Food and Agriculture Organization of the United Nations


EXECUTIVE SUMMARY

# Spatio-temporal dynamics of air pollution and the delineation of hotspots in Lao People's Democratic Republic

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by

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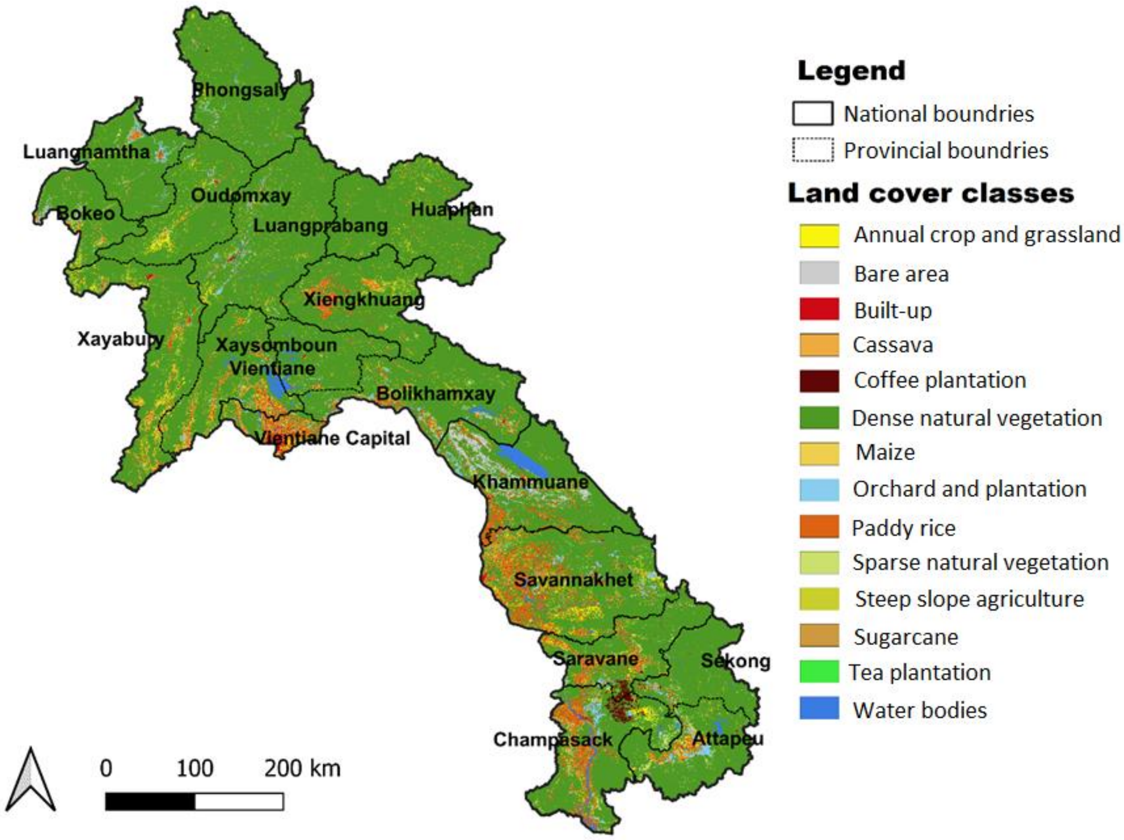
## Introduction

Southeast Asia faces a heavy burden in terms of air pollution and haze (Association of Southeast Asian Nations, 2021). Out of the 7 000 000 deaths worldwide attributed to household and ambient pollution in 2016, 2 000 000 occurred in Southeast Asia (WHO, 2018). Crop residue burning, slash and burn practices, and waste burning, among other sources, contribute to emissions in the agricultural sector. In Lao People's Democratic Republic, as in other countries in Southeast Asia, the dynamics and the contribution of air pollution from the agricultural sector are not well known. With a focus on the mitigation and adaption to climate change, Lao People's Democratic Republic has joined numerous conventions and policies, including the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Sustainable Development Goals, the Paris Agreement, the National Green Growth Strategy, the Reducing Emissions from Deforestation and Forest Degradation (REDD+) framework, and the Advancing the Clean Air, Health and Climate Integration Agenda in the Association of Southeast Asian Nations (ASEAN) Region project. However, there is still a lack of comprehensive and routine monitoring of air pollution and its sources in the country. Strengthening technical capacities to monitor air pollution through innovative and integrated approaches has the potential to guide actions towards sustainable development and improve environmental and life conditions.

