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REAL-TIME FORECASTING METHOD OF URBAN AIR QUALITY BASED ON OBSERVATION SITES AND THIESSEN POLYGONS

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Abstract- This paper proposes a real-time urban air quality forecasting method based on monitoring sites and Thiessen polygon. Firstly, the concentration of pollutants affecting air quality is obtained through the real-time observations of the monitoring sites deployed in wireless sensor network, according to which the air quality index (AQI) can be calculated and air quality levels and categories can be graded. Then, Thiessen polygons are constructed based on the monitoring sites and the air quality conditions from the only site within any polygon will be the representative to that of any other points within this polygon. Finally, the monitoring sites and Thiessen polygons rendered with standard air quality colors will be visualized on a geographical map for the realization of real-time forecasting method taking Thiessen polygons as forecasting units. Taking Shanghai city as an example, a real-time and visualized air quality prediction platform has been constructed in downtown Shanghai city, the real-time visualization of urban air quality forecasting and early warnings under the constraints of Thiessen polygon have been realized.

Index terms*:* Thiessen polygons, air quality, air quality index, PM2.5, real-time forecasting.

I. INTRODUCTION

In recent years, with the accelerating process of urbanization and the great increase of urban population density, the impact of human activities on the urban environment becomes more and more obvious. Vehicle exhaust and dense smoke from factory chimneys directly results in the decrease of the urban air quality. The problem of urban air pollution is getting more and more attention from the government and the public and people urgently need to timely know the status of air quality around to minimize the effects of air pollution on health. In view of this, many scholars carried out in-depth researches in urban air quality forecasting and monitoring . Liu, et al (2012) proposes an urban air quality monitoring system[1] deployed to the main roads in the Taipei city to monitor the carbon monoxide (CO) concentration caused by vehicle emissions based on the technology of wireless sensor networks (WSNs) [2], which is also integrate with the global system for mobile communications (GSM). Based on enormous amount of atmospheric environment parameters and field testing materials, Du, et al (2002) carried out the research of air quality numerical forecast model and realized the numerical air prediction in Ji'nan City based on the model[3]; With the third-generation air quality model(Models-3) released by USA Environmental Protection Administration, Zhang, et al (2004) carried out the simulation study of tropospheric ozone value in East Asia[4]; Chelani and Devotta (2006) develop a hybrid methodology that can deal with both the linear and nonlinear structure of the time series, the exploitation of unique features of linear and nonlinear models makes it a powerful technique to predict the air pollutant concentrations[5]. Using MM5/CMAQ model, Zhang, et al (2010) simulated the effects on air quality in Shanghai city that were caused by the transmission and extension of atmospheric pollutants in Yangtze River Delta region and developed quantitative study of the contributions of transports in local source and external source region made to the air quality in Shanghai city[6]; Pradeepta, et al (2010) used air quality index (AQI) to represent the air quality status of India Choudwa area and analyzed the air pollutants sources in the area[7];Based on the products of CMAQ and multi-class predictors, Chen, et al (2012) established a prediction model that reported daily pollutant concentration and developed a study about the air quality forecasting system in Fuzhou city[8];Wang, et al (2012) conduct air quality and haze weather forecast for Yangtze River Delta region, and a new classification standard on haze level was proposed, which take the key parameters such as relative humidity, PM2.5 and visibility into account and get better performance on air quality and haze weather prediction[9];Hand, et al(2013) carried out the research of spatial and temporal trends in PM2.5 Organic and Elemental Carbon across the United States[10]; A simple optimized method based on the meteorological similarity criteria and the traditional BP neural network was proposed by Lu, et al (2013) and Applications of this model to forecasting air quality with respect to SO2,NO2 and PM10/2.5 in eight monitoring stations of Guangzhou City was given[11]; Qin, et al(2014) using hybrid models to forecasting the particulate matter (PM) concentration levels over four major cities of China[12]; Georgianagomir and Oprea(2014) presents the use of some nonlinear modeling methods for air quality forecasting to reduce air pollutants' effects on human health[13]; Chen , et al(2014) using CMAQ model to design effective emissions control strategies for regulatory applications about primary PM 2.5 in California's San Joaquin Valley[14]. Djalalova, et al (2015) described a new post-processing method for surface particulate matter (PM2.5) predictions from the National Oceanic and Atmospheric Administration (NOAA) developmental air quality forecasting system using the Community Multiscale Air Quality (CMAQ) model[15].In general, there are two main types of the existing prediction methods, one of which is based on the prediction model of quantitative numerical forecast. Although the forecast method is a developing trend of air quality forecast in the future, at present the numerical forecasting method of business can not meet the public requirement of daily air quality forecast. The other one based on the monitoring sites is called the qualitative quality forecast. It usually takes administrative regions as prediction units to deploy within the administrative area with the site monitoring results as forecasting basis to carry out the forecast, contending that the monitoring results of monitoring sites deployed in the administrative areas can reflect the air quality of the entire administrative areas. This forecast method is the current mainstream method of air quality forecast exposed to the public. However, the administrative regionalization is a humane geographical element, whose division is artificial, and air pollutants can not cut off by the administrative regionalization. On the whole, the diffusion of atmospheric dust is of the characteristics affected by wind speed and continuous mobility of direction control, and the correlation of air pollution degree between two points is inversely proportional to the distance between them. Therefore, the air quality forecast method based on the administrative regionalization has shown its disadvantage obviously. It is necessary to study and employ the regional air quality forecast method which takes observation station as the center and takes into account the spatial proximity. Thiessen polygons was put forward by the Dutch climatologist A.H.Thiessen in 1908s and originally applied to the prediction of rainfall, and was a kind of

