of emissions is of paramount importance. For the EU, relevant provisions were first made in the Environment Act/Air Quality Management Areas (AQMAs) of 1995 [17]. This was augmented by the Ambient Air Quality and Clean Air for Europe Directive [18], which requires EU member states to operate appropriate measurement systems and defines the rules under which the setup of observation networks should take place [19]. In terms of PM10, the threshold for the protection of human health has been set at 40 mg/m^3 over the course of a year, while a concentration of 50 mg/m^3 shall not be exceeded for more than 35 days a year. Similarly, for PM2.5, the annual threshold has been set at 20 mg/m^3 [20,21].

The setup of such thresholds has been made possible by advancements in monitoring and modeling. For example, satellite measurements, utilizing the Moderate Resolution Imaging Spectroradiometer (MODIS) and/or Multi-angle Imaging Spectroradiometer (MISR), can be used to obtain an overview of PM2.5 concentrations over large geographical areas [22–25]. In addition, the use of models has gained traction as these can be used to integrate different datasets, auxiliary datasets and estimate and predict air pollution, utilizing spatial and/or temporal coverage of observations [22,26–31]. However, continuous air quality monitoring can be performed only by ground-based monitoring stations, which have the added advantage of being able to provide real-time information in case of limit exceedance. Moreover, although such systems provide time series of different air quality parameters that are relevant to the direct vicinity of a particular location, when combined with sampling of particulate matter, they can be characterized, the source identified and toxicity studied [32,33].

Scientists and decision/policymakers have long stressed the need for science-based decision support systems [34–37]. Moreover, for air quality data to be effective, they need to be provided in a timely manner (so that decisions can be taken at the time an event is occurring), but also in a format that will be easy to understand by the potential users. There are a number of studies that show that when local and/or national authorities are successfully informed with real-time air pollution data, then hospital admissions are significantly reduced [38]. Although there is room for the improvement of air quality management systems worldwide, this is particularly true for developing countries, where such efforts are hampered by a lack of commitment from relevant authorities, reduced participation of stakeholders, policy or regulation weaknesses and also, of the physical systems that will provide real–time air quality data and emission inventories [39].

The advent of information technologies has led to the development of a huge number of different online air quality information sources [40]. In an influential work, Karatzas et al. [41] described the techniques that are available for the effective dissemination of urban air quality information to the public using mobile applications, street panels and mass media. In the EU, most member states provide air quality information on publicly available websites and through regular print publications [42]. In the USA, air quality information is shared with the public via AIRNow [43], which provides real time measurements and forecasts for 300 cities. In South Africa, a system has been developed, which allows information related to air quality to be disseminated through mobile application tools [44]. Finally, in China and India, both print and electronic media are employed, alongside street panels and web pages, for the dissemination of air quality information to the public in urban areas [45,46].

Given the background discussed above, it is imperative for air quality measuring stations to operate and record environmental measurements on a continuous basis. However, faults often occur, with the end result that important information is often left unrecorded for periods that last from a few hours to several days. Moreover, modern analyzers also measure critical diagnostic parameters of their function, such as flow, pressure, temperatures, etc., which can be accessed by technical personnel during site visits or stored using appropriate software for later review. However, for systems that present live measurements, these parameters need to be controlled continuously.

The manuscript presented herein provides an effective way of monitoring air quality measurement stations through the development of a dedicated software, AirDMS [47]. This dedicated software comprises of a set of tools that supports the collection and reporting of air quality and associated meteorological data. It also focuses on data quality control and provides tools that can address difficult and time-consuming validation tasks, by providing real time and user-friendly information on multiple platforms. AirDMS can not only enhance data quality and support quick decision-making, it can also reduce operations and maintenance costs. Although the AirDMS system is being continuously improved and expanded, in its current configuration, it handles information from 6 networks that include over 55 air pollution monitoring stations that are located throughout Greece. Through this practical application, it has been shown that it can allow network operators to increase the availability rate of measurements even to rates greater than 99%. It also has the capability of accepting custom-made additional components (modules) to meet national and local requirements. Thus, it can provide a valuable tool for the timely and correct information of relevant technical personnel, policy/decision-making authorities, but also, for the general public at large.

2. The AirDMS Information System Architecture

The AirDMS information system consists of: (i) the Communication system (CS) which is the system responsible for collecting data, and (ii) the cloud-based information system with four subparts: (a) the web interface, which disseminates environmental data including air quality, meteorological, and noise data, (b) the Remote Communication System (RCS), which automatically retrieves data through the Application Programming Interface (API) protocol, (c) the AirDMS Service, which disseminates instrumentation diagnostics, and lastly, (d) the AirDMS Alerts system, which sends alerts to authorized personnel in case of instrumentation failure or measurement exceedances over high or low limits. These systems are described in detail in the sections that follow. A schematic workflow diagram of the AirDMS information system is presented in Figure 1.

2.1. Communication System

The communication system (CS) is responsible for collecting the data, and after performing quality control (described below) and calculating average values (usually 5 min, hourly, 8 h, and daily average value), it sends the data to the central AirDMS database, which is located on the cloud. It is noted that the average values are calculated only if the data availability is more than 75% for the reference period. For every measurement value, a flag that holds the measurement's quality check is associated and stored. Possible flags occur: (a) when the measurements are not logged, for example, when an analyzer is being maintained, (b) when the values are invalid due to an analyzer's diagnostic parameters being outside of the pre-determined limits, (c) when not enough measurements are available to calculate an average value, (d) when there is no communication with an analyzer, and (e) when a value is valid. In the case of incorrect values, these get stored for further evaluation but are not displayed on the web interface, indicating only the abbreviation according to Table 1.

Table 1. Abbreviation status explanation (flags).

Instrument Status	Abbreviation
Measurements are not recorded	OffScan
No Data	ND
Not enough measurements to calculate average	Sample<
No Communication	NC
Valid data	Valid

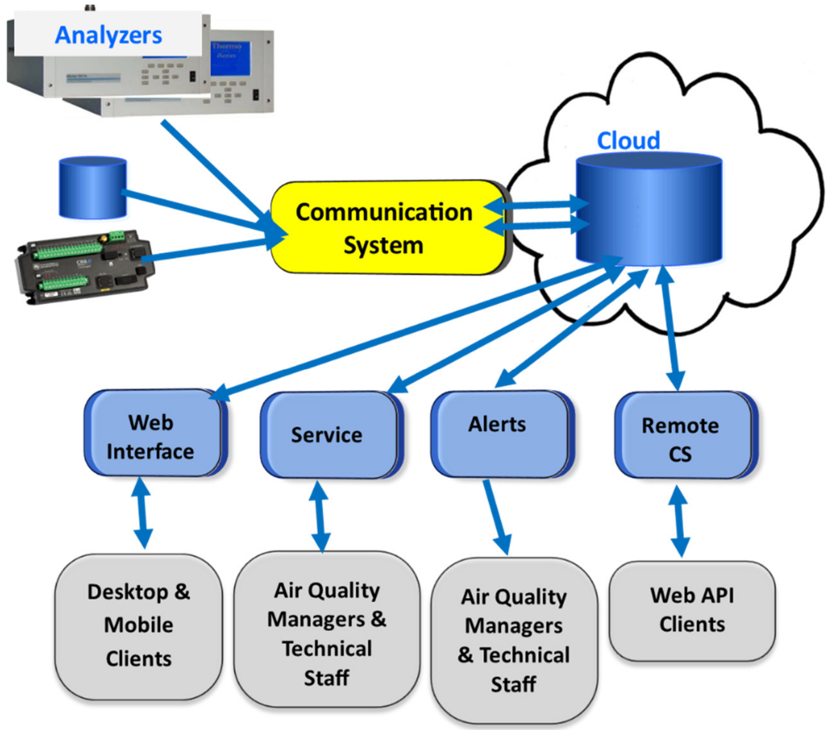

Figure 1. Workflow Diagram of AirDMS.

