$PM_{2.5}$ MAPPING AND MONITORING IN VIETNAM USING SATELLITE AND GROUND-BASED DATA

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OUTLINE

- Introduction
- Satellite $PM_{2.5}$ estimation in Vietnam
- Use cases of $PM_{2.5}$ datasets
- The Status of $PM_{2.5}$ and its impact on public health in Vietnam 2021
- POPGIS – An application service for air pollution management and analysis in Vietnam
- Conclusion

INTRODUCTION

STATE OF AIR POLLUTION IN VIETNAM

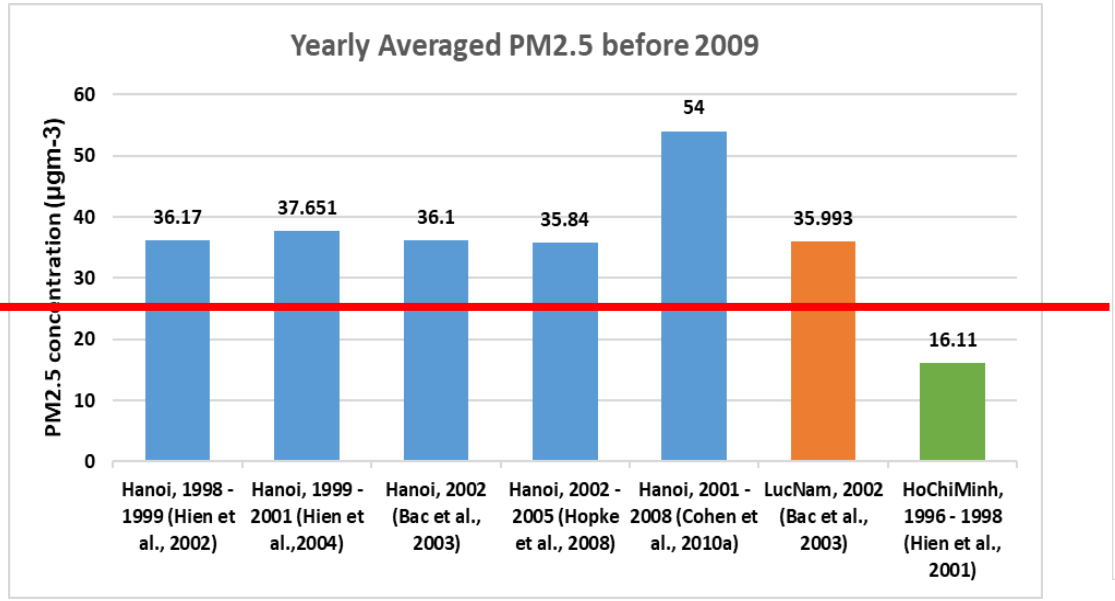
- Air pollution is one of the major environmental challenges facing nations worldwide.
  - Exposure to air pollutants causes over 6 million early deaths annually, with nearly 99% of the global population living in areas with unsafe concentrations of ambient air pollutants (Cohen et al., 2017; Health Effects Institute, 2020; World Health Organization, 2022)
  - The health effects of air pollution extend beyond respiratory illnesses. Residents breathing polluted air have higher rates of heart disease, cancer, and diabetes (Bourdrel et al., 2017; Martoni, 2018; Turner et al., 2020). Recent evidence also indicates a link between chronic exposure to air pollutants and susceptibility to COVID-19 (Kim and Bell, 2021; Wu et al., 2020).
- Air pollution in Vietnam has been and continues to be a concerning issue due to increasing emissions from domestic sources and long-range transport, especially at big urban areas.

RANK	COUNTRY	SCORE	REG
1	Iceland	96.0	1
2	Sweden	94.0	2
3	Finland	93.5	3
4	New Zealand	93.2	4
5	Norway	92.4	5
6	Australia	91.1	6
7	Ireland	89.1	7
8	Canada	88.0	8
9	Switzerland	84.3	9
10	France	82.0	10
11	Luxembourg	81.0	11
12	Denmark	80.5	12
13	Japan	78.9	1
14	United Kingdom	78.6	13
15	Portugal	78.1	14
16	United States of America	77.0	15
17	Netherlands	76.8	16
18	Germany	75.2	17
19	Austria	75.0	18
20	Belgium	74.6	19
20	Estonia	74.6	1
22	Spain	74.0	20
23	Malta	73.2	21
24	Italy	69.4	22
25	Singapore	69.2	2

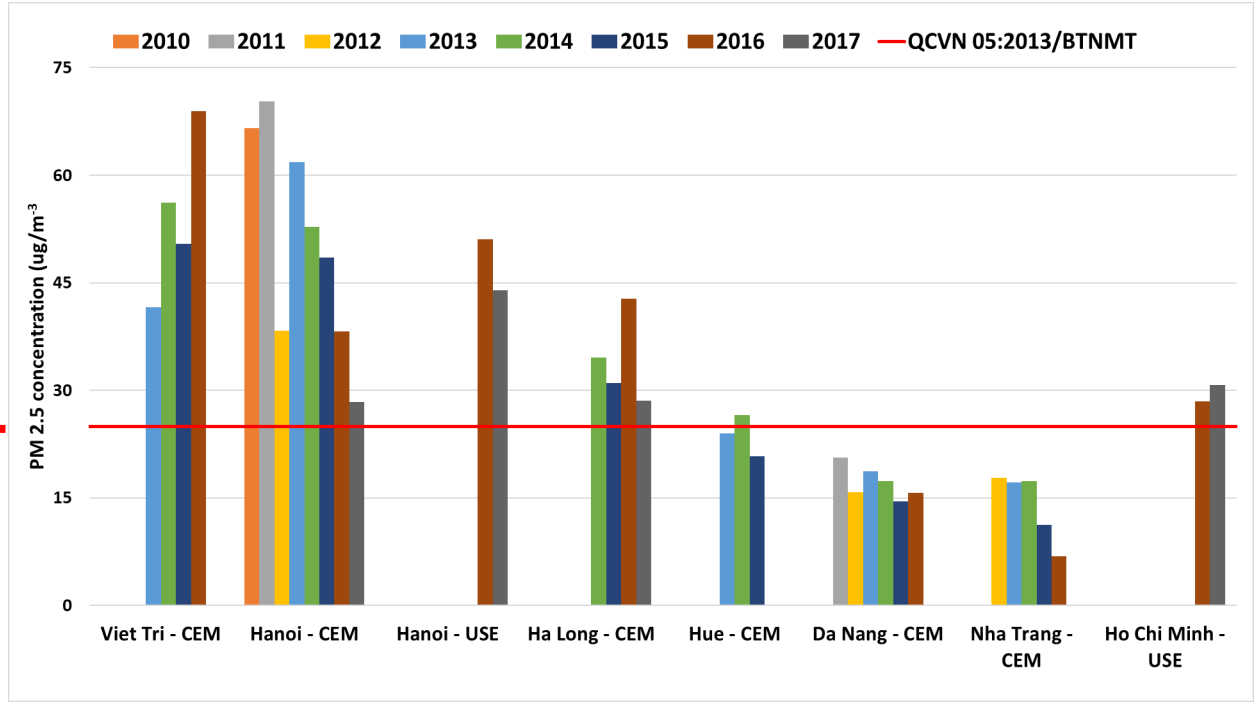
RANK	COUNTRY	SCORE	REG
121	Liberia	28.3	11
122	Haiti	28.2	32
123	Cabo Verde	28.0	12
124	Georgia	27.9	8
125	Bosnia and Herzegovina	27.8	18
126	Uganda	27.4	13
127	Niger	27.1	14
128	São Tomé and Príncpe	26.8	15
129	Mali	26.7	16
130	Viet Nam	26.5	18
131	Burkina Faso	26.1	17
132	Cambodia	25.9	19
132	Philippines	25.9	19
134	Gabon	25.7	18
135	Dem. Rep. Congo	25.1	19
136	Rwanda	24.7	20
137	Chad	24.3	21
138	Zimbabwe	23.9	22
139	Zambia	23.6	23
140	Kyrgyzstan	23.5	9
141	Angola	23.1	24
142	Equatorial Guinea	22.9	25
143	Morocco	22.7	15
144	North Macedonia	22.6	19
144	Laos	22.6	21

Vietnam ranked at 130/180 nation on air quality in 2022 (EPI, Wolf et all., 2022

WHEN DID AIR POLLUTION START?