Spatial statistical analysis which predicts the frequency of occurrence in adjacent areas according to the certain phenomenon results of observation sites[16]. It was then widely applied in the fields of climate, agriculture, environment[17], etc. In this paper, the Thiessen polygons algorithm is introduced to the real-time forecast of urban air quality, and the focus is put on the study of the real-time forecast method of urban air quality based on monitoring sites and Thiessen polygons, thus to guarantee the method is applied to the real-time forecasting and warning of air quality in Shanghai city.

II. THIESSEN POLYGONS

The basic idea of the Thiessen polygons is that the best value of unknown point is determined by the nearest sample point. Thiessen polygons are constructed entirely following the distribution of the data points. If the data point is distributed like a regular square, Thiessen polygons is equal to the grid-sized square; if the data point distribution is irregular, Thiessen polygons will be the irregular-shaped convex polygons that are constructed by Thiessen polygons generation algorithm[18] (Fig.1). From the perspective of geometry, taking point O as the "core" of Thiessen polygons, the value of any point (Such as point A in Fig.1) is:

$$V(A) = V(O) * f(d)$$

In the formula above: V (O) is a certain attribute value of O points, Such as the concentration of PM2.5; V(A) is the mutual attribute value of point A and point O; f (d) is a function symbolizing the distance between OA. In general, suppose f (d) =1, that is: V (A) =V (O). That is to say, the Thiessen polygons are isosurfaces based on the "core" values. Therefore, Thiessen polygons can be dynamically generated according to the number and spatial distribution of data points, among which each data point is contained in the unique polygon block, and the distance from any point to the data points can be the shortest, thus to ensure that the data point is the optimally estimated location of their Thiessen polygons area. With regards to the prediction of regional air quality grounded on the monitoring results of monitoring stations, monitoring site structure based on the Thiessen polygons, again with the Thiessen polygons area for air quality forecast unit is obviously more reasonable compared with the method taking administrative unit as the prediction unit.

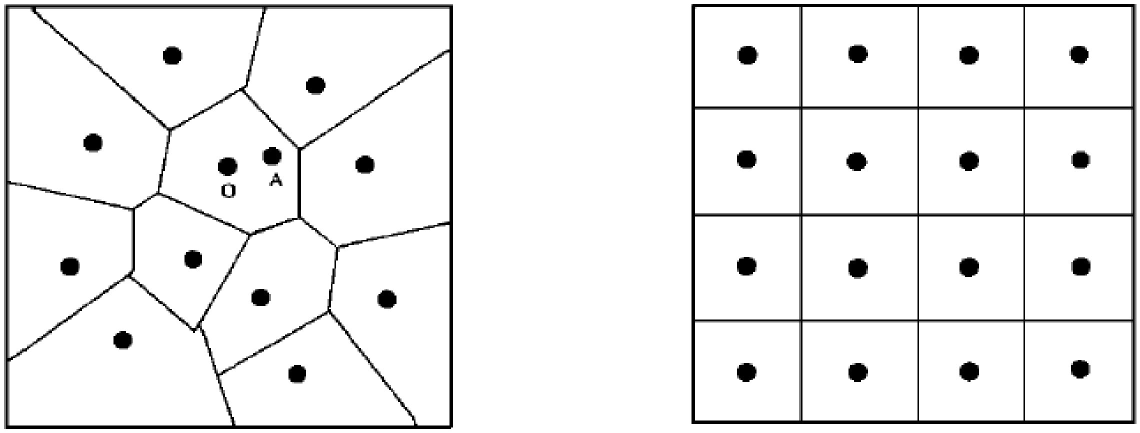

Figure 1. Schematic diagram of Thiessen polygons [18]

