Formulation and Assessment of Neural Network and Multiple Linear Regression Models to predict PM_{10} Levels in Rourkela, India

Thesis Submitted for the partial fulfillment of the requirements for the Degree of Bachelor of Technology (B. Tech) in Department of Civil Engineering at National Institute of Technology, Rourkela.

Submitted By

Mohit Ambwani

110CE0517

Project Supervisor

Prof. Kakoli K. Paul

Department of Civil Engineering,

National institute of Technolgy, Rourkela.

Certificate of Approval

This is to certify that the thesis entitled ***'Formulation and Assessment of Neural Network and Multiple Linear Regression Models to predict PM_{10} levels in Rourkela, India'*** submitted by **Mohit Ambwani** (110CE0517) has been carried out under my supervision in partial fulfillment of the requirements for the Degree of Bachelor of Technology (B. Tech) in Department of Civil Engineering at National Institute of Technology Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Prof. Kakoli K. Paul

Department of Civil Engineering

National Institute of Technology, Rourkela

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Mohit Ambwani

(110CE0517)

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[1.1] Introduction to Air Pollution

Air is arguably the most important constituents of man's environment. An average human being requires about 12 kg of air each day, which is nearly12 to 15 times greater than the amount of food consumed. Eventually, even a small concentration of pollutants present in the air becomes magnified by the same order in its effect and more harmful to human health, in comparison to similar concentrations of pollutants present in the food. The clean and pure air, free from the outside solid, liquid or gaseous polluting substances, called pollutants, is evidently very essential for human health and survival. Any change in the natural or normal composition of air, either qualitative or quantitative, they may adversely affect the living system, particularly the human life, invariably causes air pollution.

Air Pollution is, therefore, defined as the presence of any solid, liquid or gaseous substance (including noise) present in the atmosphere in such concentrations that may or tend to be injurious to human beings, or other living organisms. The solid, liquid or gaseous substances which when present in the air, cause harmful effects on the biotic and abiotic components of our environment are eventually called air-pollutants. When the quantum of air pollutants exceeds the self cleansing properties of the ambient air, and start causing harmful effects on the human health and his surrounding abiotic world, then the air is said to be polluted.

Air pollution, can be caused by naturally occurring events, like volcanoes – which release huge amounts of ash, dust, sulphur and other gases in the atmosphere or by the forest fires – that may occasionally be caused by lightening etc. In addition, air pollution may be caused by human activities, such as burning of fossil fuels, intentional burning of forests to clear land for urbanization or agriculture, etc. Whereas, the air pollutants caused by the natural hazardous events tend to remain in the atmosphere for a short time; the air pollutants released by human activities may continue to stay in the air environment for long periods and may even lead to permanent atmospheric changes. One of the reasons for this is the fact that the natural hazardous events causing air pollution do occur very

infrequently; while the man-made release of air pollutants is an ongoing continuous phenomena on daily basis.

Since the air pollution caused by the natural hazardous events is very infrequent and is automatically taken care of by the environment, we generally ignore this type of air pollution, and whenever we talk of air pollution, we always mean air pollution caused by the human activities (Garg, 2010)

[1.2] Air Pollutants

The atmospheric air may contain hundreds of air pollutants from the natural or the anthropogenic sources. All these pollutants which are emitted directly from the identifiable sources, either from the natural hazardous events like dust storms, volcanoes, etc or from human activities like burning of wood, coal, oil etc. in homes, industries and automobiles etc. are called the primary pollutants. The following five primary pollutants contribute to about 90% (Garg, 2010) of the global air pollution:

1. Oxides of Sulphur, particularly the sulphur dioxide (SO_2).
2. Oxides of Carbon, like carbon monoxide (CO), carbon dioxide (CO_2).
3. Oxides of Nitrogen, like NO, NO_2, NO_3 (expressed as NO_x).
4. Volatile Organic Compounds, mostly Hydrocarbons.
5. Suspended Particulate Matter (SPM).

Certain less important primary pollutants are hydrogen sulphide (H_2S), hydrogen flouride (H_2F) and other fluorides; methyl and ethyl mercaptans etc. which are usually rarely found in our general atmosphere, although if present, may prove quite harmful (Garg, 2010).

These primary pollutants often react with one another or with water vapour, aided and abetted by sunlight, to form entirely a new set of pollutants, called the secondary pollutants. These secondary pollutants are the chemical substances, which are produced from the chemical reactions of natural or anthropogenic pollutants or due to their pollutants or due to their oxidation etc caused by the

energy of the sun. These new pollutants are often more harmful than the original basic chemicals that produce them.

The important secondary pollutants are:

i. Sulphuric Acid (H_2SO_4)
ii. Ozone (O_3)
iii. Formaldehydes, and
iv. Peroxy-acyl-nitrates (PAN) etc.

The H_2SO_4 is formed by the simple chemical reaction between SO_2 and H_2O vapour, and is much more toxic pollutant than SO_2, having far reaching effectson environment, since it causes acid rains.

Other secondary pollutants like ozone, formaldehyde, PAN etc. are formed by the photochemical reactions, caused by the sunlight between two primary pollutants. Ozone is formed due to photochemical reactions between hydrocarbons (HC) and nitrogen oxide (NO). Similarly, aldehydes may be formed by photochemical oxidation of hydrocarbons in the atmosphere (Garg, 2010).

Now, our focus in the present context is on the Suspended Particulate Matter.

[1.3] Importance of PM_{10}

The particulate matter in air may occur in largely solid form as particles of dust, fume, smoke etc. and also in liquid form as mist and fog. The particles larger than a molecule but small enough to remain suspended in air are called aerosols. Brief descriptions of various types of solid and liquid particles, constituting total suspended particulate matter in air are indicated in Table 1 (Garg, 2010).

The suspended particulate matter in the atmosphere is a variable component, and is introduced either through a natural phenomenon like winds, volcanic eruptions, pollens and spores, decomposing particles of organic matter etc. or through human activities like mining, burning of fossil fuels, industrial processes etc (Garg, 2010).

The deposition trend of suspended particles in Nasopharyngeal, Tracheo-bronchial and Pulmonary regions of the Respiratory tract is shown in the figure 1, while percentage of particles of different sizes deposited in the respiratory tract is shown in figure 2, respectively.

Table 1: Types of suspended particulate matter (Garg, 2010)

Serial Number	Term	Brief Description	Examples
(A)	**Liquid Particles**		
1.	Mist	Aerosols consisting of liquid droplets	Sulphuric Acid Mist
2.	Fog	Aerosols consisting of water droplets	
(B)	**Solid Particles**		
1.	Dust	Aerosols consisting of solid particles that are blown into the air or are produced from the larger particles by grinding them down	Dust Storm
2.	Smoke	Aerosols consisting of solid particles or a mixture of solid and liquid particles produced by the chemical reaction, such as by fires.	Cigarette Smoke, smoke from burning garbage etc.
3.	Fumes	Generally means the same as smoke, but often used to indicate aerosols produced by condensation of hot vapour of metals	Zinc/ Lead fumes etc.

The suspended particulate matter in air may prove to be harmful to human health, inspite of the fact that the human respiratory system has a number of mechanisms for protecting the lungs from the entry of particles from air along

with respiration. Infact, the bigger particles (>10μ) can be trapped by hairs and sticky mucus in the lining of the nose (Figure 1 and Figure 2).

Smaller Suspended particles up to 10 microns (μ) can although reach Tracheo-bronchial system, but get trapped there in the mucus. They are sent back to the throat by beating of hair like cilia, from where they can be removed by spitting or swallowing. However, very small suspended particle may still reach the lungs, and damage the lung tissues, causing diseases like asthma, bronchitis and even lung cancer, when such particles bring with them toxic and carcinogenic pollutants attached to the surfaces of the particles (Garg, 2010) .

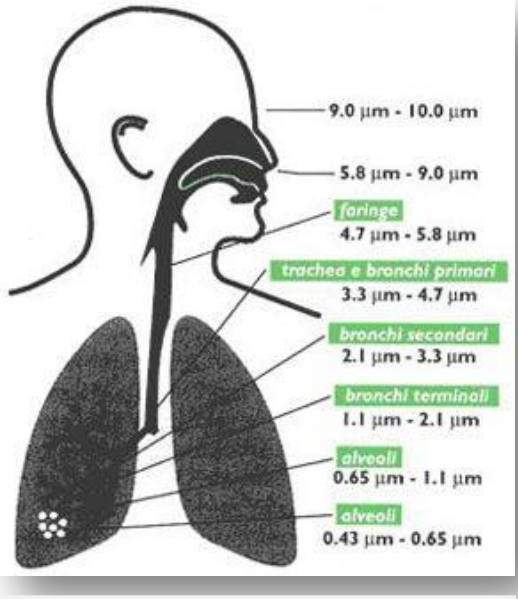

Figure 1. Deposition trend of Suspended Particles in Nasopharyngeal, Tracho-bronchial and Pulmonary regions [USEPA AQI, 2003]

