Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

Microbial-Based Solutions to Mitigate Climate Change Impacts in Pakistan with Special Emphasis on Smog Formation

Kinza Khan
Department of Microbiology, Faculty of Veterinary and Animal Sciences, The Islamia University of Bahawalpur, Pakistan
Asim Ali
Faculty of Veterinary Sciences, Bahauddin Zakariya University, Bosan Road, Multan Pakistan
Muhammad Sajjad Haider
School of Pharmacy, Multan University of Science and Technology, Multan Pakistan
Asmaa Jan Muhammad
School of Pharmacy, Multan University of Science and Technology, Multan Pakistan
Zohaib Saeed
Multan College of Veterinary Sciences, Multan University of Science and Technology, Multan Pakistan
Muhammad Rizwan
Multan College of Veterinary Sciences, Multan University of Science and Technology, Multan Pakistan
Muhammad Awais*
Multan College of Veterinary Sciences, Multan University of Science and Technology, Multan Pakistan Email: awaisjutt646478@gmail.com
Misbah Niaz*
Elementary and Secondary Education Department, District Lakki Marwat, Khyber Pakhtunkhwa Pakistan Email: misbahahmad9988@gmail.com
Waqar Ahmad Khan
Khalifa Gul Nawaz Teaching Hospital Bannu, Khyber Pakhtunkhwa Pakistan
Waseem Ahmad Khan
District Headquarters Hospital Lakki Marwat, Khyber Pakhtunkhwa Pakistan

Author Details

Keywords:.

Received on 15 Dec 2025
Accepted on 17 Jan 2026
Published on 27 Jan 2026

Corresponding E-mail & Author*:
Muhammad Awais*
Email: awaisjutt646478@gmail.com
Misbah Niaz*
Email: misbahahmad9988@gmail.com

Abstract

A combination of climate change and extreme annual smog, a photochemical haze as a result of NOx oxides and volatile organic comp reacting to sunlight under conditions of temperature inversion is a critical twofold threat to Pakistan. Some of the severe health threats of this dangerous mix of ground-level ozone and particle matter are respiratory and cardiovascular diseases. New, long-term solutions are needed since conventional mitigation methods have been found to be ineffective. This paper considers the massive potential of microbial-based solutions to alleviate smog formation and broader climatic consequences. The major smog precursors are directly degraded by special microorganisms: the industrial volatile organic compounds (VOCs) can be broken down effectively by bacterial and fungal consortia, and the NOx is reduced to non-toxic nitrogen gas by denitrifying bacteria (e.g. *Pseudomonas* and *Para coccus*) in bio filters. Methanotrophs in a developed bio cover oxidizes methane, a powerful

greenhouse gas and ozone precursor- of landfills. Microbes also indirectly give systemic solutions by offering alternatives to the significant sources of emissions, such as microbial consortia that may rapidly decompose crop residues in situ instead of open burning which is a major source of smog. Moreover, bio fertilizers will decrease the reliance on synthetic nitrogen fertilizers and thus decrease the related NOx emissions during their manufacturing and consumption. Although these biological tools are difficult to scale, and the environment is not always stable, the approach of incorporating the tools into national climate and air quality policies is an affordable multi-pronged intervention in Pakistan. With the potential to reduce smog and ensure a more resilient climate through microbial metabolism to intercept pollutants and promote sustainable processes, Pakistan can optimize both routes to cleaner air and a more sustainable climate.

