03.12.2 Average Annual Air Pollution Levels: Model Data, 2024 (Environmental Atlas)

Summary

The **Digital Berlin Air Quality Map** captures air pollution across the city in 50 × 50 metre grid cells. The map is based on 2024 annual average concentrations of **NO_2**, **PM_{10}** and **$PM_{2.5}$** and classifies pollution levels into five categories, ranging from 'very low' to 'high'. This classification follows the World Health Organization (WHO) guidelines and interim targets designed to achieve air quality standards that do not pose a risk to human health according to the current state of scientific knowledge.

Results and spatial distribution:

- **48%** of the urban area exhibits low levels of air pollution. Yet, only **15%** of the population lives there (e.g. Müggelsee, Grunewald).
- **74%** of Berlin's residents live in regions with **moderate air quality**, mostly housing estates near roads. These areas make up just **46%** of the city's total area.
- **6%** of the area experiences **elevated pollution levels**, affecting **11%** of the population (e.g. along major roads).
- There are currently no **regions with 'very low' pollution levels** or full WHO compliance.

Health impacts: particulate matter, especially $PM_{2.5}$, is harmful to human health, even at very low levels. It can lead to cancer, neurological disorders, and respiratory illnesses, among other effects, and poses risks to unborn children. These pollutants can travel through the respiratory system and reach internal organs, including the brain.

Measures to improve air quality:

- **Transport** – low-emission zones, speed limits, expansion of public transport
- **Heating** – low-emission systems, filters, proper use of wood-burning stoves
- **Industrial and transboundary sources** – Europe-wide measures to reduce emissions

The map supports both residents and local authorities in identifying where targeted air quality improvements are needed.

Introduction

With measures such as low-emission zones, modern buses, and the expansion of both public transport and cycling infrastructure, Berlin has succeeded in improving air quality. Nonetheless, further reductions in air pollution remain necessary. Concentrations of certain pollutants still exceed the air quality guideline levels set by the World Health Organization (WHO) across the city. These limits are designed especially to protect vulnerable population groups. Particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2) are considered particularly harmful to human health. They can cause cardiovascular and respiratory diseases, especially in children, older adults, and individuals with preexisting conditions. Diesel soot has been classified as carcinogenic by the WHO. NO_2 is primarily emitted by traffic. It contributes

to the formation of particulate matter and ozone, and places additional strain on soils and ecosystems.

The 'FAirQ' model, developed by INWT Statistics GmbH, was designed to provide a citywide overview of air quality in Berlin. It supports both short-term predictions for the coming four days and the calculation of average air pollution levels for an entire calendar year. The model is built on AI and big data methods, drawing on a range of input data including air monitoring values, weather forecasts, traffic data, large-scale pollution predictions, and urban structure information. Using decision trees, it analyses relationships among these variables to predict concentrations of NO_2, PM_{10}, and $PM_{2.5}$ across a 50 × 50 metre grid. The model's outputs largely align with actual measurements, although deviations may occur in certain spots, such as near busy roads.

The model provides a comprehensive and nuanced picture of air pollution levels across Berlin and is regularly updated.

Statistical Base

Air quality in a metropolis like Berlin depends on many factors, from weather and traffic volumes to the development structure of individual districts. Berlin relies on a data-driven, adaptive model that integrates multiple data sources to generate reliable forecasts of air pollutant trends. This model not only provides up-to-date assessments of air quality but also serves as a basis for policy measures to improve urban living conditions.

Diverse Data Sources and Solid Modelling Foundations

At the heart of the model lies the intelligent integration of different types of data, which together provide a comprehensive picture of air pollution across the city. In total, three main categories of data feed into the model:

- **Historical data** – past measurements of air pollutants such as nitrogen dioxide (NO_2) and particulate matter (PM_{10}, $PM_{2.5}$), along with weather conditions and traffic data. These provide the foundation for the model to recognise and learn the relationships between variables.
- **Current, time-varying data** – snapshots of traffic data and the latest weather information available in real time or with a short delay. These allow the model to respond to the present situation and improve short-term predictions.
- **Spatially variable data** – information that reflects how the city is structured, including information on land use (e.g. green spaces, residential areas), building density, and the layout of the road network. The impact of these factors on air quality varies by location.

To consolidate this information, the model draws on a variety of sources, including:

- BLUME, the Berlin Air Quality Monitoring Network (available in German only), providing accurate measurements of air pollution levels at numerous locations across the city,
- **weather forecasts from** Germany's Meteorological Service (DWD),
- Copernicus CAMS, a European programme sharing environmental data on atmospheric conditions at continental and global scales,
- traffic data from Berlin's viz.berlin.de platform, offering detailed insights into traffic volumes and vehicle movements,
- urban structure data from the **Geoportal Berlin**, including information on urban development, road layouts, and land use, and
- even **school holiday schedules**, as these are known to greatly influence traffic volumes and, in turn, air quality.