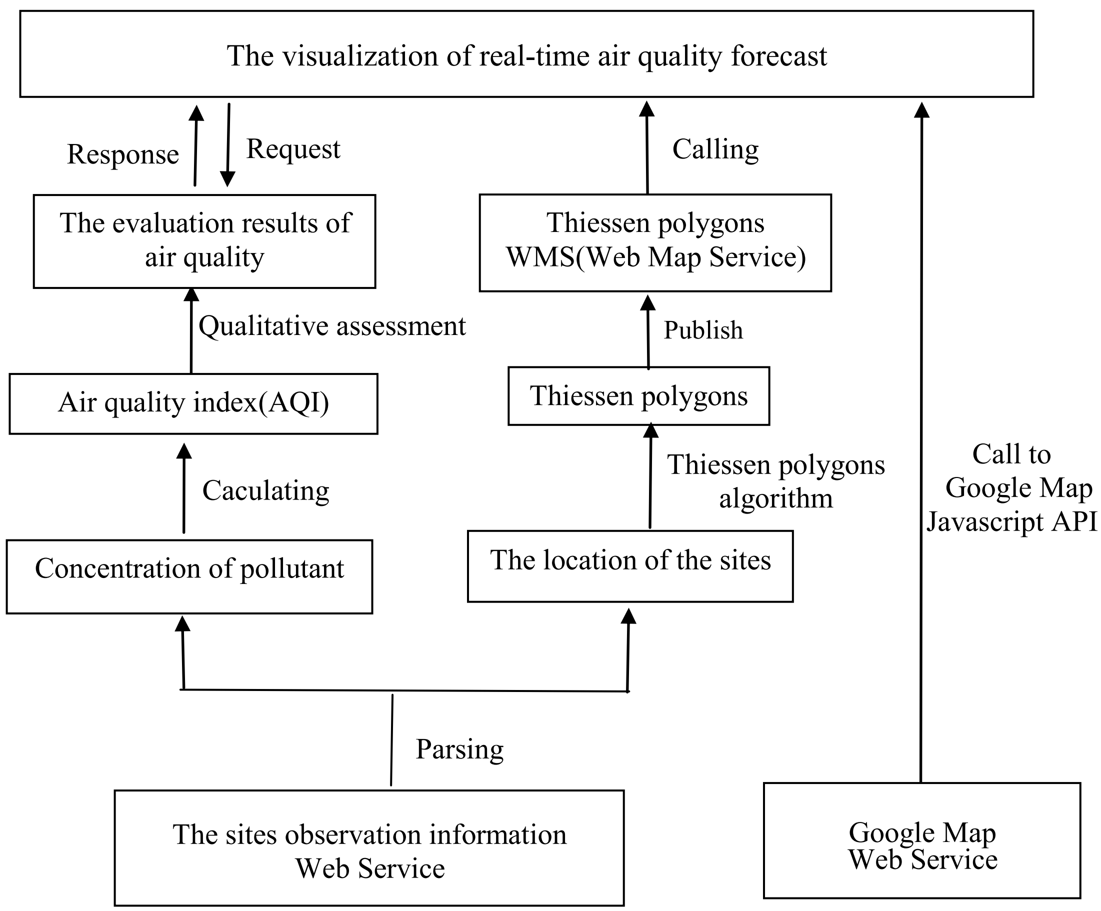

Figure 2. The implementation scheme of real-time urban air quality forecasting under the constraints of Thiessen polygons