As CS has been developed using Java, it can be installed on many operating systems such as Windows, Linux, and MacOS. Moreover, it can collect data from many sources, including SQL Server, text files, Web API, and TCP/IP (Transmission Control Protocol/Internet Protocol). It collects the data directly from the analyzers (streaming or internally stored) or from any data logger in which the data are already collected. Another advantageous feature of the CS is that it can operate with Arduino compatible boards with IoT sensors or can even be installed in a Raspberry Pi. Both are low-cost controllers, which have proven valuable measurement tools especially for indoor environment quality [48].

2.2. Cloud-Based Information System

As is well understood, cloud services provide cost-effective options to access, process, and disseminate data and information in real-time [49,50]. For AirDMS, the cloud-based system consists of four parts: (a) the web-based system, which displays real time data on a 5-min basis on the web site, (b) the Remote Communication System, which can collect or provide data in an automated way to authorized users, (c) the AirDMS Service, which provides the diagnostic measurements of the analyzers and stations' operating status (e.g., internal temperature, current voltage, door status), and (d) the AirDMS Alerts. The above was developed using the PHP scripting language with JavaScript and Html version 5, which are especially suited to web development.

2.2.1. Web Interface (WI)

The web interface has been constructed in a way that is as simple and easy to use as possible, while also offering tools for monitoring the network of measuring stations that appear within the application and optimizing data presentation.

Data can be accessed with username and password credentials generated by the system administrator. As the system incorporates multiple networks with many stations, each user may be authorized by the administrator to have access to certain networks or stations. Users may also be given access to other functions (such as, reports, data export, scientific graphs, data statistics, log files, analyzers manual) that collectively make up a complex tool with multiple access levels.

Moreover, in compliance with the European Union ambient air quality directive [18], certain information (such as the air pollution index) may be made available to the public at the request of network operators.

The spatial distribution of data utilizes OpenStreetmap (OSM) [51], which provides free geographic data, such as street maps. These are generated with the use of Leaflet.js, which is one of the most popular open-source JavaScript libraries for interactive maps [52,53]. Leaflet allows developers to display tiled web maps, with optional tiled overlays. It can load feature data from GeoJSON files, style them, and create interactive layers, such as markers with popups when clicked.

Figure 2 presents measurements for ambient temperature (value inside the circle) and wind in the form of a vector which changes direction and length according to the wind measurements. The circle's color changes dynamically based on temperature. Legends are included to help understand the context of each display. The chosen parameter displayed in the circle can be changed dynamically by the user, allowing for a personalized view based on user preferences.

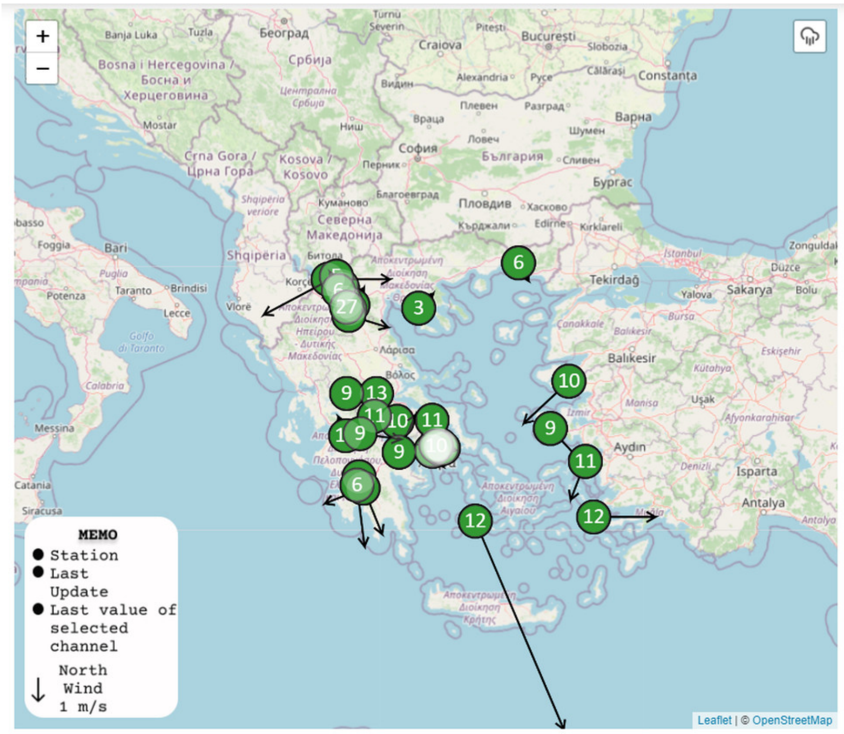

Figure 2. Map with metrological parameters for every network station (value inside the circle corresponds to ambient temperature).

The map in Figure 3 shows air pollution in multiple locations. The data obtained are classified according to the Daily Air Quality Index (DAQI), which has ten points that are further grouped into four bands: low, moderate, high, and very high. The DAQI has been developed to provide advice on expected levels of air pollution, and also, information on the short-term effects on health that might be expected to occur at the different bands of the index. It is used by the UK's Department for Environment, Food, and Rural Affairs (DEFRA) and is recommended by the Committee on the Medical Effects of Air Pollutants (COMEAP) [54].

