INTEGRATION OF GIS AND INTERNET OF THINGS (IOT) IN DISASTER MANAGEMENT OF SEVERE WEATHER CONDITIONS

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Abstract - The evolutionary approaches of information technology and the need for human comfort life lead to more demands for accurate weather forecasts at different spatial and temporal scales. This is also important in order to minimize the danger and damage that result from severe weather conditions. In this context, the application of emerging technologies for increasing the accuracy and skill of the weather alert calls for special attention. This paper aims to propose a GIS-based alerting system for severe weather conditions. The proposed systems integrate the Internet of Things (IoT) technology in the detection and alerting processes in disaster management of severe weather conditions. The system receives data measured by sensors distributed in different locations. It produces alerts disseminated simultaneously and in real-time to the responsible governmental entities and the public through multiple delivery mechanisms. These delivery channels include text-based SMS, email notifications, live alerts on online social media sites. The system has a significant advantage in which it can work with sensors that measure weather elements or with automatic weather stations. A multi-layered geodatabase is developed with the integration of the IoT data. The developed GIS is used to carry out spatial analysis to identify areas vulnerable to disasters due to the severe weather conditions detected by the IoT measurements. The system produces alerts in different forms. The results show the ability of the system to identify severe weather conditions and visualize the spatial coverage of potential risks.

Keywords - Disaster Management, GIS, IoT, Severe Weather

I. INTRODUCTION

Weather and climate have great impacts on different aspects of human life, which requires accurate information in near real time. Aviation, maritime navigation, agricultural and environmental sectors are the most dependent sectors of meteorological monitoring [1]. Different weather conditions affect various daily human activities. The warnings issued by meteorological monitoring help to avoid human obstruction and to get ready for different weather conditions. Geographic information systems (GIS) are computer-based systems for capturing, storage, manipulation, analysis, and visualization of spatially-referenced data [2]. GIS help in the analysis of a wide range of geospatial Data. GIS are utilized to provide spatial information about disasters [3]. GIS help to manage great level of data for vulnerability and risk management. GIS is a good tool for disaster reduction especially in the domain of weather and forecasting [4]. Warning and disaster management are important services which GIS

Provide [5]. GIS lets us visualize and interpret data to understand spatial relationships, patterns, and trends [6].

The Internet of Things (IoT) is also one of the key technology trends based on wireless sensor networks technology (WSN) being used for natural monitoring to provide early prediction which able to detect an emergency incidents like flood, forest fire, gas emergencies,…etc. that caused hazard to human life. IoT architecture is the fundamental knowledge for the development of application based on IoT [7]. Meteorologists carry out weather monitoring using weather stations. These stations use different types of sensors to measure wind speed and direction, rainfall, humidity, temperature and more to obtain real-time data related to weather and environment without human intervention [8]. Meteorologists analyze the gathered information in order to produce weather forecasts [9].

This paper aims to introduce an innovative GIS-based IoT alerting system for severe weather conditions. There is a need for automatic alerting systems for severe weather conditions. This will help to reduce severity of weather disasters that may take place. The proposed system integrates the Internet of Things (IoT) technology in the detection and alerting processes. The GIS-based system can be used in order to model and apply emergency scenarios depending on the measured meteorological data. This will be useful in reducing natural disasters and to speed the responses. The system is also useful to take the advantages of sensors embedded in automatic weather stations. The rest of the paper is organized as follows. Section (II) is a survey of previous related work. Section (III) introduces and describes the proposed weather alert system. Section (IV) Describes the System structure. Section (V) explains the system implementation and evaluation. Section (VI) presents the conclusion of this research work.

II. RELATED WORK

GIS and IoT-based disaster management is a powerful concept that aims to leverage a number of modern technologies to support different types of disaster