Annual average of PM2.5 in Hanoi, Luc Nam, and Ho Chi Minh city before 2009 *



Annual average of PM2.5 in Viet Tri, Hanoi, HaLong, Hue, Da Nang, and Ho Chi Minh city from 2010 – 2017*

The redline is Vietnamese standards (25 µg/m^3) for annual average $PM_{2.5}$ (WHO recommendation is 5 µg/m^3 in 2022)

(*) *Nguyen et al, "Current status of $PM_{2.5}$ and its mitigation in Vietnam"*

OBJECTIVES

- Supplementing $PM_{2.5}$ monitoring at country-wide using satellite observation;
- Developing products to provide status of $PM_{2.5}$ concentrations across the country to communities in different forms;

Published article: *Ngo et al, 2023. A daily and complete PM2. 5 dataset derived from space observations for Vietnam from 2012 to 2020, Science of The Total Environment 857, 159537*

SATELLITE DERIVED $PM_{2.5}$ IN VIETNAM

GOALS

- Produce and validate daily $PM_{2.5}$ map over Viet Nam using multi-sourced data and a machine learning model

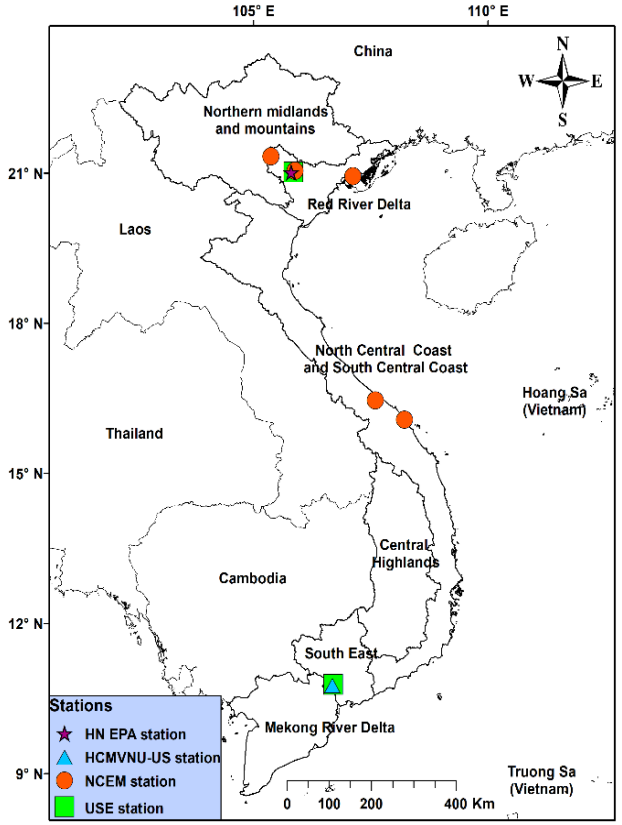
- Difficulties encountered in Vietnam
  - Data missing
    - Lack of ground monitoring stations, data missing, …
    - Missing satellite data due to cloud, orbit track, bright surface,…
  - Data quality
    - Ground data
    - Satellite data

RELATED WORK

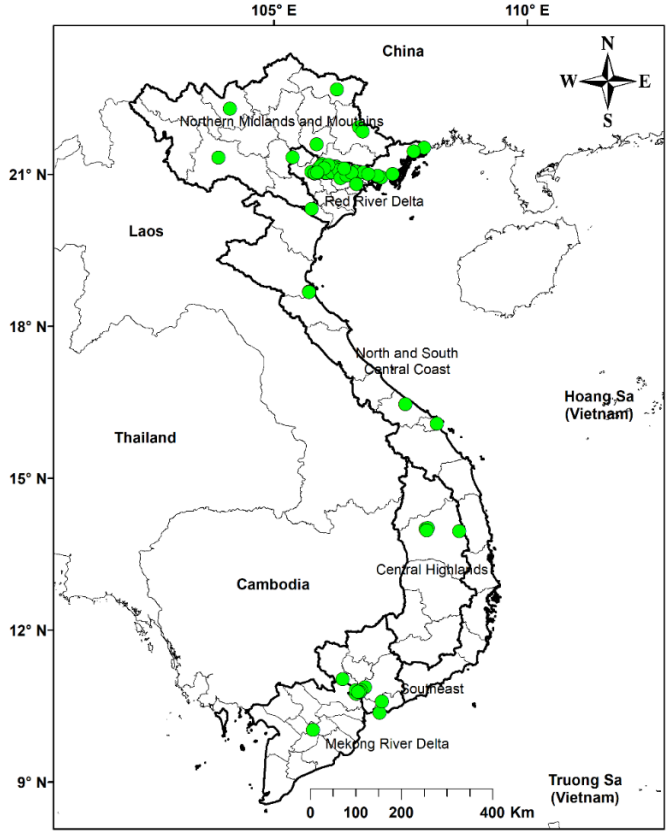
Author	Study Area	Study Priod	No of station	Methodology	Results
Gupta et al 2016	Global	2000-2002	26	Linear Regression (LR)	R^2 = 0.92
van Donkelaar et al 2016	Global	1998-2014	-	GEOS Chem Geographical Weighted Regression (GWR)	CV R^2 = 0.81
Xuefei Hu et al 2013	US	2003	119	GWR	CV R^2 = 0.71, RMSE = 3.81 µg/m³
Ma et al 2014	China	2012-2013	835	GWR	CV R^2 = 0.64, RMSE = 32.98 µg/m³
You et al 2016	China	2014	943	GWR	CV R^2 = 0.85, RMSE = 24.86 µg/m³, MRE = 19.7%
Kloog et al 2012	US	2000-2008	161	Mixed Effect Model (MEM)	CV R^2=0.82, RMSE = 1.38 µg/m³
Kloog et al 2014	US	2003–2011	161	MEM	CV R^2 = 0.88, RMSE = 2.33 µg/m³
Lee et al 2016	US	2006-2012	123	MEM	CV R^2 = 0.66, RMSE = 5.69 µg/m³
Just et al 2015	Mexico	2004-2014	12	MEM	CV R^2 = 0.724, RMSE = 5.55 µg/m³
Zheng et al 2015	China	2013	101	MEM	CV R^2: 0.77 - 0.8, RMSE: 12.47 - 23.07 µg/m³
Thanh et al 2014	Hanoi, Vietnam	2010-2012	1	LR Support Vector Regression (SVR)	- LR: Pearson r = 0.598, RMSE = 31.071 µg/m³ - SVR: Pearson r = 0.593, RMSE = 31.674 µg/m³
Thanh et al 2015	Vietnam	2010-2014	6	LR	- MODIS Aqua: R2 = 0.602, RMSE = 8.53 µg/m³, RE = 33.35% - MODIS Terra: R2 = 0.58, RMSE = 8.78 µg/m³, RE = 53.35%

TARGET DATA

- Ground $PM_{2.5}$ measurements from standard stations with hourly mean, from 2012 – 2021.



