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A new air quality monitoring and early warning system: Air quality assessment and air pollutant concentration prediction

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ABSTRACT

Air pollution in many countries is worsening with industrialization and urbanization, resulting in climate change and affecting people's health, thus, making the work of policymakers more difficult. It is therefore both urgent and necessary to establish amore scientific air quality monitoring and early warning system to evaluate the degree of air pollution objectively, and predict pollutant concentrations accurately. However, the integration of air quality assessment and air pollutant concentration prediction to establish an air quality system is not common. In this paper, we propose a new air quality monitoring and early warning system, including an assessment module and forecasting module. In the air quality assessment module, fuzzy comprehensive evaluation is used to determine the main pollutants and evaluate the degree of air pollution more scientifically. In the air pollutant concentration prediction module, a novel hybridization model combining complementary ensemble empirical mode decomposition, a modified cuckoo search and differential evolution algorithm, and an Elman neural network, is proposed to improve the forecasting accuracy of six main air pollutant concentrations. To verify the effectiveness of this system, pollutant data for two cities in China are used. The result of the fuzzy comprehensive evaluation shows that the major air pollutants in Xi'an and Jinan are PM_{10} and $PM_{2.5}$ respectively, and that the air quality of Xi'an is better than that of Jinan. The forecasting results indicate that the proposed hybrid model is remarkably superior to all benchmark models on account of its higher prediction accuracy and stability.

1. Introduction

With the rapid expansion of China's economy and growth in the number of vehicles and industries, the problem of air pollution is becoming more serious. The economic take-off in a country of 1.4 billion people requires the consumption of more fossil energy and natural resources, and this has led to a change in the chemical composition of the atmosphere. The Environmental Performance Index (EPI) shows that the air quality in China is the second worst among 180 countries included in the index this year (EPI (Environmental Performance Index, 2016)). Fig. 1 shows the ten countries with the poorest air quality in 2016, and their corresponding EPI scores. Air pollution has important implications on the ecological environment (Wang et al., 2016), and could also destroy vegetation and monuments (Brook et al., 2004; Baker and Foley, 2011). In addition, air pollution can cause lung cancer and related diseases, and many epidemiological studies have consistently shown an association between particulate air pollution and cardiovascular and respiratory diseases (Gorai et al., 2014). To assist people in keeping fit and improving the quality of their lives, the development of a robust, accurate, yet simple, air quality monitoring and early warning system is highly desirable.

Environmental monitoring and early warning is the basic function of environmental protection work, not only in relation to scientific decision-making, but also long-term development. The people of China want to improve air quality and reduce haze weather. To achieve this, more than 2700 monitoring stations have been established with more than 268,000 sets of monitoring instruments, and approximately 60,000 monitoring personnel (MEP Ministry of Environmental Protection, 2015). Air quality systems are very complicated, and, although China has made great progress in reducing the haze and

Abbreviations: EPI, Environmental Performance Index; PSI, Pollutant Standard Index; AQI, Air Quality Index; MEP, Ministry of Environmental Protection; AHP, Analytic hierarchy process; CTMs, Chemical transport models; ARIMA, Autoregressive integrated moving average; MLR, Multi-linear regression; ANN, Artificial neural network; SVM, Support vector machine;; RBF, Radial basis function;; FL, Fuzzy logic; EEMD, Ensemble empirical mode decomposition;; CS, Cuckoo search; BP, Back-propagation artificial neutral networks; ENN, Elman neural network; CEEMD, Complementary ensemble empirical mode decomposition;; DE, Differential evolution algorithm; IMF, Intrinsic mode function;; D-M, Diebold-Mariano test; EMD, Empirical mode decomposition; GRNN, Generalized regression neural network

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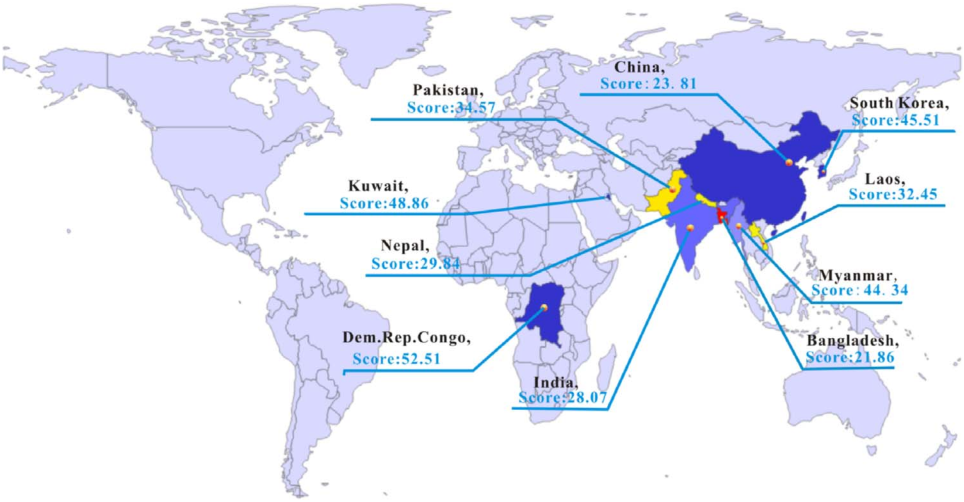

Fig. 1. Shows the ten countries with the poorest air quality in 2016.

improving air quality, the continuing challenges of reducing air pollutants still need to be addressed. Air quality problems are not unique to China; many countries, especially developing countries , suffer from air pollution. In recent years, significant research has been conducted on air quality monitoring and evaluation systems. The research can be divided into air quality assessment and air pollutants forecasting.