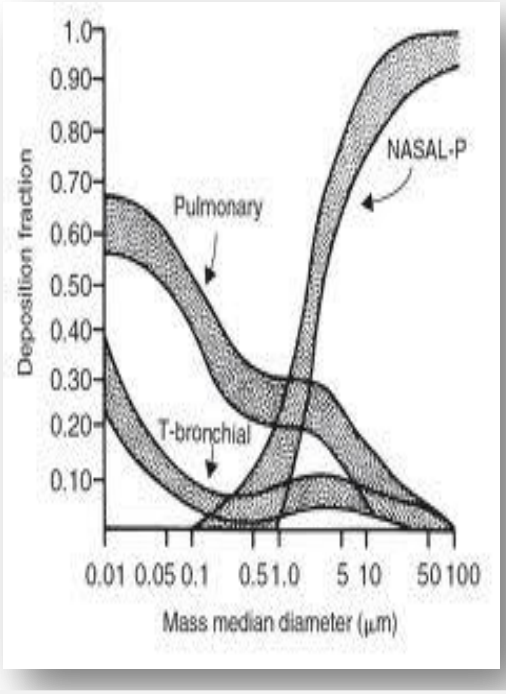

Figure 2.Percentage of particles of different sizes deposited in the Respiratory Tract. [Garg S. K., 2010]

During air pollution monitoring, it, therefore becomes necessary as to not only study and control the total suspended particulate matter, but also the more harmful smaller Respiratory Suspended Particulate Matter (RSPM). The smaller sized particles up to 10 micron in size are designated as PM_{10} or RSPM. The

National Ambient Air Quality Standards in India prescribe the maximum annual average concentrations of RSPM as 60µg/m^3 (NAMP, 2012).

Further advancements in air pollution studies have also shown that the particles which are smaller in size than 10 µ, prove to be highly more dangerous to human health. Such smaller particles of sizes up-to 2.5 µ, called $PM_{2.5}$, are hence also being monitored in the modern days. Considering their importance, the National Ambient Air Quality Standards of India have specified maximum annual concentration of $PM_{2.5}$ as 40µg/m^3. (NAMP, 2012).

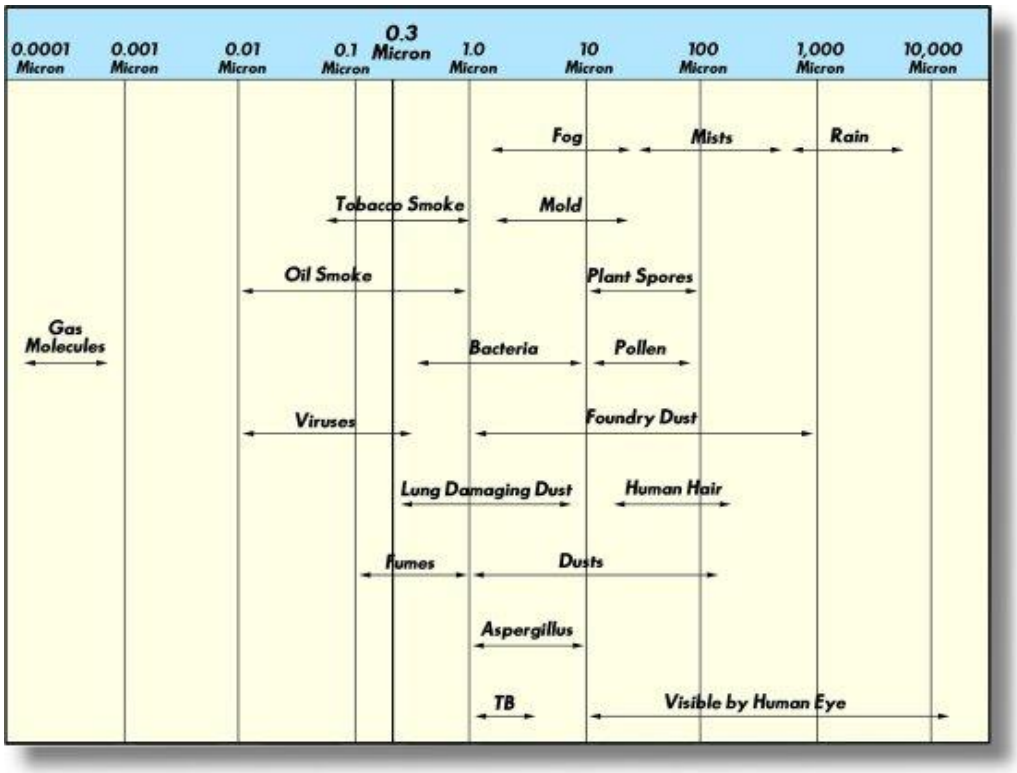

Figure 3. Various types of suspended particles in air with respect to their relative sizes. [Garg S. K., 2010]

[1.4] Health effects of PM_{10}

Particles' smaller than 10 micrometers in diameter can cause or aggravate a number of health problems and have been linked with illnesses and deaths from heart or lung diseases. These effects have been associated with both short-term

exposures (usually over a 24-hour period, but possibly as short as one hour) and long-term exposures (years). Sensitive groups for particle pollution include people with heart or lung disease, older adults (who may have undiagnosed heart or lung disease) and children.

People with heart or lung diseases—such as congestive heart failure, coronary artery disease, asthma, or chronic obstructive pulmonary disease—and older adults are more likely to visit emergency rooms, be admitted to hospitals, or in some cases, even die. When exposed to particle pollution, people with heart disease may experience chest pain, palpitations, shortness of breath, and fatigue. Particle pollution has also been associated with cardiac arrhythmias and heart attacks (USEPA AQI, 2003).

When exposed to particles, people with existing lung disease may not be able to breathe as deeply or vigorously as they normally would. They may experience symptoms such as coughing and shortness of breath (USEPA AQI, 2003). Healthy people also may experience these effects, although they are unlikely to experience more serious effects.

Particle pollution also can increase susceptibility to respiratory infections and can aggravate existing respiratory diseases, such as asthma and chronic bronchitis, causing more use of medication and more doctor visits (USEPA AQI, 2003).

Particulate matter has been consistently associated with cardiovascular disease development and progression (Miller, 2012) and is believed to contribute to development either indirectly through the autonomic nervous system or inflammatory responses, or directly via entry into systemic circulation and subsequent damage to blood vessels (Nelin, 2012). However, it's unclear whether changes in the microcirculation—the small veins (venules) and arteries (arterioles) that compose the majority of the circulatory system—might also contribute (Johnson, 2008).

A new study in Environmental Health Perspectives (EHP, 2013) explores the impact of particulate matter on small blood vessels by studying the retina

(Louwies, 2013). Researchers suspect that air pollution may cause heart disease, in part, by limiting the blood vessels' ability to bring blood to the heart. This hypothesis has been difficult to test since looking at the very small blood vessels in people's hearts is challenging. By using photographs of the tiny, hair-like blood vessels in people's eyes, researchers are able to get a direct look at how air pollution may affect other very small blood vessels in the body like those that bring blood to our hearts.

This approach was used in a previous analysis of data from the Multi-Ethnic Study of Atherosclerosis (MESA), a multicenter prospective investigation of cardiovascular disease (Adar, 2010). They found that both short- and long-term exposure to elevated levels of fine particulate matter was associated with narrowing of the arterioles and widening of the venules, measured as central retinal arteriolar equivalents (CRAE) and central retinal venular equivalents (CRVE), respectively (Louwies, 2013).

Extending that approach to younger and healthier cohort investigators in the current study recruited 84 individuals aged 22–63 years old with no history of cardiovascular disease or diabetes. The participants, all of whom worked at the Flemish Institute for Technological Research (VITO) in Mol, Belgium, completed up to three clinical visits and answered questionnaires about current health, lifestyle factors, and time spent in traffic in the preceding 24 hours. Study visits included photography of the fundus (interior surface) of the right eye for each participant as well as blood pressure and heart rate measurements for participants who completed two or three visits (Barrett, 2013).

An air monitoring station within 10 km of the institute provided coarse particulate matter and black carbon exposure data at 2, 4, 6, 24, and up to 48 hours prior to each visit. During the course of the study (January to May 2012), observed CRVE did not change significantly, but decreases in CRAE were measured in association with higher exposures to coarse PM_{10} and black carbon. Associations remained significant in multiple statistical analyses no matter how the data was looked at. s. It is a convincingly robust conclusion. CRAE and CRVE were both associated with

cardio-vascular disease in other studies, although it is unclear whether they trigger the disease process or simply arise from it.

The authors are not implying that the observed association has any immediate clinical implications. But the finding is consistent with downstream effects of air pollution that are already known to lead to atherosclerosis. The repeated measurements design is the strength of the study. By collecting multiple (i.e., repeated) measurements on the same people over time, the authors were able to estimate the impacts of day-to-day fluctuations in pollution on individuals free of confounding by characteristics that vary among people.

The estimated changes in CRAE were about three times larger than those associated with similar levels of air pollution in the MESA analysis. However, the authors of the current study suggest that the younger and healthier study population may have had blood vessels that were better able to adapt to changing pollution conditions (Adar, 2013). The current study also looked solely at short-term exposures (2–24 hours)

versus the short- and long-term exposures (24 hours and 2 years) evaluated in the MESA analysis. The researchers found no evidence of a threshold below which changes were not seen, consistent with the MESA analysis and other studies[R D Brook R. D., 2010 and Adar S. D., 2010]. This well-conducted study confirms the previously published findings from the MESA study, which indicated that air pollution may affect the very small blood vessels in our body.

