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Neuro-Fuzzy approach to forecasting Ozone Episodes over the urban area of Delhi, India

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HIGHLIGHTS

- Ozone episodes were occurred approximately 31% of the total observations for the year 2012 in Delhi urban area.
- Worst ozone episodes were observed in the summer seasons of Delhi.
- Neural–Fuzzy model has been found the better forecasting model for ozone episodes.

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ABSTRACT

Tropospheric ozone is a major air pollution problem, both for public health and for the environment, which is not directly emitted by human activities. It is a secondary pollutant, which produces due to reaction with volatile organic compounds and nitrogen oxide concentrations, both emitted by anthropogenic activities. Therefore, ozone episode has been studied in Delhi, the urban area, where anthropogenic emissions are playing major role in ambient air pollution. The 8-hourly analysis of past data pattern in each season at different monitoring stations in Delhi suggests that the ozone episodes were occurred approximately 31% of the total observations and the summer seasons is the worst performer of ozone concentrations in Delhi. The correlation matrix shows that the dew point temperature, NO_2, and relative humidity are the dominating variables for Ozone (O_3) concentrations in Delhi. The present study aimed to analyze the ozone episodes in a year and to develop the artificial intelligence based forecasting methodologies over Delhi megacity. Further, the hourly ozone forecasting models have been developed through different modeling techniques, e.g., multiple linear regressions (MLR), artificial neural network (ANN) and artificial intelligence based Neuro-Fuzzy (NF) techniques. The air pollutants as well as meteorological parameters have been used to analyze the ozone episodes. The forecasted results from different models are compared with the observed values with statistical measures, e.g., correlation coefficients (R), normalized mean square error (NMSE), fractional bias (FB) and index of agreement (IOA). The performed statistical analysis has indicated that the artificial intelligence implementations have a more reasonable agreement with the observed values.

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1. Introduction

Shortness of breath, dry coughs or pain when taking a deep breathe, tightness of the chest, wheezing, and sometimes-even nausea are common responses to excessive ozone. It is found in the Earth's lower atmosphere as a criteria pollutant

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and in the range of 5–30 ppb, which is within the limit of health point of view (Jacob, 1999). It is formed when two types of pollutants, i.e., volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) react in the presence of sunlight. The hot sunny days are particularly responsible for increment the concentrations of O_3 in urban environments. It is a major part of urban smog, that can inflame breathing passages, pain when inhaling deeply, decrease the lungs' working capacity, wheezing, and coughing. Since the wind can transport the ozone pollution to a long distance and results high ozone episodes at rural areas. Many factors impact ground-level ozone development, such as temperature, wind speed, direction, time of day, and vehicle activity. Due to its dependence on weather conditions, O_3 is typically a summertime pollutant and a chief component of summertime smog, but can be a year-round issue in some areas. O_3 levels can vary from one area to the other and also vary over time (Varotsos et al., 2012). Its production occurs during a time of high temperatures and solar radiation, such as during stagnant high-pressure systems. It often occurs during the summer due to increased NO_x and VOC emissions, which are emitted by anthropogenic activities (Atkinson, 2000; Debaje and Kakade, 2006; Sillman, 2003). The ozone concentration trend is increasing due to the growth of emissions of its precursors, and many countries are now equipped with an air quality monitoring network which follows the ozone concentration at the ground levels. The maximum emissions are coming from vehicular sources in Delhi, the capital of India (Mishra and Goyal, 2015a). The maximum ozone values have been observed in the late afternoon and minimum value in the early morning hours over urban areas of Delhi corresponding to office hours. Ozone also enters in the plants through leaf stomata and oxidizes plant tissues, causing changes in biochemical and physiological processes that reduced photosynthesis and other damage to plant functions and lead to reduced growth and biomass. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses. It also affects sensitive vegetation and ecosystems, including parks, wildlife refuges and forests, especially slow-growing crops and long-lived trees. It damages the leaves and needles of sensitive plants, causing visible alterations such as defoliation and change of leaf color (Committee, 2014).

