Air Pollution Deterministic Index Modeling: Application in Quetta, Pakistan

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Abstract: Mathematical model are applied to predict the sensitivity of climate to changes produced by natural phenomena and human activities. In this paper Air Pollution Deterministic Index Modeling (APDIM) for Pakistan is developed with the practical implication in Quetta City. The modeling is based on deterministic model and Pollution Indices to monitor the Ambient Air condition in Quetta City. The novelty of the model is adding a coefficient in the basic deterministic formula. The values of the coefficient balance the theoretical and experimental validations for Ambient Air. The tool gives the alerts about the weather conditions in simple indices or colour coding displays. These indices indicate the air pollution situation in the city by a single number or colour code. The application of the applied model is done in Quetta city, six criteria pollutants (CO, SO\textsubscript{x}, NO\textsubscript{x}, O\textsubscript{3}, TSP and PM\textsubscript{10}) are chosen for modeling according to the WHO criteria which have harmful health effect on the communities. The results of the modeling indicate that the gases (CO, SO\textsubscript{x}, NO\textsubscript{x}, and O\textsubscript{3}) are touching the boundary of satisfactory to unsatisfactory zone. The cause of concern is TSP and PM\textsubscript{10}, which lies in the hazardous zone. APDIM is an important tool of decision making, which determine the risk assessment for communities. The aim of the tool is to inform the general public of the local area about the severity of ambient air pollution, and the possible health hazard it causes, particularly on vulnerable groups or people with existing cardiac, lungs and breathing diseases. Further the tool helps the environmentalists and policy makers to modify the policy and strategies according to the provided air data.

Keywords. Air Pollution Deterministic Index Modeling, Ambient Air Pollution Indices, Deterministic modeling.

1. Introduction:
Human being in the conquest for food and better living conditions is modifying the environment. In this craze for progress and development, he added a lot of dust, smoke, poisonous gases, hazardous waste and harmful radiation on the face of the earth [1]. Through environmental modifications either man made or artificial, not only the physical, geological, geographical and topographic surfaces but also the biological configuration of the planet is liable to constant change. Such alterations involve not only the gradual disappearance of the developed ecosystems and the reappearance of new ones but also the processes may continue long after the human species have been extinct [2].

The major constituents of the ecosystems and all the ecological complex units of the earth-water-atmosphere systems are being somehow interconnected and intimately, but naturally linked together. Any interaction of one will trigger repercussions on the others and vice versa culminating to a general state of imbalance, disruption of equilibrium and deteriorations [3]. Degradations and modifications of the physical and the biological specifications of man’s environment are potentially capable of inducing responses and repercussions in the human mind, human reflexes, human metabolism and human activities, etc. [4]. The extent of such responsive attitudes could only be revealed long after the phenomenal changes have taken place and ultimately culminating in physical, mental and genetic modifications of the human species [5, 6].
Many of the urban centers in the developing countries are beset with the environmental problem especially air pollution due to increasing population, industrialization growing transportation. Exposure to air pollution has become an unavoidable part of metropolitan life and millions of people faces health and environmental problems due to air pollution besides owing to poor shelter and lack of safe water, sanitation, drainage and other environmental contamination. These problems are compounded by dangerous releases caused mainly by fossil fuels, automobiles emission and smoke from industries / domestic combustion. The proportion at which these metropolises are developing with the general absence of pollution control methods in many of them urban air quality will continue to deteriorate.

2. Mathematical Modeling in Environmental Management

A model is defined as the creation of an idealized representation of reality in order to demonstrate its most important properties. The model building is a complementary way of thinking about the world. Environmental mathematical models (Empirical & Simulation) facilitate, to a certain extent, the study, analysis and investigation of certain basic results to be expected regarding the environmental disruption and the mean of prediction [7, 8]. The desired prediction of environmental trends and developmental disruption phenomena are preceded by a series of concrete factual data properly analyzed and processed [9]. Such results will enable scientists to project a mathematical model representation culminating to the desired prediction and preventive objective [9].

3. Development of Air Pollution Deterministic Index Modeling

APDIM is based on the deterministic model which is used to develop the Pollution Indices for the Air quality. Air Pollution Deterministic Index Modeling is typically based on a function $\alpha$, where $\alpha$ is a number indicating conditions of air quality. The model takes the weighted values of individual pollutants parameters measured at spatial points and then compares this to the single number in the air quality standards. The attraction of this model is that the number $\alpha$ is a non-dimensional number (not in ppm or mg/m$^3$) [10]. The Pollution indices have fixed values to represent air quality. Each value is presented by a Colour code that’s level is understandable by the public.