As in other studies, individual exposure data were not available, raising the possibility of exposure misclassification. Further, the participants were not representative of the general population, so the results may not be broadly applicable. However, the investigators have already begun follow-up research with wearable air-monitoring devices, Global Positioning System devices, and a more diverse study population (Barrett, 2013).

[1.5] Scenario of the Indian cities

Almost half of the total cities monitored under National Air Quality Monitoring Program (NAMP), an initiative by Central Pollution Control Board (CPCB), have critical levels of PM_{10}. CPCB classifies cities as critically polluted if the levels of criteria pollutants are more than 1.5 times the standards (60μg/m^3 annually for PM_{10}). Levels up to 1.5 times the standards are labeled high. Levels that reach up to 50 per cent of the standards are moderate. And lower than that is low. In 2007 data of 121 cities was analyzed and only three cities Dewas, Tirupati, Kozhikode recorded low pollution level (NAMP, 2012).

Indian cities are reeling under heavy particulate pollution with 52 percent of cities (63 cities) hitting critical levels (exceeding 1.5 times the standard), 36 cities with high levels (1–1.5 times the annual standard) and merely 19 cities are at moderate levels, which is 50 per cent below the standard.

The PM_{10} levels remain persistently high in the northern region. In the NCR towns Noida, Faridabad including NCT Delhi have high levels of PM_{10} and in past two years the levels have increased. Only in hill towns such as Shimla, Gajraula and Parwanoo PM_{10} levels are low. In western and eastern India, there is usually a mixed trend. Eastern cities, including Shillong, Angul, Rourkela and Howrah, show an increasing trend and in the west PM_{10} levels have declined in some cities like Ahmedabad, Solapur, Nagda and Jamnagar but increased in Mumbai, Kota and Satna. In southern India, though the cities generally have lower PM_{10} levels compared to the northern ones, some cities show an increase. In cities such as Hyderabad, Visakhapatnam, Tuticorin, and Bangalore there is an increasing trend. A sharp declining trend has been noted in Thiruvanthapuram, Kochi and Mysore during 2000-2007 (NAMP, 2012).

[1.6] Prediction of Concentrations of Air Pollutants

[1.6.1] Dispersion of Air Pollutants into the Atmosphere

When once a pocket of smoke, containing air pollutants, is released into the atmosphere from a source like an automobile or a factory chimney, it gets dispersed in the atmosphere into the atmosphere into various

directions depending upon the prevailing winds and temperature and pressure conditions in the environment.

From our knowledge of meteorology and hydrology, we know that the temperature conditions of the environment are defined by a technical term called lapse rate.

In the troposphere, the temperature of the ambient (surrounding) air normally decreases with an increase in the altitude. This rate of change of temperature is called lapse rate. This rate differs from place to place and even time to time at the same place. Hence, the prevailing lapse rate at the particular time and particular place, which can be determined by sending up a balloon equipped with a thermometer and a self-recording mechanism, is known as the environmental lapse rate (ELR).

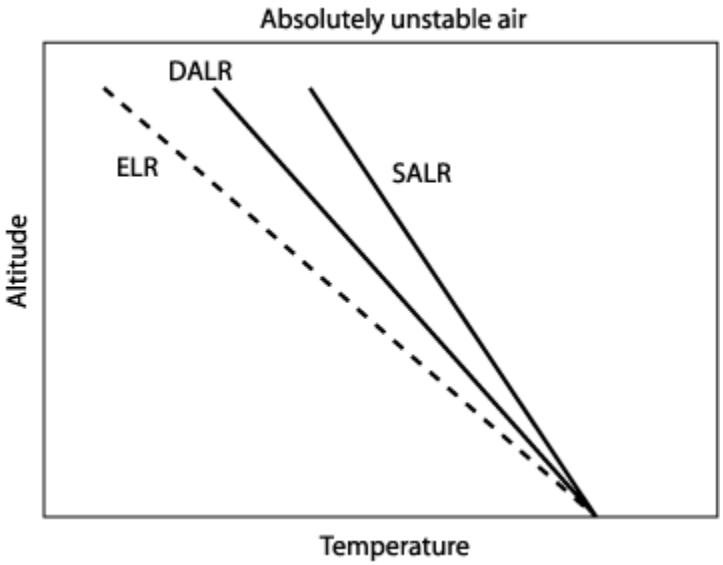

Figure 4. Change of temperature with height in the environment called ELR. [Garg S. K., 2010]

Under the prevailing environmental conditions, when a parcel of air, which is hotter and lighter than the surrounding air, is released, then naturally it tends to rise up, until of course, it reaches to a level, at which its own temperature and density becomes equal to that of the air surrounding it, at that height. Hence, when a pocket of artificially heated air is emitted into the environment, it rises up, expands, becomes lighter and gets cooled. The

rate at which the temperature decreases, as this parcel gains height may be considerably different from the environmental lapse rate of the air through which the smoke parcel moves. Hence, it is very necessary to differentiate between the environmental lapse rate and the internal temperature change which occurs within the rising parcel of air gases.

This internal decrease of temperature with height, which occurs in the rising parcel of the air mass, can be theoretically calculated, by assuming the cooling pressure to be adiabatic. Using the law of conservation of energy and gas laws, therefore, it has been possible to mathematically calculate this rate of decrease of temperature with height called Adiabatic Lapse Rate (ALR).

Dry air, expanding and cooling adiabatically cools at $9.8^{o}C$ per Km and it is called dry adiabatic lapse rate. In saturated air, this rate is calculated to be $6^{o}C$ per km and it is known as wet adiabatic lapse rate.

Since a rising parcel of emitted smokes, will normally, neither be fully dry nor be fully saturated, the actual adiabatic lapse rate, representing cooling of emitted smokes will be somewhere between the dry adiabatic rate ($9.8^{o}C$ /Km) and wet adiabatic rate ($6^{o}C$ /Km). Depending on the relative positions of the ALR line and the ELR line on the graph sheet, the stability of the environment is determined.

The three major relative positions of the ELR line with reference to ALR line are discussed below:

When the ELR is more than the ALR, then the environment is said to be unstable. In such a case, the rising parcel of air will always remain warmer than the surrounding environment. This is so because, as we go up, the environment is getting cooler more quickly than the rising parcel of the lighter air, and hence the rising parcel of air will always remain warmer than the environment. The reverse is also true, and hence a descending parcel of heavier air will always cooler than the surrounding air, because as we go down, the environment is getting warmer more quickly than the parcel of air.

It, therefore, follows that in such a case, when the environment lapse rate is more than the adiabatic lapse rate, a rising parcel of warmer lighter air will continue to lift up; whereas a parcel heavier cooler air will continue to move down. In such circumstances, the environment is unstable, and the dispersion of pollutants will be rapid due to marked vertical mixing of the air, although, however, the degree of turbulence may even sometimes bring the smokes touch the ground, under the pressure of the downward moving heavier air.

The prevailing Environmental Lapse Rate (ELR) in such a condition is known as adiabatic lapse rate, as it is more than the adiabatic lapse rate.

In the reverse case, when the ELR is less than the ALR, the environment is said to be stable, and this prevailing environmental lapse rate is called sub-adiabatic lapse rate (as it is less than the adiabatic lapse rate).

The third case would be the one, when ELR equals the ALR and both the lines coincide. The environment in such a case is called neutral.

In an unusual case, when the temperature of the environment (that is, ambient air) increases with the altitude, then the lapse rate becomes negative from its normal state. Negative lapse rate occurs under conditions, usually referred to as inversion, a state in which the warmer air lies over the colder air below. Such temperature inversions represent a highly stable environment. There are two types of inversions – radiation inversion and subsidence inversion.

The radiation inversion is a phenomenon occurring from the unequal cooling rates for the Earth and the air above the Earth. This type of inversion may extend a few hundred meters into the friction layer, and is characteristically a nocturnal phenomenon that is likely to breakup easily with rays of the morning sun. Such an inversion in the environment, helps in the formation of the fog when the air is wet, and simultaneously catches gases and particulate matter, as it stops their upward lifting, thereby creating concentration of pollutants in our close environment. This type of inversion is more common in winters than in summer because of the longer

nights. Valley areas also have an inversion frequently, because of the absence of the horizontal movement of air doe to the surrounding high ground.

The subsidence inversion is usually associated with a high pressure system, and is caused by the characteristic sinking or subsiding motion of air in a high pressure area surrounded by a low pressure area (anti-cyclone). The air, circulating around the stationary high pressure, descends gently @ about 1000m per day. As the air sinks, it is compressed and gets heated to form a warm dense layer over the cool layer below. Such inversion layers may be formed from the ground surface to about 1600m or so. Such an inversion layer, by stopping the upward movement of polluting smokes, will cause the concentration of pollutants in our immediate environment. When the thickness or height of this inversion layer is less than 200m or so, extreme pollution would occur. Such an inversion will be more dangerous than the radiation inversion, and may occur at modest altitudes and may often remain for several days.

Sometimes, both the radiation as well as subsidence inversion may occur simultaneously, causing what is known as double inversion.

