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Analyzing and predicting particle pollution in ambient air using stationary wavelet transforms

Vishal Chauhan

Asst. Professor, Department of Physics, Graphic Era Hill University,

Dehradun, Uttarakhand India 248002

Abstract: Particle pollutants in the ambient air (such as PM2.5 and PM10) are harmful and play a significant role in air pollution, especially with regard to human health and climate. Signals may have their local characteristics and information extracted using wavelet transformations. Exactly as many samples are used in the input in stationary wavelet transforms.Relative to discrete wavelet transforms, the resultant reconstruction has lower error values and quicker convergence, and this is maintained at all levels of decomposition. Since the linear predictor is a non-unique projection onto the wavelet domain, the prediction work is done directly with the general linear predictor and the wavelet predictor. Both the approximation and the detail reveal aspects of the signal's average behaviour or trend and its differential behaviour or variations. Both the original and the augmented signal undergo wavelet and statistical analysis, and the results are reported.

Keywords: PM2.5, PM10, prediction, wavelet

Introduction

Most of the particles that make up particle pollution, also known as particulate matter (PM), are dangerous solid and liquid particles that float through the air. Smoke, pollen, dust, soot, and even liquid droplets are all part of the complicated composition.[1]. These particles range in terms of size, content, and even origin. The larger particles would be trapped in the nasal duct and filtered out. Fine particles are less than 2.5 m in size, whereas coarse particles are between 2.5 and 10 m in size. Air pollution's severity is largely determined by its chemical make-up. The sulphur makes the particles hygroscopic, and when combined with high humidity and cold temperatures, the sulphur dioxide is transformed into sulphate. The end outcome is that visibility is diminished. Condensation of a metal or organic substance results in the formation of sub-microparticles. When burned at a high enough temperature, these substances become vaporised. Condensation of gases that undergo transformation into low-vapour-pressure compounds during atmospheric processes is another source of the microparticles. The majority of the average yearly PM2.5 and PM10 content comes from organic compounds and sulphate.

For PM concentrations above 50 ug/m3, nitrates are the primary component of PM2.5 and PM10 [2-3]. Particle size is a significant factor in human exposure and dosage, making it imperative to investigate ambient particulate matter.Smaller than 10 micrometres in diameter are considered safe for human inhalation. [4]. When many inhaled particles are expelled, no material is left behind in the respiratory system. Particles should have a diameter of around 0.5 m to cause minimum deposition. Lung deposition is proportional to particle size for particles with diameters between 0.5 and 10 m, but inversely proportional for particles with diameters below 0.5 m. The mechanism, rate, and status of clearance are all affected by where in the lung deposition occurs. Particles that are soluble in extracellular fluids or mucus are absorbed by epithelial cells and subsequently released into the bloodstream. Insoluble small particles are also absorbed into the respiratory epithelium and may reach the bloodstream within minutes [5]. radiation are altered, leading to the production of a negative radiative force overall [6]. When atmospheric particles alter Earth's radiative budget in any indirect way, this is known as the "indirect aerosol effect."result in a shift in the local climate as a consequence of changes to cloud patterns and other factors. Any radiative change outside of direct impacts is absorbed by atmospheric particles like soot, etc. in the semi-direct effect. It is less well defined than direct and indirect aerosol impacts because it involves several distinct pathways. Reduced evaporation from the Indian Ocean owing to the human aerosol impact might cause the Indian monsoon to fail on occasion.Particulate matter has been the leading cause of today's severe air quality and climate issues.Since Fourier transforms globally mix information, it is difficult to detect a signal's or function's local property at a given time and frequency. Not only are the mathematical sciences able to benefit from wavelet transformations [7-8], but so may Physics and Engineering. Functions at different places and scales may be represented using wavelet transformations, which are well recognised for their spectral behaviour.Because atmospheric aerosols affect both incoming and outgoing solar radiation, they have a direct impact on the climate of any given region. Aerosols may have direct, indirect, or even semi-direct impacts on the environment, all of which contribute to the observed shifts. In the direct aerosol effect, atmospheric particles interact with radiation directly by absorption, scattering, etc., and both short and long wave radiation are affected.