The applied methodology used for the preparation of model depends upon on the concentrations from ambient air monitoring data. The data is presented by mean and standard deviation. The pollutants consider for the modeling are CO, SOx, NOx, O$_3$, TSP and PM$_{10}$. A modification is made in the deterministic model by introducing a coefficient. The theoretical and experimental values are different for Air data that why a coefficient balance these values. The calculated value of the range for the coefficient for different Pollutants lies in-between 0.1 to 0.3; other researchers also use these types of constants with different situations [11, 12, 13]. The non-dimensional $\alpha$ is calculated by the following formula;

$$\alpha = \alpha_i + \frac{\alpha_{i+1} - \alpha_i}{C_{i+1} - C_i} (C - C_i) \times K \text{ (coefficient)}$$

Where

- $\alpha = $ Pollution Standard Index
- $\alpha_i = $ break point from one quantity to another
- C = Ambient pollution concentration
- $C_i = $ Corresponding concentration in ppm
- K = coefficient- Variation Range 0.1 to 0.3

In APDIM only comparison is made with the Pollution Indices. Pollution Indices have fixed values ranges and is used only to indicate the quality of air i.e. good, satisfactory, unhealthy and hazardous. Therefore, these levels are divided into seven categorizing zones and are also presented by a colour code i.e.
1. Good Quality
2. Satisfactory
3. Unhealthy
4. Hazardous – Alert
5. Hazardous – warning
6. Hazardous – emergency
7. Hazardous – critically harm

The break points for Breakpoints Pollution Indices Category Showing Pollution Indices, Categorizing Range, Color coding and Concentration time, are given in table-1:

| Category Range        | Pollution Indices (PI) | Concentration (ppm) | Color Code |
|-----------------------|------------------------|---------------------|------------|
| Good                  | <50                    | ≤0.07               | Green      |
| Satisfactory          | 50-99                  | 0.14                | Yellow     |
| unhealthy             | 100-199                | 0.3                 | Orange     |
| Hazardous – Alert     | 200-299                | 0.35                | Blue       |
| Hazardous – warning   | 300-399                | 0.6                 | Purple     |
| Hazardous – emergency | 400-499                | 0.8                 | Maroon     |
| Hazardous – critically harm | 500- above         | 1.0                 | Red        |

The health outcome information used with the Pollution Indices is pollutant-specific. Associated likely health impacts for different PI categories and pollutants have also been suggested, shown in table 2.

| Pollution Indices (PI) | Category Range         | Associated Health Impacts                                                                 |
|------------------------|------------------------|--------------------------------------------------------------------------------------------|
| <50                    | Good                   | The pollutants have insignificant health effects                                             |
| 50-99                  | Satisfactory           | Problems occur for those having respiratory problems - Minor breathing discomfort to sensitive people. |
| 100-199                | Unhealthy              | Respiratory discomfort when peoples are exposed to longer time Breathing, and uneasiness to people those have hearth problem. |
| 200-299                | Hazardous – Alert      | Asthma and other respiratory attacks, lung problems and heart problems may occur especially in children and elders. |
| 300-399                | Hazardous – Warning    | If the exposure prolongs then causes lung heart and respiratory illness.                    |
| 400-499                | Hazardous – Emergency  | causes lung heart and respiratory illness respiratory impact even on healthy people,       |
| 500- above             | Hazardous – Critically Harm | Serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity. |
4. Application of Air Pollution Deterministic Index Modeling (APDIM) at Quetta City

Quetta is a funnel shape valley and the capital city of Balochistan, Pakistan and lies between 66°15′ 00″ to 67° 15′ 00″ Easting and 30° 00′ 00″ to 30° 25′ 00″ Northing in the survey of Pakistan Topo-sheets 34 N/3 & 4 and 34 J/15 & 16. The main valley of Quetta or Shal proper (comprising an area of 1720 sq. km), which unites the two sides at the toe of the horse-shoe, is a parallelogram about sixteen miles by eight [14]. The ambient Air data is collected at three sites of Quetta city. These sites are selected as per guidelines provided by UNEPA. The monitoring sites are shown in figure 1. The data of the Ambient Air for Quetta city is given in the table-3.