Vehicle activity, fuel combustions, and other activities on the urban area's atmosphere produce a large number of pollutants, which can direct affect the public health and vegetation. Vehicular sources are the main anthropogenic emissions sources and results the ground-level ozone concentrations. The other sources of VOC's include emissions from the industries, especially from chemical and petroleum. The significant amounts of NO_x originate from the combustion of fossil fuels in vehicle's, power plants, industries, and indoor activities. These air pollutants are generically called "smog" because it is associated with reduced visibility, which is due to scattering of solar radiation by high concentrations of anthropogenic emissions. Smog is primarily made up from ground level O_3 combined with other gases and particle pollution, e.g., CO, SO_2, NO_2 and fine particulate matter present ($PM_{2.5}$).

Ozone is a powerful oxidant and can irritate the lungs, causing coughing, wheezing, a burning sensation and shortness of breath. When you inhale ozone, it travels throughout your respiratory tract. Because it is very corrosive, it damages the bronchioles and alveoli in your lungs, air sacs that are important for gas exchange. Repeated exposure to ozone can inflame lung tissues and causes respiratory infections. According to OTA (1988), a 120 $\mu g/m^3$ seasonal average of seven-hour mean ground level ozone concentrations are likely to lead to reductions in crop yields in the range of 0.9%–51% for wheat, 0.3%–5.1% for corn, 16%–35% for cotton, and 5.3%–24% for soybeans. In addition to physical damage, ground level ozone may cause reduced resistance to fungi, viruses, bacteria, and insects, reducing growth and inhibiting yield and reproduction. Therefore, the forecasting of ozone episodes is more important.

Air quality forecasting model like deterministic models are distinguished from statistical models as the principle of it is to solve differential equations that describe the atmospheric state (Zhang et al., 2012a,b). These models are used in more general conditions than statistical models, but are more complex and demand important computational resources as well as a good knowledge of atmospheric processes and pollutant sources (Kumar and Goyal, 2013). However, statistical models need local data of variables in relationship with the predicted variable (Mishra et al., 2015). They are difficult to interpret, but can outperform determinist models. Such models can be a good solution to develop a forecasting tool if pollution observed data are available. Therefore, the statistical models selected in the present study are multiple linear regression (MLR), artificial neural network-multiple layer perceptron (ANN-MLP) and artificial intelligence based Neuro-Fuzzy (NF) model. Although MLR and ANN-MLP models have been used for forecasting of air pollutants in different studies (Heo and Kim, 2004; Engardt, 2008; Kumar and Goyal, 2011; Moustris et al., 2012; Mishra and Goyal, 2015b; Goyal et al., 2015) and only few studies are available for ozone forecasting at limited locations though NF model. Thus, the present study is the first attempt to use NF model for ozone forecasting over Delhi urban area and the additional novelty of the present study is that NFs have not previously been evaluated over Delhi, the most polluted city of the world.

Lack of experience, entangled cause-and-effect relationships and imprecise data make it difficult to assess the degree of exposure to certain forecasting types. The availability of these data may be beneficial to build and implement more appropriate operational risk models using a newer artificial intelligence based neuro-fuzzy model. The forecasting tools are developed by the combination of fuzzy expert and neural network systems. The forecasting of the concentrations of pollutants can be considered as a non-linear regression problem between predictors (such as meteorological and air quality variables) and predictand (in the present study, hourly concentrations of O_3). The time series forecasting by using different methods, including ANN approaches due to the significant properties of handling non-linear data with self-learning capabilities (Hornik, 1991) can forecast the concentrations, but it cannot be known the degree that an input influence the output (Pao, 1989). While, fuzzy logic is an effective rule-based modeling in soft computing that not only tolerates imprecise information and also makes a framework of approximate reasoning. The only disadvantage is the lack of self-

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