Literature Review

Mallick et al. (2014) observed the variability of SO2, CO, and light hydrocarbons over Kolkata, India and explored the effects of emission sources, transportation, regional and local sources on the concentration of SO2, CO and light hydrocarbons. The order of average hourly SO2 concentration was found to be winter (6.4 ppbv ~ 16.768 µg/m3) > post monsoon (3.5 ppbv ~ 9.17 µg/m3) > pre monsoon (0.83 ppbv ~ 2.175 µg/m3) > monsoon (0.72 ppbv ~ 1.886 µg/m3). They concluded that early morning enhancements in SO2 and several NMHCs during winter might be attributed to boundary layer effects and inter-species correlations and trajectory analyses portray the transport of SO2 from regional combustion sources (e.g., coal burning in power plants, industries) along the east of the Indo-Gangetic plain

Adame and Sole (2013) focused on the study of the levels and variability of surface O3 in the lower Ebre Valley and explored the origin of the surface O3. They investigated the ozone trends over the whole seasonal period, weekly and daily variation and incidences of exceedence of the legal limit. The limit for the protection of the human health has been exceeded from March to September, with an average of 33 times per year. The obtained results suggested that high O3 level could be associated with long range horizontal transport.

Kolev et al. (2011) looked at how the surface concentration of O3 changed across different parts of Sofia, Bulgaria, as the stable boundary layer (SBL) and residual layer (RL) collapsed and the convective boundary layer (CBL) formed. Leaner was used to take readings of the features and development of the boundary layer. They determined that the mixed layer's greatest height coincided with the highest values of O3 concentration at ground level. It was discovered that summer had a greater surface ozone concentration than autumn.

Materials and Methods

The scope of the research, as well as methods for gathering both primary and secondary data. Included in this section are explanations of how air samples are collected and analysed for various contaminants, as well as the air quality index (AQI) and the national ambient air quality standard (NAAQS). Both bivariate and multivariate statistical techniques are explored that may be used to the task of assessing and monitoring air quality. The geographical and temporal change of air pollution in a GIS context may be effectively explored with the use of digital elevation models (DEMs). Finally, the methods of air pollution prediction and projection using statistical and numerical modelling are discussed.

Description of the study area

The city of Durgapur (the one that was ultimately selected) located in the Burdwan district of West Bengal, India. It rests on the Damodar River's bank. Topography here is undulating and averages out around 65 m above sea level; the soil here is comprised of Red and Yellow Ultisols..

Meteorological background

The climate in this region is transitional, falling somewhere between the arid tropics and the more humid subtropics. From March until around the middle of June, temperatures hover around 32°C on a daily basis, making for a very uncomfortable summer. The monsoon season, which brings heavy rain and somewhat cooler temperatures, follows them. The majority of Durgapur's average annual rainfall of 52 inches occurs during this time. After the monsoon, there is a comfortable, dry winter. Daily averages hover around the comfortable 20-degree mark. Temperatures average approximately 25 degrees Celsius throughout the year, with a brief fall at the end of October and a brief spring in February.

Extraction of sample

Microwave extraction was used to remove the specified heavy metal samples from the filter paper. Using plastic forceps, a piece (100 cm2) of the filter paper was cut and positioned on its edge in a clearly labelled centrifuge tube. The filter strip was pressed into the centre tube's base until the whole filter paper was submerged in the acid. Each centrifuge tube received 10 ml of extraction solution (3% concentrated HNO3 and 8% concentrated HCl). The centrifuge tubes were submerged in 31 ml of deionized water, which was held in a Teflon container. Hand-tight pressure release valves on the vessel were used in conjunction with the capping station to achieve a constant torque of 12 ft-lb. The microwave carousel was loaded with the containers. After placing the carousel containing the sample vessels and the airflow vessel on the turntable of the microwave unit, we attached the Teflon tubing used for the connection. The sample containers were subjected to 23 minutes of irradiation at 486 W (power output). After the pressure had dropped, the carousel holding the vessels was taken out of the pressurised area and cooled in running water for 10 minutes. The samples were withdrawn from their labelled centrifuge tube and the microwave containers were opened. Each centrifuge tube had 10 ml of deionized water added to it, then the tubes were sealed and shaken vigorously for 2-3 minutes to ensure a full extraction. Following the above steps, 20 ml of total extracted volume can be expected. Whatman No. 41 filters were used to purify the extracted fluid, which was then diluted to 100 ml. This filtered sample may be put through further examination, and a piece of unexposed filter paper can be digested in the same way for blank correction.