Introduction

Pakistan is in serious trouble due to climate change and smog formation (Usman et al., 2019). Smog is an unpleasant mixture of gases and airborne particles created by smoke and fog in the presence of sunlight. The weather and the geography of the land have a direct impact on the formation of smog (Gaffney et al., 2009). As altitude increases, the air temperature drops by roughly 6.4°C each kilometer. Warmer air on the ground continuously climbs to the upper atmosphere under typical circumstances (Benhammou et al., 2023). Because of the continuous air movement, contaminants are dispersed, preventing smog from building up on the ground. A phenomenon known as temperature inversion occurs when the temperature gradient is inverted (Liu et al., 2022), with the air above being warmer than the air below. The warmer months of the year have a varied makeup for air pollution (Webster, 2024). Photochemical haze is the term for this type of smog. Smog, frequently increasing in Pakistan and we have to control it by use of different microbes (Iram et al., 2025). One kind of ozone that is prevalent in the environment is called Los Angeles smog poses a risk to human health. Exposure to potentially dangerous substances. These substances suspended in the air are one of the variables that can be changed (Miloştean & Flori). Numerous factors can lead to respiratory problems. One of the key points is that while fungi can accelerate degradation, particularly in paint application and manufacturing emissions, bacteria are good at eliminating contaminants (Espinosa-Ortiz et al., 2022). Toluene, which is employed as a solvent in the production of paints, gums, pitches, and elastic, as well as a reagent in the creation of drugs, colors, and scents, is more effectively removed by fungi (Pavlović et al., 2022). Hydrogen sulfide (H2S), odor, a variety of volatile organic compounds (VOCs17) (including chlorinated and non-chlorinated species, ketones, organic amines, aldehyde, ether, toluene, and aromatic hydrocarbons), and numerous other pollutants can all be eliminated using bio filter and bio trickling filters. However, VOC emissions are far lower than H2S, which is a major source of odor; ammonia (Joo et al., 2023), which is mostly produced by the food processing and petrochemical refining industries, also contributes to odor.

The alternative method is bio filtration, a biological process with a wide range of uses, low maintenance costs, greater effectiveness, and less hazardous byproducts (Srivastava & Majumder, 2008). Variations in temperature, moisture content, and irregular sources of pollutants can all have an impact on its performance (Biswas et al., 2018). While the convergences of particular VOC types are lower, the removal efficiencies for H2S degeneration are generally similar to those of VOC contaminants. Few studies have been conducted on the potential health and safety of using bio filters (Ralebitso-Senior et al., 2012). People who are sensitive to these organisms will wear a face covering to reduce contact with airborne bacteria and mold microorganisms due to the reliance on natural microbes in manure, soil, or fertilizer (Yang et al., 2019).

During development, maintenance, and media removal, breathing assurance is advised (Coté et al., 2019).
In this article we have to discuss in detail about the formation of smog in the air. However we also study about the control of climate change by using microbes (Tiedje et al., 2022).

Effect of smog on climate change

Photochemical smog is created when sunlight interacts with nitrogen oxides and at least one volatile organic compound (VOC) in the atmosphere (Chaudary et al.). Nitrogen oxides are released by coal-fired power plants, automobile emissions, and manufacturing pollution. VOCs are released by paints (Munsif et al., 2021), gasoline, and other cleaning solvents. These substances create ground-level ozone, frequently referred to as smog, and airborne particles when exposed to sunlight. Dusts of different sizes make up the solid material suspended in the fog (Lazaroiu & Jarcu, 2024). The Environmental Protection Agency (EPA) has collected classified data from several businesses in one place. One toxic gas is carbon monoxide (Stucki & Stahl, 2020). This poisonous, colorless, and odorless gas is produced when carbonaceous molecules like coal, gasoline, and diesel fuels are burned. CO forms bonds with other molecules on hemoglobin in red blood cells, preventing oxygen from entering the cell and traveling to various parts of the body (Acharya & Singh, 2024). CO also forms bonds with the cell's surface. When the cell's electron transport chain's terminals oxidized, the mitochondria shut down and respiration stopped (Tabassum et al., 2020). The CO body is the main goal of the human cardio-respiratory system. It is clear that ambient air pollution has a significant role in the etiology of lung cancer (Berg et al., 2023). This is because the two compounds have similar chemical compositions. tobacco smoke, pollution, and inhalation risk. The bronchial epithelium is not far from them. The malignancies that, according to histopathology, seem to be brought on by tobacco use (Yasin et al., 2022).
Lung cancer comes in two varieties: small-cell lung cancer and squamous cell carcinoma (Megyesfalvi et al., 2023). Lung cancer mortality is also mostly caused by dust and sulphates. Although nitrogen dioxide seems to be one of the main carcinogens, dust and sulphates are also largely to blame for lung cancer deaths (Kusumawardani et al., 2023). For men, lung cancer is the most common cause of cancer-related death; for women, it ranks second (Jani et al., 2023).