Agriculture in Lao People's Democratic Republic is a major sector, representing 16.1 percent of GDP in 2021 (along with forestry and fishing) (World Bank, 2022) and 10 percent of total land area (FAO, 2020). Rice is the dominant annual crop (approx. 850 000 ha in 2018), followed by maize (150 000 ha in 2019) and cassava (100 000 ha in 2019), whereas coffee, rubber, and banana are the main perennial crops (FAO, 2020). In recent years, agricultural production has increasingly been impacted by unpredicted extreme weather events (WHO, 2016). In parallel, the migration of rural people to urban areas has increased, contributing to the expansion of urban areas, industrialization and indirectly to air pollution (Ministry of Natural Resources and the Environment, 2020). Air pollution has become a raising national concern (Ministry of Natural Resources and the Environment, 2017), reinforced with a surge in investment in the mining, hydropower, transport, energy, industrial and agricultural sectors.

**Figure 1:** National land cover map of Lao People's Democratic Republic, 2018




Source: Land cover map, Department of Agriculture Land and Management (DALaM), 2018. https://www.fao.org/3/cb3699en/cb3699en.pdf. Administrative boundaries obtained from National Geographic Department (NGD) of Lao People's Democratic Republic.

To better understand the spatio-temporal dynamics of air pollution in Lao People's Democratic Republic, this assessment integrates various data sources and uses geospatial technologies to support pollution mitigation strategies. In particular, this assessment i) analyses the spatio-temporal dynamics of air pollution and the delineation of hotspots; ii) assesses the contribution from different sectors to air pollution based on the pollution indicators nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), ozone ($O_3$), the ultraviolet aerosol index (UVAI), and aerosol optical depth (AOD), as well as data of potential sources (e.g. fire activity, agricultural production, climate data etc.); and iii) implements small-scale field data collection to better understand the air pollution in Lao People's Democratic Republic.

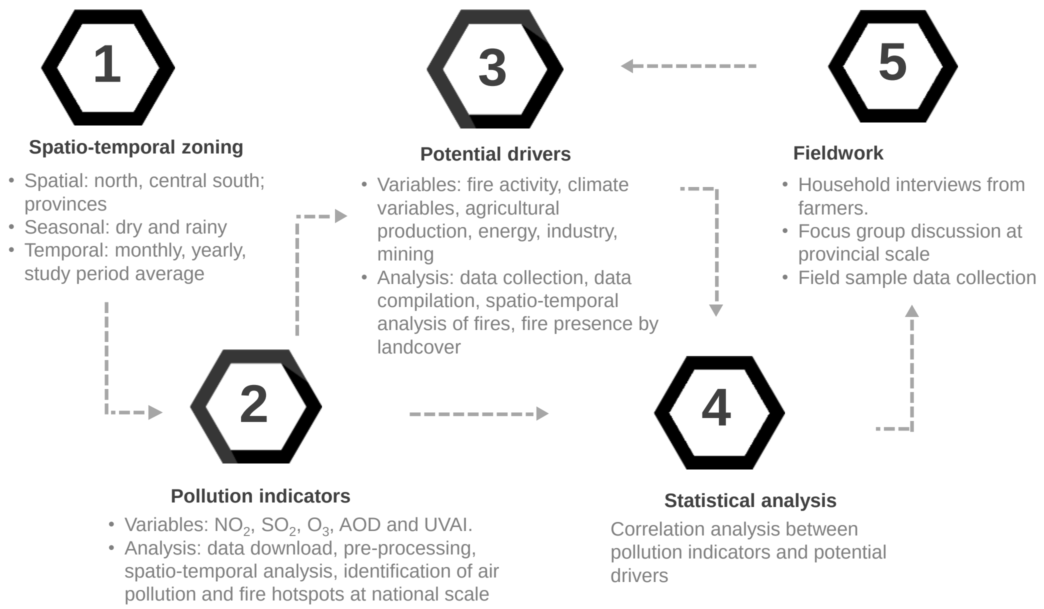
## Methodological approach

The methodological approach has been developed based on identified and collected available global and national datasets. It follows five key components (Figure 2) that integrate the various tabular and spatial datasets available as follows:

**1)** Spatio-temporal zoning: three spatial zones (north, centre and south); two temporal (dry [November to April] and rainy [May to October]).
**2)** Identification of air pollution hotspots through the assessment of spatio-temporal trends.

**3)** Identification of potential drivers (considering climate, agriculture, population, transport, mining, energy, industrial activities and fire).[1]
**4)** Statistical analysis of pollution indicators and potential drivers.
**5)** Field data collection was broadly divided into three sections: (1) focus group discussion with local government officials; (2) household surveys at the village level in selected clusters; and (3) field data collection on pre-selected locations at the cluster level. A cluster in this study is defined as a single hexagon block with a 10 $km^2$ area. The cluster selection was random within the defined areas of interest using a hexagonal grid in two provinces (Luangrabang [north] and Savanakhet [south]). Due to time and resource limitations, only two districts per province were picked for the field exercise. Additional details about the sampling strategy can be found in the main report of this work.

**Figure 2:** Methodological approach for the assessment of the spatio-temporal air pollution dynamics in Lao People's Democratic Republic




Source: Authors' own elaboration.

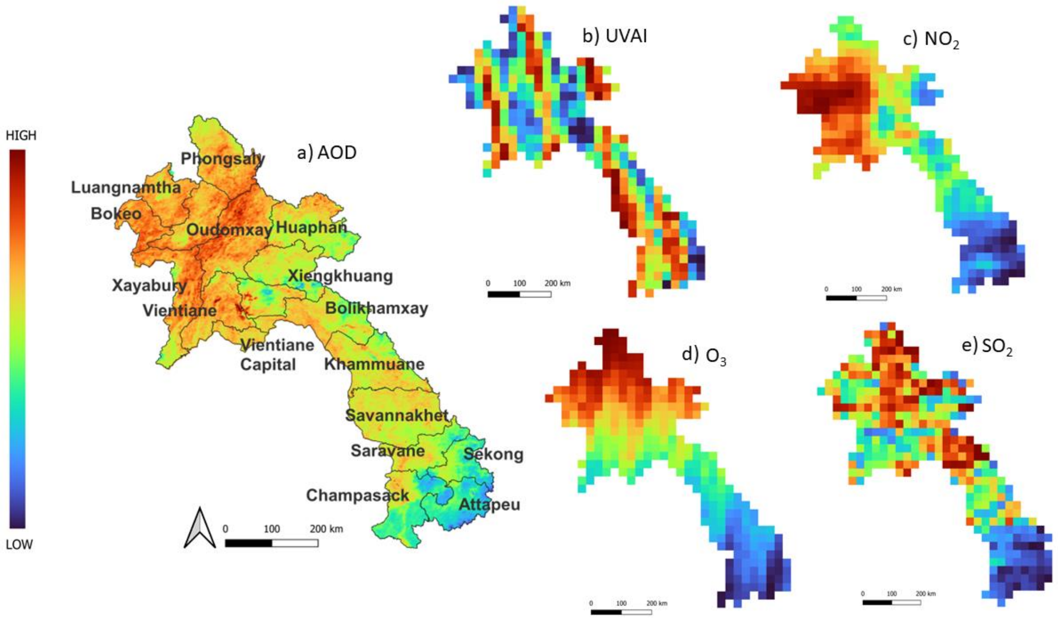
**Spatio-temporal trends of pollution indicators**

The spatio-temporal analysis showed higher concentrations of all pollution indicators in the north, except for UVAI (Figure 3). AOD, $NO_2$ and $SO_2$ yearly-averaged column amounts are higher in the dry season. In contrast, yearly-averaged $O_3$ column amounts and UVAI values are higher during the rainy season, although UVAI monthly values peak during the dry season, while elevated values are maintained during the rainy season (Figure 4).