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Analysis of sample by Atomic Absorption Spectroscopy

The heavy metal samples were analysed using flame atomic absorption (FAA) spectroscopy. For this, we use a GBC Abanta Atomic Absorption Spectrophotometer. The analyte (heavy metal) atoms are stimulated from their ground state by passing a beam of light through the flame at the wavelength that corresponds to that amount of energy. By measuring the quantity of light absorbed by the element in question, a monochromator and detector may determine how many atoms are in their ground state in the flame. By selecting the proper hollow cathode lamp, orienting the instrument, and setting the monochromator to the manufacturer-recommended value, the atomic absorption spectrophotometer was prepared for the standard condition. After determining the ideal monochromator slit width, turning on the light source, adjusting the fuel and oxidant flows, fine-tuning the burner for optimal absorption and stability, and finally balancing the metre, the process is complete.Table 1: Specifications of required wavelength, slit width, optimum working range and sensitivity for the analyses of different heavy metals

Heavy metal	Wavelength required for analysis (nm)	Slit width (nm)	Optimum working range (µg/ml)	Sensitivity (µg/ml)
Lead (Pb)	217.0	1.0	2.5 - 20	0.06
Nickel (Ni)	232.0	0.2	1.8 - 8	0.04
Manganese (Mn)	279.5	0.2	1 – 3.6	0.02
Cadmium (Cd)	228.8	0.5	0.2 – 1.8	0.009

The calibration curves of SO2 in monsoon, post monsoon, winter and pre monsoon seasons are given in Figure 1.

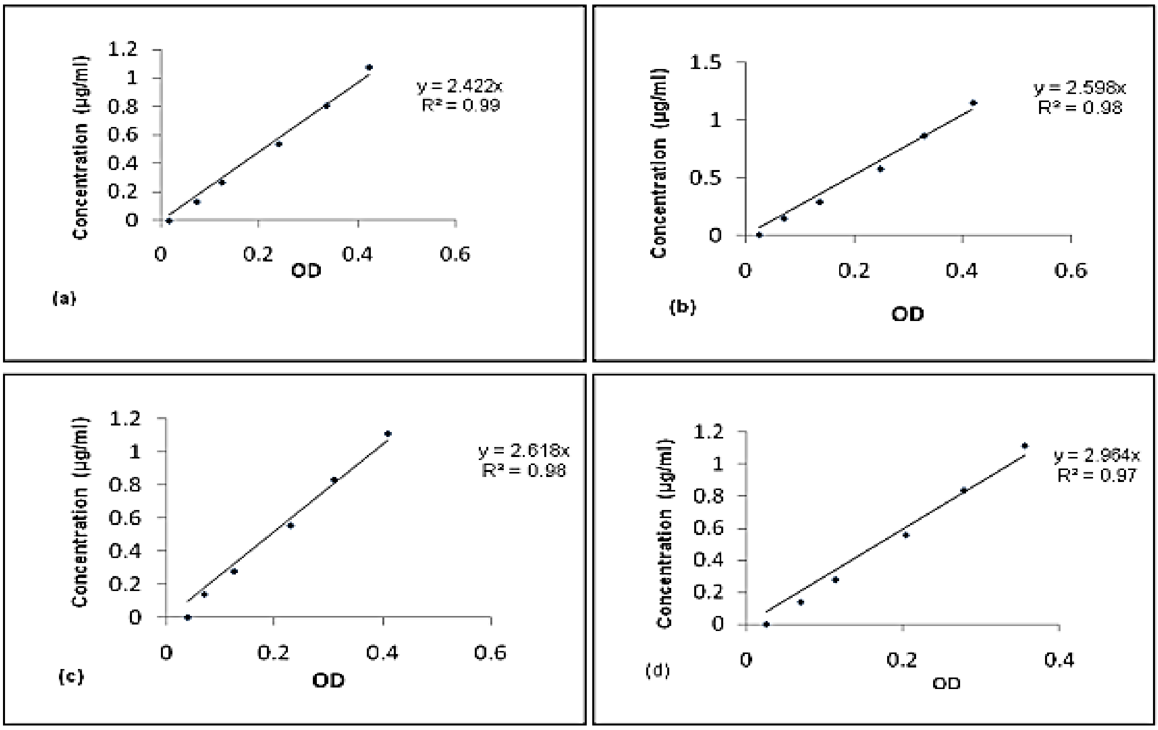

Figure 1: Calibration curves of SO2 in (a) monsoon, (b) post monsoon, (c) winter and (d) pre monsoon seasons

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Wavelet Decomposition

Wavelets are oscillating functions that may quickly decay to zero. Bandpass filters are often used in wireless transceivers. The primary function of such a filter in a transceiver is to limit the frequency range of the output voltage to the frequency range of the signal being sent. This ensures the transmitter won't cause any serious interference to the other devices [25]. Band-pass filtering signals of varying frequencies is the job of the wavelet transform.