[1.6.2] Impact of Winds on Dispersion of Pollutants

The moving air is known as wind. Such a movement of the air is caused by the unequal distribution of the atmospheric temperature and pressure over the earth's surface, and is largely influenced by the rotation of the earth. The direction of winds is always from the high pressure areas to low pressure areas, but the coriolis force tends to deflect the air currents out of these expected patterns. Regional and local geographical and topographical features may also affect the direction and speed of winds.

The quicker heating and cooling of the earth as compared to the neighbouring sea, may also cause the flow of sea breezes from sea to land during the day time, and flow of land breezes from land to sea during nights after sunset, respectively. Such a wind pattern may also contribute to air pollution problems.

In the friction layer at the Earth surface, winds are generally gusty and changeable, primarily due to locally generated effect or thermal turbulence.

Wind speed is generally measured by an anemometer at a height, Z_o. Knowing the wind velocity (u_o) at the anemometer height Z_o, we can work out the velocity u at any other height Z by using the formula

$$u = u_o[z/z_o]^k \quad \ldots(1)$$

where, k is a constant =(1/9) for large lapse rates, and (1/3) for marked normal inversions, the average normal value being (1/7). [Garg S. K., 2010]

The direction and the speed of the surface winds primarily govern the drift and diffusion of the polluted gases and particulate emissions from automobiles and factories etc. emitted near the ground levels. The higher the wind speed at or near the point of emission, the more rapidly the pollutants would be calculated away from the source. The pollutants so dispersed, will not exist at the same concentration, but will rapidly be diluted with greater and greater volumes of air.

On the other hand, when wind speeds are slow, the pollutants tend to concentrate near their source of emission; and the longer the duration of such light winds, the larger will be the concentration of pollutants.

Gustiness, which is directly proportional to the wind speed, is another important characteristic of the surface winds and determines the extent to which the pollutants are mixed and diluted with the ambient air.

Wind Speed, can thus, be related to the concentration of pollutants, both being inversely proportional to each other. This simple relationship is, however complicated by various other factors, like atmospheric turbulence and stability, geographical barriers in the flow of winds, presence of moisture in the atmosphere etc. [Garg S. K., 2010]

[1.6.3] Lapse Rates and Dispersion of Pollutants

By comparing the two lapse rates, it is possible to predict to some extent, as to what will happen to gases emitted from a source; the emitted gases being known

as plume and their source of origin as stack. Typical types of environmental conditions, characterized by different relative positions of environmental lapse rate and adiabatic lapse rate lines, which are generally encountered in the lower atmosphere (less than 300m above the ground) and the manner in which the emitted plume behaves under each of these conditions is explained below:

Looping plume has a wavy character and occurs in super adiabatic environment; which produces highly unstable atmosphere, because of rapid mixing. During the high degree of turbulence, the dispersion of plume would be rapid, yet higher concentrations near the ground may occur due to turbulence, before the dispersion is finally completed. Hence, in areas where environment is generally super-adiabatic, higher stacks may be needed to prevent premature contact of pollutants with the ground. Such conditions will then ensure very good dispersion of pollutants; but the automobile exhausts cannot be dispersed well, because they are released at the lower levels (Garg, 2010).

Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the environment lapse rate is equal to or very near to the adiabatic lapse rate. The upward lifting of the plume will continue till it reaches an air of density similar to the plume itself (Garg, 2010).

The neutral plume tends to cone, when the wind velocity is greater than 32km/hr, and when the cloud cover blocks the solar radiation by day and terrestrial radiation by night. Coning plume also occurs under super-adiabatic conditions (ELR>ALR). Under such conditions, the environment is slightly stable and there is a limited vertical mixing, thereby increasing the probability of air pollution in the area. The plume dispersion is known as coning, because the plume makes a cone like shape about the plume line (Garg, 2010).

Under extreme inversion conditions, caused by negative environmental lapse rate, from the environmental lapse rate, from the ground and up-to a considerable height, extending even above the top of the stack, the emission will spread only horizontally, as it cannot lift due to extremely stable environment. In such a case, there will be no vertical mixing, and the plume will simply extend horizontally over large distances. Such a plume pattern is called fanning plume. In

areas, here such conditions are caused by radiation inversion, high-rise stacks, rising higher than the usual inversion layer, may be adopted .But, in areas, where subsidence inversions are of frequent occurrence, even such a step is not practical and economical, because subsidence inversions usually extend to much greater heights (Garg, 2010).

When there exists a strong super adiabatic lapse rate above a surface inversion, then the plume is said to be lofting. Such a plume has minimum downward mixing, as its downward motion must be prevented by inversion, but the upward mixing will be quite rapid and turbulent. The dispersion of pollutants will therefore, be rapid, and no concentrations will touch the ground. Hence, this would be the most ideal case for dispersion of emissions (Garg, 2010).

When an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below the stack, then the plume is said to be fumigating. In such a case, the pollutants cannot escape above the top of the stack because of inversion layer, and they will be brought down near the ground due to turbulence in the region above the ground and below the inversion, caused by the strong lapse rate. This represents quite a bad case of atmospheric conditions for dispersion (Garg, 2010).

When inversion layers exist above the emission source, as well as below the source, then naturally the emitted plume will neither go up, nor will it go down, and would remain confined between two inversions. Such a plume is called trapping plume, and is considered a bad condition for dispersion, as dispersion cannot go above a certain height (Garg, 2010).

[1.6.4] Impact of Moisture and Precipitation on Dispersion of Air Pollutants

The moisture content and the form in which it is present in the atmosphere, may considerably affect the quality of air at a particular region. The presence of water vapour affects the air quality, primarily by blocking and obstructing the solar radiation reaching the ground, and also the heat radiation reflected from the surface. Humidity also leads to the formation of fogs, and increases the earth's corrosive action of air pollutants.

Excessive moisture in the atmosphere will finally lead to rainfall, which is helpful in increasing the quality of ambient air, because they wash down the pollutants to the earth, to be ultimately drained out with rain-runoff. [Garg S. K.,2010]

[1.7] Brief description of the study area - Rourkela

A steel city, Rourkela, is selected as a study area in the present research work. It is one of the most important industrial cities in the Sundargarh district of the State of Odisha in India. It has a population of more than four hundred thousand people, many of them tribals, belonging to different indigenous communities (Orissa State Water Plan Report, 2004).

Table 2. Rourkela : Facts and Figures (Orissa State Water Plan Report, 2004)

A Brief Profile of Rourkela	
Annual Rainfall	128.8 cm. Average
Temperature	46.3°C (Max.) in Summer 07° C (Min.) in Winter
Latitude	22°-12° North of the Equator
Longitude	84°-54° East of Meridian
Altitude	219 Mts above Sea Level
Area	200 Sq. Km. Approx..
Density of Population	2,500 per Sq. Km. Approx.
Sex Ratio	835 Female per 1000 male (as per the censes of 1991)
Literacy	86.5% (1996)
Per Capita income	Highest in Orissa
Population (1991)	3,98,864 SC 35,687 ST 66,627
Population (2001)	4,84,292 (Township: 206,566, Rourkela:224,601)
Total Carbon Emissions (RSP)	16.54 MTPA
Increased Emission from Expansion Rourkela Steel Plant (TSP)	9.48 MTPA

The population density in the industrial complex is 3,288 persons per square kilometer. The Industrial complex is situated approximately 215-230 m above the mean sea level (MSL). The city is spread over an area of 121.7 km^2 in close proximity of iron ore, dolomite, limestone and coal belts. The region is surrounded by the Durgapur hill range. The perennial Koel River flows through this valley and meets another perennial river Sankh at Vedavyas on the outskirts of Rourkela. Beyond this, the river is known as Brahmani. Brahmini is one of the 14 major river systems in the country and is considered among the most polluted

in parts. Brahmini, Koel and Sankh rivers form the major drainage in the area (Orissa State Water Plan Report, 2004).

[2] Method for measurement of PM_{10} [IS 5182(Part 23): 2006]

[2.1] Terminology:

Respirable Suspended Particulate Matter PM_{10}, size convention closely resembles the thoracic size distribution and has a 50 percent penetration at 10 micron equivalent diameter/aerodynamic diameter.

Inhalable Particles (IPM), are particles that can be breathed through the nose or mouth— or all particles that enter the human respiratory tract.

Thoracic Size Distribution includes particles that travel past the Larynx and reach the gas exchange region of the lungs (IS 5182(Part 23): 2006).

[2.2] Principle:

Air is drawn through a size-selective inlet and through a 20.3 cm x 25.4 cm filter at an flow rate of about 1 000 l/min. Particles with aerodynamic diameter less than the cut-point of the inlet are collected by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM_{10} in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled (IS 5182(Part 23): 2006).

[2.3] Range and Sensitivity:

Lower Quantifiable Limit - For a 24 h sample duration at about average 1000 l/min, the lowest detection limit is determined by the reproducibility of the filter weight difference which shows a standard deviation of approximately +2 mg. The three sigma detection limit is then approximately 3.5 $\mu g/m^3$. The three sigma lower quantifiable limit depends on the filter used and may be even 5 $\mu g/m^3$.

Upper Quantifiable Limit - For a 24 h sample duration at about average 1000 l/min, the upper quantifiable limit is 1 000 $\mu g/m^3$. However, the exact value depends on the nature of the aerosol being sampled; very small particles will clog

the filter at a relatively low mass loading while larger particles will bounce off during sample transport at high concentrations (IS 5182(Part 23): 2006).