[1] Data obtained from the Department of Agriculture Land and Management (DALAM), the Department of Planning and Cooperation, Department of Forestry (DoF) under the Ministry of Agriculture and Forestry; the Natural Resources and Environment Research and Statistic Institute (NRERSI); the Department of Meteorology and Hydrology (DMH), under the Ministry of Natural Resources and Environment (MONRE); Lao Statistics Bureau; the Lao People's Democratic Republic Statistical Yearbook 2020, the Ministry of Planning and Investment, the Department of Energy Policy and Planning, under the Ministry of Energy and Mines, the Department of Planning and Cooperation, the Ministry of Public Works and Transport, the Department of Industrial and Handicrafts, the Ministry of Industry and Commerce.

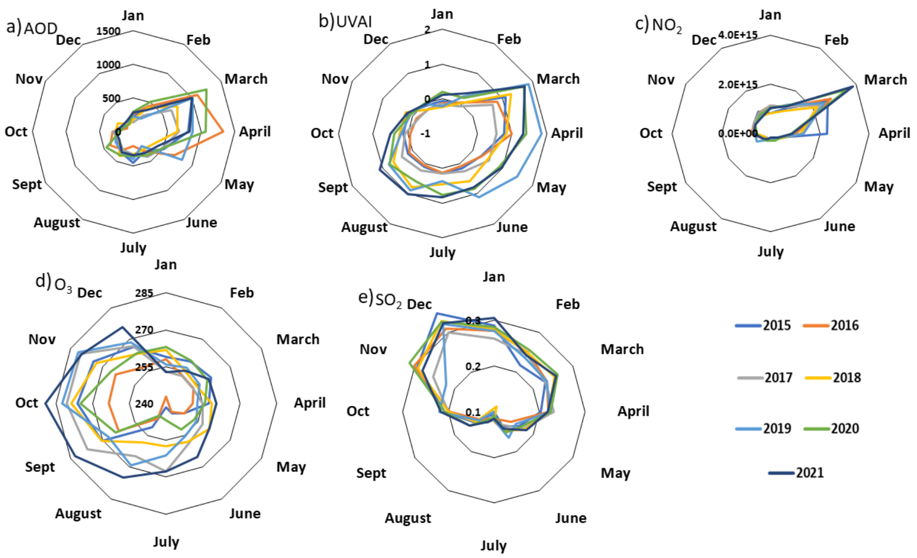
The trends in pollution indicators between 2015 and 2019 do not significantly change, with the exception of UVAI, with values increasing over the period.

**Figure 3:** Yearly means for the period 2015–2021 for a) aerosol optical depth (AOD) and b) ultraviolet aerosol index (UVAI) and average column amounts of c) nitrogen dioxide (molec/cm$^2$); d) ozone (DU) and e) sulphur dioxide (DU)




Source: Authors’ own elaboration and administrative boundaries obtained from National Geographic Department (NGD) of Lao People’s Democratic Republic.

**Figure 4:** Monthly averaged values of a) aerosol optical depth (AOD), b) ultraviolet aerosol index (UVAI), c) nitrogen dioxide (molec/cm$^2$); d) ozone (DU) and e) sulphur dioxide (DU) for each year of the study period