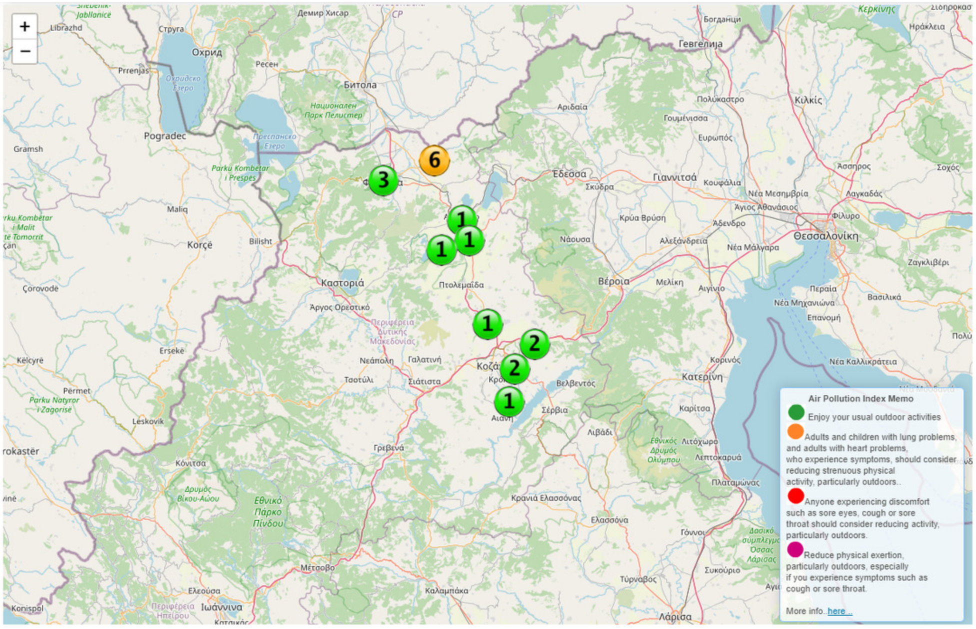

Figure 3. Air quality map (values and color in the circle correspond the DAQI).

From the different JavaScript-based libraries that can be used to visualize data as 2D charts (such as HighCharts, Google Charts, Flot Charts, and RGraph), AirDMS makes use of the RGraph [55], as it many different types of charts (50–60), using both HTML5 Canvas and Scalable Vector Graphics (SVG; a web-friendly vector file format), which give it the ability to represent many types of data quickly and efficiently. Other features that make RGraph appealing for such applications are that it is entirely unrestricted to use (being available under the MIT license) and is suitable for all websites, with charts being rendered using JavaScript, SVG, and canvas. The size of the JavaScript files and the code to make a chart is small and can be further reduced with minification and compression. Therefore, it offers significant speed boosts to websites. For AirDMS, version 6.06 of the library was utilized. The WI library includes simple graphs consisting of one or more parameters (e.g., meteorological parameters, noise levels, or pollutant concentrations) over time, coming from one or more measuring locations (Figure 4). More complex graphs, utilizing two axes with different scales may also be created.

Except for the basic graphs, RGraph was also expanded and is capable of producing different graphs, such as the ones shown in Figures 5–7. In Figure 5 we have combined Leaflet and RGraph to produce novel pollution rose chart with leaflet map as a background. The map is centered in place of the station and the zoom can be selected by the user dynamically. The type of pollutant chosen by the user is subcategorized in eight (8) different sections of wind direction and four (4) wind speed classes. This way, we calculate the mean value of pollutant per wind direction and per speed class. In the case of calm conditions, i.e., no wind, the pollutant concentrations refer to local sources, while in greater wind speeds, they refer to pollution transported from longer distances. This categorization, along with the map as a background, gives a rough image for the authentication/determination on the origin of a pollutant, especially in high concentration cases.

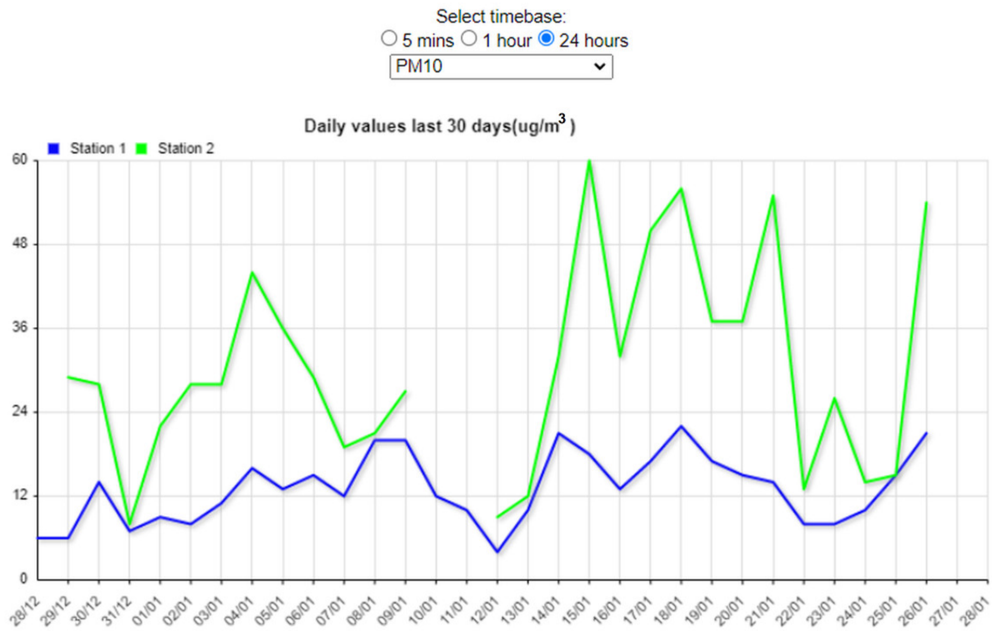

Figure 4. Group diagram for selected time-period.

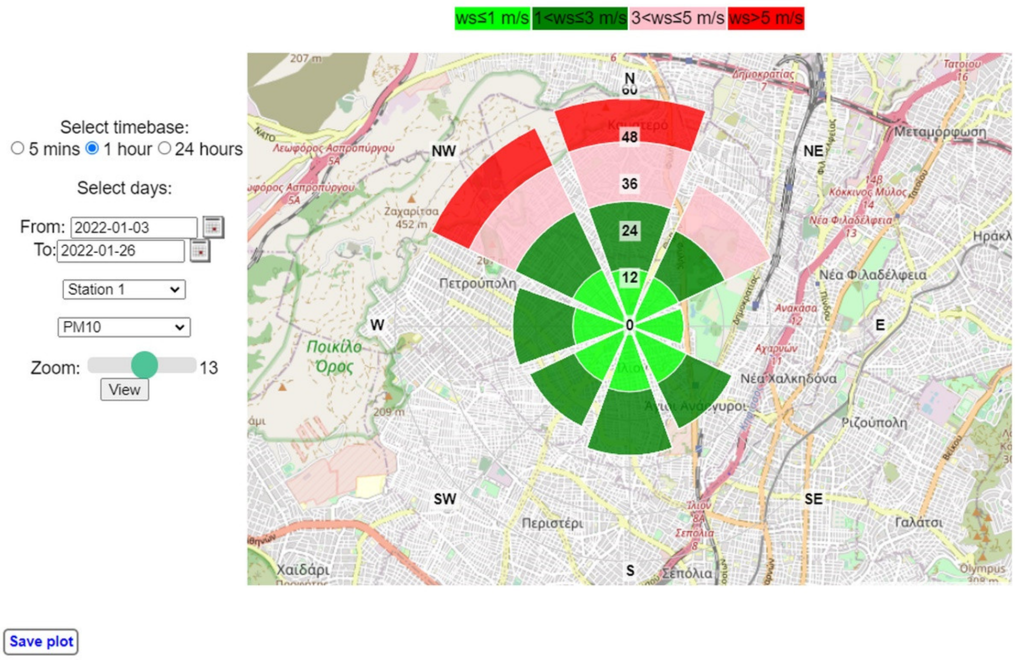

Figure 5. Pollution rose diagram.