Distribution of standard stations in Vietnam from 2012 - 2019

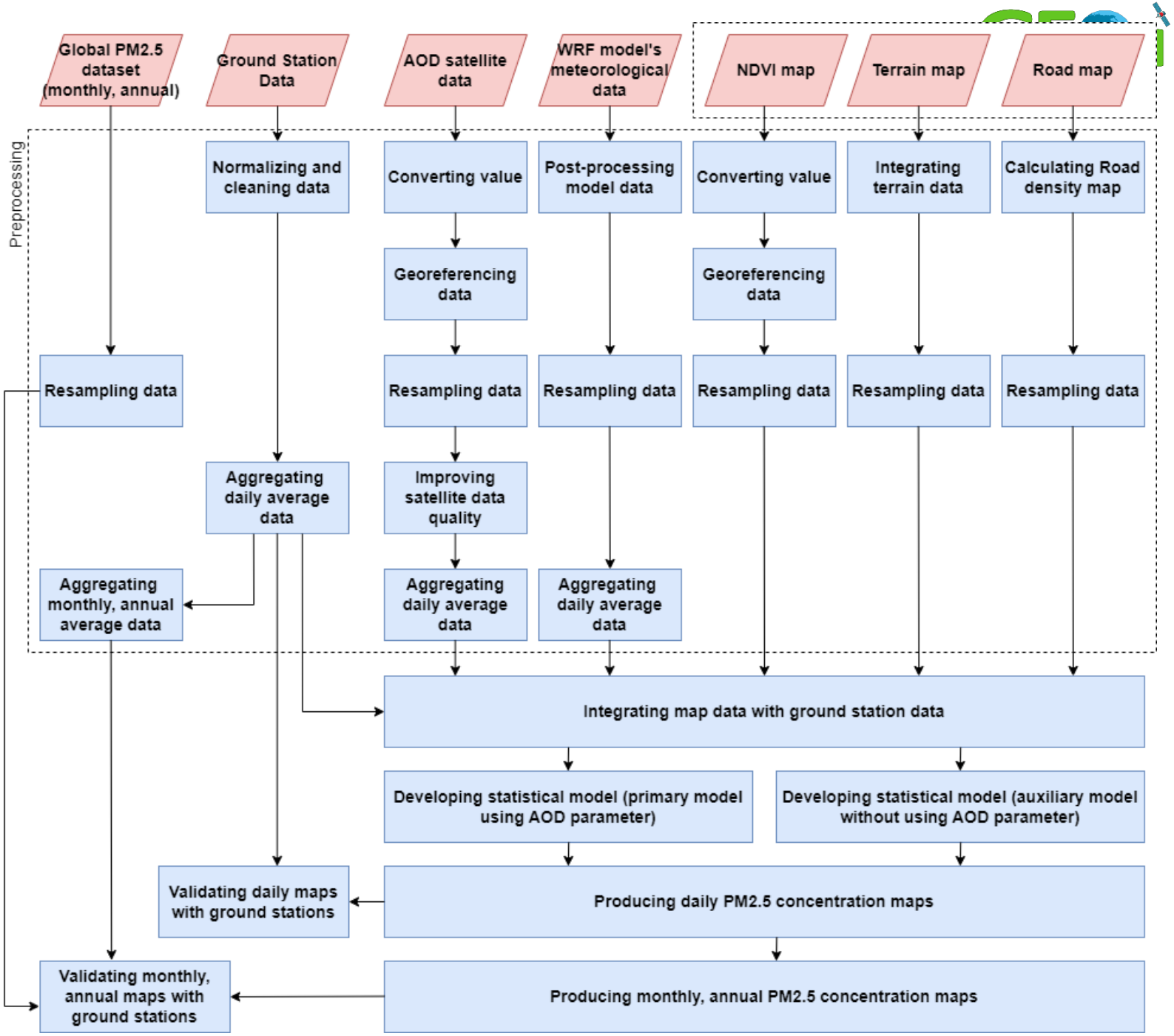


Distribution of standard stations in Vietnam since 2020

INPUT DATA

Type	Parameter	Description	Sources
Raster Maps	Aerosol Optical Depth (AOD)	- AOD from MODIS onboards TERRA and AQUA and VIIRS on Suomi NPP - Spatial resolution 6km (VIIRS AOD) – 3 km (MODIS AOD) - Each product has 2-5 images captured some areas in Vietnam every day	NASA, NOAA
Raster Maps	Meteorology parameter (Temperature, RH, Pressure, Wind Speed, PBLH)	4 maps every day (0h, 6h, 12h, 18h) at 5km spatial resolution	Results of WRF using ERA-5 Reanalysis data as input and running for Vietnam
Raster Maps	Traffic	Traffic information (name, type, length, width, …)	Vietnam Department of Surveying, Mapping and Geographic Information
Raster Maps	Normalize Difference Vegetation Index (NDVI)	Product from MODIS Terra: 1 image/15 days at 250m spatial resolution	NASA
Raster Maps	Population Density	Annual Average, 100m spatial resolution	WorldPop

METHODOLOGY



MODEL PARAMETER SELECTION

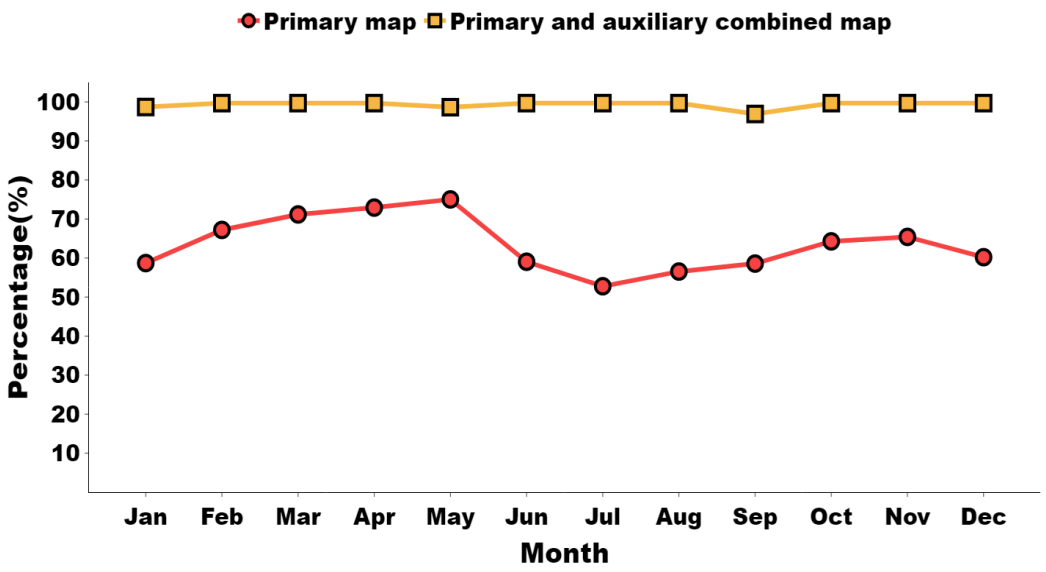
Parameter	Coefficient	p-value	VIF
AOD	0.31	0.001	1.14
Humidity	-0.46	<2e-16	1.29
NDVI	-0.23	3.37e-07	1.53
Road Density	0.3	<2e-16	1.67
PBLH	-0.41	5.42e-10	1.2
Terrain	1.03	<2e-16	1.29

- The signs of the coefficients reflect the correlation relationship between the parameter and the $PM_{2.5}$ concentration.
- All model parameters are statistically significant (p-value < 0.05) and there is no multicollinearity issue (VIF < 3).