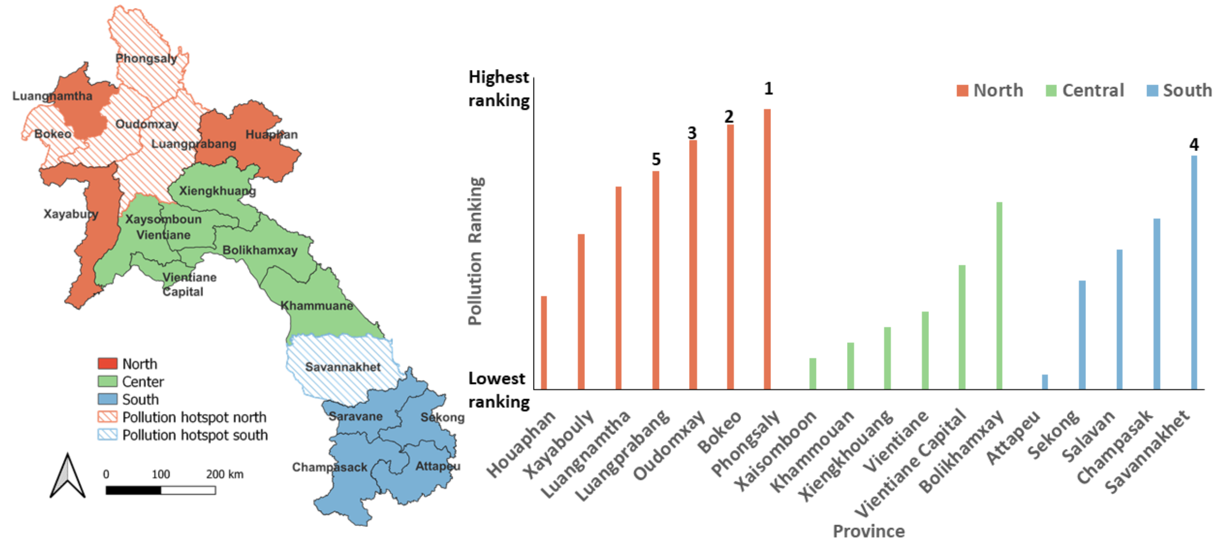



Source: Authors' own elaboration.

## Air pollution hotspots

Bokeo, Phongsaly, Oudomxay, Luangprabang and Savanakhet have been identified as the provinces with the highest values for each pollution indicator (Figure 5). The majority are located in the north, as this zone generally exhibited the highest pollution indicator values, while the selection of Savanakhet in the south is attributed to the elevated UVAI values for this province.

**Figure 5:** Five provinces with highest pollution indicators based on provincial means of each pollution indicator averaged over study period (left: geographic locations; right: provinces ranked)




Source: Authors' own elaboration and administrative boundaries obtained from National Geographic Department (NGD) of Lao People's Democratic Republic.

## Drivers of air pollution

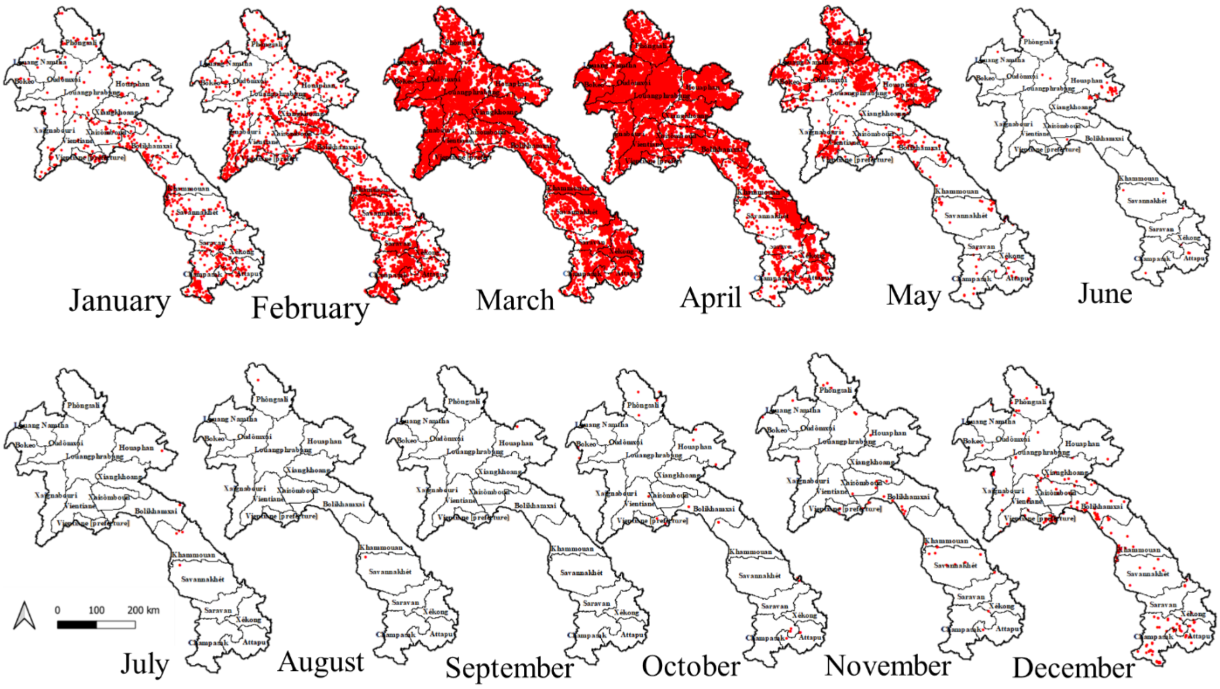
The following drivers were considered to understand air pollution dynamics in the country: fire count and fire radiative power (FRP) (annual and monthly scale); climate indicators (temperature, rainfall, windspeed, sunshine hours and relative humidity) (annual and monthly scale); agricultural production (annual scale); transport (annual scale); population (annual scale); energy generation (available approximately over past 10 years); and industry and mining activity (available approximately over past 10 years).