III. METHODS AND IMPLEMENTATION

The real-time air quality information in this method comes from the real-time observing of the observation sites, and the control area by each site depends on the only Thiessen polygon containing the site. First of all, to get access to the location information of monitoring sites and real-time monitoring data of pollutants; Then, to construct Thiessen polygons according to location information of the site and to calculate the air quality index based on the real-time pollutant monitoring data, such as PM2.5, PM10, CO, NO2, O3 concentration, etc, and to obtain air quality assessment results based on the national ambient air quality standards， besides, take the formed Thiessen polygons published as WMS through ArcGIS Server, furthermore, to associate Thiessen polygons with evaluation results; And finally, to visualize the sites, Thiessen polygons, real-time air quality evaluation results in the client, achieving the visualization of real-time air quality forecasting constrainted by Thiessen polygons and realizing request/response style interaction between user and client (Fig.2).

a. Sensor and Data Sources

Air quality monitoring data required for this study from each node of the state-controlled air quality monitoring sensor networks constructed by Chinese government. The sensors on the network nodes are deployed in the central city of the large and medium-sized cities, in order to ensure the monitoring data is representative, and to characterize the overall air condition monitoring area. In addition to try to ensure the uniformity of monitoring site in space, the site is usually deployed in a relatively open, non traffic hub, which is far from the air pollution source. Each monitoring sites were used in line with international standards of high quality, high precision automatic air quality monitoring instrument (Fig.3), and also the monitoring instrument uses the oscillating microbalance and β-ray absorption technology, using the cutting principle in atmospheric PM2.5 in the sample. First of all, sensors installed on the monitoring instrument (probe) breathe air samples into the top of the container, then filtering through the first layer at the top of the instrument, the air particles are separated, larger than 10 microns in diameter less than 10 microns are imported sample tube, PM10 samples is completed; Moreover, the secondary filtration and separation of particles larger than 2.5 microns, less than 10 microns in diameter, from particulate matter less than 2.5 microns in diameter, complete PM2.5 sampling.

Currently, the public can not request directly to each node state-controlled air quality monitoring sensor network for monitoring data, but as a window of external services, these sites and real-time monitoring data are published to the Web Service form on the Web. By parsing the data come from these Web Service, the public can get real-time and historical data on air quality data (Table 1). In this paper, the air quality data come from the Web Service.

Figure 3. Air quality monitoring instrument deployed on sensor network nodes

Table1. The data contained in Web Service published by air quality monitoring sensor network

AQI	Area	Pm2_5	Pm10	Position _name	No2	CO	O3	Station _code	Time_point
43	Beijing	35	35	HaiD-S	25	0.6	37	1007A	2015-10-25T20:00:00Z
36	Beijing	48	57	HuaiL-S	17	1.2	40	1009A	2015-10-25T20:00:00Z
39	Beijing	35	39	ChangP-S	26	0.8	36	1010A	2015-10-25T20:00:00Z
29	Beijing	30	31	AoL-S	35	0.7	31	1011A	2015-10-25T20:00:00Z
56	Beijing	32	23	GuC-S	30	1.4	46	1012A	2015-10-25T20:00:00Z
67	Shanghai	48	49	HongK-S	36	1.7	27	1143A	2015-10-25T20:00:00Z
52	Shanghai	36	45	XuH-S	40	0.9	33	1144A	2015-10-25T20:00:00Z
48	Shanghai	30	35	YangP-S	54	1.1	42	1145A	2015-10-25T20:00:00Z
63	Shanghai	42	48	QingP-S	35	0.7	36	1146A	2015-10-25T20:00:00Z
...	...	...	...	...	...	...	...	...	...

b. Site information parsing

Monitoring data from each air quality monitoring sensor network node are released to the public in the form of Web Service. Web Service is a platform independent, loosely coupled, self-contained web application, the overall or part of the data of which can be obtained by using conventional data analysis methods[19][20]. This paper first reads the quasi real-time air quality data asynchronously through the AJAX (Asynchronous JavaScript and XML) technology[21], and then returns a JSON (JavaScript Object Notation) [22]format data request response via the HTTP form. In JSON format data, multiple objects are enclosed in symbol "[]"(Fig.4), and each object contains multiple attributes(such as AQI, area, pm2_5, pm10, no2, o3, position_name, station_code, time_point, etc.). Through the JAVA programming language, the useful data of json document can be selectively parsed out to get the site location and real-time monitoring data related to environmental quality.The json parsing project based on JAVA programming language can briefly described as follow, First of all, the server converts the data source into a json string, and then, the client convert json string to the corresponding javaBean, Finally, obtain the javaBean and jsonObject.