Moreover, we extended RGraph in order to produce different innovative graphs that can help scientists and authorities to effectively monitor the quality of ambient air. As an example, in the graph presented in Figure 6, the user can pick a pollutant and date of interest to display the mean value per hour. At the same time, the graph shows the wind speed vector. The size of the vector depends on wind speed, and it is calibrated towards the north. In Figure 6, we can see the concentration relative to the wind (speed and direction) making for an easier and more understandable graph compared to Figure 4. Moreover, WI clients can quickly analyze the symmetry of distribution and investigate the extreme points of the data using boxplot at different times (Figure 7).

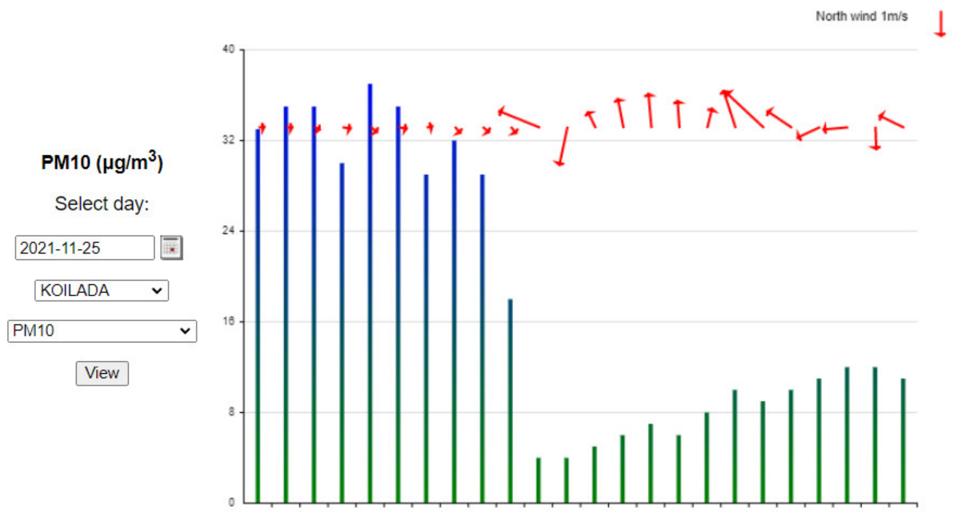

Figure 6. Pollutant with wind data diagram.

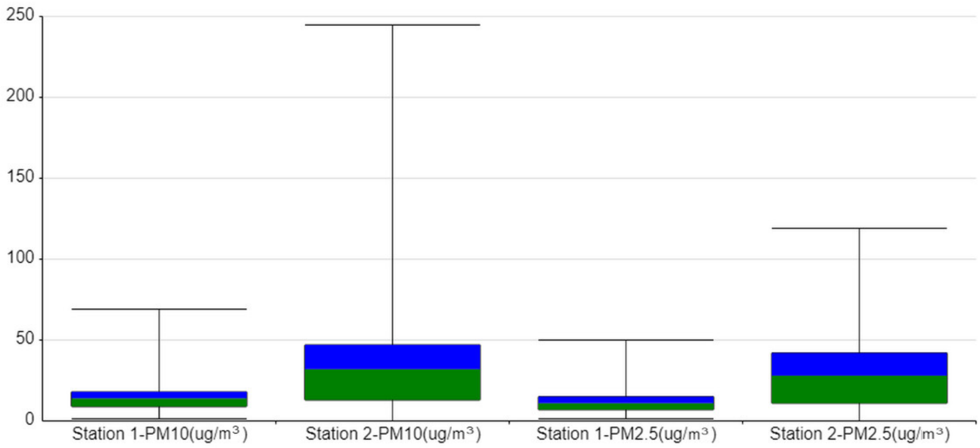

Figure 7. Box plot diagram.

All current and historical data can be presented in a table form and can be exported to spreadsheet or pdf files (Figure 8). The data are acquired from the database in 5 min, 60 min, 8 h, or 24 h intervals. To present the data in a table form, we use ApPHP DataGrid software [56]. The ApPHP DataGrid script is a simple, innovative, and powerful tool for generating data-bound grid control. It is excellent for online-based data administration and also useful for dynamic content management. In order to export data in a spreadsheet file format, we use the PhpSpreadsheet library [57], which offers a set of classes that allow the reading and writing of various spreadsheet file formats such as Microsoft Excel [58] and LibreOffice Calc [59]. Moreover, for the pdf file format, we use mPDF [60], a PHP library which generates PDF files from UTF-8 encoded HTML.

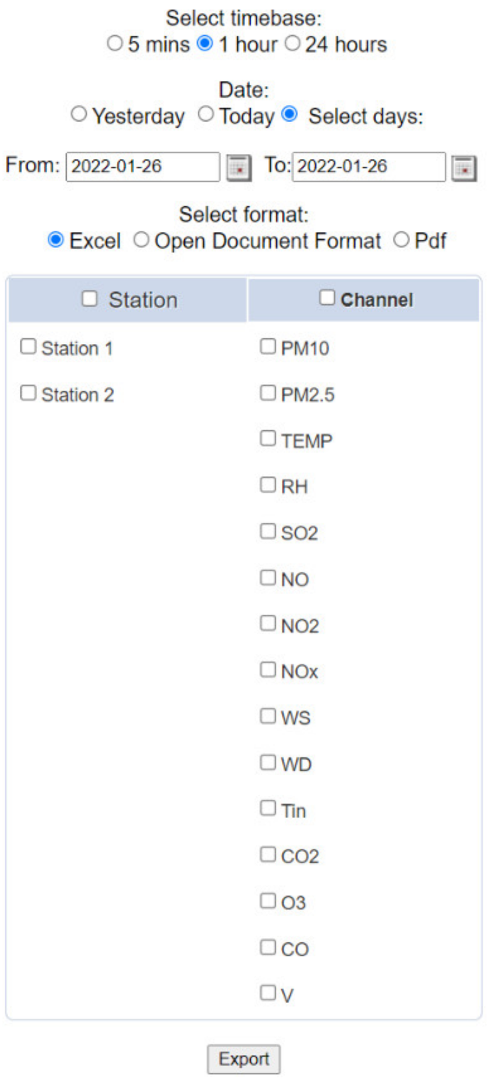

Figure 8. Data export form.

