

## **A GIS-Based System for Real-Time Air Pollution Monitoring and Alerting Based on OGC Sensors Web Enablement Standards**

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Received: 31.01.2020

Revised:15.08.2020

Accepted: 21.11.2020

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**ABSTRACT:** Air pollution is a significant concern for both managers and disaster decision-makers in megacities. Considering the importance of having access to correct and up to date spatial data, it goes without saying that designing and implementing an environmental alerting and monitoring system is quite necessary. A standard infrastructure is needed to utilize sensor observations so as to be ready in case of critical conditions. The use of sensor web is regarded a fundamental solution to control and manage air quality in megacities. The proposed system uses the SWE framework of OGC, the reference authority in spatial data, to integrate both sensors and their observations, while utilizing them in the spatial data infrastructure. The developed system provides the capability to collect, transfer, share, and process the sensor observations, calculate the air quality condition, and report real-time critical conditions. For this purpose, a four-tier architectural structure, including sensor, web service, logical, and presentation layer, has been designed. Using defined routines and subsystems, the system applies web sensor data to a set of web services to produce alerting information. The developed system, which is assessed through sensor observation, measures the concentration of carbon monoxide, ozone, and sulfur dioxide in 20 stations in Tehran. In this way, the real-time air quality index is calculated, and critical conditions are sent through email to those users, who have been registered in the system. In addition, interpolation maps of the observations along with time diagrams of sensors' observations can be obtained through a series of processes, carried out by the process service.

**Keywords:** Sensor Web, Web GIS, AQI, Tehran.

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### **INTRODUCTION**

Air pollution is one of the most critical environmental issues in both developed and developing countries (Delavar et al. 2019). As a consequence of advances in technology together with increasing rate of population growth, air pollution has become one of the most severe environmental issues

(Alesheikh et al. 2005; Saukh et al. 2012). Recent decades, as a result of population growth and improvement in living standards, have witnessed a greater rate of fossil fuel usage as the primary resource for energy supply. (Abbaspour and Soltaninejad 2004). In such circumstances, determining the real amount of pollutants, describing the existing air quality condition compared to standard conditions, and providing people

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with simple, rapid, and accurate information play a pivotal role to mitigate the devastating impact on city dwellers and help officials make effective measures where air quality is undesirable and pollutant concentration exceeds the standard level (Pummakarnchana et al. 2005). The continuous monitoring of air pollutants is considered one of the essential elements in decision-making and public awareness of air pollution management. Correct quantitative and qualitative analysis of air condition is impossible without sufficiently accurate and valid data (Zheng et al. 2013). It is necessary to use observations of several types of in-situ and mobile sensors. Given the wide-ranging presence of sensors in today's living environment as well as their abilities, current sensors and sensor networks provide the required information on several environmental monitoring applications, such as pollution monitoring and transportation management to urban managers and decision-makers, as these sensors have the ability to control the environmental conditions permanently and work under conditions that are very hard or impossible for human users to act. Also with advances of technology, sensors, too, have witnessed remarkable progress in terms of efficiency, not to mention a significant decrease in their price. Most importantly, they are entirely economical in terms of energy consumption, making their use for environmental monitoring and alerting systems in today's circumstances completely practical and undeniably beneficial. Ambient health effects, related to air pollution exposure, have mainly occurred in megacities in developing countries, due to high ambient air pollutant concentrations (Yousefian et al. 2020). The air pollution in Tehran has been a serious concern for public health during the last decade, which shows the importance of management planning (Jaafari et al. 2020). Regarding the importance of air pollution issue, it seems necessary to design and

implement a system to monitor air pollution and create an alert for citizens to reduce the harmful impacts of air pollution on people's life and health. In this context, given the vitality of interoperability among responsible organizations, it seems necessary to create and use sensors and sensor networks to simplify and realize the sharing and integration of data from several types of sensors to increase system efficiency (Wiemann et al. 2015). As a standard solution, Open GeoSpatial Consortium (OGC) has introduced the SWE framework to standardize sensors' information management (Wiemann et al. 2015). The framework has been designed to access sensors' resources, data retrieval, and subscription to receive alerts from sensor data processing and enable sensors to control their observations. It also provides interoperability among several sensors, simulation models, simulation systems, and decision-making and alert systems (Hu et al. 2015; Botts et al. 2006). The present research has designed a flexible and interoperable architecture based on SWE standard framework. It has implemented it to monitor sensors' observations in a real-time manner and provide real-time information through standard web services to registered users. Furthermore, it has provided maps and updated dynamic diagrams of air pollution to increase the decision-making-support systems' efficiency. The idea of using web sensors to make observations by several sensors available on the Internet network was first introduced by NASA JPL laboratory in 1999 to explore unknown places (Delin and Jackson 2001). Markovic et al. (2009) addressed the application of OGC standards in the problem of water pollution in their research, where they designed and developed a smart system based on OGC standards and smart DMA decision-making factors, which was in charge of automating spatial queries and geo-sensors. In their system, a framework was responsible for

storing, analyzing, and retrieving sensors' data by means of OGC standard. Further research in this topic tackled the problem of real-time air quality data management (Henneböhl et al., 2009). Henneböhl et al. (2009) proposed a service-oriented architecture to manipulate air pollution data, acquired from sensors using OGC standard. Their case study was Europe, since air quality data were available for this region. They designed a WPS to interpolate air quality data. One main advantage of this research is that the system is able to store the output of the process on WCS and apply it for retrieval and future purposes. Foerster et al. (2010) developed a framework for the fusion of geo-spatially-enabled data with sensor observations in order to calculate the health index for a specific area. Their framework employed an architecture, using a pair of event processor services integrated with WPS, capable of calculating a health index for urban areas. It should be noted that researches have always focused on handling Spatio-temporal data. Stasch et al. (2012) developed a system based on SWE services that enables users to do real-time storage, analysis, and retrieval of sensor observations. They evaluated the potentiality of the proposed system for storage and visualization of real-time air pollutant concentration data, obtained by the spatial sensor. Another research dealt with the application of space-based sensors for air quality monitoring (Resch et al. 2011). In this research, Resch et al. (2011) proposed a novel system to overcome the weaknesses of available systems in handling, manipulating, and processing space-based sensors. Apart from researches focused on the application of geospatial sensors for air pollution monitoring, other researches applied OGC standard for other applications such as disaster management (Jirka et al. 2009; Degrossi et al. 2013; Chen et al. 2014) and traffic monitoring (Boulos et al. 2011; Pirotti et al. 2011). Degrossi et al. (2013) used an OGC

framework to monitor floods. The integrated sensor data from a set of geosensors and their system was able to monitor a risk index for flood disasters. Such a system can widely be employed in flood vulnerability assessment. A newer idea in the sensor web is to use citizens as sensors (Goodchild 2007). Boulos et al. (2011) designed and developed a real-time system for environmental monitoring based on the sensor web enabling standard. Their research's advantage was their use of various sensors, because every volunteer citizen can act as a sensor. Thus, the data could be gathered from various sources, enhancing the system's reliability. Horita et al. (2015) proposed an architecture, based on OGC standard for flood monitoring by means of the integration of volunteered geographic information and sensor data. This system was implemented for Brazil and gave promising results and achievements in real-time flood monitoring. Bröring et al. (2015) designed an Android program for smartphones, called "enviroCar platform", which is able to acquire car movement data and send them to a server. This platform is able to use this information for traffic monitoring. Furthermore, it can use VGI data from car trajectories for carbon emission estimation. Gong et al. (2015) developed a real time GIS platform and data model for effective environmental data management. They used a sensor web platform along with GIS data model and gathered meteorological, soil temperature, soil moisture, air quality, and landslide data. In their platform, users could retrieve the sensor's observation and extract thematic maps (Kumar et al. 2017).