[2.4] Interferences:

Passive Deposition - Passive deposition occurs when windblown dust deposits on a filter both prior to and after sampling.

Re-circulation - Re-circulation occurs when the blower exhaust, which contains carbon and copper particles from the armature and brushes, is entrained in the sample air. Positive bias of up-to 0.15 $\mu g/m^3$ has been measured, which is insignificant mass interference but which may affect carbon and copper measurements. Re-circulation can be minimized by assuring a tight seal between the blower and the sampler housing or by ducting blower exhaust away from the sampler. If the cyclone walls or the cup below are not cleaned and have accumulated too much particulate some of these may get re-entrained and reach the filter paper causing erroneously high PM_{10} values to be reported.

Filter Artifact Formation - Sulphur dioxide, nitrogen oxides, nitric acid and organic vapours can be absorbed on the filter medium along with the suspended particles thereby causing positive biases. Samples taken in the presence of high SO_2 concentrations have been shown to yield up to 10 $\mu g/m^3$ of excess sulphate on glass fiber filters.

Filter Conditioning - Filter conditioning environments can result in different mass measurements as a function of relative humidity (RH). Hydroscopic particles take on substantial quantities of water as RH increase, especially above the deliquescence point of approximately 70 percent RH. Increased mass deposits of 50 percent or more have been observed as RH increases to 100 percent. Twenty four hours at a constant temperature and RH is considered adequate for sample equilibration.

[2.4.5] Shipping Losses - Particle loss during transport occurs when filters are heavily loaded with large dry aerosols. It is more prevalent on membrane than on glass fiber filters. Particle loss is minimized by shorter sample duration in heavily

polluted environments, use of fibre as opposed to membrane filters, folding the filter prior to transport and careful shipping procedures (IS 5182(Part 23): 2006).

[2.5] Apparatus:

Sampler — The essential features of a typical cyclonic fractionating sampler for respirable particulate matter are those of a compact unit consisting of protective housing, blower, voltage stabilizer, time totalizer, rotameter and filter holder capable of supporting a 20.3 cm x 25.4 cm glass fibre filter.

Cyclonic Size Selective Inlet for PM_{10} Sampling

Volume Flow Controllers — For a PM_{10} Sampler flow rate is maintained within 15 percent of the designed flow rate (1000 l/min) for the cyclone separating device. An automatic flow controller with flow sensing device and feedback should be provided to constantly monitor the flow rate and compensate for decrease in flow rate due to filter choking by dust load or flow rate changes on account of voltage fluctuation. A voltage stabilizer may be provided to compensate for voltage fluctuation.

Analytical Balance — having a sensitivity of 0.01 mg.

Elapsed Timer — accurate to + 1 min.

Flow Metering Device — accurate to +5 percent.

Equilibration Rack— The rack to separate filters from one another so that the equilibration air can reach all parts of the filter surface.

Numbering Machine — An incrementing numbering machine that prints 4 to 8 digit ID numbers.

Psychrometer

Filter Media — A 20.3 cm x 25.4 cm glass fibre filter.

Filter Jacket — A smooth, heavy paper folder or envelope is used to protect the filter between the lab and field and during storage. Filter and sampling data are

often recorded on the outside of the jacket, but this should not be done while the filter is in the jacket to prevent damage. [IS 5182(Part 23): 2006]

[2.6] Procedure:

Calibration of Sampler - The sampler shall be periodically calibrated at least once in six months or whenever a major repair/ replacement of blower takes place, by using top loading calibrator traceable to national standard (Manual of Instrumex NPM-HVS/R).

Filter Inspection - Clean the light table surfaces. Filters should be handled with clean hands to prevent contamination. Clean lands each filter on the light table and examine it for pinholes, loose particles, tears, creases, limps or other defects. Loose particles may be removed with a soft brush. Filters not meeting the above visual criteria shall not be used. If chemical analyses are to be performed, one or two filters from each lot shall be analyzed for blank levels.

Filter Identification - Apply an ID number to the upper right hand comer on the smoothest side of each filter with the incrementing number machine. Gentle pressure is to be used to avoid damaging the filter. Record this number in a chain of the custody log-book and on a filter jacket. The chain of custody log-book contains columns opposite every filter ID to record dates and technician initials for filter inspection. Equilibration, pre-weighing, shipment to field, receipt from field, re-equilibration, post-weighing and storage - these records identify the disposition of each sample and prevent the creation of two samples with the same ID.

Filter Equilibration - Place blank or exposed filters in air tight desiccators having active desiccant in the control temperature 15 to 27°C and 0 to 50 percent relative humidity environment for 24 h prior to weighing. The rack should separate filters such that all surfaces are exposed to the equilibration environment. Measure the temperature and relative humidity of the controlled environment and record the values in the equilibration column of the chain of custody log-book.

Filter Weighing - Weigh filters in-groups of 10 to 50. Use clean hands for all filter handling. Stack filter jackets with data forms printed on them in the same order (in ascending order of filter ID number, if possible) as the order of filters in the equilibration rack. Adjust the balance tare to read zero with nothing in the weighing chamber and adjust the span to read (or verify that it read) 30000 g +/- 0.0003 g with the 3 g standard weight on the weighing pan. Place a filter on the weighing pan and obtain a stable reading. Record the weight on the data form in

the blank or exposed filter column. Verify the zero and span every ten filters. Place each tilter in its filter jacket when weighing is complete, but do not seal the jacket opening. A separate technician randomly selects four filters or 10 percent of all filters in the batch (whichever is larger), re-weigh them and subtract this check-weight value from the corresponding routine weigh. lf any cheek-weight differs by more than 4.0 mg from the routine weight, re-weigh all the filters. Seal filter jackets and ship blank filters to the field or place exposed filters into storage.
Field Sampling - Tilt back the filter house cover and secure it according to the manufacturers' instructions. Loosen the faceplate wing nuts and remove the faceplate. Remove the filter from its jacket and center it on the support screen with the rough side of the filter facing upwards. Replace the face-plate and tighten the wing-nut to secure the rubber gasket against the filter edge. Gently lower the inlet. Inertial jet and cyclonic inlets must have their seals in contact with the top of the faceplate. Look underneath the inlet just as it is coming into contact with the faceplate to assure that this contact is being made. It may be necessary to re-adjust the position of the filter motor assembly in the sampler housing to obtain such a seal. Excessively windy and wet conditions should be avoided when changing samples. Pre-loading in a filter cartridge assembly, temporary removal of the sampler to a protected area, or a wind or rain shield may be used it the sample must be changed in inclement weather. Set the timer for the desired start and stop time. Replace the chart paper in the flow recorder, if there is one, set the proper time and mark the time and date on the chart. For a manually flow controlled sampler turn on the motor for 5 min and measure the exhaust pressure with a pressure gauge or rotameter. Read the flow rate corresponding to its exhaust pressure from the calibration curve and record it on the data sheet. Turn off the motor and assure that the timer is in its automatic mode. For automatically flow-controlled units, record the designed flow rate on the data sheet. Record the reading of the elapsed time meter. The specified length of sampling is commonly 8 h or 24 h. During this period several reading (hourly) of flow rate should be taken (IS 5182(Part 23): 2006).
After sampling is complete, record the final flow rate and the elapsed time in the same manner. Subtract the initial elapsed time from the final elapsed time to determine the sample duration. Remove the faceplate by removing the wing nuts. Fold the filter in half lengthwise by handing it along its edge with the exposed side inward. Insert the filter in its jacket. Note the presence of insects on the deposit, loose particles, non-centered deposits, Evidence of leaks, and unusual

meteorological conditions on the data sheet. Mark the flow-recorder chart, if any, and return it with the data sheet (IS 5182(Part 23): 2006).

[2.7] Calculation:

[2.7.1] Calculation of volume of air sampled:

V=Qt

Where,

V = volume of air sampled, in m^3;

Q = average flow rate, in m^3/min; and

t = total sampling time, in min.

[2.7.2] Calculation of PM_{10} in ambient air

PM_{10} (as $\mu g/m^3$) = $(W_2-W_1)/V*10\text{^}6$

Where,

PM_{10} = mass concentration of particulate matter less than 10 micron diameter, in m^3;

W_1 = initial of filter, in g;

W_2 = final weight of filter, in g;

V = volume of air sampled, in m^3; and

10^6 = conversion of g to µg.

(IS 5182(Part 23): 2006).

[2.8] Precision and Accuracy:

Mass of the filter deposit, flow rate .through the filter, and sampling time have typical precision of +2 mg, +5 percent and ((+/-)1 min, respectively, as determined from performance tests. The accuracy of those measurements can be well within these tolerances when determined with independent standards. These uncertainties combine to yield a propagated precision of approximately (+/-)13 percent at 10 $\mu g/m^3$. The filter deposit mass, measurement precision dominates at low concentrations while the flow rate precision dominates at high concentrations (IS 5182(Part 23): 2006).