Effect of microbes against smog formation

By enzymatically breaking down the primary chemical precursors of smog before they can undergo photochemical reactions in the atmosphere, direct microbial mitigation of smog works (Isha et al., 2024). By converting reactive pollutants into inert or less dangerous compounds, this method successfully stops the production of smog at its source. Reactive nitrogen oxides can be biologically converted by microorganisms into innocuous dinitrogen gas (N_2), which eliminates them from the atmospheric cycle that produces ozone (Fenice, 2021). There are two main methods used to accomplish this. Nitrate (NO_3^-) is first reduced to nitrite (NO_2^-) (Aydin, 2025), nitric oxide (Espinosa-Ortiz et al.), nitrous oxide (N_2O), and lastly benign N_2 gas via the anaerobic respiration process of denitrification, which is carried out by a variety of bacteria, including Pseudomonas, Paracoccus, and Bacillus. These denitrifying communities are successfully harnessed by engineered systems such as bio trickling filters to treat industrial flue emissions (Barla et al., 2024). For example, studies using customized microbial consortia in bench-scale bioreactors showed over 95% NOx removal effectiveness.
Volatile organic compounds are prime targets for microbial degradation because they are essential substrates for the production of ozone (He et al., 2023), and bio filtration is a key technique in this process. In order for bio filters and bio trickling filters to

work, contaminated air must travel through a moist, porous media that is colonized by a strong biofilm of specific microorganisms, such as compost, peat, or synthetic packing (Kanematsu & Barry, 2020). Oxygenase enzymes are used by fungi from genera like Exophiala and Cladosporium as well as bacteria like Pseudomonas putida and Rhodococcus spp. to degrade a variety of hydrocarbons, alcohols, ketones, and aromatic chemicals (Rani et al., 2024).

Microbial methanotrophs are the sole important biological sink for atmospheric CH_4, despite the fact that methane is primarily a powerful warming gas and also contributes to tropospheric ozone chemistry (Guerrero-Cruz et al., 2021). Engineered methane bio filters, sometimes known as "bio covers," have been created for concentrated point sources such as landfills (Chan et al., 2023). In order to accomplish high-efficiency oxidation of methane into CO2 before it escapes into the atmosphere, these systems use designed soil layers seeded with high-affinity methanotrophs, such as Methylocystis (Samanta & Sani, 2023). Additionally, the activity of native methanotrophic communities in rice paddies and grazing pastures can be greatly increased in agricultural contexts by improving soil parameters, such as moisture, porosity, and nutrient balance. By reducing emissions from one of the main sources of anthropogenic methane, this management approach indirectly improves air quality (Hanif et al., 2022).

To treat off-gases, bio filters and bio trickling filters employ beds of immobilized microorganisms (Oyarzun et al., 2019). Microbes break down pollutants when contaminated air moves through. In his evaluation of bioremediation methods for Pakistan, Raza a researcher noted that bio filters, which use bacterial species like Pseudomonas and Thiobacillus to remove VOCs and SO_2, are suitable for treating emissions from the textile, fertilizer, and chemical industries (Barbusiński et al., 2021). Oil spills and hydrocarbon dumps, which are secondary sources of VOCs that cause smog, can be cleaned up by microbes. Natural hydrocarbon clastic bacteria that were isolated from contaminated soils in Rawalpindi and showed excellent degrading efficiency in the local environment (Aqeel et al., 2021).

Contribution of microbe in climate change

Soil microbes and their metabolic activity can affect land-atmosphere carbon exchanges in a variety of ways, but they can be broadly classified into two categories (Nottingham et al., 2022). One of those that control soil carbon loss through respiration and methane production, and other that affect ecosystem carbon dioxide and methane uptake (Bao et al., 2022). The activities of soil microbes that feedback greenhouse gases to the atmosphere and contribute to global warming are significantly impacted by climate change in both direct and indirect ways. Direct effects include the impact of temperature, precipitation, and extreme weather events on soil microbes and greenhouse gas production (Amante & Wedajo, 2024). While indirect effects are caused by changes in plant productivity and diversity brought on by climate change that modify soil physicochemical conditions. The amount of carbon that is added to soil, as well as the makeup and activity of microbial communities that are engaged in soil degradation and carbon release (Bailey et al., 2019). Here, we highlight the function of soil microbes and microbial metabolism in carbon cycle feedbacks and the implications for climate change using a framework of direct and indirect effects of climate change (Naylor et al., 2020).