Given the importance of air pollution issue, and the researches carried out in this regard, introducing a comprehensive system to make web sensors data and observations available becomes an effective solution to reduce harmful consequences of air pollution in hazardous situations. For this purpose, it would be a suitable solution to use the

standard geospatial framework, introduced by OGC, implementing the concept of sensor web and SID standard. Thus some sensor web standards have been developed that help gathering and retrieving sensor data, wherein the sensors benefit from an SID interface for plug and play. This mechanism makes it possible to utilize any type of sensors in the sensor web platform in real-time, which in turn addresses the syntactic part of interoperability by creating sensor SID and introduce its data format to the SOS.

## **MATERIAL AND METHODS**

Since current urban management systems operate in a wide range of uses, including several organizations, interoperability is quite vital for them. Apart from the sensitivity of this issue and the need for disaster management systems, this system should be online to meet the need for real-time data to respond to the requirements of disaster management system. For this purpose, a set of web services and consensual standard data frameworks are required to implement an interoperable and efficient standard system for performing environmental alerting and monitoring. As an authentic reference for spatial standards, OGC has introduced and standardized the SWE framework so that it can ensure sensors accessibility throughout web infrastructure by providing the following data frameworks and standard services:

**Sensor Observation System (SOS):** a standard service for the purpose of submitting the requests to search spatially and temporally among sensor observations and then retrieve sensors observations and metadata (Na and Priest 2007).

**Sensor Event Service (SES):** a standard service with the goal of creating the capability to monitor sensors observations through a pattern matching mechanism. In this system, users subscribe to their desired and emergency conditions to the service by using prepared standard patterns in order to become informed of the alerts issued from

sensors' observations monitoring (Echterhoff and Everding 2008).

**Web Notification Service (WNS):** a standard interface for sending messages or alerts asynchronously through a communication mechanism, defined by the user (Simonis and Wytzisk 2003). In some online systems such as the alerting and monitoring ones, users need to be aware of situations permanently without considering their online status in order to be informed of the alerts. In such circumstances, it seems necessary to use the system, which transfers the messages asynchronously, i.e., it issues alerts even if the user is not online.

**Observation and Measurement Framework (O&M):** In order to set up interoperability at all levels, some standards are required for data modeling. In response to this need, the SWE framework has modeled the observations and metadata relevant to sensors' observations under this standard framework (Botts and Robin 2007).

**SensorML:** This is defined as an XML-based standard data framework, and model for modeling of metadata related to sensors as well as of processes performed on observations (Botts and Robin 2007).

**Sensor Interface descriptor:** It is an XML-based standard data framework, based on OGC SensorML standard. A SID for a particular sensor enables a SID interpreter to translate between the sensor's communication protocol and the Sensor Web (Broering et al. 2010).

The primary purpose of air pollution alerting and monitoring systems is to monitor the urban pollutant conditions and alert urban authorities and citizens alike in disastrous occasions, thus urging them to reduce the harmful consequences of air pollutions. Since the system should be capable of providing information and opportune necessary alerts, it should be able to give the authorities environmental conditions in a real-time, online, and direct manner by means of real-time observations of the sensors. For this purpose, it is possible to

make use of the standards, presented in the SWE framework to implement the online monitoring and alerting system. A service-oriented architecture is a fundamental infrastructure that can enable its users use distributed systems and services. The architecture distributes the required duties and processes to separate units (called Service) (Kotsev et al. 2015). These distributed services are able to explore, request, and disseminate their features through the web. They communicate with each other through a notification mechanism, using an XML framework (Lorkowski and Brinkhoff 2015b). By using service-oriented architecture, the SWE web services are able to cooperate with each other and create a specific application. The architecture can also help reusing the services in other applications (Jiang et al. 2015). A multi-tier service-oriented architectural mechanism has been forecasted and designed in order to design the environmental alerting and monitoring system architecture and ensure the flexibility of the system and its elements as well as its capacity to reuse its elements, with respect to the purpose of the system interoperability. As discussed in the following, in order to implement the alerting and monitoring system, a four-tier architecture, consisted of display, logic, web service, and sensors physical layers, has been

used. Figure 1 shows the structure of the designed architecture layers.

*Presentation layer:* The presentation layer includes two separate parts; the user interface, and the display of spatial features and considered maps. The former has been designed and implemented to be used by urban managers and ordinary users of a web portal. It presents spatial maps and user interfaces. The latter has employed display maps and spatial features, WMS, and WFS, which are standard services to provide web maps.

*Logic Layer:* In this layer, several services are called, and service chains as well as workflows are being performed, using the two sub-systems: WPS (Standard Web Processing Service) and Monitoring System Engine (MSE) sub-system, which make it possible to integrate spatial services and present automatic workflows.

*Web Service Layer:* In this layer, OGC standard services, introduced by the SWE standard framework, as well as a number of interface services have been designed to complete used working processes. Through the designed user interface, users are able to utilize the working cycles designed on the logic layer so as to make their requests (Yue et al. 2015). The working cycles serve users by calling and integrating web service layer services.