Figure 5. PM_{10} Sampler

[3] Observations

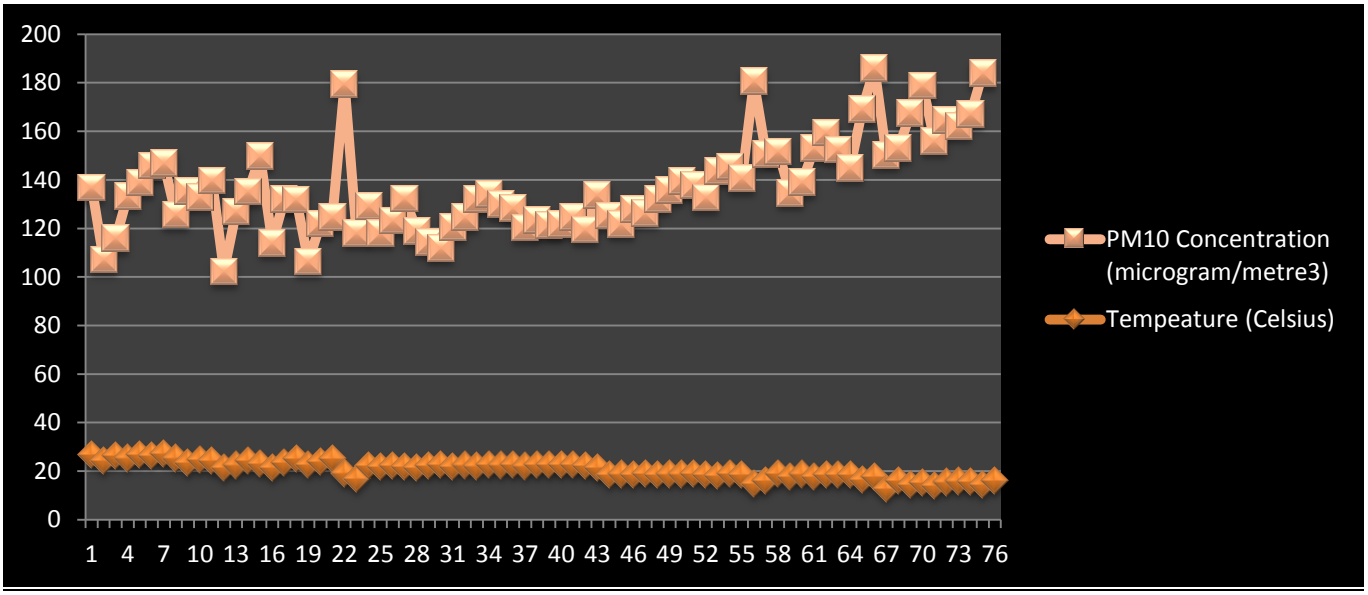

Figure 6. Plot showcasing the variation of temperature and corresponding PM_{10} concentration with time in days.

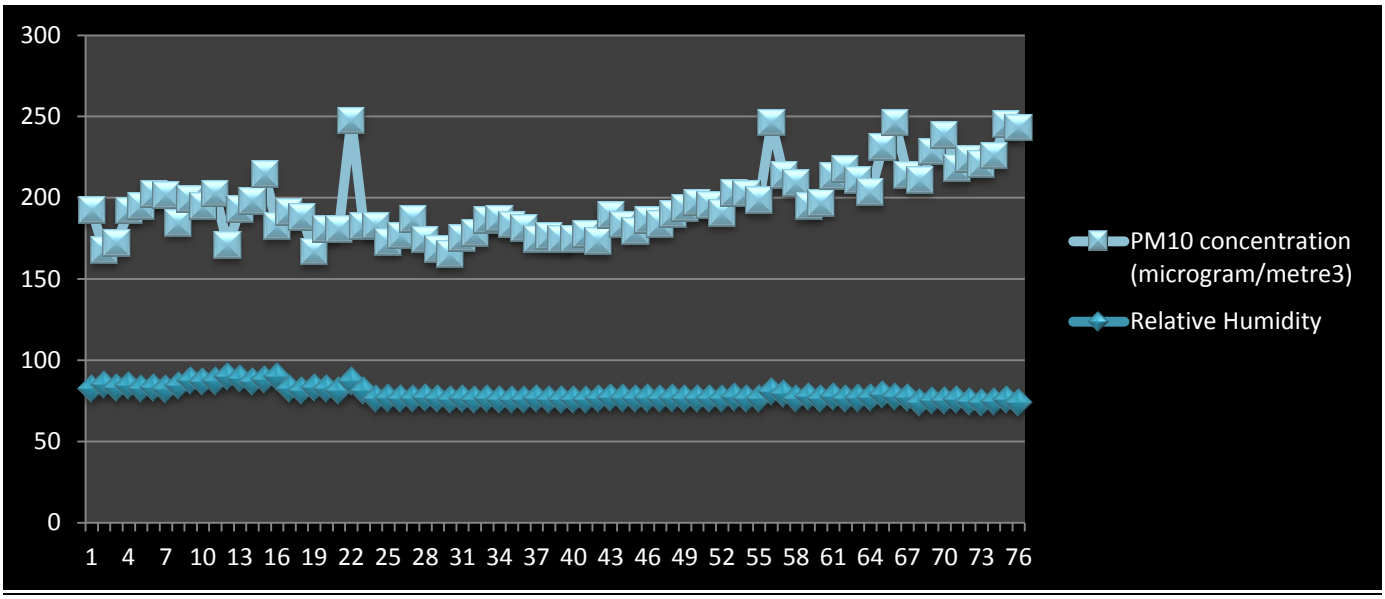

Figure 7. Plot showcasing the variation of Relative Humidity and corresponding PM_{10} concentration with time in days

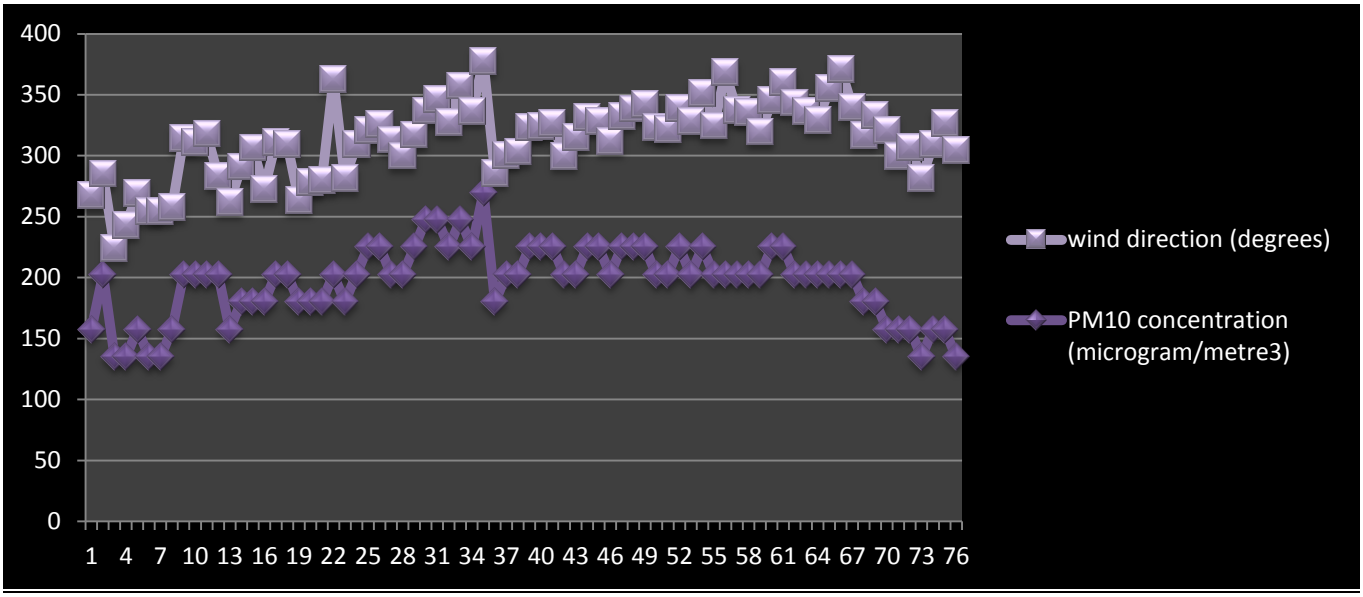

Figure 8. Plot showcasing the variation of Wind Direction and corresponding PM_{10} concentration with time in days