Conclusion

To sum up, Pakistan has breakdowns of both disastrous smog and climate change, which need a paradigm shift in the form of sustainable and nature based solutions. Microbial technologies represent a powerful, versatile set of tools to address these problems at their source. Microbes act as bio tropic air filters by directly capturing smog precursors by oxidation of methane in bio covers, oxidation of NOx in biomimetic denitrification, and oxidation of VOCs in bio filters. They provide systemic alternatives to major sources of emission-generating activities simultaneously. The destructive open burning periods which choke the Indo-Gangetic Plain annually can be prevented due to the rapid in-situ microbial decay of crop residues. Bio fertilizers can also be used to reduce the usage of synthetic nitrogen that will cut upstream industrial nitrous oxide emissions and downstream soil nitrous oxide emissions.

Microbial methods particularly fit a poor country such as Pakistan because of low cost of the methods, low energy consumption, and non-toxic byproducts even though the methods have scaling problems, environmental stability of consortia, and initial investment problems. The trick of success is to integrate these tools of biology into the national clean air and climate strategies. That would require dedicated investments in local research to form powerful, indigenous microbial consortia, pilot initiatives to demonstrate effectiveness at scale, and extension services targeted at farmers to facilitate adoption. The use of this microbial potential is a strategic requirement and not only a technical choice. By harnessing the catalytic capabilities of microbes, Pakistan can find a way to not only clean its air, but also make its agriculture more sustainable, as well as more resilient to climate change, thus ensuring a safer, healthier future of its population.

References:

Acharya, A., & Singh, A. P. (2024). Haemoglobin-The Breath of Life within Our Cells: An Update.

Amante, G., & Wedajo, M. (2024). Impacts of Climate change on soil microbial diversity, distribution and abundance. International Journal on Food, Agriculture and Natural Resources, 5(2), 158-168.

Aqeel, A., Hussain, Z., Aqeel, Q.-U.-A., Zafar, J., Ehsan, N., & Tariq, M. (2021). Enrichment and characterization of hydrocarbon degrading bacteria from various oil-contaminated sites in Pakistan. Geomicrobiology Journal, 38(7), 577-587.

Aydin, D. (2025). Kangaroo Rat Burrow Biofilms to Improve Soil Stability: Biofilm-Induced Cementation and Microbial Mechanisms.

Bailey, V. L., Pries, C. H., & Lajtha, K. (2019). What do we know about soil carbon destabilization? Environmental Research Letters, 14(8), 083004.

Bao, Y., Liu, T., Duan, L., Tong, X., Zhang, Y., Wang, G., & Singh, V. P. (2022). Variations and controlling factors of carbon dioxide and methane fluxes in a meadow-rice ecosystem in a semi-arid region. Catena, 215, 106317.

Barbusiński, K., Parzentna-Gabor, A., & Kasperczyk, D. (2021). Removal of odors (mainly H2S and NH3) using biological treatment methods. Clean Technologies, 3(1), 138-155.

Barla, R. J., Raghuvanshi, S., & Gupta, S. (2024). A comprehensive review of flue gas bio-mitigation: Chemolithotrophic interactions with flue gas in bio-reactors as a sustainable possibility for technological advancements. Environmental Science and Pollution Research, 31(23), 33165-33189.

Benhammou, M., Boubekeur, L., Youcef, A., & Korti, M. C. (2023). Evaluating cooling and thermal performances of a double pipe rectangular Earth-to-Air Heat Exchanger provided with a convection zone. Journal of Energy Storage, 72, 108490.

Berg, C. D., Schiller, J. H., Boffetta, P., Cai, J., Connolly, C., Kerpel-Fronius, A., Kitts, A. B., Lam, D. C. L., Mohan, A., & Myers, R. (2023). Air pollution and lung cancer: a review by international association for the study of lung cancer early detection and screening committee. Journal of Thoracic Oncology, 18(10), 1277-1289.