2.2.2. Remote Communication System (RCS)

Considering the need for a tool capable of integrating data from multiple sources and disseminate those data to authorized users, the concept of a dedicated Application Programming Interface (API) was initiated. API is actually an interface with a set of functions and allows programmers to acquire the data of an application. The RCS service is programmed to fetch (poll) data from a cloud database on demand in order to disseminate the information to authorized users in json format. Moreover, it stands between the cloud database and CS. It accepts the data in json format and after checking the data, stores it in the database. The communication is done by ensuring encryption of the data while in no case is there any direct communication of users with the database data, ensuring that the data remain protected. Exception handling is implemented in most of the API routines to avoid any runtime issues.

2.2.3. AirDMS Service

Environmental data are effective when communicated in a user-friendly format for timely decisions. In order for the decisions to be correct, however, there must be timely information on the validity of the data presented. Conventional environmental information dissemination applications to date focus on presenting data without being able to control their quality in real time [33–36,61].

Modern atmospheric quality recording analyzers have recording capabilities for many parameters, setting limits outside which the analyzer does not work properly, resulting in recorded values which are considered incorrect. These operating parameters are recorded (both current and historically) in AirDMS. This enables the air quality managers on the one hand, to judge whether the pollutant values were correct, while on the other, the technical staff can be informed of problems in order to take appropriate action. Furthermore, technical personnel, based on historical diagnostics, can prevent damage (e.g., observing the rate of change of a certain functional parameter or its rate of approach to the limit of abnormal operation) and can proactively schedule the repair of the analyzer. Moreover, as in large environmental monitoring networks the distances between stations are long, the AirDMS can help to get rid of unneeded field service engineer travel, saving time and funds.

Figure 9 shows the operating status of the stations supervised by a service engineer. The stations are represented as dots on a map of the area. Depending on the operational status of the station (communication with the station, supply voltage of the station, communication with the analyzers, operational parameters of the analyzers), the color of the dot changes according to the legend on the map. Selecting one of the stations (Figure 10) displays the operational data for the specific station, while selecting one of the analyzers, whose diagnostics are recorded, revealing a table displaying the current values of the analyzer operating parameters as well as their minimum and maximum values for valid operation (Figure 11).

Finally, the historical data for the operational parameters of the analysts can be displayed in tables and graphs by freely selecting the time-period of their presentation.

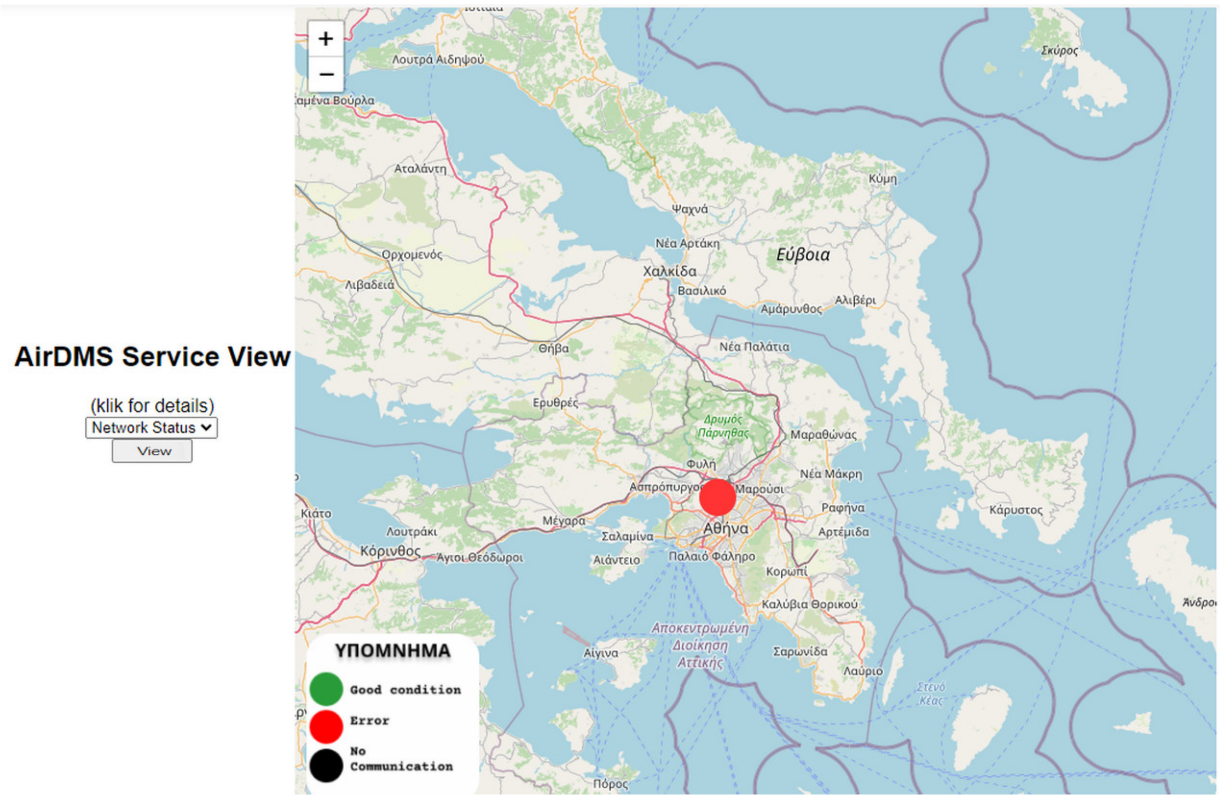

Figure 9. Operating status of the network stations.