MODEL EVALUATIONS AND CROSS-VALIDATION

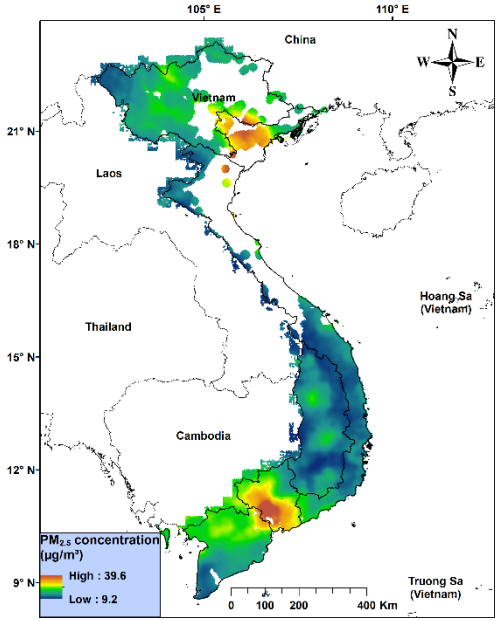
		N	**r**	R^2	**RMSE (μg/m³)**	**MRE (%)**
Model validation	Primary (wAOD)	10,614	0.83	0.68	14.14	40.99
	Auxiliary (nAOD)	34,208	0.81	0.65	14.8	48.58
10-fold cross validation	Primary (wAOD)	1,061	0.7	0.49	18.14	52.71
	Auxiliary (nAOD)	3,420	0.75	0.56	16.64	54.2
Leave One Station Out Cross Validation	Primary (wAOD)	-	0.67	0.49	14.96	57.9
	Auxiliary (nAOD)	-	0.67	0.5	14.11	58.14

DATA COVERAGE

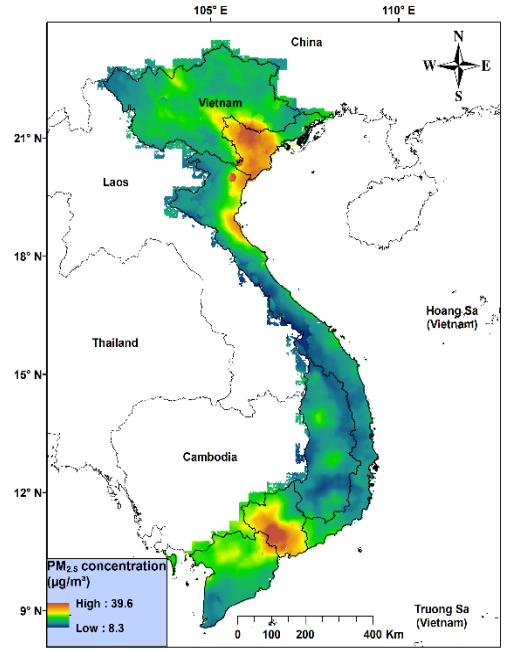


Data coverage

- Maps estimated by primary model have data coverage from 50-75%
- Combined maps have data coverage at ~ 100%



A map estimated by Primary model (wAOD)



A combined map

MAP VALIDATION

2012-2020		Study's maps				Global maps*			
	No of samples	R^2	Pearson r	RMSE (μg/m³)	MRE (%)	R^2	Pearson r	RMSE (μg/m³)	MRE (%)
Daily mean	13,886	0.75	0.87	11.76	36.57	-	-	-	-
Monthly average	480	0.79	0.89	8.5	25.93	0.58	0.76	11.9	37.07
Annual Average	42	0.8	0.9	5.6	17.07	0.65	0.81	7.21	21.6

Validation of monthly and annual maps with ground measurements
& Comparison with the global maps