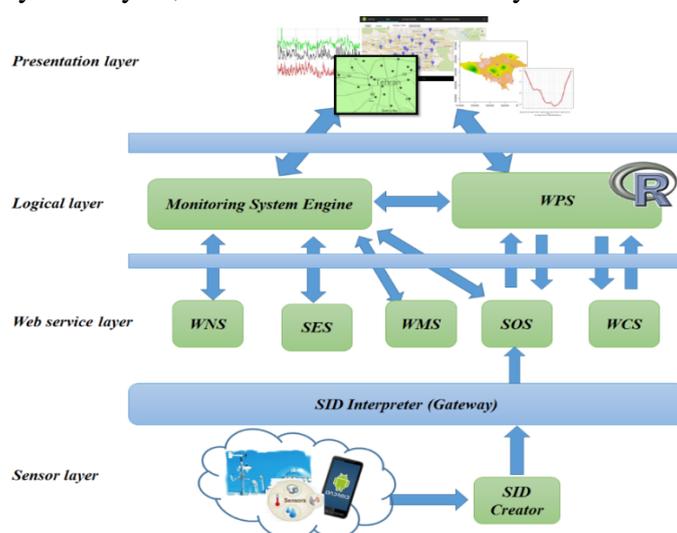


Fig. 1. The four-tier architectural structure of the alerting and monitoring system

*Sensors Layer:* One of the features, considered in designing the system, is its ability to manage the use of several types of sensors with different characteristics and functions in the context of environmental monitoring. For this purpose, the sensors in this architecture have become equipped to connect and make simultaneous use of the system. The sensors interface description standard, being the developed version of SensorML, has been used in the system in order to resolve the issue of lack of interoperability among several types of sensors and different outputs in the system and render the sensors usable in a near real-time approach. A Sensor Interface Descriptor (SID) has also been used for the connection port so as to address the interoperability issue.

In creating the environmental monitoring system, WNS, SES, SOS standard web services, and O&M Standard metadata have been used to standardize the sensor's observations data structure, with SensorML standard data framework to standardize the relevant metadata. Taking advantage of SOS service, which is responsible for providing access to the data collected from the sensors in the system, sensors' observations are collected and stored on the service with the metadata relevant to them as well as the metadata related to the sensors, themselves.

The main part of the system is the one that processes the input observations, collected by the sensors, so as to produce the higher-level information by applying filters, considered by the user to these observations (Jung et al. 2013). This is performed by SES service, an improved version of Sensor Alert Service (SAS). In SES, at first users subscribe to the service in order to receive alerts when the considered pattern exists, or define their specific conditions and alert conditions. All of the abovementioned conditions are modeled in EML language, where they can be processed by SES service (Everding and

Echterhoff 2008). By applying the pre-defined and registered filters to the sensor's observations, the system would be able to discover desirable conditions for users. Then, its use of a pattern-matching algorithm on the sensor observations indicates critical conditions (Jung et al. 2013, Yue et al. 2014), where alert notifications are issued by the service and sent to the WNS service in order to inform the users. Finally, the WNS service notifies the subscribed users of the alerts occurring in the SES service by means of standard protocols such as HTTP and its own standard protocol (Shafi et al. 2014).

Alerting and registering users is one of the major parts of the alerting and monitoring system, where the user records their personal details to the system through the interface and becomes registered in the system. In the next stage, the user is able to define their current conditions as an event and subscribe to the considered filter and other pre-defined filters, concerning to the specified conditions and the filters determined for real-time refining of the sensor's observations. After giving the personal information, the intended alerting system, and considered alerting conditions which makes up the whole process of the user's registration, the system starts the process of monitoring sensors' observations, as shown in the sequence diagram of figure 2.

In this automatic sequence, several sensor's observations are continuously monitored and assessed. If the user has considered some conditions that happen in the real life, they will be alerted through the information and alerting system.

One of the fundamental applications of an alerting and monitoring system is its ability to store and retrieve sensor observations with the highest efficiency and flexibility. In the present system, sensors observations have been used in the standard format of O&M, which can be used by other elements as well in order to set up flexibility and interoperability.

Considering the variety of sensors as the type of observation phenomenon and the variety of their manufacturers as well as responsible organizations for them, the first step to set up interoperability is to standardize the input process for observations. Initially, the relevant sensor interface descriptor is produced for each sensor and is introduced to the system by an application, as shown in Figure 3. In this sensor output interface, the required processes and relevant outputs are modeled. Using the automatic sensor interface descriptor producer along with the SID document, itself, the sensors will be able, in a comprehensive system, to add a new sensor to the system without applying any fundamental change in a

short period of time, and provide the alerting and monitoring system with the Plug & Play capability. Thanks to this, several types of new sensors in a standard form would be able to provide observations and information for the system. In the structure, represented in Figure 3, at first the SID document needed by the sensor is produced by the automatic SID creator, followed by the input to the descriptor. After describing the interface and compiling the communication protocols, the descriptor receives the considered observations through the protocol defined in the interface. Once the processing commands are issued, if present, will send the observations to SOS to store the observations for later uses.

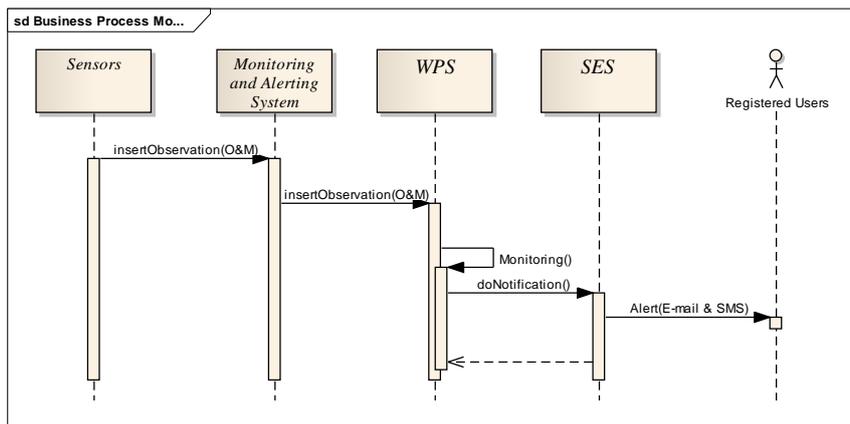


Fig. 2. Sequence diagram of sensors' observations monitoring and alerting users

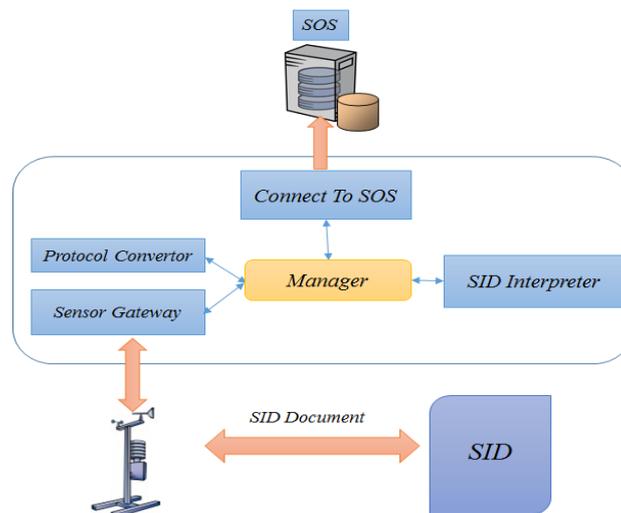


Fig. 3. Integration of physical layer and sensor web infrastructure to use heterogeneous sensors

In this mechanism, several heterogeneous sensors became accessible by the system through the connection port of the sensors descriptor. In this way, lack of interoperability among several sensors for a synchronous use and connection of several types of sensors can be resolved. With such an architecture, several types of sensors could be plugged into the system rapidly, and the sensor will be usable in the system as soon as the sensors interface descriptor is produced. This feature does enable the managers to implement as many sensors as they need to study special situations in a real-time manner.