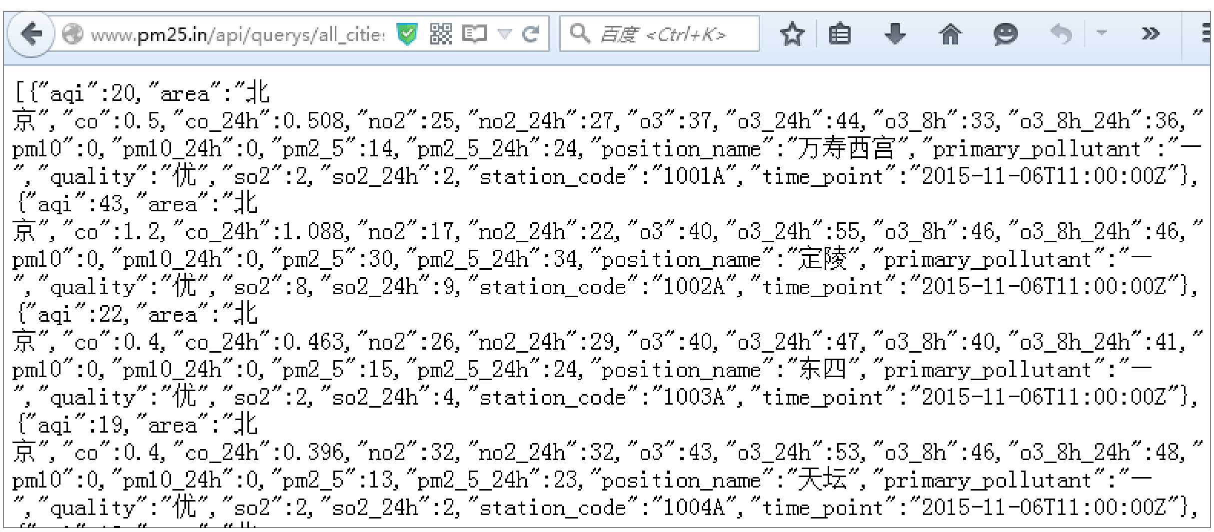

Figure 4. The air quality JSON data of Site information

c.Site air quality assessment

The "ambient air quality monitoring standards" issued by the State Environmental Protection Administration illustrates the index calculation methods of ambient air quality and air quality grading standards (Table 2) [23, 24]. First of all, to calculate the Air Quality Index (AQI) according to the calculation method and pollutant concentrations parsed out, and then to give a qualitative evaluation of each site according to the criteria for the classification in Table 2.

Table 2: Air quality classification and the corresponding color code [23]

Air Quality Index(AQI)	Level	Category	Color	Color code
0-50	Ⅰ	Good	Green	
51-100	Ⅱ	Moderate	Yellow	
101-150	Ⅲ	Lightly Polluted	Orange	
151-200	Ⅳ	Moderately Polluted	Red	
201-300	Ⅴ	Heavily Polluted	Purple	
>300	Ⅵ	Severely Pollution	Maroon	

Some Web Service of monitoring sites have included the value of Air Quality Index (AQI) , which ensures that the AQI value can be parsed out directly, and real-time air quality levels and categories can be obtained according to Table 2.

d. The generation of Thiessen polygons

Currently, the generation method of Thiessen polygons in Two-dimensional point set can be broadly divided into two categories: direct and indirect methods[25][26].The direct method , first , is to calculate the Minimum Bounding Rectangular(MBR) based on all non repeated points set, In far away from the points set of the corners of the MBR added four additional points , And then the triangle net is converted into Thiessen polygons after triangulation.The indirect method opposed to this, first to making the plane point set with triangular subdivision and then generating Thiessen polygons by triangle after subdivision. In this paper, we use the indirect method because the indirect method has the characteristics of fast generating speed, easy to implement, etc. First of all, the site locations that are parsed are mapped to a projected coordinate system of the plane (in Fig.5 points P1, P2,...) and then the sites are connected to constitute a triangle mesh, to the greatest extent to be acute triangle, which refers to the connection to the recent site (the dotted line in Fig.5); Then, the perpendicular bisectors are drawn respectively on each edge of triangles, and the points of intersection of bisectors constitute the vertex of a polygon, while bisectors constitute each side of the polygon (Fig.5, solid lines).Such polygons are characterized by each polygon with the unique site and the distance from any point to the internal site being shorter than that from any point to any other site, and the polygons generated are called site Thiessen polygons.