Biswas, B., Qi, F., Biswas, J. K., Wijayawardena, A., Khan, M. A. I., & Naidu, R. (2018). The fate of chemical pollutants with soil properties and processes in the climate change paradigm—A review. Soil Systems, 2(3), 51.

Chan, R., Chiemchaisri, W., & Chiemchaisri, C. (2023). Exploring effective bio-cover materials for mitigating methane emission at a tropical landfill. Applied Sciences, 13(3), 1990.

Chaudary, A., Mubasher, M. M., & Qounain, S. W. U. (2021). Modeling the strategies to control the impact of photochemical smog on human health.

Coté, C. J., Wilson, S., American Academy of, P., & American Academy of Pediatric, D. (2019). Guidelines for monitoring and management of pediatric patients before, during, and after sedation for diagnostic and therapeutic procedures. Pediatrics, 143(6), e20191000.

Espinosa-Ortiz, E. J., Rene, E. R., & Gerlach, R. (2022). Potential use of fungal-bacterial co-cultures for the removal of organic pollutants. Critical reviews in biotechnology, 42(3), 361-383.

Fenice, M. (2021). The nitrogen cycle: An overview. Nitrogen Cycle, 1-21.

Gaffney, J. S., Marley, N. A., & Frederick, J. E. (2009). Formation and effects of smog. Environmental and Ecological Chemistry; Sabljic, A., Ed.; Eolss Publishers Co., Ltd.: Oxford, UK, 2, 25-51.

Guerrero-Cruz, S., Vaksmaa, A., Horn, M. A., Niemann, H., Pijuan, M., & Ho, A. (2021). Methanotrophs: discoveries, environmental relevance, and a perspective on current and future applications. Frontiers in microbiology, 12, 678057.

Hanif, S., Lateef, M., Hussain, K., Hyder, S., Usman, B., Zaman, K., & Asif, M. (2022). Controlling air pollution by lowering methane emissions, conserving natural resources, and slowing urbanization in a panel of selected Asian economies. Plos one, 17(8), e0271387.

He, Y., Shen, J., Alharbi, N. S., & Chen, C. (2023). Volatile organic compounds degradation by nonthermal plasma: a review. Environmental Science and Pollution Research, 30(12), 32123-32152.

Iram, S., Qaisar, I., Shabbir, R., Pomee, M. S., Schmidt, M., & Hertig, E. (2025). Impact of air pollution and smog on human health in Pakistan: A systematic review. Environments, 12(2), 46.

Isha, Ali, S., Khalid, A., Naseer, I. A., Raza, H., & Chang, Y.-C. (2024). Bioremediation of Smog: Current Trends and Future Perspectives. Processes, 12(10), 2266.

Jani, C. T., Singh, H., Abdallah, N., Mouchati, C., Arora, S., Kareff, S., Salciccioli, J., Thomson, C. C., & Velcheti, V. (2023). Trends in lung cancer incidence and mortality (1990-2019) in the United States: a comprehensive analysis of gender and state-level disparities. JCO Global Oncology, 9, e2300255.

Joo, H., Han, S.-W., Lee, C.-S., Jang, H.-S., Kim, S.-T., & Han, J.-S. (2023). Field application of cost-effective sensors for the monitoring of NH3, H2S, and TVOC in environmental treatment facilities and the estimation of odor intensity. Journal of the Air & Waste Management Association, 73(1), 50-64.

Kanematsu, H., & Barry, D. M. (2020). Biofilm problems and environments. In Formation and Control of Biofilm in Various Environments (pp. 173-200). Springer.

Kusumawardani, I. A. J., Indraswari, P. G., & Komalasari, N. (2023). Air pollution and lung cancer. J Respi, 9, 150-158.

Lazaroiu, G., & Jarcu, E.-A. (2024). Effect of Air Pollutants Produced by Traditional Energy Sources. In Energy Transition Holistic Impact Challenge (ETHIC): A New Environmental and Climatic Era (pp. 129-153). Springer.

Liu, B., Ma, X., Ma, Y., Li, H., Jin, S., Fan, R., & Gong, W. (2022). The relationship between atmospheric boundary layer and temperature inversion layer and their aerosol capture capabilities. Atmospheric Research, 271, 106121.