One of the major functions of every monitoring system is to retrieve sensor observations on the form of several types of users' spatial and temporal requests so as to let both users and managers make decisions on critical occasions. Such output structures include tables, diagrams, KML documents, and interpolation maps. For this purpose, the SOS has been employed here to strengthen disaster managers in their management of environmental monitoring. In order to use the observations stored in the considered service, this system provides observation time-series charts. A scenario has been used to retrieve sensors' observations and create a time-series diagram, in addition to fitting a regression curve to the observations. In order to carry out statistical and geostatistical processes, the R software package has been employed as the processing unit for the system. The R software is responsible for these processes. The system uses its processing capabilities as a processing part of WPS to carry out geo-statistical processes like interpolation of observations by several algorithms, including Kriging and IDW algorithm, as well as to perform statistical processes.

In this scenario, the user firstly records their personal details via the user interface, there to sign up in it. In the next step, they are able to define its considered conditions

and subscribe to the considered filter, with respect to the specified conditions and the filters determined for real-time refinement of the sensors' observations. The Events Markup Language has been used to define filters in the system. These filters include spatial observation filtering, refining based on the type of observation, threshold-exceeding filters, and becoming lesser than the considered limit. With respect to the importance of air pollution and the proposed system abilities to manage several types of sensors, the monitoring scenario has been implemented in the system. In this scenario, once the input enters the alerting and monitoring system, sensors observations are transmitted to the WPS processing service, using the observations' monitoring system in order to calculate the air quality index. Results from the calculation are considered input of the refining filters in the SES service, already defined in accordance with air pollution standards. AQI is an index for reporting air quality and its impact on several strata of society. The index includes six different intervals, each with its own color to indicate the severity of its impact's harmfulness on health to both the authorities and the public (Khedo et al. 2010). For calculating the index, the pollutant concentrations and the amount of AQI are classified in Table 1. The amount of AQI is calculated, using equation 1, where  $BP_{hi}$  and  $BP_{lo}$  for each pollutant and  $I_{hi}$  and  $I_{lo}$  for the interval of AQI amounts are extracted from a standard table.

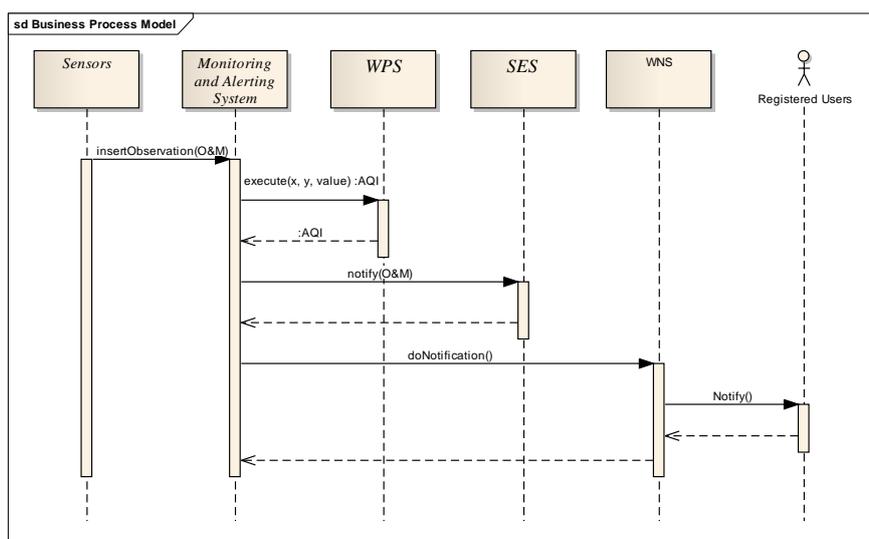
$$AQI = \frac{I_{hi} - I_{lo}}{BP_{hi} - BP_{lo}} (Co - BP_{lo}) + I_{lo} \quad (1)$$

The AQI index is classified into six groups so as to display the impacts on people's health better, as shown in Table 1, according to which each color in the table has its own definition.

With full knowledge of AQI, the air pollution alerting and monitoring scenario has been implemented according to the working mechanism, illustrated in Figure 4.

**Table 1. Air quality index colors and its impact on different groups of the society**

Air Quality Index			Concept
	Good	0-50	Air quality is satisfying, Very low rate of pollution and no danger
	Medium	51-100	Air quality is acceptable.
	Harmful for sensitive groups	101-150	Air quality conditions are harmful for sensitive groups.
	unhealthy	151-200	Air quality is unhealthy for the general public.
	Very unhealthy	201-300	Emergency conditions alert
	Dangerous	301-500	Health Danger: All individuals are exposed to the harmful impacts of pollution.



**Fig. 4. Air pollution alerting and monitoring system mechanism**

In this working mechanism, sensors observations are first entered into the alerting and monitoring system in a real-time and online manner. Upon entry, the observations are transmitted to the WPS processing service in order to extract the air quality index. Then, the air quality index, extracted from these observations, is entered into the monitoring cycle as the input of the SES service. If critical patterns, based on pollution standards, occur, the information related to alerts is transmitted to the relevant users through the WNS service.

The case study is the city of Tehran, located between 35.56–35.83 N and 51.20–51.61E. Tehran is surrounded by Alborz Mountains on the north, which trap the pollutants in the absence of permanent winds (Akbari and Samadzadegan 2015). Air pollution is a challenging problem for

the city, as its pollution exceeds air quality standards several days during each year (WHO 2018). In order to monitor air quality in Tehran, the system uses the information, collected from 20 in-situ pollutant concentration measuring stations installed in regions susceptible to air pollution. To assess the system’s performance, the used data include the ones, collected from the sensors to measure the concentration of carbon monoxide, ozone, and sulfur dioxide and are recorded by these 20 in-situ stations, as shown in Figure 5. Given that the system is able to add several types of sensors in the form of plug and play, the sensor’s distribution map is also generated through service and process chaining by WPS. The current research has designed and tested a prototype system for Tehran city to test the designed system and has implemented the

system preliminary based on a simulated online network of sensors and real-time data injection. Results show it is a practical plan for urban administration and disaster managers to make proper decisions in order to mitigate the devastating impact of air pollution on public health. In this system, a web client has been designed and implemented to see air quality conditions, retrieve several types of archives and real-time observations, define the considered filters for monitoring observations, and subscribe to the implemented filters, as shown in Figure 5. Additionally, Using WMS and WFS standard services, the system provides users with spatial maps and data.