monitoring, disaster prevention and disaster response. The use of mobile devices, wireless sensor networks, and IoT-based systems to support people in emergencies has been targeted by many researchers. This section reviews past research contributions in these directions. Garnero and Godone (2013) compared between different GIS interpolation algorithms and techniques. They concluded that the Inverse Distance weighting (IDW) algorithm gave the best results in this comparison [10]. Lei et al. (2014) proposed a crowdsourcing-compatible disaster information management system based on GIS [11]. In addition, they analyzed its advantages in information production and transmission. The proposed Disaster Information Management System (DIMS) was designed to merge the PGC-DI and the UGC-DI, in order to provide the government and the public with differentiated services. The system was divided into five layers: data acquirement, database, platform, application and user interface. Chen (2014) developed a platform to monitor and provide an early warning system called "mountain torrent disaster prevention system" which collects rainfall data, gaging and images of river basin [12]. The data are transmitted to the flood prevention command center and flood disaster management team. Kumar et al. (2015) presented a solution to reduce and eliminate frequent flooding problems using a system that predicts flooding of river via given parameters, specifically rainfall level, water flow level and water level [13]. The proposed system predicts the flood and a warning to be issued at a specific field unit in the river. Anand (2016) specified an IoT to develop a flood warning system. This system provides users with potential flood information [14]. Ravi and Mandal (2016) introduced a home and office-use weather station made up of four sensors for measuring temperature, pressure, and raindrop [15]. They used cloud computing technology to upload the data to the cloud. The data are then analyzed and disseminated to alert people to take necessary measures. Tan et al. (2017) proposed and implemented a novel approach for building information collection based on GIS system [16]. The proposed system was divided into four levels, which include base layer, data layer, business layer and interactive layer. In addition, this system provides the capability of simultaneous online interoperations for users from more than 540 communities and has collected more than 44,000 data records. Ray et al. (2017) published a survey paper and discussed the integration of IoT in disaster management [17]. They presented the state of the art scenarios to handle disastrous events. They illustrated selective studies on market-ready IoT-enabled off-the-shelf products and highlighted open challenges and research trends in IoT-enabled disaster management systems. Tan et al. (2018) discussed a research and application of the GIS-based earthquake disaster prevention system of Beijing [18]. In addition, a four-level system architecture design is presented. Such architecture maintains a multi-source data integration management, data query, spatial analysis, and user authorization management. Further, the system has been deployed and applied in practical work.

This paper aims to introduce an innovative GIS-based IoT alerting system for severe weather conditions with the integration of Internet of Things (IoT). This will serve to reduce natural disasters and to speed the responses.

III. THE PROPOSED WEATHER ALERT SYSTEM

This section explains a proposed framework for severe weather alerts. This framework will serve as an early warning system. The main benefit is to reduce the damages that may result from late response to severe weather conditions. The proposed framework relies on integrated units. The system inputs come from IoT sensors that measure different weather elements. The instruments may include anemometer sensors for measuring wind speed, wind vane sensor for measuring wind direction, barometers for measuring atmospheric pressure, rain gauges for measuring precipitation and hygrometers for measuring relative humidity. The data will be stored in a SQL database on the server. The weather alert program (WAP) checks weather parameters values and identifies when parameters reach or exceed certain values. The references for the exceeded values are based on Beaufort scale wind force observations as shown in Table 1 [19] and World Meteorological Organization (WMO-No.702) [20]. The system is designed to respond when specific criteria are met. Then, it will generate a notification and disseminate different alert types. These alert types include SMS messages and emails to be sent to the decision makers to take the proper actions. Posts on Facebook are also one of the well-known social media applications towards preparing facilities to reduce what will happen in the city and to alert individuals as well.

Beaufort NO	Description	Wind Speed knots	km/hr	Observations
0	Calm	0–1	0–2	Smoke rises vertically
1	Light air	1–3	2–6	Direction of wind shown by drifting smoke, but not by wind vanes
2	Slight breeze	4–6	7–11	leaves rustle; wind vanes moved by wind; flags stir

3	Gentle breeze	7–10	12–19	Leaves and small twigs move; wind will extend light flag
4	Moderate breeze	11–16	20–29	Wind raises dust and loose paper; small branches move; flags flap
5	Fresh breeze	17–21	30–39	Small trees with leaves begin to sway; flags ripple
6	Strong breeze	22–27	40–50	Large tree branches in motion;
7	High wind	28–33	51–61	Whole trees in motion; inconvenience felt walking against wind; flags extend
8	Gale	34–40	62–74	Wind breaks twigs off trees; walking is difficult
9	Strong gale	41–47	75–87	Slight structural damage occurs (signs and antennas blown down)
10	Whole gale	48–55	88–101	Trees uprooted; considerable damage occurs

Table 1: Beaufort Wind Scale used in the proposed system [19]

IV. SYSTEM STRUCTURE

The proposed system consists of a set of elements that work in integration to identify the potential severe weather conditions and to produce alerts when necessary. The following are the integrated components of the proposed system as shown in Figure 1:

1. Sensors for weather parameters measurements and acquisition.
2. Data Loggers to capture and store data received from different sensors.
3. Data collection Software to assemble data coming from data loggers and export it to a text file.
4. Database server to read the text file generated from Data collection Software, parse it and insert into the SQL database. Data will permanently kept in the storage units for archiving and further processing in the future.
5. A server that acts as an alert system server in the form of a modular computer program. This reads the inputs from database and use algorithms to analyze and process data then produce and disseminate different alerts in case of extreme values. This depends on specific criteria inserted as rules when the received conditions may require alerting. In case we need to increase any additional alert type, just modify the alert function parameters and add the new alert function routine.