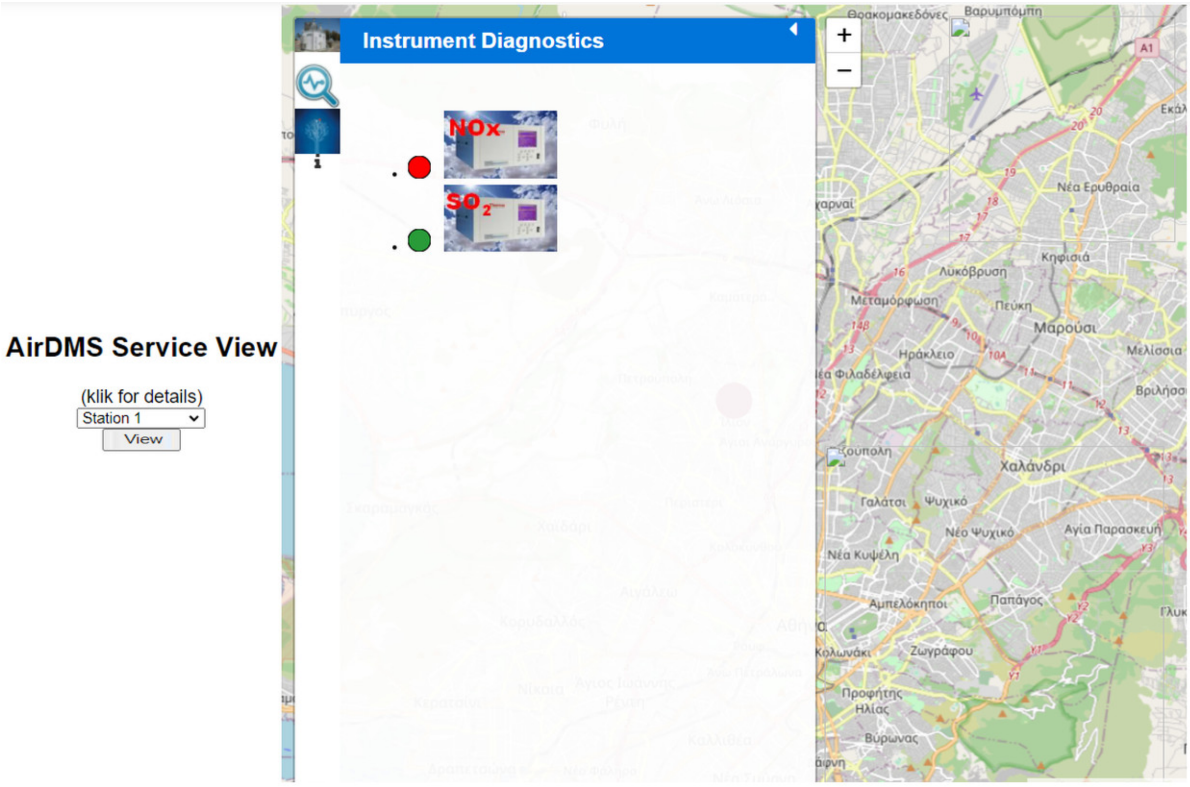

Figure 10. Operating status for analyzers of selected station.

Station Diagnostics: Station 2

Date	10/02/2022 20:00	Minimum Value	Maximum Value
NO concntration(ppb)	0.16	0.000	0.000
DIF concentration(ppb)	7.00	0.000	0.000
noy concentration(ppb)	7.16	0.000	0.000
Pmt voltage(Volts)	-728.90	-1200.000	-600.000
Pmt temp(°C)	-2.90	-5.000	-1.000
Internal temp(°C)	34.90	8.000	47.000
react temp(°C)	50.50	47.000	51.000
Convertor temp(°C)	325.00	300.000	375.000
pressure(mm Hg)	248.60	50.000	300.000
sample flow(l/m)	0.58	0.350	0.900
ozonator flow(l/m)	0.00	0.049	0.051
no coef()	0.00	0.000	0.000
nox coef()	0.00	0.000	0.000
no bkg(ppb)	0.00	0.000	0.000
nox bkg(ppb)	0.000	0.000	0.000

Figure 11. Operating parameters for selected analyzer.

2.3. AirDMS Alerts

Timely update of environmental parameters, especially in cases of limit exceedances of pollutants or severe weather phenomena, is a critical process for the protection of citizens. In addition, it allows service engineers to be informed of the operational condition of the equipment in order to intervene as quickly as possible, avoiding unnecessary travel time. For the above reasons, AirDMS software has been enriched with the addition of another important tool, AirDMS Alerts.

AirDMS Alerts is a personalized information tool for AirDMS users. It can be programmed through the web interface and send messages to users in various ways, such as email, SMS, and push notifications through the mobile application. The application works as an operating system service and shows push notifications for the user. Currently, it is available only for mobile phones and tablets using the Android operating system.

The station administrator can schedule to send a message in one of the above formats in various cases, such as in exceeding a maximum or minimum limit for any parameter set by the user or operating condition of the station in relation to parameters, such as its internal temperature, mains voltage, etc., or finally, for the operating parameters of the analyzers based on the limits specified by the manufacturer or the service engineer of the station.

3. Conclusions

This manuscript presents an effective way to monitor air quality and environmental parameters (such as noise or meteorological data) using modern technologies, through the development of a dedicated software, AirDMS. As is well understood, air quality monitoring plays an important role in the protection of human health. However, it is expected to be of even greater importance in the future, due to the adverse effects on air quality that will be brought about by climate change. Thus, it is critical for citizens to be informed about air quality in real time in order to avoid prolonged exposure to high concentrations of pollutants, but it is equally important that the information given to the public is correct, and in the case of equipment malfunction, corrective actions to be undertaken in a timely and efficient manner.

With the use of AirDMS, this is done immediately, as technical personnel and air quality managers are constantly updated on the operational status of the measurement analyzers. Thus, the AirDMS focuses on how to effectively manage air quality monitoring networks, but also on informing the public in a simple and easy to understand way. The presentation of data is done using modern technologies. A JavaScript charting library (RGraph) was extended in AirDMS, and thus, data are visualized in an efficient way, giving a clear picture of air quality even to non-specialized people.

An important issue to consider when dealing with air quality monitoring is that, in many cases, analyzers may record incorrect values. It can, as often happens in the field, take several days to repair the fault, especially when it comes to a large monitoring network with long distances from the stations to the management center. It is therefore advisable to record and review the operational status of the analyzers performing the measurements. In AirDMS, these are available in real time, in addition to environmental quality parameters and critical parameters such as analytical operating parameters and station status (room temperature, mains voltage, etc.). Thus, the current and historical situation of the critical operational parameters of the analyzers can be reviewed.

Moreover, for the air quality data review to be effective, evaluation should be done immediately and automatically. AirDMS allows network technical and administrative personnel to receive messages in the event of failures, overruns, or abnormal values. This is done via email, SMS, or push notifications using native mobile application. In this way, the AirDMS users can save time and money, while at the same time having high data availability rates. Although the AirDMS system is being continuously improved and expanded, in its current configuration, it handles information from 6 networks that include over 55 air pollution monitoring stations that are located throughout Greece. Experience while operating the system has shown that data availability rates can exceed 99% during the year. Although at present the system is being operated only in Greece, it can be easily adapted for use in other countries or regions. Future expansion of the system's capabilities will include the incorporation of artificial intelligence in recognizing technical failures in monitoring stations.

