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Final Report

Exploring the Spatial Extent, Causes, Composition and Intensity of Winter Smog Over Plains of Punjab



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# Executive Summary

Recently, air pollution has emerged as one of the major environmental challenges affecting the health of the masses in Pakistan. Major cities of Pakistan are ranked among the most polluted cities in the region and the world regularly. The unprecedented increase in emissions of toxic gases and aerosols from vehicles, industrial units, power generation, biomass burning activities have impaired the air quality resulting in various harmful effects including monetary losses. Severe smog episodes during the months of October- November have emerged as a regular phenomenon, in addition, to a rise in aerosol pollution levels throughout the year. Especially, extreme smog hangs over the plains of Punjab Province and is causing severe disruption in the socio-economic circles during the post-monsoon and winter seasons. These smog episodes are causing unprecedented damage to the health and environment of the local inhabitants.

In terms of air quality, Pakistan has also been ranked as the country with the 3rd highest premature mortality rate associated with increased levels of PM2.5,with around 105 deaths per year. According to estimates by the WHO, outdoor air pollution has been responsible for around 22,000 premature deaths and 163,432 DALYs (Disability Adjusted Life Years) in Pakistan. This study was designed under the umbrella of HEC-PBAIRP and mainly focused on highlighting the spatial and temporal extents of the smog events over Punjab, along with examining the potential sources including trans-boundary pollution, industrial, vehicular, and anthropogenic activities in Punjab, Pakistan. As well as estimating the yearly socio-economic costs incurred because of the yearly smog events. The research proceeded by exploiting both satellite and ground-based observations of aerosols and various toxic gases over the affected region. These observations have been used to understand the influence of factors such as meteorology, aerosols, fires, and transboundary emissions on the onset of periodic smog episodes in the region. Field experiments comprising mainly of car MAX-DOAS field campaigns and continuous monitoring of criteria pollutants have been conducted. Health incidents and RTA (Road Traffic Accident) data were also collected, and a survey was conducted to identify potential socio-economic constraints amongst the farming community and linkage of seasonal rice paddy fires with the annual smog episodes and their possible health effects.

Visibility and meteorological data for the cities of Lahore and Multan were compiled for the period year 2015-2020. The analysis of these meteorological parameters, as well as the timing of the identified smog incidences, revealed that the low visibility conditions prevailing across the plains of Punjab (currently termed Lahore smog) are more accurately caused by smoke resulting from agricultural fires. Only a few incidences of smog/fog formations were identified mainly during the early-morning and mid-night periods in the study area. This smoke produced primarily is a result of the paddy fires started by the Indian farmer for clearing their fields for the next crop and causes severe disruptions in the socio-economic circles of both east and west Punjab. The air quality of Lahore and other regions is further deteriorated by the emission of toxic gases and aerosols from local sources. The situation in Pakistan is further complicated due to a lack of proper air quality monitoring infrastructure and undocumented baseline conditions. Satellite observations can address this monitoring gap to some extent by providing vital information about the air pollution levels over the region. In this study, satellite-based aerosol optical depth (AOD) has been used as a precursor for aerosol loads and used for determining the air quality and pollution levels in the region.

Satellite observations for the time period of 2002-2020 have revealed a statistically significant increase of around 15 to 25% in the AOD levels over Multan and Lahore. The increase in AOD levels has been more pronounced from the year 2010 onwards. Further, an increase in the spatial extents of AOD levels over the years predominantly southwards is identified. Additional meteorological information and visibility data for the period of 2015-2020, has revealed a temporal shift of one to two weeks (shift from early November to late October) in the onset of yearly smoke episodes.

Satellite observations were supported through ground-based observations at two sites namely: Site#1: GCU-Lahore and Site#2: BZU-Multan for the period of 2018-2019. The analysis of parameters such as PM2.5 and PM10 revealed that nighttime concentrations were on average higher than daytime concentrations. This might be attributed to the influence of lower atmospheric mixing during nighttime, but might also have been a result of nighttime trash burning activities by cottage industry of the Lahore region ( in order to avoid the raids of regulatory authorities) and emissions from heavy-duty vehicles (as HVT is allowed after 1000 PM only). The findings were further validated through an independent source of data obtained from the U.S. Embassy and Consulates’ air quality monitors. These data set were used to calculate the AQI for the cities of Lahore and Multan. Unfortunately, the AQI measurements revealed that in Lahore, not a single day during the year 2019 was categorized as safe. While the city of Multan experienced only 20-30% of clean days during the study period. The air quality conditions during 2020 and the COVID-19 conditions improved significantly indicating the severe impacts of anthropogenic activities and their role in defining the air quality in Lahore and Multan Cites.