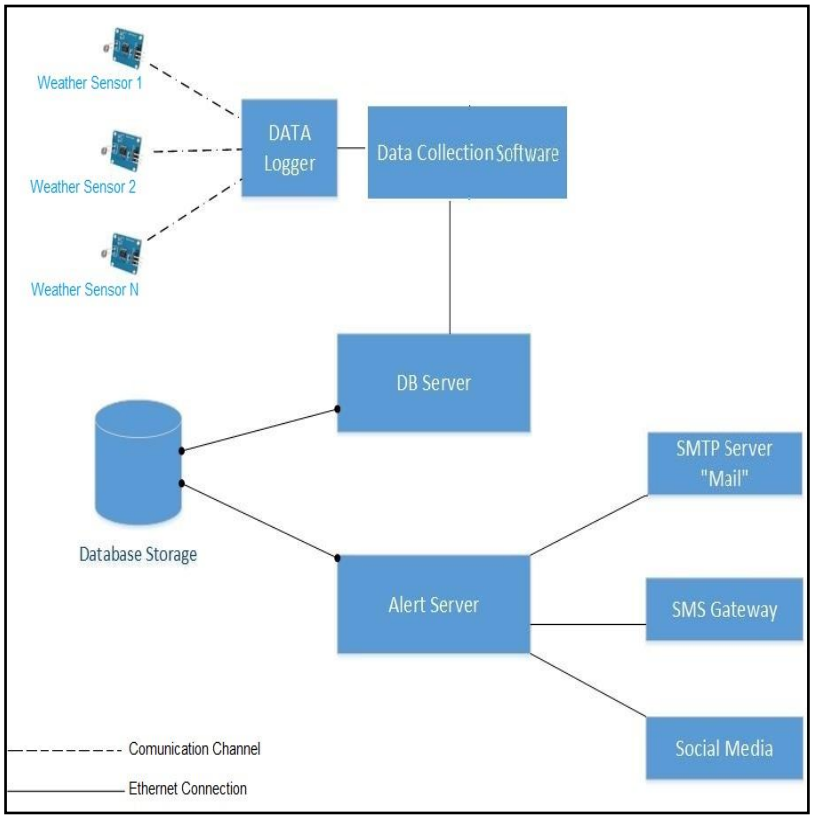


Figure 1: A block diagram of the proposed integrated Alert system

V. SYSTEM IMPLEMENTATION AND EVALUATION

The proposed system is implemented in two parts. The first part is the WAP or weather alert program. The input, IoT data or sensor measurements, is uploaded to the database server. The measured values are analyzed in the alert server using the algorithm named Weather alert algorithm. Emails, SMS and Facebook posts are published whenever the threshold limit is exceeded. The system is implemented using visual C++ programming language. A sample output from the proposed system is shown in Figure 2. A Sample output alert on SMS message and post on Facebook is shown in Figure 3.1 and 3.2

Weather alert algorithm:

Input: wind direction , wind speed _knots , humidity , wind gusts , cloud, Precipitation, Air pressure ,Temperature
Output: Alerts _ SMS ,email, Facebook post
1- Query from database values: wind direction , wind_speed, humidity, n weather elements …
2- if prec_mm <=1, then the state is "Shower"
else if prec_mm <=3 then the state is "Rain"
else if prec_mm <=6 then the state is "Heavy rain"
3-Call function CheckForNotifications with the values read from Step 1
if (humd >= 80 && wind_direction>=90 && wind_direction<=270 && && wind_speed<=6)
Message = state + " :Be attention it will be a chance of fog و Humidity is : (" + humd +"%) and
Wind Direction is : (" + wind_direction +" Degree) and windspeed is : ("+ wind_speed +" Kts)"
if (wind_speed>=22)
Message = state + " :Be attention wind speed is "+ wind_speed +" Kts"
Message = state + " :Be attention it will be a chance of strong breeze"
Else if (wind_speed>=28 && wind_speed <= 33 && wind_direction>=90 && wind_direction<=270)
Message = state + " :Be attention wind speed is : ("+ wind_speed + " Kts) Wind Direction is : ("+ wind_direction+" Degree)"
Message = state + " :Be attention it will be a chance of High wind & may chance of sand storm "
4- Call SendEMail
Call SendSMS
Call postFacebook
Print the Message on the form