Author Contributions: Conceptualization, C.L. and V.E.; software, V.E., G.E. and M.L.; investigation, N.D.C. and V.E.; writing—original draft preparation, V.E. and N.D.C.; visualization, G.E.; supervision, V.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Health Organization. Air Pollution. Available online: https://www.who.int/health-topics/air-pollution (accessed on 3 January 2021).
2. Sielski, J.; Kaziród-Wolski, K.; Jóźwiak, M.A.; Jóźwiak, M. The influence of air pollution by PM2.5, PM10 and associated heavy metals on the parameters of out-of-hospital cardiac arrest. *Sci. Total Environ.* **2021**, *788*, 147541. [CrossRef] [PubMed]
3. Zoras, S.; Triantafyllou, A.; Evagelopoulos, V. Aspects of year-long differential optical absorption spectroscopy and ground station measurements in an urban street canyon near industrial pollution sources. *Atmos. Environ.* **2008**, *42*, 4293–4303. [CrossRef]
4. Fattore, E.; Paiano, V.; Borgini, A.; Tittarelli, A.; Bertoldi, M.; Crosignani, P.; Fanelli, R. Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. *Environ. Res.* **2011**, *111*, 1321–1327. [CrossRef] [PubMed]
5. Meister, K.; Johansson, C.; Forsberg, B. Estimated Short-Term Effects of Coarse Particles on Daily Mortality in Stockholm, Sweden. *Environ. Health Perspect.* **2012**, *120*, 431–436. [CrossRef] [PubMed]
6. Correia, A.W.; Pope, C.A., III; Dockery, D.W.; Wang, Y.; Ezzati, M.; Dominici, F. The effect of air pollution control on life expectancy in the United States: An analysis of 545 US counties for the period 2000 to 2007. *Epidemiology* **2013**, *24*, 23–31. [CrossRef] [PubMed]
7. Fang, Y.; Naik, V.; Horowitz, L.W.; Mauzerall, D.L. Air pollution and associated human mortality: The role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present. *Atmos. Chem. Phys.* **2013**, *13*, 1377–1394. [CrossRef]
8. Jiang, X.-Q.; Mei, X.-D.; Feng, D. Air pollution and chronic airway diseases: What should people know and do? *J. Thorac. Dis.* **2016**, *8*, E31–E40. [CrossRef] [PubMed]
9. Kortoçi, P.; Motlagh, N.H.; Zaidan, M.A.; Fung, P.L.; Varjonen, S.; Rebeiro-Hargrave, A.; Niemi, J.V.; Nurmi, P.; Hussein, T.; Petäjä, T.; et al. Air pollution exposure monitoring using portable low-cost air quality sensors. *Smart Health* **2021**, *23*, 100241. [CrossRef]
10. Ma, X.; Zhang, T.; Ji, C.; Zhai, Y.; Shen, X.; Hong, J. Threats to human health and ecosystem: Looking for air-pollution related damage since 1990. *Renew. Sustain. Energy Rev.* **2021**, *145*, 111146. [CrossRef]
11. Orach, J.; Rider, C.F.; Carlsten, C. Concentration-dependent health effects of air pollution in controlled human exposures. *Environ. Int.* **2021**, *150*, 106424. [CrossRef]
12. Khomenko, S.; Cirach, M.; Pereira-Barboza, E.; Mueller, N.; Barrera-Gómez, J.; Rojas-Rueda, D.; de Hoogh, K.; Hoek, G.; Nieuwenhuijsen, M. Premature mortality due to air pollution in European cities: A health impact assessment. *Lancet Planet. Health* **2021**, *5*, e121–e134. [CrossRef]
13. Poole, J.A.; Barnes, C.S.; Demain, J.G.; Bernstein, J.A.; Padukudru, M.A.; Sheehan, W.J.; Fogelbach, G.G.; Wedner, J.; Codina, R.; Levetin, E.; et al. Impact of weather and climate change with indoor and outdoor air quality in asthma: A Work Group Report of the AAAAI Environmental Exposure and Respiratory Health Committee. *J. Allergy Clin. Immunol.* **2019**, *143*, 1702–1710. [CrossRef]
14. Salthammer, T.; Schieweck, A.; Gu, J.; Ameri, S.; Uhde, E. Future trends in ambient air pollution and climate in Germany–Implications for the indoor environment. *Build. Environ.* **2018**, *143*, 661–670. [CrossRef]
15. Ahmed, T.; Kumar, P.; Mottet, L. Natural ventilation in warm climates: The challenges of thermal comfort, heatwave resilience and indoor air quality. *Renew. Sustain. Energy Rev.* **2021**, *138*, 110669. [CrossRef]
16. Zhang, Y.; Wang, H.; Han, Y.; Wang, D.; Zhu, G.; Lu, X. Shale gas development in China: Implications for indoor and outdoor air quality and greenhouse gas emissions. *Environ. Int.* **2020**, *141*, 105727. [CrossRef]
17. McLaren, J.; Williams, I. The impact of communicating information about air pollution events on public health. *Sci. Total Environ.* **2015**, *538*, 478–491. [CrossRef]
18. EC Directive 2008/120/EC. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0120&from=EN (accessed on 16 February 2022).
19. Wiemann, S.; Brauner, J.; Karrasch, P.; Henzen, D.; Bernard, L. Design and prototype of an interoperable online air quality information system. *Environ. Model. Softw.* **2016**, *79*, 354–366. [CrossRef]
20. Evagelopoulos, V.; Charisiou, N. Smart air monitoring for indoor public spaces using mobile applications. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *899*, 012006. [CrossRef]
21. Hoff, R.M.; Christopher, S.A. Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land? *J. Air Waste Manag. Assoc.* **2009**, *59*, 645–675. [CrossRef]
22. Engel-Cox, J.; Oanh, N.T.K.; van Donkelaar, A.; Martin, R.V.; Zell, E. Toward the next generation of air quality monitoring: Particulate Matter. *Atmos. Environ.* **2013**, *80*, 584–590. [CrossRef]
23. Cooper, M.J.; Martin, R.V.; Van Donkelaar, A.; Lamsal, L.; Brauer, M.; Brook, J.R. A Satellite-Based Multi-Pollutant Index of Global Air Quality. *Environ. Sci. Technol.* **2012**, *46*, 8523–8524. [CrossRef]
24. Li, J.; Zhang, H.; Chao, C.-Y.; Chien, C.-H.; Wu, C.-Y.; Luo, C.H.; Chen, L.-J.; Biswas, P. Integrating low-cost air quality sensor networks with fixed and satellite monitoring systems to study ground-level PM2.5. *Atmos. Environ.* **2020**, *223*, 117293. [CrossRef]