Wavelet Denoising Method

Because useful information in the data may be obscured by noise, it is crucial to extract useful information from research data by consciously filtering out irrelevant and distracting noise. In the fields of communication science and pattern recognition, noise is defined as any external factor that acts as a distraction to the conversation between the speaker and the audience. Both internal and external sources of noise may disrupt communication at any time and place. In the wavelet domain, the effective signal is represented by large coefficients, while noise is represented by tiny ones. To get rid of the threshold value of noise in the wavelet domain, we still need the coefficients corresponding to the noise to fulfil the Gaussian white noise distribution, which may be measured using wavelet coefficients or raw signals. Methods like the fixed threshold, the minimax threshold, and the heuristic are now used for determining threshold values. The Colour space, which describes the appearance of a painted pixel in terms of the ratio of its Hue, Density, and Valuation, is the source of the Fixed Thresholding Methods property. The concentration value tells the reader how "light" a colour combination is, from pure black and white (concentration value of 1) to a plain colour (concentration value of 0). The threshold function was first developed to filter the wavelet coefficients with noise once the threshold selection technique became available. A Boolean function, a threshold function indicates whether or not the input data has reached a certain level of value or opportunity. Such logic can be enforced by a device called a threshold gate.

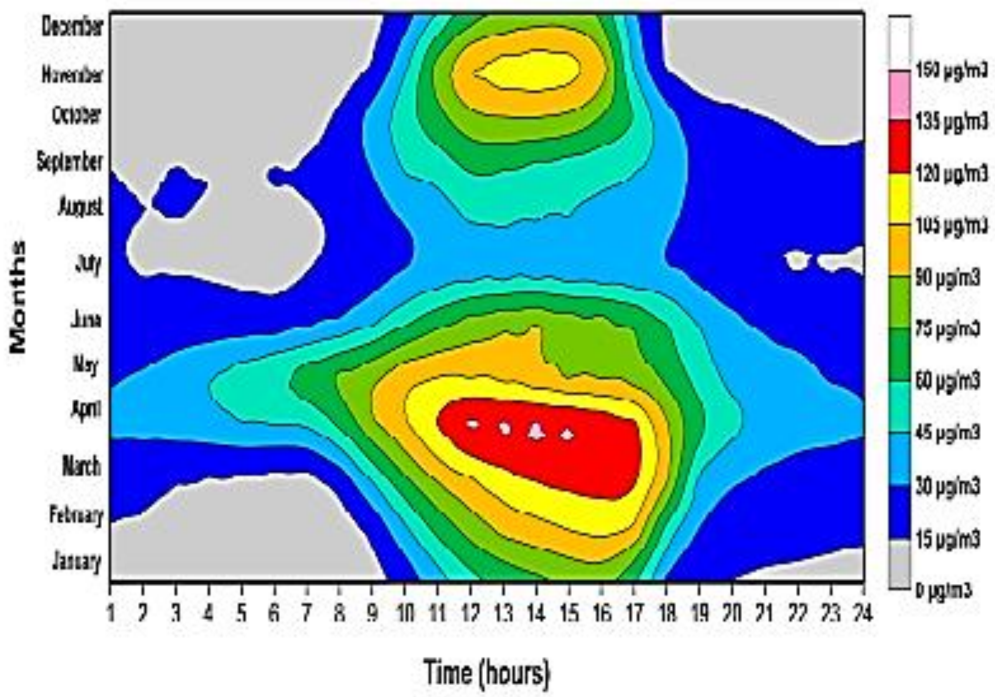

Figure 2.Scatter Plaot using Wavelet Decomposition

Conclusion

Wavelet transformations are useful for analysing nonstationary time series and for revealing previously concealed aspects of a signal or dataset. Decomposing a signal into its mean and variance may be done using the wavelet approach. The skewness parameter describes the unevenness and kurtosis of the signal. There is a direct and strong relationship between PM2.5 and PM10 in the air, as shown by the positive and high value of the correlation coefficient. As seen above, there have been significant fluctuations in the PM2.5 and PM10 time-series for Moradabad during the last year. Skewness and Kurtosis are positively skewed, whereas correlation is strongly negative. With the aid of the amplified signal, we can predict that the probability distribution will be neither flat nor wide in the near future, and that the magnitude and the direction of any deviation from symmetry will decrease somewhat. These findings support the idea that spectral analysis of PM2.5 and PM10 using stationary wavelet transforms can be used as a straightforward and reliable tool for studying and predicting the behaviour of these ubiquitous air pollutants.

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