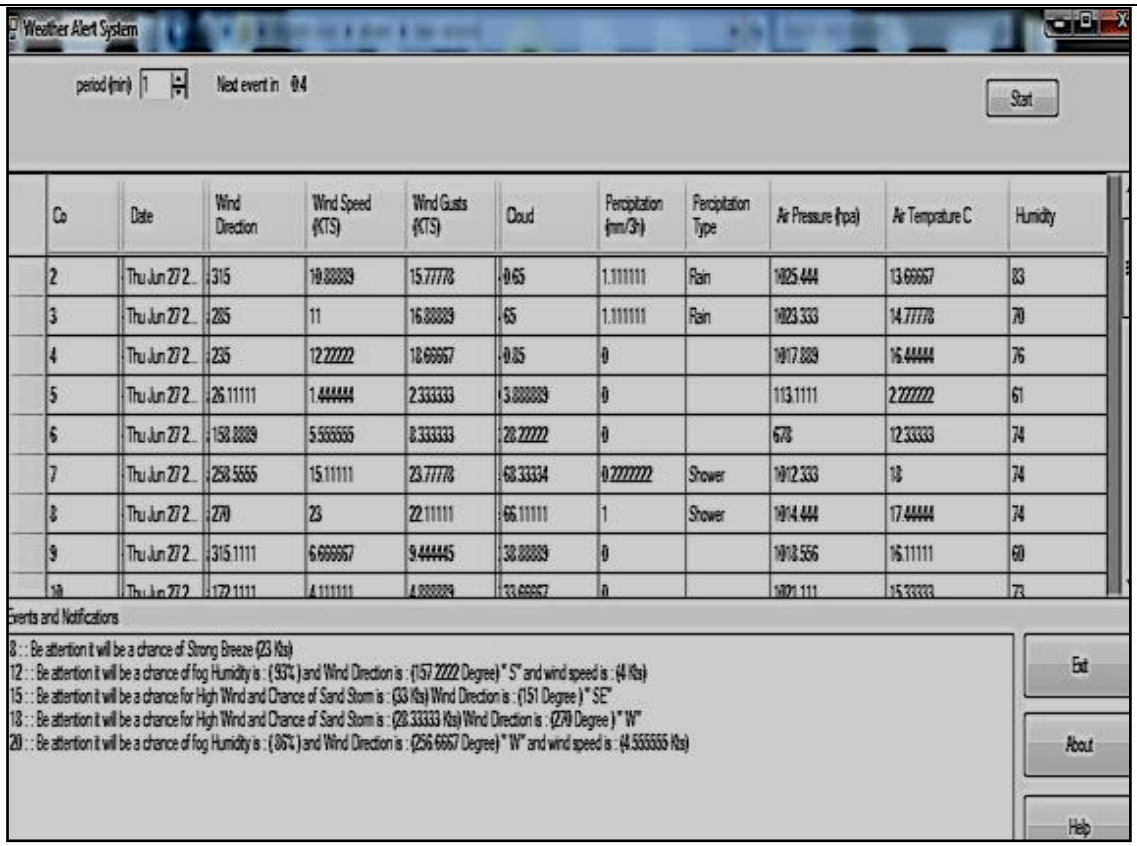


Figure 2: A sample output from the WAP system

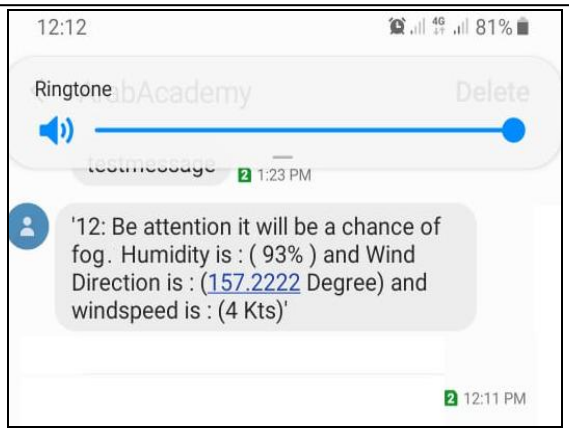


Figure 3.1: a sample output from SMS alert

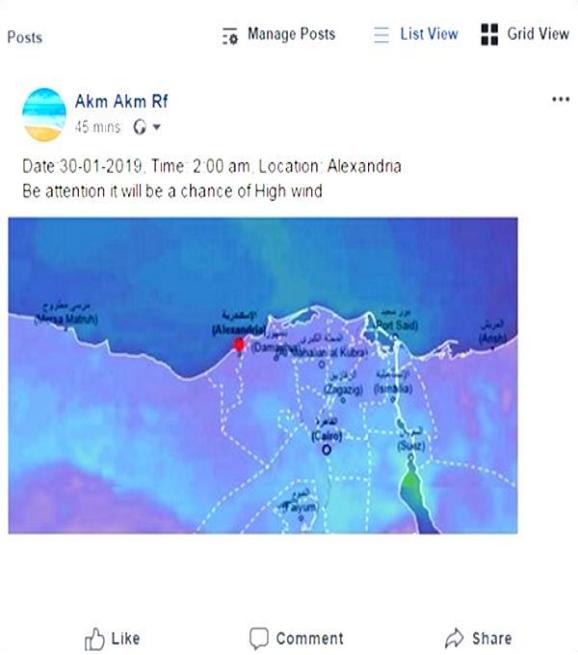


Figure 3.2: a sample output from a Facebook

Geodatabase Design

The second part of this research concerns the development of a GIS-based model. A geodatabase is designed and implemented in ArcGIS 10.4.1 environment. The visualization functions in GIS help to investigate the weather parameters and the coverage areas vulnerable to sever weather conditions. The data inputs are acquired by distributed sensors in an IoT network. The data measured are integrated in near real-time with the developed detection and warning system. The location of the weather ground stations is shown in Figure 4.

The data for each weather parameter is imported to ArcGIS (version 10.4.1). Then, the data is saved as GIS layer called stations. The station layer is projected to UTM, WGS 1984, and Zone 36N to be in UTM metric coordinate system using the project function in ArcGIS. A GIS model is built using model builder in ArcGIS to obtain the distribution of the weather parameters. Four distinct GIS layers are created namely; wind Speed, wind gusts, wind direction and humidity as illustrated in Figure 5. Inverse distance weighted (IDW) interpolation algorithm is used to map the distribution of the weather parameters in the whole study area. The IDW determines the unknown pixel values using a linearly weighted combination using the data of the ground stations. The weight is a function of inverse distance. An interpolated surface maps are created representing various weather parameters. All the interpolated maps are clipped by the use of the border of Egypt using the extract by mask function in ArcGIS.