At the provincial level, significant correlations were observed between AOD, $NO_2$ and $O_3$ with fire, agriculture and climate indicators, and between UVAI, population and the agricultural production for several crops (lowland rice, dry season paddies, and starchy root production) during the period 2015–2021. Based on the available provincial monthly means (pollution indicators, climate and fire data), all pollution indicators showed significant correlations with the climatic variables. With the exception of $SO_2$, all other pollution indicators exhibited a significant correlation with fire count and FRP. Note that $O_3$ is negatively correlated with the fire variables. $O_3$ is not directly emitted from biomass fires, however its precursors are, thus there is a time lag between the fire activity and the formation of $O_3$. The results indicate the strong link between the pollution indicators and the potential sources of climate, fire activity and agricultural production over varying temporal scales.

## Contribution from fires

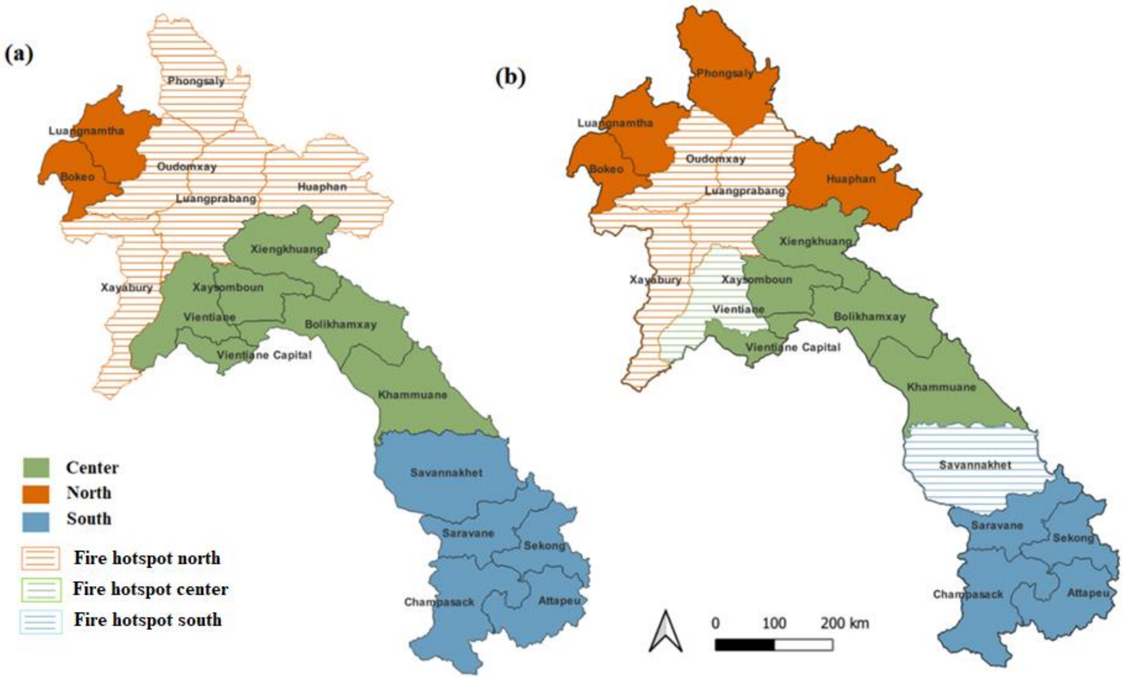
The annual fire distribution by province reveals the highest number of fire events to occur in almost all northern provinces. However, the fire season varies slightly for the upper and lower regions of the country, with peak fire seasons observed during March–May in the northern zone and January–April in the southern and central zones (Figure 6). The presence of fire events was analysed according to land cover using the 2018 land cover map (Figure 1). In total, 89 percent of the fires occurred in forest land, whereas only 10 percent originated from the agriculture sector. Note that the forest land and agricultural land extent were extracted from the land cover map of 2018 (Figure 1) by combining the forest and agricultural classes in the respective categories. The plantation class was included in the forest class.