25. Semlali, B.-E.B.; El Amrani, C.; Ortiz, G.; Boubeta-Puig, J.; Garcia-De-Prado, A. SAT-CEP-monitor: An air quality monitoring software architecture combining complex event processing with satellite remote sensing. *Comput. Electr. Eng.* **2021**, *93*, 107257. [CrossRef]
26. Van Donkelaar, A.; Martin, R.V.; Brauer, M.; Kahn, R.; Levy, R.; Verduzco, C.; Villeneuve, P.J. Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application. *Environ. Health Perspect.* **2010**, *118*, 847–855. [CrossRef]
27. Zoras, S.; Evagelopoulos, V.; Pytharoulis, I.; Kallos, G. Development and validation of a novel-based combination operational air quality forecasting system in Greece. *Arch. Meteorol. Geophys. Bioclimatol. Ser. B* **2010**, *106*, 127–133. [CrossRef]
28. Zoras, S.; Triantafyllou, A.G.; Evagelopoulos, V. Modelling of PM2.5 Episodes in Four Cities of Northwestern Greece. *Frese-Nius Environ. Bull.* **2006**, *15*, 306–313.
29. Evagelopoulos, V.; Charisiou, N.D.; Zoras, S. Dataset of inhalable particulate matter concentrations in the region of West Macedonia, Greece for an 11-year period. *Data Brief* **2022**, *41*, 107883. [CrossRef]
30. Tolis, E.I.; Missia, D.A.; Charisiou, N.D.; Bartzis, J.G. Polycyclic aromatic hydrocarbons and ionic species associated with particulate matter in ambient air in Kozani City, Greece, during cold period. *Fresenius Environ. Bull.* **2010**, *19*, 2006–2012.
31. Dimitriou, K.; Kassomenos, P. Estimation of North African dust contribution on PM10 episodes at four continental Greek cities. *Ecol. Indic.* **2019**, *106*, 105530. [CrossRef]
32. Iordanidis, A.; Zoras, S.; Triantafyllou, A.; Buckman, J.; Asvesta, A.; Evagelopoulos, V. Characterisation of Airborne Particles Collected Proximal to Lignite Mines and Power Plants of Ptolemais-Kozani Area, Northern Greece. *Fresenius Environ. Bull.* **2008**, *17*, 378–398.
33. Papadimitriou, C.; Evagelopoulos, V.; Samaras, P.; Triantafyllou, A.; Zoras, S.; Albanis, T. Toxicity of Atmospheric Particu-late Matter Using Aquatic Bioassays. *WIT Trans. Biomed. Health* **2006**, *10*, 31–39.
34. Baklanov, A.; Cárdenas, B.; Lee, T.-C.; Leroyer, S.; Masson, V.; Molina, L.T.; Müller, T.; Ren, C.; Vogel, F.R.; Voogt, J.A. Integrated urban services: Experience from four cities on different continents. *Urban Clim.* **2020**, *32*, 100610. [CrossRef] [PubMed]
35. Grimmond, S.; Bouchet, V.; Molina, L.T.; Baklanov, A.; Tan, J.; Schlünzen, K.H.; Mills, G.; Golding, B.; Masson, V.; Ren, C.; et al. Integrated urban hydrometeorological, climate and environmental services: Concept, methodology and key messages. *Urban Clim.* **2020**, *33*, 100623. [CrossRef] [PubMed]
36. Molina, L.T.; Velasco, E.; Retama, A.; Zavala, M. Experience from Integrated Air Quality Management in the Mexico City Metropolitan Area and Singapore. *Atmosphere* **2019**, *10*, 512. [CrossRef]
37. Von Schneidemesser, E.; Kutzner, R.D.; Schmale, J. A survey on the perceived need and value of decision-support tools for joint mitigation of air pollution and climate change in cities. *Elem. Sci. Anthr.* **2017**, *5*, 68. [CrossRef]
38. Gulia, S.; Nagendra, S.S.; Khare, M.; Khanna, I. Urban air quality management-A review. *Atmos. Pollut. Res.* **2015**, *6*, 286–304. [CrossRef]
39. Naiker, Y.; Diab, R.; Zunckel, M.; Hayes, E. Introduction of local Air Quality Management in South Africa: Overview and challenges. *Environ. Sci. Policy* **2012**, *17*, 62–71. [CrossRef]
40. Johansson, C.; Burman, L.; Forsberg, B. The effects of congestions tax on air quality and health. *Atmos. Environ.* **2009**, *43*, 4843–4854. [CrossRef]
41. Karatzas, K.; Dioudi, E.; Moussiopoulos, N. Identification of major components for integrated urban air quality management and information systems via user requirements prioritisation. *Environ. Model. Softw.* **2003**, *18*, 173–178. [CrossRef]
42. The Danish Environment Research Institute (DNERI). *Comparison of the EU and US Air Quality Standards and Planning Requirements*; A Project of DG Environment Carried Out by Milieu Ltd.; The Danish Environment Research Institute and The Center for Clean Air Policy: Roskilde, Denmark, 2004; 58p.
43. AIRNow. Available online: https://www.airnow.gov.com (accessed on 15 January 2022).
44. Gwaze, P.; Mashele, S.H. South African Air Quality Information System (SAAQIS) mobile application tool: Bringing real time state of air quality to South Africans. *Clean Air J.* **2018**, *28*, 3–4. [CrossRef]
45. AQICN. Available online: https://aqicn.org (accessed on 15 January 2022).
46. SAFAR-India. Available online: http://safar.tropmet.res.in (accessed on 15 January 2022).
47. AirDMS. Available online: https://www.airdms.gr (accessed on 15 January 2022).
48. Coulby, G.; Clear, A.; Jones, O.; Godfrey, A. A Scoping Review of Technological Approaches to Environmental Monitoring. *Int. J. Environ. Res. Public Heal.* **2020**, *17*, 3995. [CrossRef]
49. Khan, Z.; Anjum, A.; Soomro, K.; Tahir, M.A. Towards cloud based big data analytics for smart future cities. *J. Cloud Comput. Adv. Syst. Appl.* **2015**, *4*, 2. [CrossRef]
50. Kaginalkar, A.; Kumar, S.; Gargava, P.; Niyogi, D. Review of Urban Computing in Air Quality Management as Smart City Service: An Integrated IoT, AI, and Cloud Technology Perspective. *Urban Climate* **2021**, *39*, 100972. [CrossRef]
51. Haklay, M.; Weber, P. OpenStreetMap: User-Generated Street Maps. *IEEE Pervasive Comput.* **2008**, *7*, 12–18. [CrossRef]
52. Brambilla, M.; Cabot, J.; Izquierdo, J.L.C.; Mauri, A. Better call the crowd: Using crowdsourcing to shape the notation of domain-specific languages. In Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering, Vancouver, BC, Canada, 23–24 October 2017; Association for Computing Machinery (ACM): New York, NY, USA, 2017; pp. 129–138.
53. Donohue, R.G.; Sack, C.M.; Roth, R. Time Series Proportional Symbol Maps with Leaflet and jQuery. *Cartogr. Perspect.* **2014**, *76*, 43–66. [CrossRef]

54. DEFRA. Available online: https://uk-air.defra.gov.uk/air-pollution/daqi (accessed on 13 January 2022).
55. RGraph. Available online: https://www.rgraph.net (accessed on 13 January 2022).
56. Apphp. Available online: https://www.apphp.com (accessed on 13 January 2022).
57. PhpSpreadsheet. Available online: https://github.com/PHPOffice/PhpSpreadsheet (accessed on 13 January 2022).
58. Microsoft Excel. Available online: https://www.microsoft.com/en/microsoft-365/microsoft-office?rtc=1 (accessed on 13 January 2022).
59. Libreoffice. Available online: https://www.libreoffice.org (accessed on 13 January 2022).
60. Mpdf. Available online: https://mpdf.github.io (accessed on 13 January 2022).
61. Triantafyllou, A.; Evagelopoulos, V.; Zoras, S. Design of a web-based information system for ambient environmental data. *J. Environ. Manag.* **2006**, *80*, 230–236. [CrossRef]