The implemented portal acts as a graphic user interface with the duty of making a connection between the

presentation layer, logic layer, and web services. Through this portal, users are able to subscribe for the alerts and receive several organization’s sensor observation services. These are in the form of interpolated maps and temporal diagrams to see sensor’s real-time observations for the number and color of air quality at those points. In what follows, the implemented system’s capabilities are presented in detail. It enables its users to make several types of spatial, temporal, and comparative inquiries while integrating them for stored data. Inputting the details relevant to its considered observations, such as spatial and temporal interval, sensor name, and the comparative criteria, then the user is able to receive these observations by processing the produced filter, selected by the user, themselves.

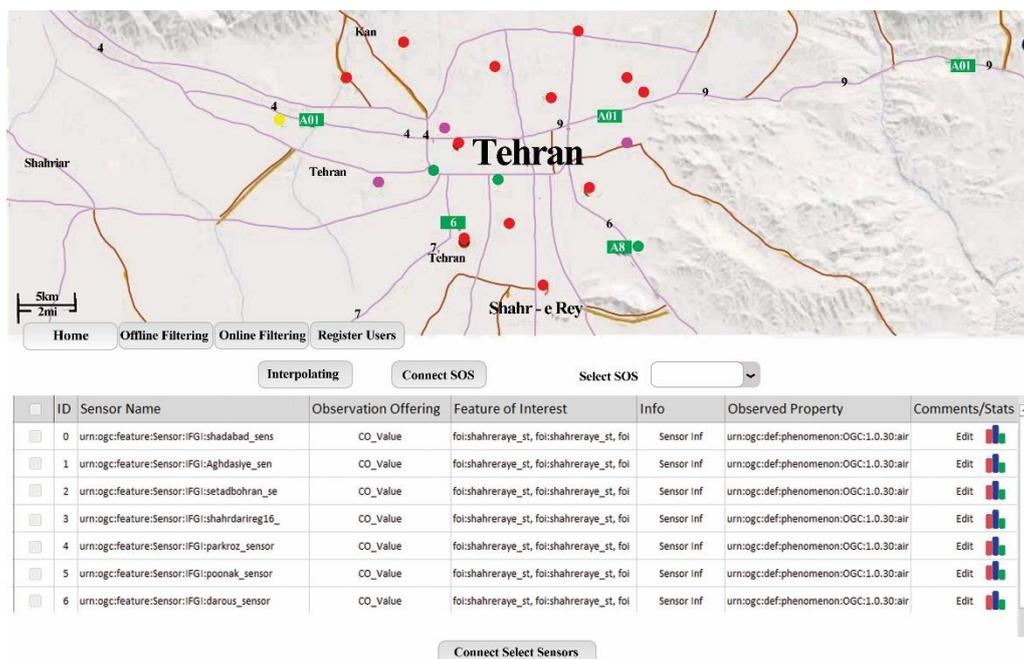


Fig. 5. Spatial portal for managing environmental sensors

The comparative operators, used in the system, are in accordance with the standard implemented by 52North, based on the service capabilities interface, including the operators smaller than, larger than, in between, exactly equal to, similar to, larger

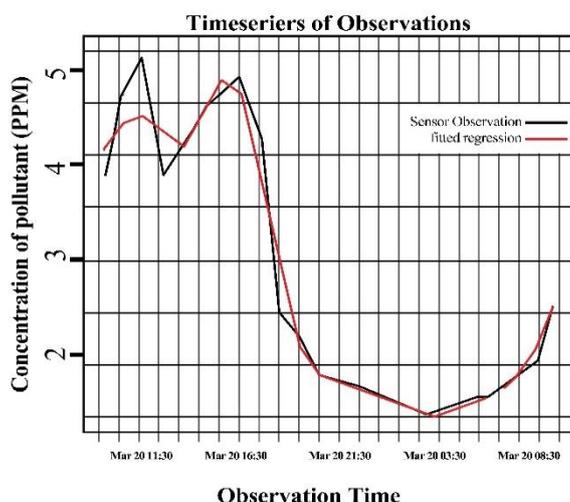
than or equal to, smaller than or equal to, or unequal to an already known number. In addition, in the offline refining sections by the sensor, the system is capable of choosing several sensors in order to retrieve their observations. What is more, the

storage service is unable to synchronously retrieve spatial and temporal inquiries; though, it becomes capable of so doing, once it is implemented. This important capability lets the user to integrate several types of spatial, temporal, and comparative inquiries in a synchronous manner. The central part of the alerting and monitoring system is the standard events processing workflow. In the proposed architecture, the WPS output is presented as an observation, to SES for the purpose of monitoring. In the implementation process, these observations are monitored by using a threshold filter. In the next step, with respect to the considered conditions and filters for real-time refining of sensors' observations, the user defines its own conditions and subscribes for the considered filter. In order to define filters within the system, Events Markup Language has been used. The used filters include spatial data filtering, refining based on the type of observation, monitoring of a specific sensor, and sensors' data monitoring by means of threshold filters. Using pattern matching algorithms, and monitoring sensors observations and adapting to the patterns, defined in the EML language, the event monitoring system discovers the occurrence of critical conditions, thence to transmit the discovered alerts to the alerting and

notification system so as to send the reports to the subscribed users. The SES monitors the data relevant to the sensor existing in the Aghdasiyeh region called "Aghdasiye". If the sensor's observations exceed the threshold, which in this case is 20 PPM, the sensor will issue an alert through the communication port, introduced to the filter. A mechanism to monitor the considered ports permanently has been introduced to the system. It issues the alert to the alerting and information service with respect to its type. The service then communicates with the user through the communication method, defined by them and notifies them of occurrence of critical conditions in a real-time manner.

## RESULTS AND DISCUSSION

With respect to the role of visualization to render the events more tangible and facilitating decision-making in the implemented system, a mechanism has been introduced to produce and present temporal diagrams for several sensors' observations. It triggers the sensors' observations in the time interval, defined by the user, appear in the form of time series. After fitting a regression, users are provided with these observations in the form of a diagram, as shown in Figure 6.



**Fig. 6. Time series diagram for sensors' observations along with the fitted regression**

Also, the user in this system can receive several observations of a set of sensors in the considered time interval at a specific point, as shown in Figure 7.

One of the problems, raised while working with sensors' observations is their remarkable number. In order to increase system efficiency, the observation data should be generalized in a way to remove the redundant ones. For this purpose, a mechanism has been designed in the system that generalizes sensor's observations and summarizes inquiries' results, presenting them to the users via the

douglas-peucker algorithm (Skopeliti and Tsoulos 2001). A user is able to retrieve the results by applying the algorithm, which happens simultaneously with data retrieval to the observations, in the forms of O&M interfaces or time-series diagram. Thus, the processing efficiency for charts and thematic maps and retrieving will increase, because the redundant data will be eliminated. Figure 8-a shows an example of these observations without generalization, and Figure 8-b the same observations by applying the noted algorithm.