Methodology

Modelling and Forecasting – How the Process Works

The actual forecasting model uses a method called **XGBoost**, a modern machine learning technique based on decision trees. This method has proven particularly effective at identifying complex relationships across a wide range of data sources.

A separate model is trained for each relevant air pollutant, i.e. **NO_2**, **PM_{10}**, and **$PM_{2.5}$**. This allows each model to focus on the influencing factors specific to that pollutant and fluctuations typically associated with it. To ensure they stay current, the **models are retrained monthly**. This allows them to account for changes in traffic behaviour or weather patterns, and other environmental variables, maintaining their adaptability.

Forecasting is carried out on a **high-resolution grid with 50 × 50 metre** cells. This means that each grid point receives a predicted air pollution level. The fine resolution is key to capturing even small-scale variations in air quality across the city.

The model uses a wide range of features, including:

- **temporal variables** – year, day of the week, time of day, and specific periods like school holidays or public holidays,
- **meteorological data** – temperature, wind direction and speed, precipitation, and other weather-related variables,
- **spatial factors** – building density, proportion of green space, and the road network, all of which affect how pollutants disperse,
- **traffic data** – predicted vehicle counts and speeds for each grid cell, and
- **past measurements** – lagged variables or 'lags', which allow the model to identify and respond to short-term trends.

Traffic Forecasting as an Auxiliary Model

Since traffic is one of the key factors influencing air quality, a separate **traffic model** is trained. It also relies on XGBoost and is tasked with predicting **vehicle volumes and speeds** across the urban area. These predictions then feed into the air pollution model.

It is important to note that this traffic model is **retrained on a quarterly basis**, as the most recent quality-assured traffic data are only available after a delay. Weather data are deliberately excluded from this sub-model, as they have little relevance for short-term traffic developments.

Model Quality Assessment – How Effective Is It?

To ensure the reliability of the model's predictions in practice, the quality of the model is verified using several statistical methods:

- The **MAE (mean absolute error)** indicates the average deviation between predicted and actual values.
- The **RMSE (root mean square error)** gives more weight to large deviations, highlighting whether major errors occur in isolated instances.
- The coefficient of determination or **R-squared** reflects how well the model explains the actual variability in the data.

Please note, this evaluation is conducted **out-of-sample**, meaning it is based on new, unseen data rather than the data used for model training. This approach provides a realistic assessment of the model's predictive accuracy for everyday use cases.

The Berlin air pollution forecasting model is a strong example of how state-of-the-art data analysis and machine learning can effectively support urban planning. By integrating current measurements, weather and traffic forecasts, and detailed urban data, it delivers **high-resolution, scientifically sound** assessments of air quality – citywide and in real time.

Regular updates, the integration of numerous influencing factors, and the ability to evaluate the impact of individual measures render this system a powerful instrument for environmental analysis and data-driven policy development.

Map Description

The air we breathe directly affects our health and well-being. To increase transparency around air quality in the urban area and support targeted improvement measures, Berlin has developed a **Digital Air Quality Map**. This map offers an up-to-date, detailed overview of pollutant concentrations across the city, highlighting areas with particularly clean or heavily polluted air.

Fine Resolution for A Realistic Picture

The map is based on a **50 × 50 metre grid model**. Pollutant concentrations are calculated and visualised for each cell, based on **2024 annual averages** for three key pollutants:

- **nitrogen dioxide (NO_2)**,
- **particulate matter PM_{10}** (particles with an aerodynamic diameter of up to 10 micrometres), and
- **particulate matter $PM_{2.5}$** (fine particles up to 2.5 micrometres).

Air pollution levels are classified into **five categories**, ranging from 'very low' to 'high'. These categories are not based on arbitrary thresholds, but follow **current recommendations from the** World Health Organization (WHO). Interim targets are also incorporated. They represent milestones on the path toward pollutant concentrations that, according to scientific consensus, no longer pose a risk to human health.