* Van Donkelaar *et al,* Environmental Science and Technology *2021*

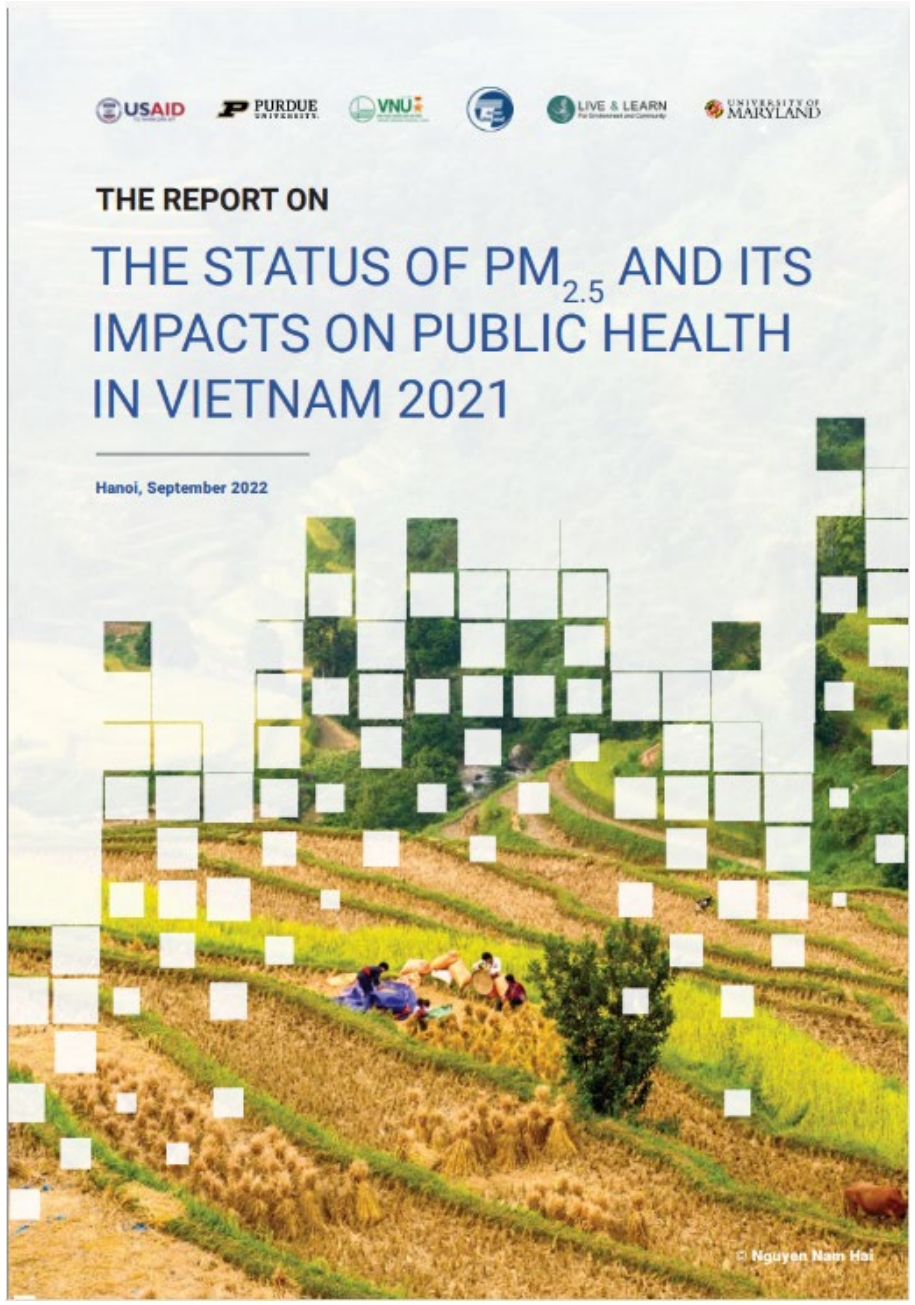
$PM_{2.5}$ DATASETS

USE CASES

- Used for **lecturing materials;**
- Assess the **impact of the COVID-19 pandemic** and **open burning on air quality;**
- Construct **provincial environmental performance index,** that reflects the environmental health of each province in Vietnam;
- Construct **provincial greenness index,** that contributed as a part of province competitiveness in Vietnam;
- Assess the **effects of $PM_{2.5}$ on children** (hospital admission for children, Child-centered climate risk mapping) **and adults** (mortality, respiratory diseases, cardiovascular diseases)**;**
- Use as a reference source to **assess current status of air pollution** and **develop Guideline for health impact assessment due to air pollution**, aimed to support local medical and environmental officers, to implement **the Provincial Air Environment Management Plan** under **Article 12 and 13 of the Environmental Protection Law**;

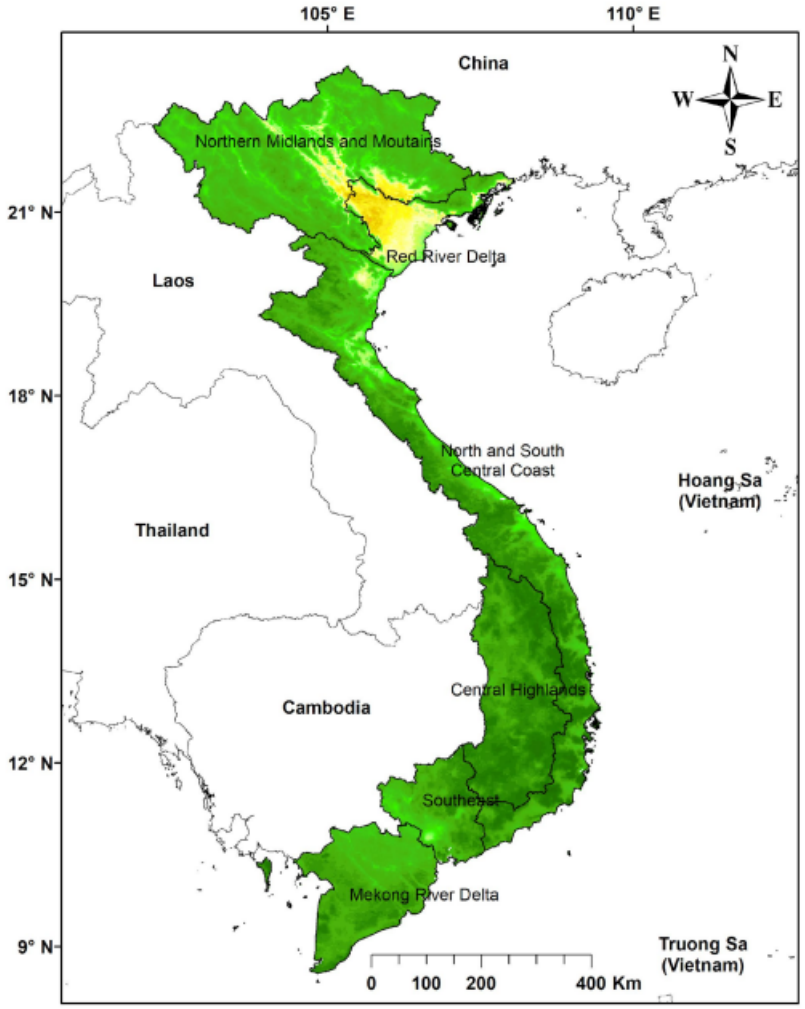
Full report at Status of PM2.5 and Its Impact on Public Health in Vietnam 2021 - LASER PULSE