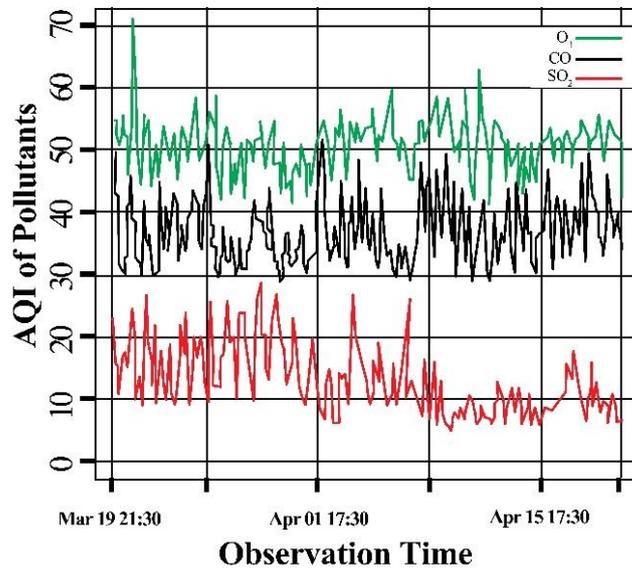


Fig. 7. Time series diagram for several sensors' observations in a specific point

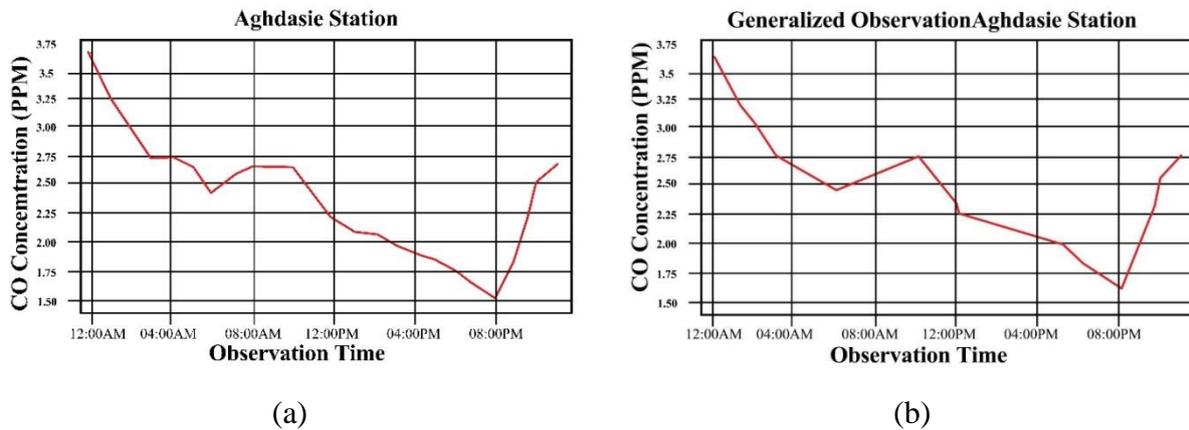
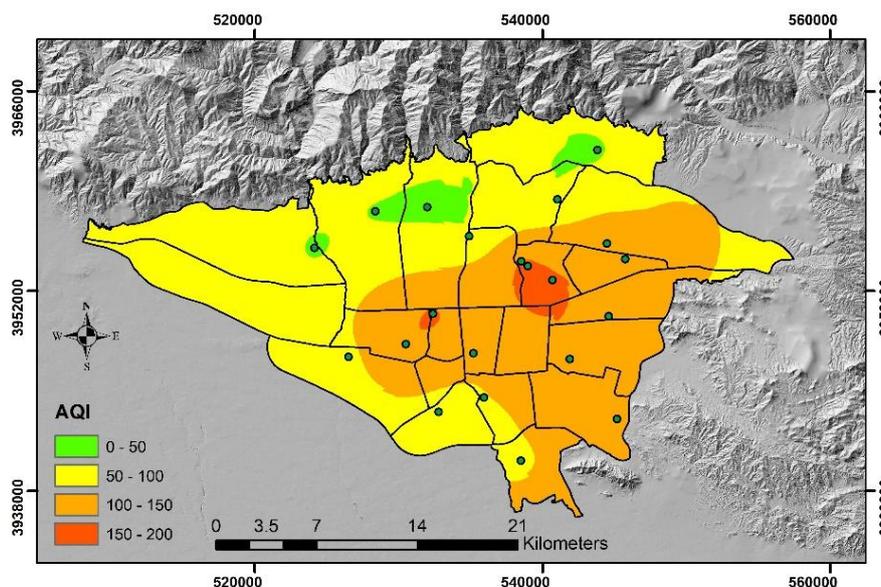


Fig. 8. Diagram of the retrieved data. a) without generalization b) with generalization

One of the major problems with the assessment of pollution conditions in a region is the impossibility of sampling all points. In order to address this issue, it is recommended to adopt a suitable strategy to generalize the results, obtained from the measured points to the others. One of the strategies to spatially analyze environmental geochemical data is to interpolation methods which study the spatial distribution pattern of the data and generate the desired maps (Lorkowski and Brinkhoff 2015a, b; Resch et al. 2015). In the present research, geo-statistics made it possible to estimate and generate quantitative maps for pollution distribution, while describing the pattern of spatial and temporal changes for the data. In order to select a suitable geo-statistics method for this research, part of the available data has

been used as checking data, with RMSE calculation performed for two Kriging and IDW models and a comparison of RMSE values turning into the basis of the work. Based on higher accuracy of RMSE value for Kriging method, this method has been used as a geo-statistical method to generate maps. Given that in the Kriging method, the estimations are based on the spatial structure, present in the environment in question and the estimation accuracy is high, this interpolation method has been applied for observations, as shown in Figure 9, below. Such valuable information helps the city manager optimize their traffic limitations and make other useful decisions in time and location to reduce the harmful effects of air pollution and, at the same time, decrease the cost of traffic limitations.