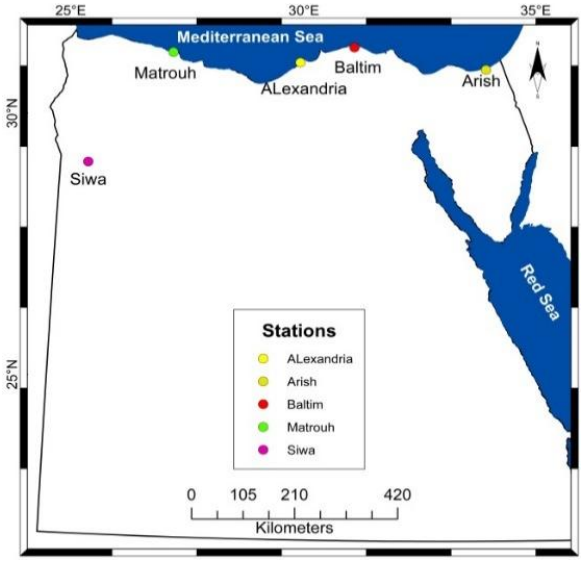


Figure 4: Locations of ground weather stations as a geodatabase layer

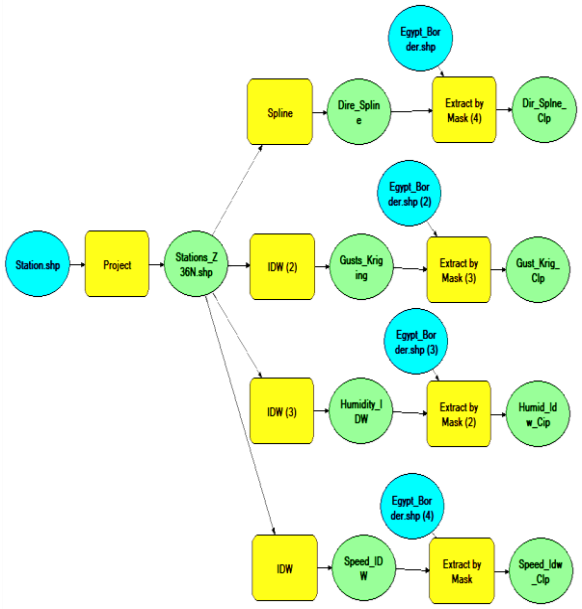


Figure 5: A GIS model for weather parameters in the study area.

The interpolation map of the humidity is shown in Figure 6. The Figure indicates that the maximum humidity is at Matrouh and Alexandria stations, whereas minimum humidity is at Siwa, Arish then Baltim stations.

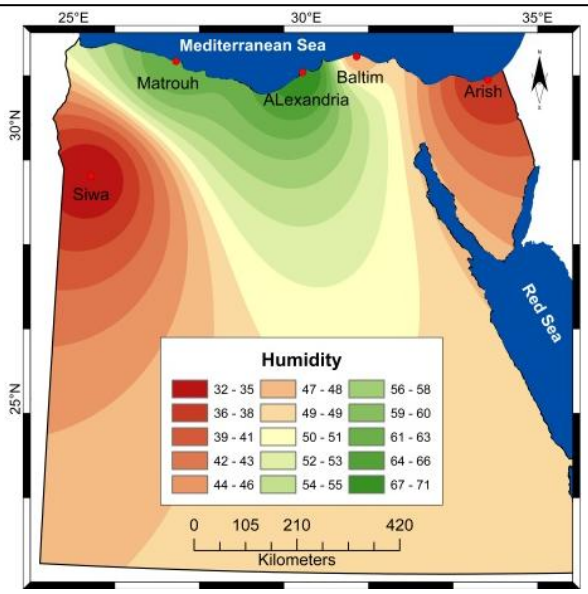


Figure 6: The geodatabase layer of interpolated humidity in the study area.

The interpolation map of the wind speed is shown in Figure 7. The Figure illustrates the maximum wind speed is at Matrouh, Baltim and Siwa stations. However, the minimum wind speed is at Arish and Alexandria stations.

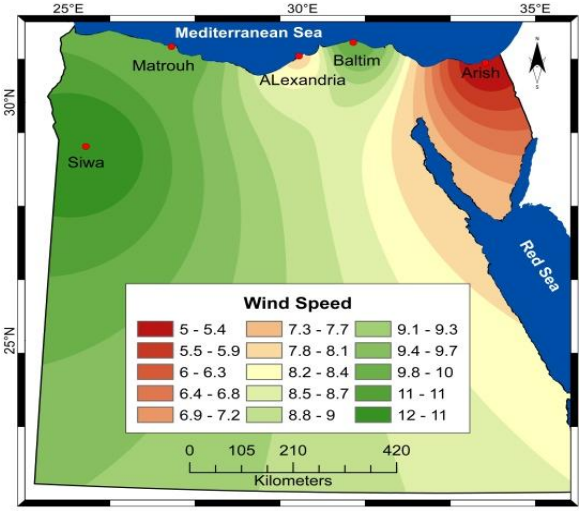


Figure 7: The geodatabase layer of interpolated wind speed in the study area.

The system performance is evaluated using different scenarios. The meteorological data are acquired from the weather station installed in the main campus of the Arab Academy for Science, Technology and Maritime Transport (AAST), Abo-Keer district, Alexandria, Egypt. The data are used to test and evaluate the developed system. Meteorological data available online from Aviation Weather Center [21] are also used.

VI. CONCLUSION

This paper proposed a GIS-based alerting system for severe weather conditions. The proposed system integrates (IoT) technology to support the detection and alerting of severe weather conditions. An algorithm is developed for the alerting system. A geodatabase is developed and used for visualization and evaluation using different scenarios. The obtained results showed the ability of the system to identify severe weather conditions and visualize the spatial risk coverage. This helps in early disaster detection and management.

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