THE STATUS OF $PM_{2.5}$ AND ITS IMPACT ON PUBLIC HEALTH IN VIETNAM 2021

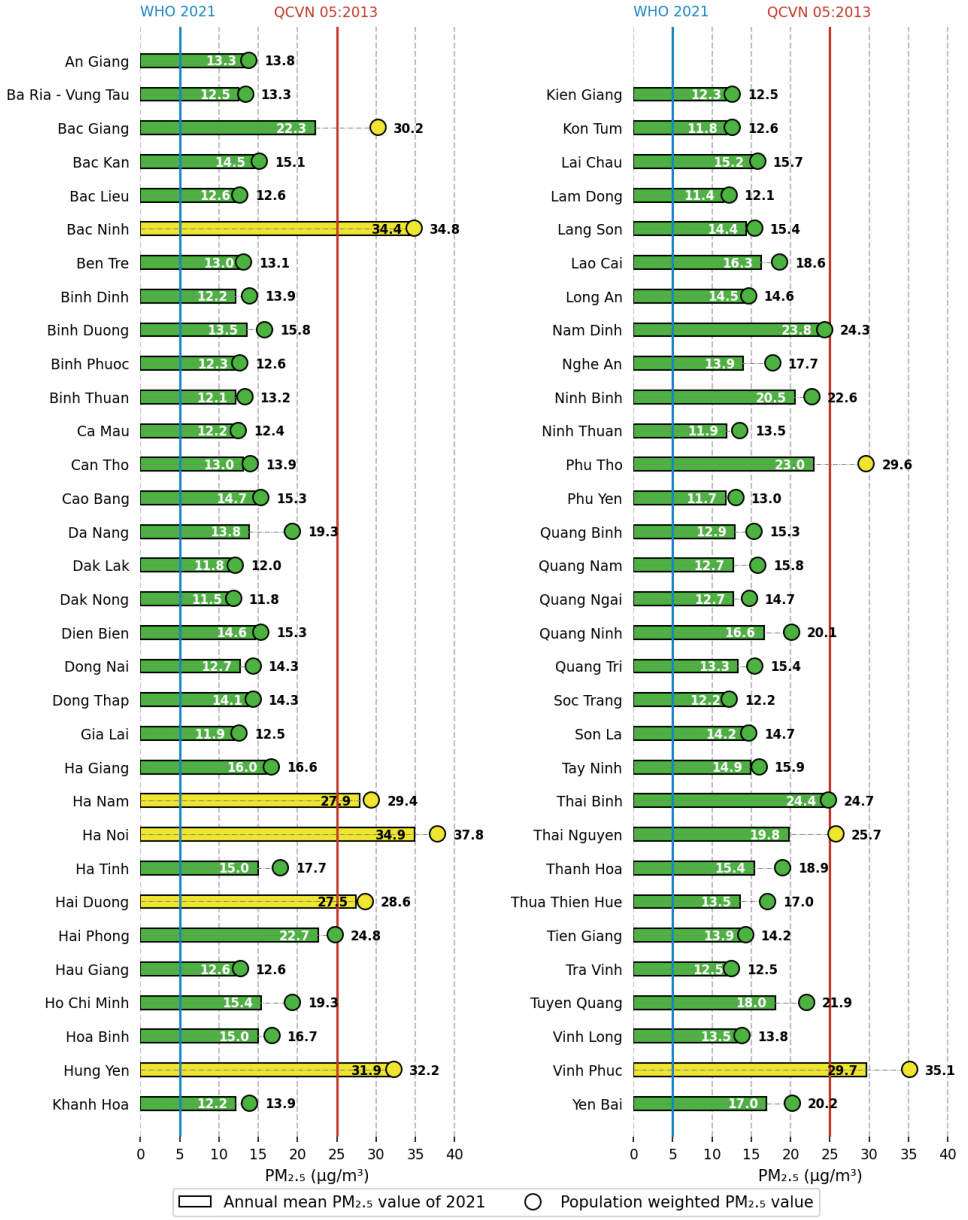


- Goals
  - Provide insight into status of $PM_{2.5}$ across Vietnam in 2021 and assess the health benefit if $PM_{2.5}$ pollution was controlled
- Target audience
  - General public, Government agencies, Media/Press
- Content
  - Status of $PM_{2.5}$ on a national scale (analysis at provincial level)
  - Status of $PM_{2.5}$ at 5 representative cities (analysis at district level)
  - Relation of $PM_{2.5}$ and urbanization
  - PM2.5 during social distancing period due to COVID-19
  - Health benefit at provincial and district levels if $PM_{2.5}$ was controlled
  - Recommendations
- Data
  - $PM_{2.5}$ maps; Death percentages (GSO)

THE STATUS OF $PM_{2.5}$ NATIONWIDE



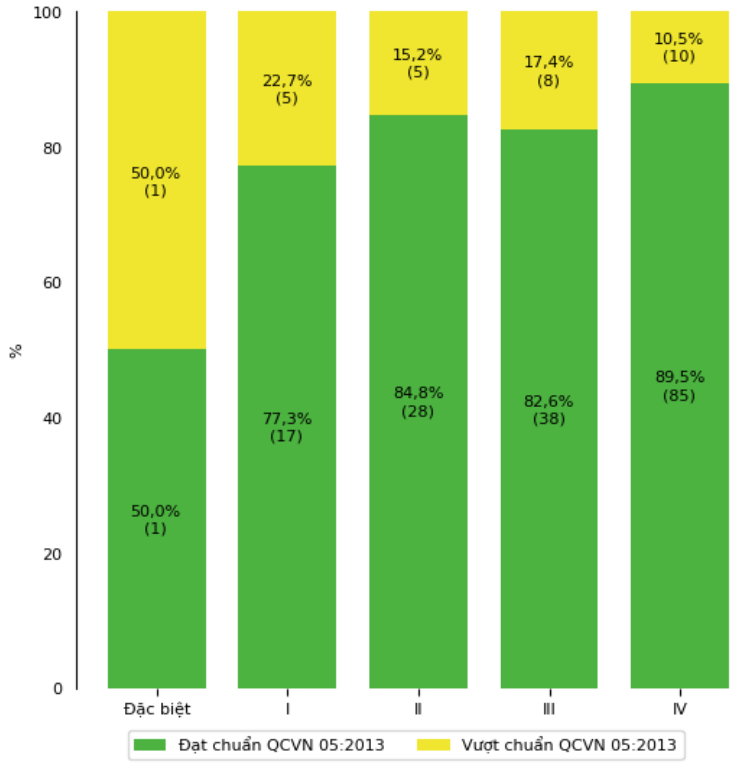
Annual mean of $PM_{2.5}$ concentration in 2021



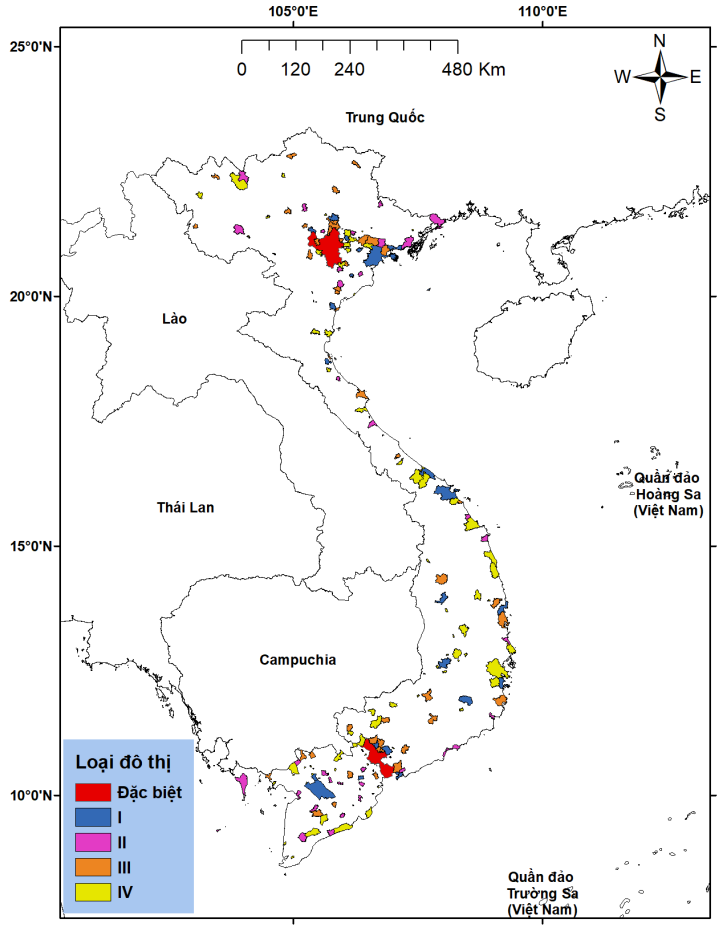
Mean of $PM_{2.5}$ concentration and population-weighted $PM_{2.5}$ concentration by province in 2021

THE STATUS OF $PM_{2.5}$ IN URBAN AREAS

- As of December 2021, Vietnam has 2 cities which are categorized as Special urban areas, Hanoi and Ho Chi Minh city, 22 type I urban areas, 33 type II, 47 type III, 94 type IV and 674 type V areas.
- $PM_{2.5}$ concentration has a tendency to increase as the level of urban development increases.