**Fig. 9. Interpolated map of sensors observations**

Finally, it should be stated that the importance of using this opportunity for recent decades is undeniable, which could be evidenced by some recent researches. An and Yu (2018) mentioned that it is a national preference to reduce air pollution in big cities, making it a performance assessment index for the provincial government. Tang et al. (2018), based on an

analysis between AQI and cardiovascular and respiratory diseases, revealed a meaningful correlation, claiming that it was not coincidental and had to be generalized to other regions. Slovic and Ribeiro (2018) evaluated the results from plans and policies of air pollution reduction of fifteen years in Sao Paulo, New York, and Paris. They concluded that although these cities

temporarily benefited from established regulations, their laws were not adequate for them to meet WHO air pollution recommended standards. In another research, Johnson et al. (2017), mentioned that sometimes new solutions, especially independent ones, have different impacts. While an individual air quality measure facility enables people to know about the local air quality, it simultaneously can weaken the provincial's control of information. Similar approaches can be a basis for collaborative act and pressurize administrations to improve the accuracy and precision of their collected air quality data. But their evidence were suggestive of public doubt about the performance of individualized solutions to control air pollution, without a significant pervasive and preventive alternative, which is optimistically a temporary expedient. And Sammarco et al. (2017) assessed the use of geosocial search for urban air pollution monitoring. They stated the implementation of a pervasive air pollution monitoring network would be too expensive and impossible, even though the costs of its technologies were decreasing. The integrated measured data to available air pollution monitoring networks usually cannot have a suitable cover for major cities and their suburbs. Of course such a system has some limitations and sensitivities such as a number of geosensors and their performance, Internet network performance, users' net access, etc. These findings confirm the need and application of such a pervasive and real-time air pollution monitoring network in cities like Tehran.

## CONCLUSION

With respect to the nature of environmental phenomena, it is unavoidable to make use of geosensors for environmental monitoring and processing, for instance for air pollution. Also, considering the need for data and sensors' real-time observations to manage the phenomenon better on

critical occasions, it is necessary for the sensors' data to be provided to urban managers and users via the idea of a sensor web. Due to sensors' heterogeneity as well as different formats of responsible organizations for their observations, on the other hand, it seems necessary to set up interoperability in this infrastructure. Hence, the present research used standard frameworks to overcome the issue of lack of interoperability, using SID and other standards. With respect to the role of OGC in providing spatial standards, the best solution is to utilize sensor web enablement framework. This system can provide all of the required information to managers in hazardous situations. Also, provided that it functions well, it can add any other sensor, needed for the system, in a matter of few seconds. Results show that a lot of information given to the decision-makers enables them to make more effective decisions in any situation, like traffic limitations, warning vulnerable people about hazardous time and location, and keeping public health safer. Based on the recommended system's framework, a prototype system has been designed, implemented, and tested for Tehran city. It needs a special hardware infrastructure to work perpetually online, which for the entire city, has been proposed to be established in future.

## ACKNOWLEDGEMENTS

We are appreciating Eng. Mohsen Saber and Eng. Maryam Talebidaloui for their collaboration in editing this manuscript. Also, we are thankful to Tehran Air Quality Control Center for providing our case study data.

## GRANT SUPPORT DETAILS

The present research did not receive any financial support.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of

this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## **LIFE SCIENCE REPORTING**

No life science threat was practiced in this research.

## **REFERENCE**

Abbaspour, M. and Soltaninejad, A. (2004). Design of an environmental assessment model on the effect of vehicle emission in greater Tehran on air pollution with economic sensitivity. *Int. J. Environ. Sci. Tech.*, 1(1), 27-38.

Alesheikh, A.A., Oskouei, A.K., Atabi, F. and Helali, H. (2005). Providing interoperability for air quality in-situ sensors observations using GML technology. *Int. J. Environ. Sci. Tech.*, 2(2), 133-140.

Akbari, M. and Samadzadegan, F. (2015). Identification of air pollution patterns using a modified fuzzy co-occurrence pattern mining method. *Int. J. Environ. Sci. Tech.*, 12(11), 3551-3562.

An, R. and Yu, H. (2018). Impact of ambient fine particulate matter air pollution on health behaviors: a longitudinal study of university students in Beijing, China. *Public health*, 159, 107-115.

Botts, M., Percivall, G., Reed, C. and Davidson, J. (2006). OGC® sensor web enablement: Overview and high level architecture. *International conference on GeoSensor Networks*, 175-190.

Botts, M. and Robin, A. (2007). OpenGIS sensor model language (SensorML) implementation specification. *OpenGIS Implementation Specification OGC*, 7(000).

Boulos, M.N.K., Resch, B., Crowley, D.N., Breslin, J.G., Sohn, G., Burtner, R., ... and Chuang, K.Y.S. (2011). Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. *Int. J. Health Geogr.*, 10(1), 67.

Broering, A., Below, S. and Foerster, T. (2010). Declarative sensor interface descriptors for the sensor web. *Proceedings of the WebMGS*.

Bröring, A., Remke, A., Stasch, C., Autermann, C., Rieke, M. and Möllers, J. (2015). enviroCar: A Citizen Science Platform for Analyzing and Mapping Crowd-Sourced Car Sensor Data. *Trans. GIS*, 19(3), 362-376.

Chen, N., Wang, K., Xiao, C. and Gong, J. (2014). A heterogeneous sensor web node meta-model for the management of a flood monitoring system. *Environ. Modell. Softw.*, 54, 222-237.

Degrossi, L.C., Do Amaral, G.G., De Vasconcelos, E.S., de Albuquerque, J.P. and Ueyama, J. (2013). Using wireless sensor networks in the sensor web for flood monitoring in Brazil. In *ISCRAM*.

Delavar, M. R., Gholami, A., Shiran, G. R., Rashidi, Y., Nakhaeizadeh, G. R., Fedra, K. and Hatefi Afshar, S. (2019). A novel method for improving air pollution prediction based on machine learning approaches: a case study applied to the capital city of Tehran. *ISPRS Int. J. Geo-Inf.*, 8(2), 99.

Delin, K.A. and Jackson, S.P. (2001). Sensor web: a new instrument concept. *Functional Integration of Opto-Electro-Mechanical Devices and Systems*, 4284,1-10.

Echterhoff, J. and Everding, T. (2008). OpenGIS sensor event service interface specification. *Open Geospatial Consortium Inc., USA, OpenGIS Discussion Paper, OGC*, 08-133.

Everding, T. and Echterhoff, J. (2008). Event pattern markup language (EML).

Foerster, T., Jirka, S., Stasch, C., Pross, B., Everding, T., Bröring, A. and Jürrens, E.H. (2010). Integrating human observations and sensor observations—the example of a noise mapping community. In *Proceedings of Towards Digital Earth Workshop at Future Internet Symposium 2010*.

Gong, J., Geng, J. and Chen, Z. (2015). Real-time GIS data model and sensor web service platform for environmental data management. *Int. J. Health Geogr.*, 14(1), 2.

Goodchild, M. F. (2007). Citizens as sensors: the world of volunteered geography. *GeoJournal*, 69(4), 211-221.

Henneböhl, K., Gerharz, L.E. and Pebesma, E. J. (2009). An OGC web service architecture for near real-time interpolation of air quality over Europe. *Proceedings of StatGIS 2009*, Milos, Greece, G. Dubois (Ed.).