For air quality assessment, numerous indices have been proposed to evaluate the quality of the air. The first index was the "Pollutant Standard Index" (PSI), which was modified and replaced by the "Air Quality Index" (AQI), both of which were developed and introduced by United States Environmental Protection Agency (US EPA, 2009). The PSI considered five air pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and particulate matter (PM_{10}). Compared to the PSI, $PM_{2.5}$ and 8-h average ozone concentrations were also included in the AQI (Cheng et al., 2007). The standards of countries using the AQI are not all same. China has its own air quality assessment system. The Ministry of Environmental Protection (MEP) of China promulgated new ambient air quality standards (GB3095-2012) to replace the previous standards (GB3095-1996) in 2012, whereby $PM_{2.5}$ and 8-h average ozone concentrations were included and the concentration of pollutants in the limits were redefined. Although it is used worldwide, the AQI system has certain limitations. Many other air quality indices have been proposed (Liu et al., 2012; Kyrkilis et al., 2007). Although traditional air quality assessment used a simple digital indicator as a dividing line, with each side divided into different levels, the classification standard is not objective. The evaluation of air quality, which is aimed at determining "the degree of pollution," is a fuzzy concept, and it is difficult to find clear boundaries; thus, the evaluation classification standard of pollution levels should also be fuzzy. Therefore, fuzzy logic is a suitable tool for air quality assessment (Zadeh, 1965; Hájek and Olej, 2009; Abdullah and Khalid, 2012; Akkaya et al., 2015), and many fuzzy-based air quality indices have been proposed (Mohammad et al., 2011; Miguel and Ignacio, 2016).

Forecasting systems have been successfully used in many fields (Wang et al., 2014; Sun et al., 2013; Qin et al., 2015). Air pollution forecasting is essential, and air quality forecasting systems would allow for more efficient countermeasures to safeguard citizens' health (Yahya et al., 2014). The forecasting methods can be divided into two major categories: deterministic models and statistical models (Geoffrey Cobourn, 2010). The commonly used deterministic model is the chemical transport model (CTM). This model can forecast air pollution concentrations in places without monitoring the site and does not rely on a large quantity of historical data, but the accuracy is highly affected by the quality of the emission data and the scale used (Feng et al., 2015; Stern et al., 2008; Sun et al., 2013). As for the statistical models, the autoregressive integrated moving average (ARIMA) model (Konovalov et al., 2009), the multi-linear regression (MLR) model (Zhang et al., 2012), and the artificial neural network (ANN) model (Lin et al., 2010; Metaxiotis et al., 2003), have all been widely used for air pollutant concentration forecasting recently. The ARIMA and MLR models, both linear, have been adopted to forecast air quality (Kukkonen et al., 2003); however, a significant shortcoming is that the forecasting accuracy depends on the linear mapping ability in nonlinear processes (Song et al., 2015). To overcome this limitation, nonlinear models, such as the support vector machine (SVM) (Osowski and Garanty, 2007; Suarez Sanchez et al., 2011; Lin et al., 2011), the radial basis function (RBF) (Paschalidou et al., 2011), and fuzzy logic (FL) (Alhanafy et al., 2010), have been adopted to forecast air pollution. In addition, hybrid models have also been proposed to improve the forecasting accuracy of air pollutant concentration. Qin (2014) (Qin et al., 2014), proposed a hybrid model combing ensemble empirical mode decomposition (EEMD), cuckoo search (CS), and back-propagation (BP) artificial neural networks for forecasting PM concentrations.

This paper develops a new air quality monitoring and early warning system that integrates air quality assessment and air pollutant concentration forecasting. Fuzzy theory is used to evaluate the air quality more scientifically, and a new hybrid model MCSDE-CEEMD-ENN, combining complementary ensemble empirical mode decomposition (CEEMD), modified cuckoo search and differential evolution algorithm (MCSDE) and Elman neural network (ENN), is proposed to improve forecasting accuracy of air pollutant concentration. Due to the inherent complexity of pollutant concentration series, describing the moving trend of pollutants and accurate prediction is difficult. To overcome this, CEEMD is utilized to decompose the original time series and reconstruct a new series with the noise removed. ENN is used to forecast the air pollutant concentrations. An improved optimization algorithm (MCSDE) that combines CS and DE has been proposed to improve the stability of convergence by optimizing the initial weights and threshold of ENN. The main six air pollutants data recorded in Xi'an and Jinan, China, were used to verify the forecasting ability. The proposed air quality system has the following advantages:

1) Based on the analysis of existing air quality evaluations, imposing fuzzy theory to make fuzzy comprehensive evaluations about air quality can determine the most prevalent air pollutants in the city.