![Map showing the monitoring sites in Quetta city](source)

**Figure 1.** Map showing the monitoring sites in Quetta city Source: Complied
Table 3. Ambient Air for Quetta city: source: compiled

| S. No | Criteria Pollutants       | Concentration of Ambient Air in Quetta City (Annual Average) |
|-------|---------------------------|---------------------------------------------------------------|
| 1     | Carbon monoxide           | 9.6 ppm                                                       |
| 2     | Sulphur dioxide           | 0.029 ppm                                                    |
| 3     | Nitrogen dioxide          | 0.037 ppm                                                    |
| 4     | Ozone                     | 0.02761 ppm                                                  |
| 5     | Hydro Carbon              | 0.841 ppm                                                    |
| 6     | Total Suspended Particle  | 544 µg/m³                                                    |
| 7     | PM₁₀                      | 304.83 µg/m³                                                 |

The APDIM is applied to calculate the situation of air in Quetta city. The seven Pollution Indices categories in APDIM are Good, Satisfactory, Unhealthy Quality and Hazardous situation. The range of hazardous level are further divided into three stages- Hazardous – Alert, Hazardous – Warning, Hazardous – Emergency and Hazardous – Critically Harm. These indices’ scale starts from very low (0) and to very high (7) that measures the relativity sensitivity of the health effects due to air pollution. The six pollutants consider for modeling are: CO, NOx, SOx, O₃, TSP and PM₁₀. And are considered for modeling are (NOx, SOx, CO, O₃, TSP and PM₁₀). The recorded time for was 24-hourly average. Results of Air Pollution Deterministic Index Modeling in Quetta City is presented in table-4.

Table 4. Air Pollution Deterministic Index Modeling for Quetta City; source compiled

| Criteria Pollutants   | Concentration of Ambient Air (Annual Avg. C) | Calculated values for (α) | Break Points (αₒ) | Pollution Indices | WHO Standards | Colour Code                  |
|-----------------------|-----------------------------------------------|---------------------------|--------------------|-------------------|---------------|-----------------------------|
| Carbon monoxide       | 9.6 ppm                                       | 50                        | 1.1-2.0            | 50 -99            | 10 ppm        | Satisfactory                |
| Sulphur dioxide       | 0.029 ppm                                     | 50                        | 0–40               | ≥ 50              | 0.0437 ppm    | Good                        |
| Nitrogen dioxide      | 0.037 ppm                                     | 172                       | 0–40               | 100-199           | 0.080 ppm     | Unhealthy                   |
| Ozone                 | 0.02761 ppm                                   | 50                        | 0.07–0.14          | ≥ 50              | 0.055 ave ppm | Good                        |
| Total Suspended Particle | 544 µg/m³                                   | 510                       | 500-above          | 500-above         | 190 ave g/m³  | Hazardous–serious harm      |
| PM₁₀                  | 304.83 µg/m³                                  | 411                       | 300-399            | 421 – 570         | 70 µg/m³      | Hazardous–serious harm      |

5. Discussion and Conclusions
Air pollution and its public health impacts are drawing increase concern from the environment point of view. Air quality has a direct influence on a public’s health status and plays a significant role in quality of natural life, years of vigorous life lived, and health discrepancies. The quality of air, indoor and outdoor is closely related to morbidity to mortality from respiratory infection to cardiovascular diseases especially from particulate matters [15]. Exposure to air pollution is associated with premature death, significant number of hospital admission, exacerbation of symptoms, chronic diseases or allergies, bronchitis, asthma, cancer, heart disease, and respiratory disease.

Recent research indicates that air pollution harms vulnerable groups more due to their age. Therefore, children and older peoples are more effected than the younger groups but depend on multiple factors. That includes age, genetic, social conditions, health conditions, personal characteristics, substantial portion of their time outside home and depends upon individual’s daily activities. Researchers notices that
cities with improved air quality have longer life expectancy. A reduction of 10 μg/m³ in ambient air pollution is associated with an estimated increase in average life expectancy of 0.61 years [16].

Environmental data and facts are the best authentic prediction tools that predict the health effects, economic effects and ecological effects that are generated by the environmental degradation. Based upon this study environmental modeling can lead to a new aspect of future planning and appropriate remedial measures. Therefore, mathematical modeling which is based on documentary data and information-collected from various independent sources and processed by modern computerized techniques provide base line value for the contemplated predictions and guide the environmentalist in their planning and development program.

Generally, standards are difficult to understand by the general public so a single digit standard which shows that how much a particular pollutant is dangerous to human health. APDIM is a simple, color-coded, unit-less index that is an effective way to communicate air pollution concentrations to the general public. The APDIM provides an indication of the quality of the air and its health effects. The aim of this paper is to better understand the environmental problems and health hazardous by a single number or condition to the public. The communities can use the APDIM to benefit them to take decisions on alfresco events; for example, different organizations such as schools and sports can check the latest info on air conditions and can decide whether outdoor sporting event should be conducted or not. The newest way to report the Air Reporting Index Modeling System is via an Internet or different computerized sign boards that can be positioned at the prominent places of the city. The impetus System APDIM is to grab the local population and government officials to take pollution control measures with in their jurisdictions and work for the improvement of air quality.

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