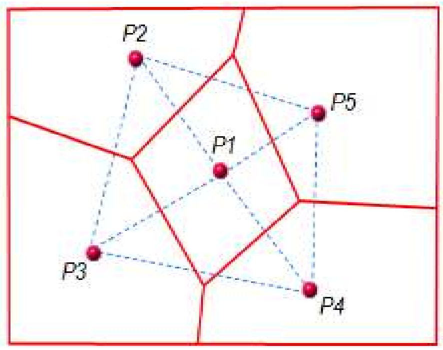

Figure 5. Generated Thiessen polygons based on the monitoring site location (The solid line is configured to generate Thiessen polygons and rectangle represents the monitoring area boundary)

e.Thiessen polygons WMS

The OpenGIS Web Map Service Interface Standard (WMS) provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases[27]. A WMS request defines the geographic layer(s) and area of interest to be processed. Besides, A Web Map Service (WMS) produces maps of spatially referenced data dynamically from geographic information. This International Standard defines a “map” to be a portrayal of geographic information as a digital image file suitable for display on a computer screen. The interface also supports the ability to specify whether the returned images should be transparent so that layers from multiple servers can be combined or not.

WMS uses a map that has the location information of the geographic space, which is defined as the performance of the geographic data. Maps are usually expressed in image format, such as PNG, GIF, or JPEG, which are sometimes expressed as vector graphics, such as SVG (scalable vector graphics) or (WebCGM). According to the OGC specification, the map service is a service that provides the shared map data. It is responsible for providing the map image, the essential information of the specified coordinates, and the function of the map service.

In this paper, First, the system analyzes the location information of Web service of the state-controlled air quality monitoring sensors in Shanghai city. Then according to OGC WMS specification, deployed the WMS into local Server, and uses ArcGIS Thiessen Polygon tool to create Thiessen polygons based on site location and Shanghai administrative boundaries[28]. At last, using ArcGIS Server, the Thiessen polygons will be published as WMS. If there are any new sites available, it repeats the above process and updates Thiessen Polygons to ensure that the site matches Thiessen Polygons. Figure 6 theoretically demonstrates the generation process of Thiessen polygon WMS.

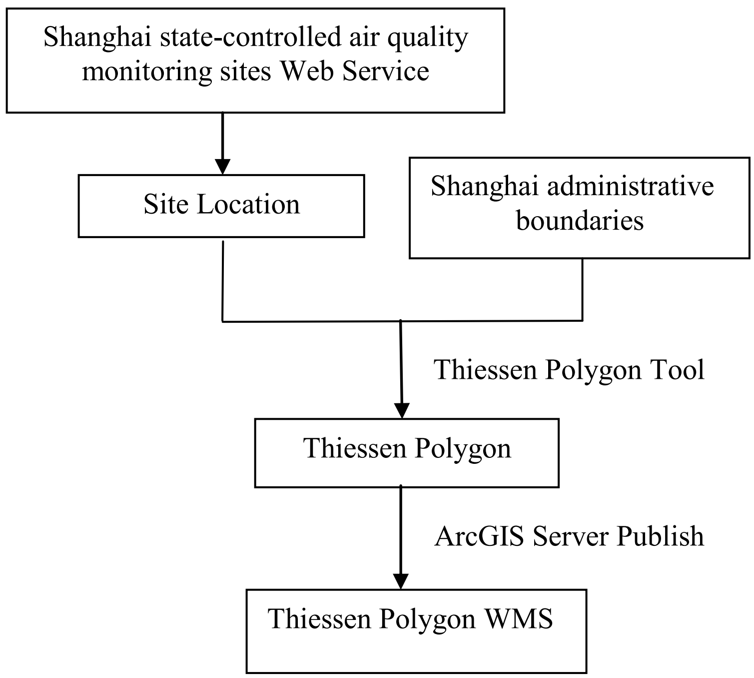

Figure 6. Thiessen polygons WMS generation process

f. Real-time visualization of air quality forecast

It uses Html and JSP technology in the visualization of static and dynamic Web pages and calls Google Map JavaScript API to obtain the basic geographic information and visualizes them. Through sending Http requests and calling the Getmap service, It loads JS files and Thiessen polygon WMS layer on the Web page, positions the observation sites, demonstrates corresponding observational properties on the map and visualizes the display according to the spatial location of observation sites to make sure that Thiessen polygons and observation properties will all be displayed on the client page at the same time. Besides, Characteristics of the

Thiessen polygons determine the best estimation of real-time air quality level represented by the real-time air quality grade of the unique site in Thiessen polygons. To associate the real-time air quality evaluation results in section b with the corresponding Theissen polygon, and load the site location and Theissen polygon into the geographical map with the spatial reference, then add labels to show site air quality and other monitoring attributes at each site location, finally, color the Thiessen polygon following the standard color code in Table 2 so as to implement real time visualization of air quality forecast.

