# Indoor Air Quality and Emission Characteristics of Household Cooking Practices in 3 Ecological Regions of Bagmati Province, Nepal

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15 April, 2026

# Presentation Outline

1. Introduction
2. Objectives
3. Study Area
4. Methodology
5. Results
6. Conclusion
7. References

# INTRODUCTION

- Air pollution contributed to around 7.9 million deaths worldwide in 2023, including 2.8 million deaths from Household Air Pollution (HAP) (HEI, 2025)
- Globally, around 2.1 billion people rely on solid fuels (like wood, coal, crop waste) (WHO, 2022).
- In Nepal, traditional fuels account for about 63% of the total energy consumption in FY 2079/80 (WECS, 2024)
- In Nepal, Air pollution contributed to ~23% of all deaths in 2023, with HAP as the leading risk factor (HEI, 2025)

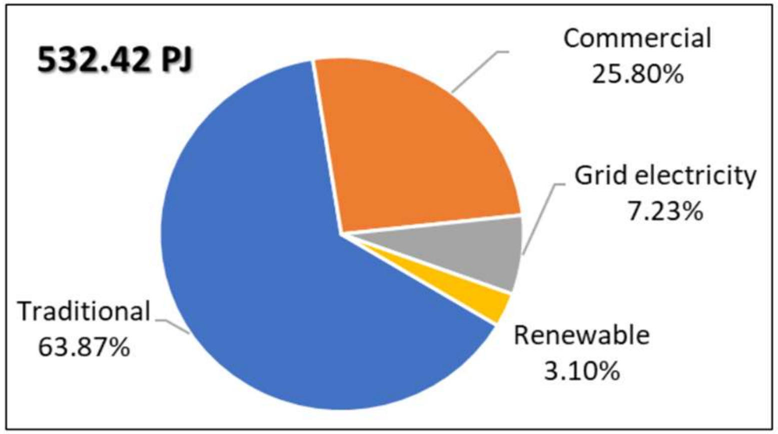


Fig: Energy consumption for FY 2079/80 by fuel type (WECS,2024)

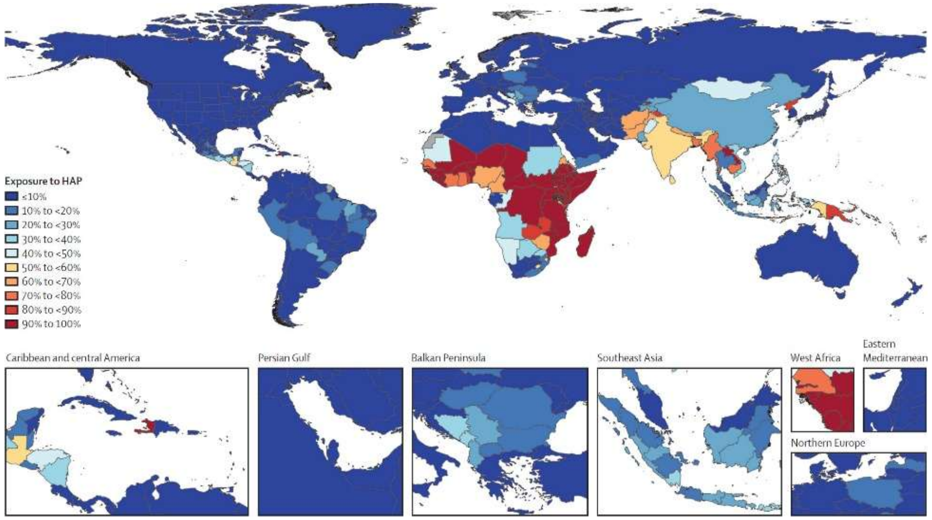


Fig: Percentage of global population exposed to HAP from solid cooking fuels, 2021 (Bennit et.al, 2025)