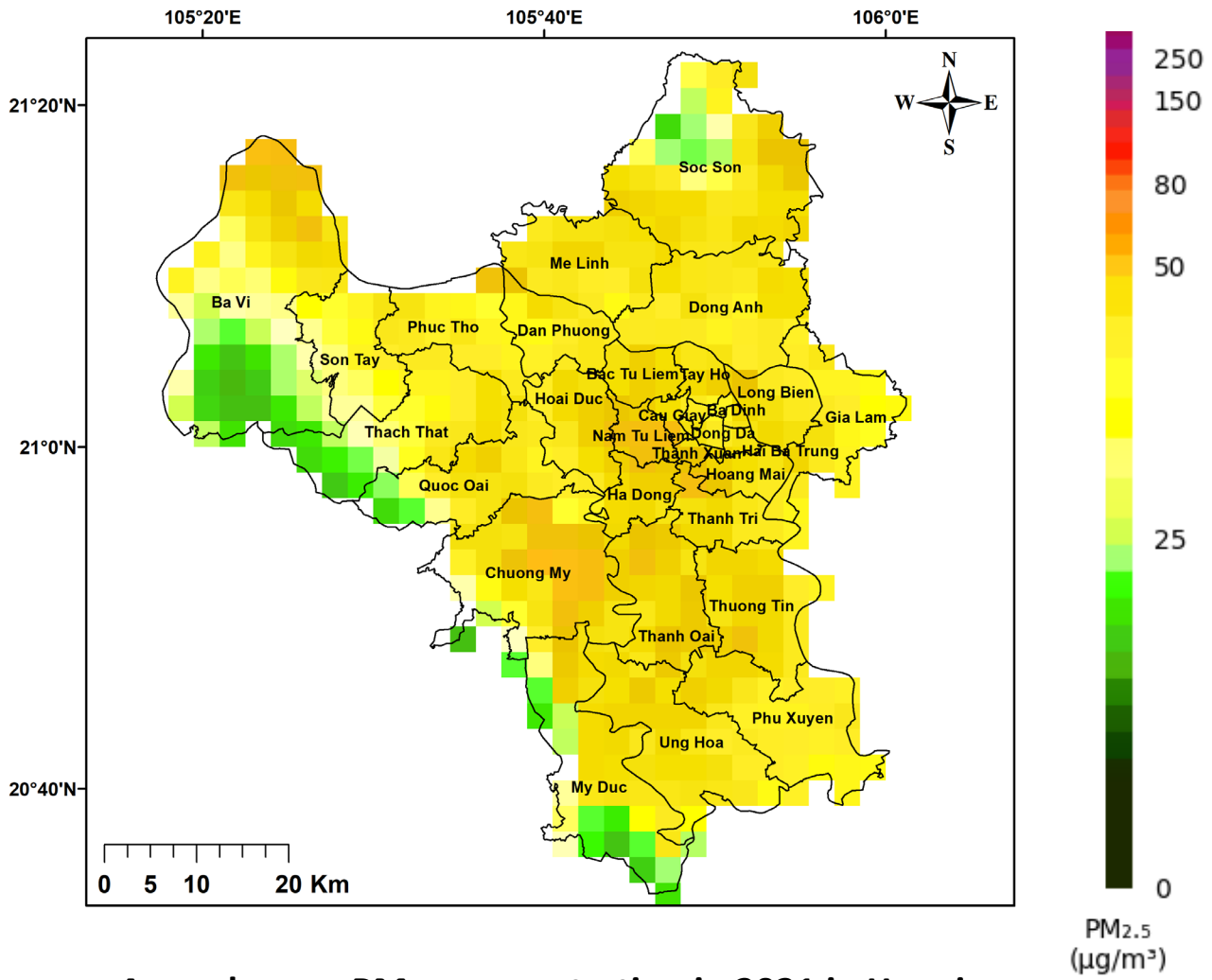


Percentage of urban areas with 2021 averaged $PM_{2.5}$ concentration exceeding QCVN 05:2013/BTNMT

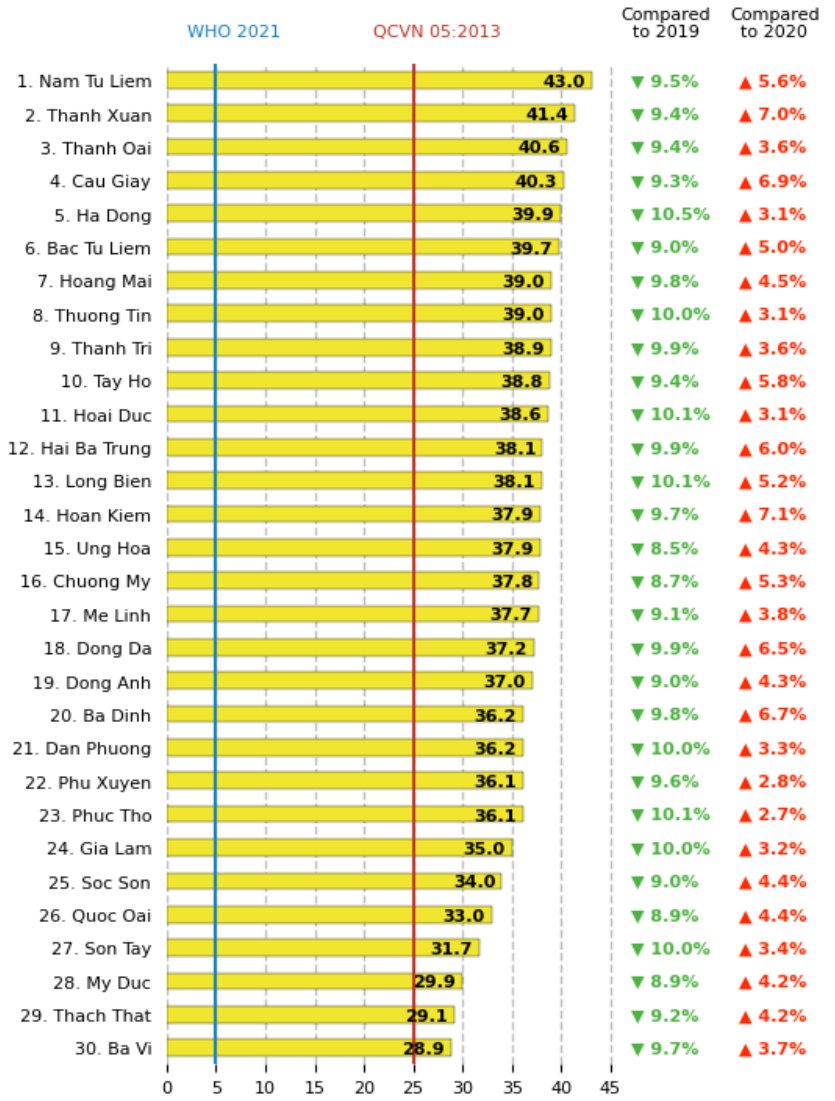


Urban classification in Vietnam from 2021-2023 (Decision 241/QĐ-TTG)

THE STATUS OF $PM_{2.5}$ IN HANOI

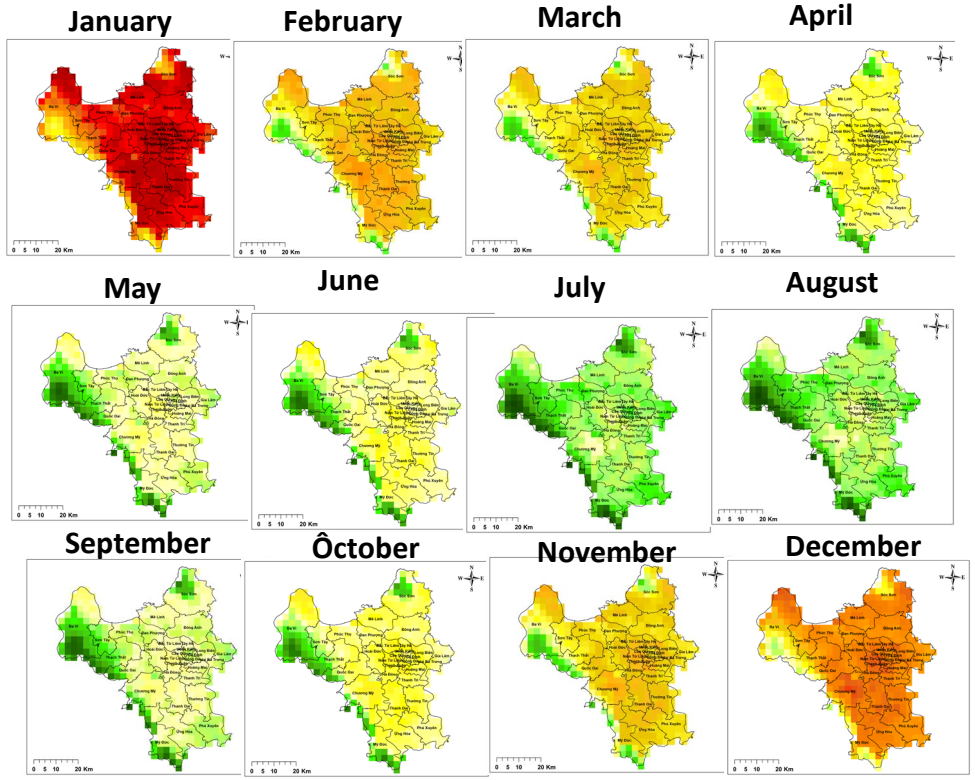


Annual mean $PM_{2.5}$ concentration in 2021 in Hanoi



Mean of $PM_{2.5}$ concentration in 2021 in Hanoi by district and compared to 2020 and 2019