IV. APPLICATION

The real-time visualization prediction of ambient air quality in the downtown area of Shanghai can be carried out based on the method proposed in this paper. At present, there are 10 state-controlled air quality monitoring stations distributed in the downtown area of Shanghai (Fig.7), respectively, HongK ST, PuD ST, JingA ST, SiP ST, ShangSD ST, PuDCS ST, ShiWC ST, PuDZJ ST, PuDXQ ST, DianSH ST, which are set to monitor the concentration of PM2.5 and PM10. These sites are under the unified management of the environmental department, and provide real-time data services in the form of Web Service. The public can get the access to the Web Service to obtain the monitoring results by parsing pollutants.

This paper sets up a Shanghai air quality forecast real-time visualization platform, which integrates the methods proposed in this paper and gets access to the Web Service in the 10 monitoring sites of Shanghai, thus realizing the real-time analysis of Web Service data. According to the statistics, the primary air pollutant in Shanghai city is PM2.5 which is closely related to human activities. In accordance with the calculation rules of the air quality index, the value of AQI is calculated mainly based on the PM2.5 concentration. In order to facilitate remote calls and timely update of Theissen polygon, the generated Theissen polygon based on sites (Fig.6) was released into the Web map service (WMS). the client achieve the client display by calling the WMS, and the update and maintenance of Theissen polygon can be completed in the background .when a new site is added, the automatic reconstruction of Theissen polygon will be realized.

Figure 7. Generated Thiessen polygons and the monitoring site location

Figure 8 and Figure 9 are the visual air quality forecasting and warning interface in different air quality state presented by Web client to the users. The figure shows the locations of each monitoring site. Icon pop-up by the click on the site displays the current PM2.5 concentration and air quality conditions as well as the Theissen polygon related to the site. The filled color in Theissen polygon is a demonstration of the air quality levels and categories in the area. The dynamic histogram at the bottom of the window is about the histogram of current concentration PM2.5 of 10 monitoring stations. The height column of the histogram represents the size of concentration, while the color column represents the air quality level. The top-right corner pointer of the dial indicates the current average concentration PM2.5 of 10 sites. By setting the warning threshold, the warning frame below the dial makes the air quality warning come true. When the air pollution reaches a certain level, the warning frame will pop out relevant tips.

Figure 8. Real-time air quality forecasting and warning interface (with haze pollution)

Figure 9. Real-time air quality forecasting and warning interface(without haze pollution)

V. CONCLUSIONS

With more and more public attention drawn to the air quality of the environment, China has incorporated the status of air quality into the daily weather forecast, but the current environment air quality forecast is usually about the average air quality status of all monitoring sites in the city, while the environmental air quality forecast in some large or medium-sized cities with many monitoring sites and sensors take secondary administrative unit within the city as forecast unit. With regard to the environmental air quality forecast in small areas, the accuracy and scientificity of these methods remains to be further improved. This paper puts forward a kind of urban air quality forecast method based on the monitoring sites and Thiessen polygons. Compared with the prediction method based on administrative unit, it is much more scientific and reasonable. It can ensure that the forecast achieves the optimal， when the monitoring sites and spatial distribution are at a certain situation. It should be pointed out that only if the monitoring sites deployed reflect the air quality of the whole area can the application of this method be realized. At present, the number of ambient air quality monitoring sites deployed in our country is still limited, and it can't meet the requirements of the prediction method of "point to surface" For example，there are currently only 10 state-controlled air quality monitoring stations in Shanghai central districts , far less than the number of sites required in "ambient air quality monitoring standards" , and the Thiessen polygons generated according to the 10 monitoring sites can not meet the needs of practical applications. The achievement of the real-time ambient air quality forecasting platform in Shanghai central city based on these 10 sites shows that the proposed method is reasonable and feasible, and it is not practical enough. But we believe that with the increase in the number of deployed monitoring sites, Thiessen polygons based on these sites will tend to be more even and reasonable , and the proposed approach will gradually achieve the practical level.

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