Spatial Variation of Air Quality and Population Density

A look at the map reveals that air quality in Berlin **varies widely across different areas** and impacts people unevenly. One particularly striking feature is the **mismatch between the proportion of land area and the distribution of the population**:

- **48% of the urban area** has **low pollution levels**. A good result, until a closer look reveals that these areas are largely uninhabited or sparsely populated. Only **15% of Berlin's population** lives there. Typical examples include expansive natural areas such as **Müggelsee or Grunewald forest**, where air quality is naturally much better than in the urban core.
- The majority of Berlin's residents, approximately **74%**, live in **areas with 'moderate' air quality**. They cover only **46% of the city**, which highlights just how densely populated many of these areas are. Often, they are **residential areas near busy roads**, where traffic increases air pollution but concentrations remain below extreme levels.
- **6% of the urban area** experiences **elevated levels of air pollution**; however, this affects as much as **11% of the population**. These areas are typically located along major roads, at transport hubs, or in densely built-up inner-city neighbourhoods characterised by heavy traffic and limited air exchange.
- Currently, there are **no areas in Berlin with very low pollution levels** or **zones that fully meet WHO guidelines**. Even the areas with the lowest pollution still exceed the thresholds recommended by the WHO to prevent health risks.

Health Risks: Why Particulate Matter Is Particularly Harmful

$PM_{2.5}$ (particulate matter with an aerodynamic diameter equal to or less than 2.5 micrometres) especially poses a serious risk to human health. It consists of particles with an aerodynamic diameter equal to or less than 2.5 micrometres. These particles can penetrate deep into the lung alveoli, while ultrafine particles can even enter the bloodstream and be transported throughout the entire body. The health effects associated with $PM_{2.5}$ exposure are well documented and include both short-term and long-term impacts. In the short term, elevated concentrations of $PM_{2.5}$ can lead to increased blood pressure, cardiac arrhythmias, and a higher incidence of emergency room and hospital admissions. Long-term exposure

causes inflammation and oxidative stress, and increases the risk of respiratory diseases such as asthma, bronchitis, and lung cancer; cardiovascular diseases such as atherosclerosis and high blood pressure; metabolic disorders such as type 2 diabetes; and neurological conditions including dementia.

The body of evidence is based on animal studies, experimental studies in humans, and large-scale epidemiological investigations. International institutions, including the United States Environmental Protection Agency (US EPA), have established a causal relationship between $PM_{2.5}$ exposure and increased all-cause mortality and cardiovascular disease. In 2021, the WHO concluded that when $PM_{2.5}$ levels rise by 10 micrograms per cubic metre of air, the risk of overall mortality increases by 8%. The risks of death from cardiovascular disease, respiratory conditions, and lung cancer grow considerably as well.

Older adults, children, and individuals with pre-existing respiratory or cardiovascular conditions are particularly affected. To date, no safe threshold has been identified below which adverse health effects are not expected to occur. Consequently, any reduction in $PM_{2.5}$ exposure is considered beneficial to human health.

Measures to Improve Air Quality

Berlin is implementing a range of measures to reduce pollution and meet WHO targets in the long term. These address various sectors and involve different stakeholders; from individual households to the EU level.

1. **Transport policy:**
    - Low-emission zones are designed to keep especially high-emission vehicles out of the densely populated inner city.
    - Speed limits* on major inner-city roads are to lower both exhaust emissions and the resuspension of particulate matter.
    - The **expansion** of public transport* is intended to encourage people to switch to more environmentally friendly alternatives to driving.
2. **Heating and energy systems:**
    - The promotion of low-emission heating systems* and the use of filters* in combustion systems contribute to lowering particulate matter concentrations.
    - Best practises in operating wood-burning stoves* using dry wood and ensuring proper air supply can lower emissions noticeably.
3. **Industrial and transboundary sources:**
    - A portion of pollutants does not originate within Berlin itself but is transported from surrounding regions. Consequently, **Europe-wide measures to reduce emissions** are essential, including stricter regulations for industrial facilities and international transport.

Links marked with an asterisk (*) lead to sources available in German only.

Benefits of the Air Quality Map for the Community and Local Authorities

The Digital Air Quality Map is much more than a simple collection of maps. It serves as a **tool for guidance, planning, and communication**:

- **For residents**, it shines a light on the air quality in their immediate neighbourhood, helping to cultivate awareness of environmental and health matters.
- For local authorities and policymakers*, it provides a data-driven basis for targeted interventions in areas where pollution levels are particularly high or where many people are impacted.

- The map also supports the **evaluation of measures**, such as new bus lanes or low-traffic areas, by objectively tracking changes.

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The Berlin Air Quality Map is a key pillar of transparent, scientifically grounded environmental policy. It identifies the most pressing challenges, reveals the connection between air quality and different social groups, and highlights effective strategies to protect public health. With its fine spatial resolution and clear evaluation criteria, it draws public attention to air pollution, specifically in the air we breathe every day, where it is often overlooked.

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