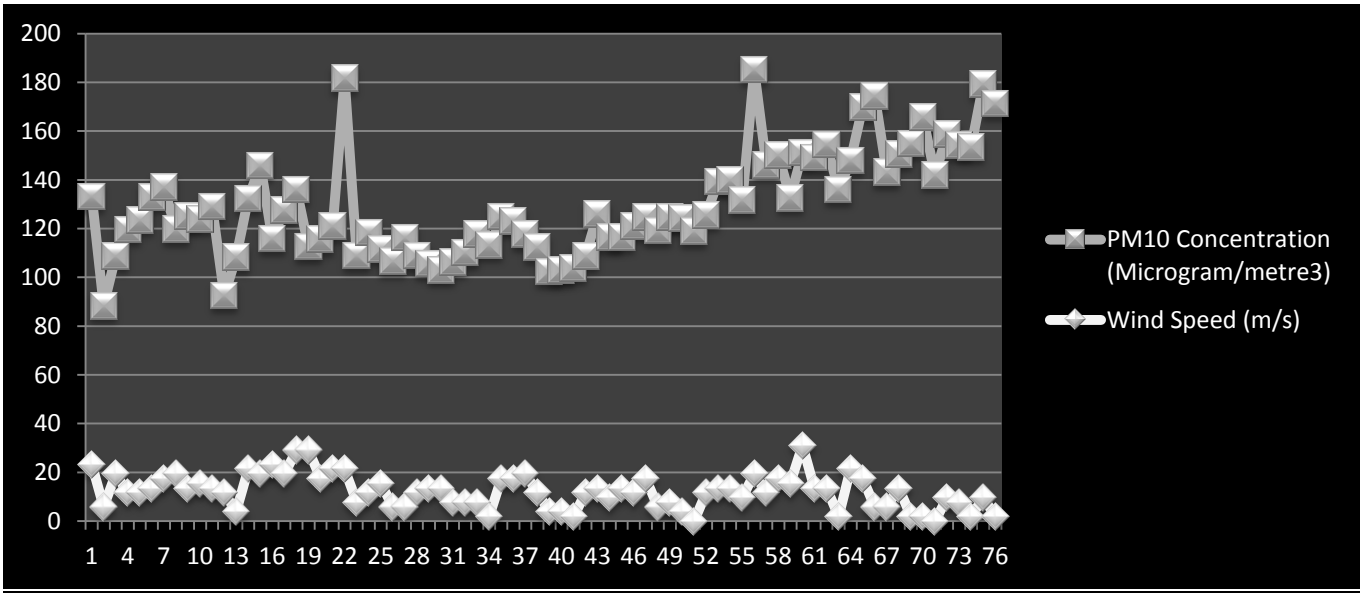

Figure 9. Plot showcasing the variation of Wind Speed and corresponding PM_{10} concentration with time in days

[4] Air Quality Modeling

[4.1] Multiple Linear Regression Analysis:

Linear regression is an approach for modeling the relationship between a scalar dependent variable y and one or more explanatory variables denoted X. The case of one explanatory variable is called simple linear regression. For more than one explanatory variable, the process is called Multiple Linear Regression.

The general expression of MLRA has the following form:

$$y = m_1 \cdot x_1 + m_2 \cdot x_2 + m_3 \cdot x_3 + m_4 \cdot x_4$$ (Kapoor, 1999).....(2)

For PM_{10},

$y = -5.6917*x_1 + 3.2072*x_3 - 0.0061*x_4 - 0.4341*x_2$ .....(3)

$R^2 = 0.6031$ (from Analysis)

Where, y the forecasted 8 hour peak value of PM_{10} concentration ($\mu g/m^3$).
x_1 is the average value of the air temperature.(^OC)
x_2 is the average value of the wind speed.(m/s)
x_3 is the average value of the relative humidity.
x_4 is the value of the angle determining wind direction.

The above model has been analyzed for performance on the threshold of various statistical parameters. These indexes are as follows:
Standard deviation (SD), which is a measure of the dispersion of a data set from its mean. The more spread apart the data is, the higher the deviation.
Mean bias error (MBE), which defines whether a model over- (positive value) or under- (negative value) predicts the observations.
Root mean square error (RMSE), which is a measure of the total deviation of predicted values from observed values.
Correlation coefficient (R), which reflects the extent of a linear relationship between the observed and the predicted values.
Index of agreement (d). It indicates the degree, to which the predictions of a model are error free.

Percent correct (PC), which represents the fraction of correct predictions over total predictions.
Range: 0 to 1. Perfect score: 1
Probability of detection (POD), which represents the fraction of correct predictions over total exceedances.
Range: 0 to 1. Perfect score: 1
Probability of false detection (POFD), which represents the fraction of false predictions over total non-exceedances.
Range: 0 to 1. Perfect score: 0
False alarm rate (FAR), which represents the fraction of false predictions over total exceedances.
Range: 0 to 1. Perfect score: 0

The formulae used to calculate the aforementioned indexes are presented in Table 3.

Table 3. Definition of Statistical Indexes, used for the evaluation of Models. (Papanastasiou, Melas & Kioutsioukis, 2007)

Index	Formula
MBE	$\mathrm{MBE} = \overline{P} - \overline{O}$ (3)
RMSE	$\mathrm{RMSE} = \left[\left(\sum_{i=1}^{N}(O_i - P_i)^2\right)/N\right]^{1/2}$ (4)
R	$R = \left[N\sum_{i=1}^{N}(O_iP_i) - \sum_{i=1}^{N}O_i\sum_{i=1}^{N}P_i\right] \Big/ \left\{\left[N\sum_{i=1}^{N}O_i^2 - \left(\sum_{i=1}^{N}O_i\right)^2\right]\cdot\left[N\sum_{i=1}^{N}P_i^2 - \left(\sum_{i=1}^{N}P_i\right)^2\right]\right\}^{1/2}$ (5)
d	$d = 1 - \left(\sum_{i=1}^{N}(O_i - P_i)^2\right) \Big/ \sum_{i=1}^{N}\left(\lvert P_i - \overline{O}\rvert + \lvert O_i - \overline{O}\rvert\right)^2$ (6)

P and O represent predicted and observed values, respectively, while the overbar indicates mean values. N is the number of values.

The mean of observed values O is 117.34 µg/m^3 which is slightly lesser to the predicted value of 128.7206 µg/m^3 by the model. The Mean Bias Error observed is 11.385 or 9.703%. The standard deviation of the observed values is 17.8 µg/m^3, a fact that demonstrates that the models managed to capture to a satisfactory degree, the variability of the observed data. The RMSE of the MLRA prediction was found to be 21.2846% of the mean of the observed values. NN model shows a higher correlation coefficient (0.609 vs 0.81) but the values of the index of agreement of both models are substantially equal to 73.33%. The index of agreement is considered to be more unbiased, as it is based on squared

differences between predicted and observed values. The high values of the index of agreement indicate a satisfying forecast of the 8h peak value of PM_{10} concentration by both models.

Table 4. Definitions of statistical indexes related to the model's ability to predict reliably the exceedances (Papanastasiou, Melas & Kioutsioukis, 2007).

Index	Formula
PC	$PC = (A + D)/(A + B + C + D)$ (7)
POD	$POD = A/(A + B)$ (8)
POFD	$POFD = C/(C + D)$ (9)
FAR	$FAR = C/(C + A)$ (10)

A is the number of exceedances that were observed and predicted, B is the number of exceedances that were observed but not predicted, C is the number of exceedances that were predicted but not observed and D is the number of non-exceedances.

In order to support that the models can predict accurately the exceedances of the imposed limit, the values of POD and FAR should be reasonably high and low, respectively. Moreover, the developed models can predict the exceedances and the non-exceedances in a satisfactory level. In particular, the values of PC show that 80% of the exceedances were predicted successfully, while the values of POFD show that only 10 and 11% of the non-exceedances were mis-predicted. In a nutshell, the following table gives various statistical valuations of the model.

Table 5. Evaluation of the Multiple Linear Regression Model

Percent Correct	**82.61%**
Probability of Detection	100%
Probability of false detection	50%
False Alarm Rate	21.05%
Mean Predicted Value	117.34 µg/m^3
Mean Bias Error	9.703%
Root Mean Square Error	21.284
Correlation Coefficient R	0.609
Index of Agreement d	0.733

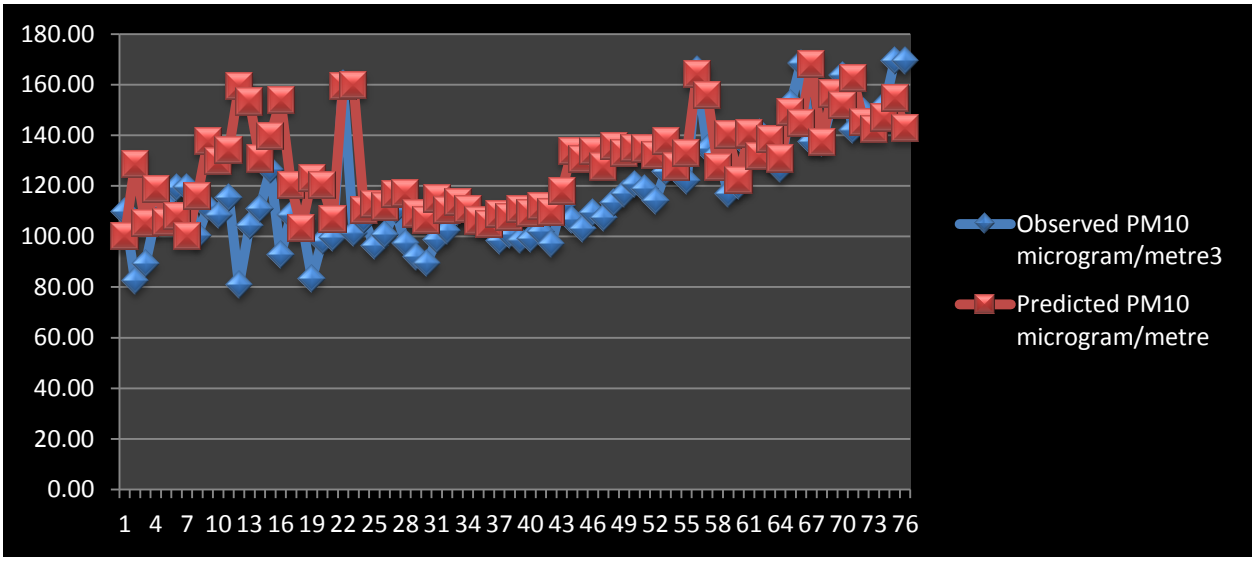

Figure 10. Plot for the comparison of Observed and Predicted PM_{10} values with time in days.

