General information: Urban air quality is a critical environmental issue directly related to the existence, operations, and metabolism of urban areas. It is intrinsically linked to city structures, urban operations, and the complex interplay of human activities that define metropolitan environments. The problem stems fundamentally from cities' primary function: serving human needs through concentrated populations, infrastructure, and economic activities. Air pollution is therefore inextricably connected to human activity and is significantly influenced by human behavior patterns, particularly in terms of mobility, energy consumption, and resource utilization. The concentration of people, vehicles, industries, and energy-consuming activities in urban areas creates unique atmospheric conditions that distinguish city air from rural environments.

Definition

Air quality refers to the characterization of atmospheric conditions, specifically focusing on the lower atmosphere where human activities occur. In the context of urban air pollution, air quality is determined by the presence of substances in the breathable air that can adversely affect quality of life, human health, flora and fauna, and urban infrastructure itself.

These harmful substances are classified as air pollutants, which represent a diverse group of chemical compounds and particles that, when present in sufficient concentrations, pose risks to environmental and human health.

Major Air Pollutants

The primary air pollutants found in urban environments include:

- Nitrogen oxides (NOx): Primarily produced by vehicle emissions and industrial processes

- Carbon monoxide (CO): A colorless, odorless gas mainly from incomplete combustion

- Volatile organic compounds (VOCs): A large group of carbon-based chemicals that easily evaporate

- Particulate matter: Including PM10 (particles with aerodynamic diameter $\leq$ 10 micrometers) and PM2.5 (particles $\leq$ 2.5 micrometers)

- Ground-level ozone (O_3): A secondary pollutant formed through photochemical reactions

- Sulfur dioxide (SO_2): Primarily from fossil fuel combustion

- Other substances: Various toxic compounds specific to local industrial activities

Categories of Air Pollutants

Air pollutants are generally classified into two main categories:

- Gaseous pollutants encompass all substances existing in gas phase, including the various chemical compounds that remain airborne as gases under normal atmospheric conditions.

- Particulate pollutants include all pollutants containing a solid phase. However, this category is more complex than it initially appears, as many particles exist simultaneously in multiple phases. A prime example is combustion particles that may consist of a solid nucleus containing liquid droplets of unburned fuel, within which gaseous pollutants may be dissolved or adsorbed.

Temporal Variations in Urban Air Quality

Urban air pollution levels exhibit significant temporal variability, fluctuating across multiple time scales:

- Daily Patterns: Air pollution concentrations vary throughout a typical day, with patterns differing between working days and weekends. These variations are directly proportional to emission levels, which are primarily driven by transportation traffic and energy consumption patterns. During typical working days, pollution follows a predictable pattern:

    o Early morning peak: Coincides with morning rush hour as people commute from homes to workplaces

    o Midday reduction: Lower traffic volumes lead to decreased pollutant concentrations

    o Afternoon/evening peak: Evening rush hour creates a second daily maximum as people return home

- Weekly Patterns: Weekends typically exhibit lower air pollution levels due to reduced commuting and decreased industrial activity, though recreational travel and activities may create different pollution patterns..

- Seasonal Variations. Air quality varies significantly across seasons:

    o Colder seasons: Often characterized by elevated pollution levels due to increased fossil fuel consumption for heating, combined with meteorological conditions that trap pollutants

    o Warmer seasons: Feature increased levels of secondary pollutants like ground-level ozone, which forms through photochemical reactions enhanced by solar radiation and high temperatures

Assessment Methods

The evaluation of urban air pollution employs two complementary approaches: measurements and estimations.

- Measurement Approaches: Reference-grade monitoring: Utilizes high-quality, expensive instruments that comply with legal frameworks governing air quality assessment. These instruments provide scientifically accurate results but require significant investment in acquisition, operation, and maintenance. They form the backbone of official air quality monitoring networks.Low-cost sensing: Employs more affordable devices that can provide reasonable estimations of air pollution levels. While potentially less accurate than reference instruments, these devices offer advantages in terms of cost-effectiveness and ease of use, making them popular for citizen science projects and dense monitoring networks.

- Modeling Approaches: Air quality modeling employs mathematical frameworks to estimate pollutant concentrations:

    o Deterministic models: Utilize comprehensive sets of equations representing atmospheric physics, chemistry, and pollutant behavior. These models simulate emission, dispersion, chemical transformation, and removal processes based on fundamental scientific principles. They account for meteorological conditions, topography, and emission sources to predict how pollutants move and react in the atmosphere.

- o Data-driven models: Employ statistical and machine learning approaches to identify patterns in historical air quality data. Rather than solving fundamental atmospheric equations, these models:

Both modeling approaches serve complementary roles in air quality management, with deterministic models providing insight into pollution mechanisms and data-driven models offering rapid assessments and pattern recognition capabilities.

Conclusion

Urban air pollution represents a complex environmental challenge that requires comprehensive understanding of emission sources, atmospheric processes, and human behavioral patterns. Effective management strategies must account for the temporal variability of pollution levels and employ both measurement and modeling approaches to provide accurate assessments and inform policy decisions. As cities continue to grow and evolve, addressing air quality challenges remains crucial for protecting public health and environmental sustainability.