Although data on the quantity and nature of pollutants released from various sectors has been limited and required more studies, the major sources of air pollution identified in this study included emissions from automobiles, industries, thermal power generation, brick kilns, crop burnings, and transboundary air pollution. Crop burning activities across the border have been considered as a major contributor to the increased smoke/smog incidences in Pakistan.

The HYSPLIT back trajectory analysis performed showed a regular and substantial increase in AOD levels throughout the study period (2016 onwards) when air masses originated from the Indian sites dominated by extensive agricultural fires. This was verified by the car-MAX DOAS field observations which indicated a 30 to 40% contribution of transboundary emissions towards the air pollution ( various toxic gases and aerosols) levels observed in the city of Lahore.

The hospital data collected in this study showed an increase in the number of patients suffering from pulmonary disorders during the periods (September to January) of both smoke and smog events. The number of diseases such as acute respiratory infection, asthma, chronic obstructive pulmonary disease, pneumonia, and ischemic heart disease was observed elevating sharply. Furthermore, the number of tractor-trolley incidents have been reported to increase from October to January, most likely due to reduced visibility during smoke/smog episodes. These events can become a major burden on the socio-economic and health care conditions of the country since its medical system runs on subsidiary policies for the general masses.

The satellite-based observations of fire counts obtained through MODIS showed a higher number of fire incidences in India as compared to Pakistan. A study was conducted amongst the farmers of Punjab, Pakistan to find out the reasons for the agricultural burning activities. This study indicated that through proactive awareness campaigns and limited subsidies agriculture burnings can be effectively controlled.

Efforts were also made to estimate the cost of CO2 emissions released from agricultural burning in Punjab, Pakistan. It revealed the cost of agricultural burning in Punjab from 2015 to 2020 was around 1.28 to 5.75 million dollars. These calculations were derived for only the emissions of CO2, if cost estimations were to be performed for all the released gases and aerosols then the cost of monetary losses incurred by these agricultural fires would rise manifold.

This study also identified major structural weaknesses in the country such as the lack of monitoring stations, cross-sectoral collaboration, and lack of proper feedback about devised policies and their implementation. To this end, various recommendations have been provided and a framework for addressing these structural issues through the involvement of the academic institutes within the policy development cycle has been proposed.

Finally, it was acknowledged that the country of Pakistan has put a lot of efforts to control the issue of smog; it has placed regular sanctions on crop burning activities around Punjab through the enactment of section 144, upgraded and shut-down outdated brick-kilns, established vehicular fitness centers in many parts of Punjab, introduced improved fuel and vehicular standards, and launched policies for electric vehicles. But without the presence of regular monitoring infrastructure, the effectiveness of these steps is difficult to quantify. Pakistan has also sought regional cooperation across borders to curtail this issue, unfortunately, no positive response has yet been obtained.

# Therefore, despite the strong efforts made by Pakistan this issue has yet to be properly resolved, as it requires regional cooperation. The results of the satellite and ground-based observations have made it clear that Pakistan alone cannot resolve the issue of smog, as addressing transboundary emissions has a major role in developing a sustainable solution to this issue. Moving forward Pakistan, India, and other countries in the region have to come together, put aside their mutual differences and work together through platforms such as SAARC or UNEP, as this is an issue that affects masses across the South Asian region. “keeping in view the holistic picture of the deteriorating air quality conditions, it is recommended that there is a strong need to share the responsibility (especially during post-monsoon) by the neighbors and share the knowledge and good practices during the rest of the year for a better future”. Air pollution in South-Asia is a multi-dimensional problem that cannot be effectively mediated without the exchange of proper information and capacity building among all stakeholders. Therefore, it urges a dire need for regional harmony as the smog issue could be an opportunity for regional cooperation or a potential source for future disputes among neighbors as Pakistan appears to be often affected by transboundary pollution during smog seasons.2. Conclusions-Findings

Air pollution has emerged as a major environmental problem/challenge in Pakistan. The onset of smog episodes has caused severe disruptions in the socio-economic circles of Pakistan. This problem is further exacerbated by the lack of preparedness, improper and inadequate measures by both the environmental regulatory authority and the Government of Punjab.

The air quality assessment presented in this study has revealed that Lahore and Multan cities are both faced with high aerosol loads, especially during post-monsoon and winter seasons. In particular, the majority of days representing the *unhealthy*, *dangerous,* and *hazardous* air quality conditions were reported in Lahore during the study period without a single day having air pollution levels within safe limits. There is a clear and definitive lack of proper monitoring infrastructure and regular monitoring methods in Pakistan due to which the air pollution levels and baseline conditions in major cities of Pakistan are unknown. This lack of monitoring facilities is a major hindrance in the characterization of pollutants, source apportionment, and assessment of adverse impacts. Especially, in case of disruption caused by severe smog episodes across the plains of Punjab on regular basis since 2016. Therefore, this study urges the immediate attention of all stakeholders to prioritize the multi-dimensional issue of persistent smog with severe implications and socio-economic circles of Pakistan. In the absence of regular air quality monitoring infrastructure, satellite observations have filled this gap to a limited extent and helped to characterize the air pollution scenario in Punjab, Pakistan. The primary scope of this study was to address the existing gaps in knowledge, data, and capacity by exploiting all means of available resources and expertise. Analyses presented in this study were able to address the aforementioned gaps (to a certain extent if not fully). Some major findings of this study are summarized as under:

* An increase in aerosol loads with respect to both spatial and temporal extents has been observed; the earlier occurrences of reduced visibility incidences during the last week of October month, and a higher amount of aerosols present in the southern districts of Punjab. Although the most significant impact of these high aerosol loads has been observed in Lahore, the increase in the spatial extent of aerosol loads towards the southern regions of Punjab might be an indication that this issue is going to extend spatially and might impact a large number of the population in the southern plains of Punjab as well.
* Aerosol observations and a closer look at the meteorological parameters in the study area, especially Lahore, indicate that early occurrences of reduced visibility incidences are mainly due to the onset of smoke from agriculture fires rather than smog.
* Analyses of yearly smog episodes revealed that the most significant sources behind these smoke/smog episodes are the transboundary fire activities supplemented by biomass burning activities.
* A detailed assessment of these transboundary agriculture fires using HYSPLIT trajectory models and Car-MAX-DOAS observations have revealed the impacts of transboundary emissions on the air quality of the study area.
* Other major sources include the transportation sector, especially the emissions from motorcycles, industrial emissions, and thermal power generation.
* Farmers' surveys conducted in the vicinity of Lahore, Sheikhupura, and Sialkot districts revealed that the majority of the farmers are unaware of the negative consequences of rice paddy fires as well as the potential link between crop residue burning, smog episodes, and negative health impacts. Most of the farmers agreed to stop crop residue burning activities in the future only when guaranteed monetary compensation to offset the cost of alternative rice paddy disposal methods.
* A significant rise in health impacts was observed during the periods of smog episodes, as evident from the increased number of hospital visits and patients suffering from various acute pulmonary and other respiratory disorders.
* The number of traffic accidents was quantified and a significant peak in traffic accidents was recorded during smog episodes especially involving vehicles like tractor trollies and trucks.
* An estimated economic cost of around 5.75 million $ was associated with the CO2 emissions (only) from agricultural burning in Punjab during the year 2019, which has shown a 22% increase since 2015 and is projected to rise even further.

In order to avoid drastic losses in socio-economic circles occurring on regular basis, the dire need of Pakistan is to explore the causes, sources, and driving mechanisms of recent intense smoke/smog episodes in Punjab, Pakistan. Keeping in view the existing scenario and outcome of this study, the results of all policy interventions cannot be properly gauged in the absence of a proper air quality monitoring network. A lack of proper feedback mechanism is severely missing in the country and requires a structural response in the institutional capacity, setup, and linkage of regulatory/air quality management in Pakistan. A way forward to address these limitations is addressed in the following section.

# Priority Recommendations/Feedback for policymakers

Based on observations, analyses, and their outcomes, the following recommendations are made:

1. Proper awareness and dissemination of appropriate information among the masses is the first step to solve the problem of consistent smoke/smog episodes and associated disruptions in socio-economic circles. Thus, extensive awareness campaigns should be undertaken on social, electronic media, and print media about the pros and cons of air pollution specifically smog episodes.
2. Especially, a robust awareness campaign needs to be undertaken across the country to educate the farmers about the effects of crop residue burning on smog formation and potential health implications.
3. Proper leadership and appropriate political will are necessary to properly address these social and health issues arising from air pollution for the betterment of the masses via tools such as policy implementations, revised guidelines, etc.
4. Implementing proper air pollution abatement laws, providing reliable electricity supply, and developing structural reforms that encourage clean fuel and technologies.
5. There is a lack of air quality monitoring facilities not only in Punjab but across Pakistan. This has placed the research agencies and academia in a difficult situation while identifying the causes for air pollution episodes like the smog over the plains of Punjab. Different monitoring facilities should be set up across Pakistan. Hence, modern and state of the art monitoring equipment should be provided to all the provincial EPAs/EPDs to properly monitor the air quality and meteorological condition across Pakistan on regular basis.
6. Any data available with the government offices, whether EPDs or meteorological departments should be made publicly available and for scientific use. Digital access to any data will lead to better research and development for air quality issues in the country.
7. Agriculture is the backbone of the country and its development depends upon the farmers and their willingness to cooperate. For this purpose, surveys should be carried out to identify the needs and demands of the farmers, and integrating their points of view into the policy design. This will aid in the development of alternative solutions to crop residue burning while conserving the interests of the farming community and ultimately reduce air pollution across the country.
8. The measures taken by the Punjab Government such as the closure of brick kilns for the duration of the winter smog and section 144 on open burning should be continued and implemented in true spirit.
9. The issue of air pollution is not limited to one location and the diffusion of pollution across the district, provincial and national borders cannot be ignored. The trans-boundary pollution from Pakistan’s neighboring country should be of policy concern as Pakistan alone cannot solve this issue.
10. Crop burning in Punjab might results in a significant amount of air pollution thus resulting in damages to the socio-economic and environmental conditions. For this purpose, the Government of Pakistan should consider providing compensation to the farmers to remove crop residue rather than burning it.
11. Modern and state of the art technologies need to be introduced and provided to the farmers at subsidized rates so that crop residue removal by incorporation into the soil or using as feedstock should be encouraged instead of burning. In this aspect, the government could promote machines such as happy seeders. This machine helps to sow seed immediately after the rice harvest, using rice straw as mulch and does not increase the cost of wheat field preparation.
12. An awareness-raising campaign regarding the use of wheat chopper machine and Kubota harvester should be planned to reduce open field burning and the use of crop residue for bio-energy consumption.
13. The use of catalytic converters is highly recommended for all vehicle types but especially motorcycles.
14. The government should encourage the industrial sector to produce electric motorcycles with priority to the red zone, green zone, and yellow zones in Punjab and other provinces as well.
15. The upcoming electric vehicle policy of Punjab is a good initiative, according to the environmental and air pollution paradigm. Other provinces should also pursue suit and electric vehicles should be introduced across Pakistan.
16. As for the implementation of the electric vehicle policy, the government should emphasize the immediate conversion of motorcycles into electric vehicles before the pursuit of Euro II or other standards
17. The government should also deploy advanced technologies (e.g., Euro IV and higher) as well as provide high subsidies and tax exemptions to promote EV sales.
18. Long term negotiations with the neighboring states and development of cross-border collaborating strategies through established platforms such as SAARC (South Asian Association for Regional Cooperation) and United Nations Environmental Program.
19. To minimize vehicular emissions, revision of vehicular emission standards for CO2, NOx, PM, CO, and SO2 is crucial. It should be based on vehicular inventories and real-time emission measurements. The vehicular inspection and maintenance policy can be one of many potential low-cost options to reduce national emissions up to 40 % as per the findings of Faiz et al., (2006). The inspection and maintenance policy should be inclusive for old model commercial vehicles as well.
20. High emitting on-road vehicles should be seriously penalized. The inclusion of the public to assist the identification of gross polluters, through the use of SMS or text message to report sightings of smoke-belching vehicles could be a viable strategy.
21. Proper policies should be developed to address the issue of traffic across the country. A proper (ITS) Intelligent transport system should be developed to have a smooth flow of vehicles across cities with 24/7 monitoring.
22. To maintain the fuel quality standards, timely inspection and fuel test of petrol pumps is essential.
23. The scraping of high emitting vehicles program can be another option through proper incentives from the government and auto-industry. To achieve better air quality or an effective low carbon transport plan, the development of comprehensive vehicular emission control policies and strategies are foremost.
24. Enforcement of best practices on construction sites, planting of trees and shrubs; and sweeping of roads to create green banks can also help reduce pollution loads throughout cities.
25. Afforestation, enforcing best practices in construction/demolition sites, planting trees and shrubs on medians and paving sidewalks, regular sweeping/vacuuming of major roads, creating green banks – pockets of trees, shrubs, and grass - so that dust that falls on them has a lower chance of floating up again.
26. The Government of Pakistan should pay for the installation of Sulphur handling equipment on all coal plants. This is equivalent to investing in renewable energy.
27. Windows or any open ventilation must be closed in winters to keep the polluted air out. Investment in air purifiers and monitors to keep track of the quality of the indoor air can also reduce the onset of diseases from indoor air quality.
28. In addition, the lack of indoor air quality standards and the use of biomass-fueled cooking equipment should be addressed as soon as possible.
29. To deal with outdoor air pollution, the use of masks when commuting is recommended during the smog/smoke episodes.
30. Children under 14 are especially vulnerable to air pollution. Growing children consume more air per pound of body weight as compared to adults. It is suggested that children do not go outside during extremely polluted conditions. Not just children, but senior citizens and pregnant women who are also at high risk from air pollution should be safeguarded against extremely poor air quality conditions through regular updates and AQI monitoring practices.
31. Upgrading of refineries and improving the quality of fuels imported into the country as well as used in the transport and energy sectors in the coming years.

Several health-risk studies have shown the impact of poor air quality on traffic policemen and other similar professions. Therefore, proper rotation of traffic officers and access to health safety equipment such as masks is highly recommended