Megyesfalvi, Z., Gay, C. M., Popper, H., Pirker, R., Ostoros, G., Heeke, S., Lang, C., Hoetzenecker, K., Schwendenwein, A., & Boettiger, K. (2023). Clinical insights into small cell lung cancer: Tumor heterogeneity, diagnosis, therapy, and future directions. CA: a cancer journal for clinicians, 73(6), 620-652.

Miloştean, D., & Flori, M. (2022). Study of air quality through suspended particles determination.

Munsif, R., Zubair, M., Aziz, A., & Zafar, M. N. (2021). Industrial air emission pollution: potential sources and sustainable mitigation. In Environmental emissions. IntechOpen.

Naylor, D., Sadler, N., Bhattacharjee, A., Graham, E. B., Anderton, C. R., McClure, R., Lipton, M., Hofmockel, K. S., & Jansson, J. K. (2020). Soil microbiomes under climate change and implications for carbon cycling. Annual Review of Environment and Resources, 45(1), 29-59.

Nottingham, A. T., Gloor, E., Bååth, E., & Meir, P. (2022). Soil carbon and microbes in the warming tropics. Functional Ecology, 36(6), 1338-1354.

Oyarzun, P., Alarcón, L., Calabriano, G., Bejarano, J., Nuñez, D., Ruiz-Tagle, N., & Urrutia, H. (2019). Trickling filter technology for biotreatment of nitrogenous compounds emitted in exhaust gases from fishmeal plants. Journal of Environmental Management, 232, 165-170.

Pavlović, J., Farkas, Z., Kraková, L., & Pangallo, D. (2022). Color stains on paper: fungal pigments, synthetic dyes and their hypothetical removal by enzymatic approaches. Applied Sciences, 12(19), 9991.

Ralebitso-Senior, T. K., Senior, E., Di Felice, R., & Jarvis, K. (2012). Waste gas biofiltration: advances and limitations of current approaches in microbiology. Environmental science & technology, 46(16), 8542-8573.

Rani, M. H. S., Nandana, R. K., Khatun, A., Brindha, V., Midhun, D., Gowtham, P., Mani, S. S. D., Kumar, S. R., Aswini, A., & Muthukumar, S. (2024). Three strategy rules of filamentous fungi in hydrocarbon remediation: an overview. Biodegradation, 35(6), 833-861.

Samanta, D., & Sani, R. K. (2023). Methane oxidation via chemical and biological methods: Challenges and solutions. Methane, 2(3), 279-303.

Srivastava, N. K., & Majumder, C. B. (2008). Novel biofiltration methods for the treatment of heavy metals from industrial wastewater. Journal of hazardous materials, 151(1), 1-8.

Stucki, D., & Stahl, W. (2020). Carbon monoxide–beyond toxicity? Toxicology letters, 333, 251-260.

Tabassum, N., Kheya, I. S., Asaduzzaman, S., Maniha, S., Fayz, A. H., Zakaria, A., & Noor, R. (2020). A review on the possible leakage of electrons through the electron transport chain within mitochondria. Life Sci, 6(1), 105-113.

Tiedje, J. M., Bruns, M. A., Casadevall, A., Criddle, C. S., Eloe-Fadrosh, E., Karl, D. M., Nguyen, N. K., & Zhou, J. (2022). Microbes and climate change: a research prospectus for the future. MBio, 13(3), e00800-00822.

Usman, M., Aamir, H. M., Naz Iqbal, H. F., & Arshad, H. A. (2019). New techniques for the prevention control of smog and air pollution in Pakistan. Environ pollut Climate Change, 2(2), 10-4172.

Webster, G. (2024). Free fare for better air? Evaluating the impacts of free fare public transit on air pollution. Transportation Research Part A: Policy and Practice, 184, 104076.

Yang, K., Li, L., Xue, S., Wang, Y., Liu, J., & Yang, T. (2019). Influence factors and health risk assessment of bioaerosols emitted from an industrial-scale thermophilic biofilter for off gas treatment. Process Safety and Environmental Protection, 129, 55-62.

Yasin, M. M., Abbas, Z., & Hafeez, A. (2022). Correlation of histopathological patterns of OSCC patients with tumor site and habits. BMC Oral health, 22(1), 305.