Horita, F.E., de Albuquerque, J.P., Degrossi, L.C., Mendiondo, E.M. and Ueyama, J. (2015). Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks. *Comput. and Geosci.*, 80, 84-94.

- Hu, L., Yue, P., Zhang, M., Gong, J., Jiang, L. and Zhang, X. (2015). Task-oriented Sensor Web data processing for environmental monitoring. *Earth Sci. Inform.*, 8(3), 511-525.
- Jaafari, S., Shabani, A.A., Moeinaddini, M., Danehkar, A. and Sakieh, Y. (2020). Applying landscape metrics and structural equation modeling to predict the effect of urban green space on air pollution and respiratory mortality in Tehran. *Environ. Monit. Assess.*, 192(7), 412-412.
- Jiang, Y., Dou, J., Guo, Z. and Hu, K. (2015). Research of marine sensor web based on SOA and EDA. *J. Ocean. U. China*, 14(2), 261-268.
- Jirka, S., Bröring, A. and Stasch, C. (2009, June). Applying OGC Sensor Web Enablement to risk monitoring and disaster management. In *GSDI 11 world conference*, Rotterdam, Netherlands.
- Johnson, T., Mol, A.P., Zhang, L. and Yang, S. (2017). Living under the dome: Individual strategies against air pollution in Beijing. *Habitat Int.*, 59, 110-117.
- Jung, Y.J., Lee, J.R., Cho, K., Leeb, D.G., Leeb, Y. K., Lee, Y. and Beard, K. (2013). Event Processing in Air Pollution Monitoring Application. *Inf. Eng. Lett.*, 3(1), 88.
- Khedo, K.K., Perseedoss, R. and Mungur, A. (2010). A wireless sensor network air pollution monitoring system. *arXiv preprint arXiv:1005.1737*.
- Kotsev, A., Pantisano, F., Schade, S. and Jirka, S. (2015). Architecture of a service-enabled sensing platform for the environment. *Sensors*, 15(2), 4470-4495.
- Kumar, R., Mukherjee, A. and Singh, V.P. (2017). Traffic noise mapping of Indian roads through smartphone user community participation. *Environ. Monit. Assess.*, 189(1), 17.
- Lorkowski, P. and Brinkhoff, T. (2015a). Environmental Monitoring of Continuous Phenomena by Sensor Data Streams: A System Approach Based on Kriging. In *EnviroInfo and ICT for Sustainability 2015*. Atlantis Press.
- Lorkowski, P. and Brinkhoff, T. (2015b). Towards Real-Time Processing of Massive Spatio-temporally Distributed Sensor Data: A Sequential Strategy Based on Kriging. In *AGILE 2015*, 145-163. Springer, Cham.
- Markovic, N., Stanimirovic, A. and Stoimenov, L. (2009). Sensor web for river water pollution monitoring and alert system. In *12th AGILE International Conference on Geographic Information Science "Advances in GIScience"*, Hannover, Germany, 2073-8013.
- Na, A. and Priest, M. (2007). Sensor observation service. *Implementation Standard OGC*, 21.
- Pirotti, F., Guarnieri, A. and Vettore, A. (2011). Collaborative Web-GIS design: A case study for road risk analysis and monitoring. *Trans. GIS*, 15(2), 213-226.
- Pummakarnchana, O., Tripathi, N. and Dutta, J. (2005). Air pollution monitoring and GIS modeling: a new use of nanotechnology based solid state gas sensors. *Sci. Technol. Adv. Mat.*, 6(3-4), 251.
- Resch, B., Britter, R., Outram, C., Chen, X. and Ratti, C. (2011). Standardised geo-sensor webs for integrated urban air quality monitoring. In *Environmental Monitoring. InTech*.
- Resch, B., Sudmanns, M., Sagl, G., Summa, A., Zeile, P. and Exner, J. P. (2015). Crowdsourcing physiological conditions and subjective emotions by coupling technical and human mobile sensors. *GI\_Forum*, 1, 514-524.
- Sammarco, M., Tse, R., Pau, G. and Marfia, G. (2017). Using geosocial search for urban air pollution monitoring. *Pervasive Mob. Comput.*, 35, 15-31.
- Saukh, O., Hasenfratz, D., Noori, A., Ulrich, T. and Thiele, L. (2012). Demo Abstract: Route Selection of Mobile Sensors for Air Quality Monitoring. *EWSN 2012*, 10.
- Shafi, S., Reshi, A.A. and Kumaravel, A. (2014). Wireless sensor network based early warning and alert system for radioactive radiation leakage. *Middle-East J. Scient. Res*, 19(12), 1602-1608.
- Simonis, I. and Wytzisk, A. (2003). Web notification service. *Open GIS Consortium Inc*.
- Skopeliti, A. and Tsoulos, L. (2001). A knowledge based approach for the generalization of linear features. In *Proceedings of 20th International Cartography Conference*, 1-10.
- Slovic, A.D. and Ribeiro, H. (2018). Policy instruments surrounding urban air quality: The cases of São Paulo, New York City and Paris. *Environ. Sci. Policy*, 81, 1-9.
- Stasch, C., Foerster, T., Autermann, C. and Pebesma, E. (2012). Spatio-temporal aggregation of European air quality observations in the Sensor Web. *Comput. and Geosci.*, 47, 111-118.
- Tang, S., Yan, Q., Shi, W., Wang, X., Sun, X., Yu, P. ... and Xiao, Y. (2018). Measuring the impact of air pollution on respiratory infection risk in China. *Environ. Pollut.*, 232, 477-486.
- WHO .( 2019). Urban outdoor air pollution database. Geneva, Switzerland, Department of

Public Health and Environment, World Health Organization; 2018. <http://www.who.int/phe>

Wiemann, S., Brauner, J., Karrasch, P., Henzen, D. and Bernard, L. (2016). Design and prototype of an interoperable online air quality information system. *Environ. Modell. Softw.*, 79, 354-366.

Yousefian, F., Faridi, S., Azimi, F., Aghaei, M., Shamsipour, M., Yaghmaeian, K., & Hassanvand, M. S. (2020). Temporal variations of ambient air pollutants and meteorological influences on their concentrations in Tehran during 2012–2017. *Sci. Rep.*, 10(1), 1-11.

Yue, P., Zhang, C., Zhang, M. and Jiang, L. (2014). Sensor Web event detection and geoprocessing over

Big data. In *Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International* (pp. 1401-1404). IEEE.

Yue, P., Zhang, C., Zhang, M., Zhai, X. and Jiang, L. (2015). An SDI approach for big data analytics: The case on sensor web event detection and geoprocessing workflow. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, 8(10), 4720-4728.

Zheng, Y., Liu, F. and Hsieh, H. P. (2013). U-Air: When urban air quality inference meets big data. In *Proceedings of the 19th ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 1436-1444). ACM.