[4.2] Radial Basis Function:

The architecture of RBF Neural networks is less well known than that of MLP. The input for this kind of architecture is a feed-forward network (MLP neuron network), but every unit of the hidden layer has a radial basis function (statistical transformation based on Gaussian Distribution Function). Like MLP Neural Networks, RBF networks are suited for applications such as pattern discrimination and classification, interpolation, prediction, forecasting and process modeling. The basis function (often a Gaussian function) has the parameters centre and width. Usually each unit of the network has a different central value. The centre of the basis function is a vector of members of the same size as the inputs to the unit. Normally, there is a different centre for each unit in the neural network.

In the first computation, the radial distance is computed for every unit between the input vector and the centre of the basis function using the Euclidean distance algorithm. In other words, the structure of the RBF has non-linear inputs for every data and the radial distance is computed between the input vector and the centre

of the basis function. The input of the RBF neural network is non-linear whereas the output is linear. Because of the properties, RBF neural networks can model complex maps more easily and quickly than MLP.

Table 6. Evaluation of the Radial Basis Function Models

Net. name	Training perf.	Test perf.	Validation perf.	Training error	Test error	Validation error	Training algorithm	Hidden activation	Output activation
RBF 4-12-2	0.711907	0.734375	0.737615	281.4109	158.5939	303.2997	RBFT	Gaussian	Identity
RBF 4-20-2	0.792630	0.745449	0.859249	209.4545	139.4999	165.2802	RBFT	Gaussian	Identity
RBF 4-12-2	0.785950	0.818140	0.854350	215.7519	111.3534	153.1730	RBFT	Gaussian	Identity
RBF 4-20-2	0.815823	0.803614	0.833183	188.4697	122.8180	163.8838	RBFT	Gaussian	Identity
RBF 4-20-2	0.865624	0.677926	0.747875	141.1235	171.0691	243.6581	RBFT	Gaussian	Identity

[4.3] Multilayer Perceptron:

Multilayer perceptron is the most common and successful neural network architecture with feed forward network topologies (having three layers of neurons). Each layer uses a linear combination function. The input layers are fully connected to the hidden layer, which is fully connected to the output layers. These networks are used to create a model and map the input to the output using historical data. Run-on in the model can be used to produce an output, even if the desired output at that point is unknown. These networks are called supervised networks. The most common supervised training algorithm is the Back - Propagation. With Back Propagation, the input data are repeatedly presented to the neural network. With each presentation, the output of the neural network is compared to the desired output and an error is computed. This error is then fed back to the neural networks and used to adjust the weights such that the error decreases with each iteration and the neural model gets closer and closer to the desired output. This process is known as training. This kind of training is relatively easy and offers good support for prediction applications. It is generally accepted that the characteristics of a correctly designed MLP network are, though worth of comparison, not better than the characteristics that can be obtained from the classical statistical techniques. Nevertheless, MLP networks outperform classical

statistical techniques in their much shorter time of development, and their adaptive capacity when faced with changes.

Table 7. Evaluation of the Multilayer Perceptron Models

Net. name	Training perf.	Test perf.	Validation perf.	Training error	Test error	Validation error	Training algorithm	Hidden activation	Output activatio
MLP 4-6-2	0.792500	0.833677	0.904524	209.3731	120.8512	119.3815	BFGS 9	Exponenti al	Identity
MLP 4-3-2	0.783575	0.832493	0.899409	219.2605	110.3335	118.3564	BFGS 11	Exponenti al	Exponen tial
MLP 4-19-2	0.789897	0.845278	0.913263	212.6217	103.2589	109.0441	BFGS 64	Tanh	Tanh
MLP 4-5-2	0.784004	0.891316	0.894904	216.6875	74.5728	123.3206	BFGS 11	Logistic	Tanh
MLP 4-3-2	0.792261	0.837160	0.904084	210.5295	104.8732	122.3779	BFGS 17	Tanh	Identity

The validation of the models revealed that NN model showed much better skills in forecasting PM10 concentrations, as the regression and the NN model can forecast 60 and 81% of the variance of the data, respectively.

[5] Potential of the study for product development

The models developed using the Multiple Linear Regression Analysis (MLRA) and the Neural Network (NN) can be used to devise and formulate the core of Air Warning Systems. Air quality warning systems are needed in order to obtain accurate advance notice that ambient pollution levels might exceed air quality guidelines or limit values. The availability of accurate and real-time forecasts of pollution levels would support the actions taken by environmental and health authorities in order to achieve compliance with the air quality standards and to preserve inhabitants' health. In particular, short-term prediction of PM_{10} levels could assist the authorities to determine issuing alerts, requiring temporary cuts in emissions or various traffic limitations and warning sensitive population groups such as individuals suffering from respiratory illnesses, children and the elderly (Papanastasiou, Melas, Kioutsioukis; 2007).

Hence, this is perhaps one of the most sought after research area for developing products for the forthcoming decades and is sure to gain considerable significance globally.

As a matter of fact, USEPA has taken an initiative in this field by coining a term called Air Quality Index (AQI). The U.S. Environmental Protection Agency (EPA) and others are working to make information about outdoor air quality as easy to understand as the weather forecast. EPA and local officials use the AQI to provide one with simple information on local air quality, the health concerns for different levels of air pollution, and how one can protect your health when pollutants reach unhealthy levels (USEPA AQI,2003).

The AQI is an index for reporting daily air quality. It tells one how clean or polluted the air is, and what associated health effects might be a concern. The AQI focuses on health effects one may experience within a few hours or days after breathing polluted air. EPA calculates the AQI for five major air pollutants: ground-level ozone, particle pollution, carbon monoxide, sulphur dioxide, and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect public health.

A specific color is assigned to each AQI category to make it easier to understand quickly whether air pollution is reaching unhealthy levels in your community. For example, the color orange means that conditions are “unhealthy for sensitive groups,” while red means that conditions may be “unhealthy for everyone,” and so on (USEPA AQI,2003).

In large cities (more than 350,000 people), state and local agencies are required to report the AQI to the public daily. When the AQI is above 100, agencies must also report which groups, such as children or people with asthma or heart disease, may be sensitive to the specific pollutant. If two or more pollutants have AQI values above 100 on a given day, agencies must report all the groups that are sensitive to those pollutants. Many smaller communities also report the AQI as a public health service (USEPA AQI,2003).

Many cities also provide forecasts for the next day’s AQI. These forecasts help local residents protect their health by alerting them to plan their strenuous activities for a time when air quality is better. [USEPA AQI, 2003]

In India, System of Air Quality Weather Forecasting and Research (SAFAR), at Pune-based Indian Institute of Tropical Meteorology, ministry of earth sciences is responsible for carrying out determination of Air Quality. However, future will be household warning systems devised to predict expected air quality and alert people; analogous to blood glucose meters for glaucoma.

Thus it is evident that as of now, current pollution levels are monitored, processed and then reported to the people in a simplified form. However, in future, it is expected that Air Quality Warning Systems will gain precedence and by regulation, it will be mandatory for various industrial or commercial sources of particulate pollution to regulate their emissions. Further, these Air Quality Warning Systems, using a technique similar to the one devised here will never let the particulate pollution levels to exceed by predicting the PM10 levels, taking into consideration the meteorological parameters and other such inputs as may be deemed necessary. Thus the manufacturing of these systems will be a multimillion dollar industry in future, thereby promoting active research to predict the pollutant levels as accurately as possible.

[6] Conclusion

The aim of this study is to develop air quality models based on Multiple Linear Regression Analysis and Neural Computing in order to predict the peak 8 h average value of PM_{10} concentration in the urban areas of industrial town of Rourkela, which houses a major steel plant. The wind speed, air temperature, wind direction and relative humidity were used as independent variables in Multiple Linear Regression Analysis. The analysis revealed that the most significant variable in predicting the 8-hour average values of PM_{10} concentration is the air temperature followed by the relative humidity. The quality and reliability of the developed models were evaluated via several statistical indexes (Mean Bias Error, Root Mean Square Error, Correlation Coefficient R and Index of Agreement d). Comparing the two models, the NN model showed much better skills in forecasting PM_{10} concentrations than the Multiple Linear Regression Analysis model. Similar conclusions have been found in the previous studies (Chaloulakou et al., 2003a, c; Comrie, 1997; Gardner & Dorling, 1998). More precisely, the NN model outmatches the MLRA model in capturing better the variability of the observed data while its R is much better. On the contrary, the values of Mean Bias Error and Root Mean Square Error are almost identical among the two models. The calculation of some additional statistical indexes (Percent Correct, Probability Of Detection, Probability Of False Detection, False Alarm Rate) did not distinguish a model, concerning to its ability to forecast the exceedances of the limit value of 100 $\mu g/m^3$. However, it was proved that the developed models are capable to predict these exceedances to a satisfactory level, considering the resources available in terms of manpower and time.

[7] References

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