**Figure 6:** Spatial distribution of fires by month during the period 2015–2021




Source: Authors' own elaboration and administrative boundaries obtained from National Geographic Department (NGD) of Lao People's Democratic Republic.

**Figure 7:** Fire hotspots by provinces according to (a) forest and (b) cropland land cover categories




Source: Authors' own elaboration and administrative boundaries obtained from National Geographic Department (NGD) of Lao People's Democratic Republic.

The highest number of fires in forest land are observed in Luangprabang, Oudomxay, Huaphan, Xayabury, and Phongsaly. The highest number of cropland fires are observed in Luangprabang, Xayabury, Vientiane, Savanakhet, and Oudomxay. The provinces Luangrabang, Oudomxay and Xayabury are identified in both categories, but in different order (Figure 7).

With regards to other drivers, the national mining dataset indicates that several mines (gold, gypsum, limestone and barite) are located in the pollution hotspot of Savanakhet, although it is not the province with the most mines (Vientiane is ranked first, followed by Khammuane). Savanakhet is also the province with the highest population and is ranked number two in terms of transportation (Vientiane Capital is number one).

## Field data analysis

The field data was collected in order to better understand the air pollution and fire dynamics in Lao People's Democratic Republic. The field team collected data from three target groups, namely, government officers (focus groups), local communities (questionnaire), and field point visits (Figure 8). The field collection took place in Luangprabang (north) and Savanakhet (south) based on the relatively high levels of fire activity and pollution indicators observed in these provinces.

**Figure 8:** Images taken from the field data collection. a) Interview with villagers/famers to assess the contribution of farming to air pollution in Parkou district in Luangprabang. b) Field location survey and data collection in Luangprabang. c) Discussion with governmental officials to assess the contribution of anthropogenic activity to air pollution in Luangprabang. c) Interview with villagers to assess the contribution of farming practices to air pollution Chomphet district, Luangprabang


Photograph Credits: ©Xaisavanh Khiewvongphachan and ©Soutvilay Douangphachan.

According to the focus group discussions with local government officials, forest fires (and other factors including dust storms) were determined to make the greatest contribution to air pollution ("high"); followed by agricultural burning, domestic burning, waste burning, industrial activity, and mining activity ("medium"); and slash-and-burn cultivation, power plants and transportation ("low"). Government officials stated that waste burning, domestic burning, power plants, mining activity and transportation increased over the past five years, while slash-and-burning cultivation and industrial activity were stable, and agricultural burning declined. Integrating the observations from all datasets implies that fires make less of a contribution to air pollution in Savanakhet compared to Luangprabang. This is because of the difference in farming system practices. For example, Savanakhet is the main paddy grower in the country, with lowland rainfed and/or irrigated farming systems, while Luangprabang practices upland agriculture systems with upland rice, cassava and other cash and perennial crops. The impacts of pollution are also lower in Savanakhet compared to Luangprabang. This coincides with the remote sensing analysis, whereby all pollution indicators were observed to be greater in Luangprabang, with the exception of UVAI. The field data highlights the contribution of waste and domestic burning to air pollution, which was overlooked in the remote sensing analysis due to lack of data.