THE STATUS OF $PM_{2.5}$ IN HANOI

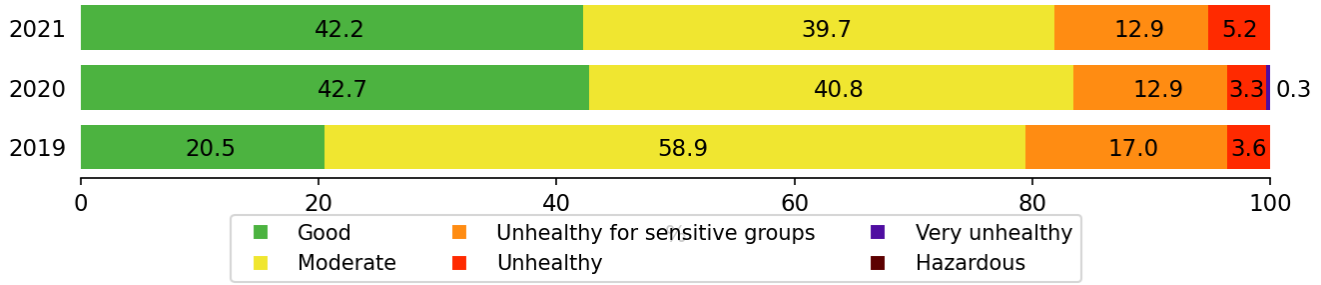


Monthly $PM_{2.5}$ concentration in 2021

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
2021	80.9	41.8	37.1	28.0	23.2	25.6	19.5	19.7	22.5	27.2	37.6	55.9	34.9
2020	44.1	53.9	37.5	35.1	26.0	23.5	22.1	17.8	22.3	25.7	43.1	51.8	33.6
2019	50.2	35.9	40.3	31.7	32.1	24.2	22.5	28.6	40.6	41.2	54.8	60.2	38.5

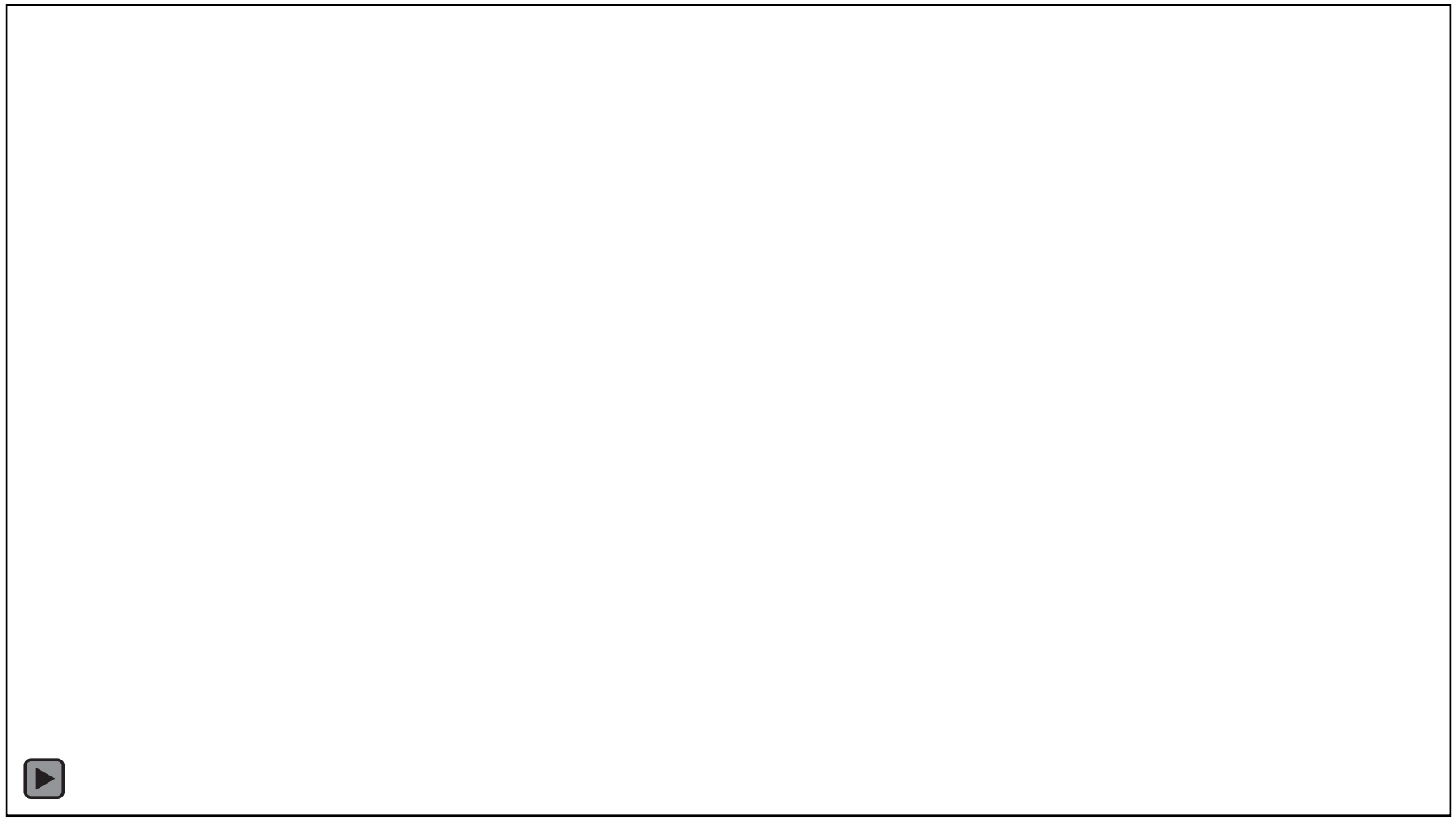
Good | Moderate | Unhealthy for sensitive groups | Unhealthy | Very unhealthy | Hazardous

Monthly mean of $PM_{2.5}$ concentration



Percentage of days at different levels of air quality in Hanoi

POPGIS – AN APPLICATION SERVICE FOR AIR POLLUTION MANAGEMENT AND ANALYSIS IN VIETNAM



CONCLUSION

CONCLUSION

- Satellite-derived $PM_{2.5}$ concentration maps can be used for air quality monitoring, environmental index development, health impact assessment, national/provincial air quality management plans.
- Prioritize air quality monitoring and management in the order of $PM_{2.5}$ status of provinces and cities and urbanization level.
- Periodically review and improve the national technical regulations on air quality and emission sources.
- Invest in advanced machine learning techniques for air pollution
- Promote research to identify the source contributors of $PM_{2.5}$ and other air pollutants.

More information at https://laserpulse.org/portfolio/improving-air-pollution-monitoring-and-management-of-vietnam-with-satellite-observation/

THANK YOU FOR YOUR ATTENTION