Note that these two provinces are distinct in terms of land cover. Forest land dominates Luangprabang (92 percent) and less than 5 percent of the land area is used for crop cultivation, while a larger land area is cultivated in Savanakhet (27 percent) and 68 percent is occupied by forest (Figure 1). Responses from the local communities reveal that deforestation is occurring in both provinces, yet the drivers are distinct, with agricultural expansion as the main driver in Luangprabang and wood extraction for Savanakhet. This is in-line with the spatial analysis, which identifies the highest number of fires in the north to be in the forest land. Moreover, according to the local communities, burning to clear (fallow) land is the most common (42.1 percent) cause of fires in Luangprabang, while for Savanakhet it is the burning of post-harvest crop residue (25.90 percent).

## Conclusion

This report investigates the air pollution dynamics of Lao People's Democratic Republic, given its increasing industrial and economic development, and the use of frequent biomass burning as an agricultural practice. The analysis reveals the majority of the pollution indicators to peak during the dry (and burning) season and in the north and central zones of the country. The provinces Bokeo, Phongsaly, Oudomxay, Luangprabang and Savanakhet are air pollution hotspots, while climate, agricultural production and fire activity are identified to have the strongest impact on the pollution indicators. Luangprabang, Oudomxay, Huaphan, Xayabury, and Phongsaly are forest fire hotspots; and Luangprabang, Xayabury, Vientiane, Savanakhet, and Oudomxay are crop fire hotspots. Integrating the field data with the other datasets reveals that fires contribute less to air pollution in Savanakhet (south) compared to Luangprabang (north). The most common cause of fires identified from the field activities is burning to clear land and post-harvest crop residue, for Luangprabang and Savanakhet, respectively. Agricultural expansion is the main driver of deforestation in Luangprabang, while for Savanakhet it is fuel wood extraction. This report acts as a basis for the Lao People's Democratic Republic Government to understand the air pollution dynamics and to take action accordingly. However, the approach can be further improved by considering other national datasets for the validation of the satellite observations.

Overall, providing evidence-based information to support national action plans based on satellite observation products is important to monitor air pollution, improve the population's health and livelihoods and ensure sustainable development. The analysis suggests to transfer the methodological approach for the operationalization of a national system by strengthening technical capacities and integrating multi-sectoral and spatio-temporal datasets through a data sharing system and the use of innovative geospatial analysis. A national platform could support up-to-date cross-sectoral data sharing protocols and field data collection campaigns, fill in the gaps in national datasets (e.g. industrial and mining activity, waste and domestic burning), include additional datasets (e.g. crop management, burned area maps) and support sustainable and resilient farming practices while reducing air pollution. A national intervention plan can support low-income farming populations in conjunction with emission reduction policies. Plans include support to farmers in replacing fires with alternatives (e.g. low-level agricultural burning, chipping, and mulching) that have a lower impact on the environment, farmer subsidies to implement these alternatives, and incentives for zero fire commodities.

Transboundary pollution is another important factor contributing to the local problem, therefore strategies to reduce the impacts of transboundary air pollution need to be considered, for example, air quality forecasts, the development of a comprehensive forest fire detection system, and the use of Earth observation data to monitor air pollution. Capacity building can increase the awareness of air pollution and the impact of open burning for local communities, as well as local and national staff, for example, raising awareness on alternative approaches to pollution and the replacement of open biomass burning over time.

A key limitation of the analysis is the lack of comprehensive national datasets on industry, mining, and energy activity (e.g. large-scale infrastructures [China-Lao People's Democratic Republic railway] and hydropower dams), making it difficult to fully quantify the contributions of different sectors in Lao People's Democratic Republic to air pollution. In addition, available ground-based measurements of the target gases and aerosol indicators are not sufficient to validate the satellite observations across the entire country and study period. Future research will aim to fill these gaps. This report can act as a basis for the Lao People's Democratic Republic Government to understand the air pollution dynamics of the country and to take action accordingly.

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