# INTRODUCTION

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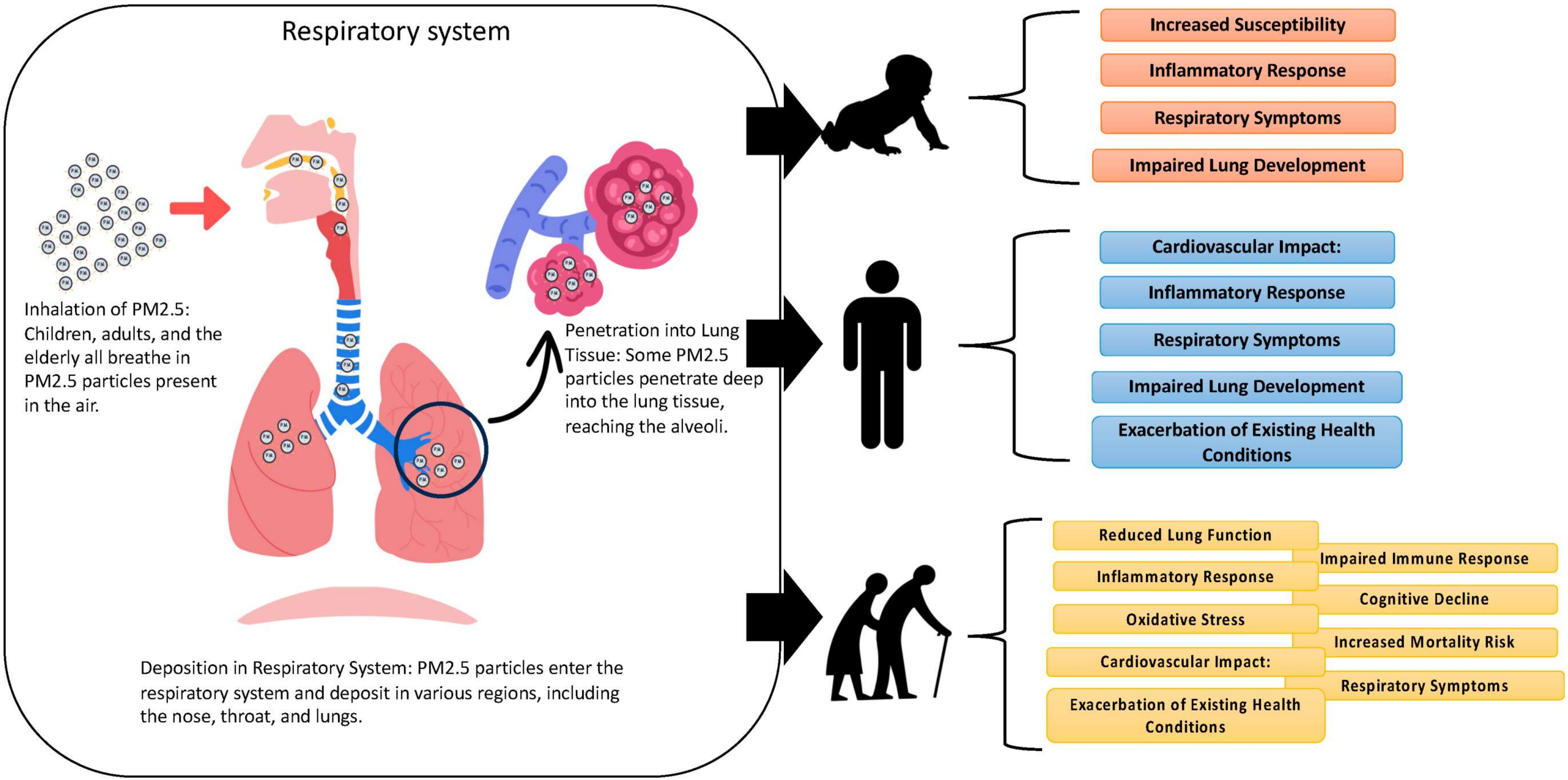





Amnuaylojaroen & Parasin, 2024

# INTRODUCTION

- Women and Children bear the most burden and smoke exposure (Ali et al., 2021)

Photo: Project Team, 2025

# INTRODUCTION

- Prior multiple studies confirmed high HAP concentration from biomass use (Adhikari et al., 2020; Parajuli et al., 2016)

- Continued reliance on solid fuel
  - Limited access to clean ene
  - High cost of LPG
  - Deep-rooted traditional coo

- Emission levels and compositior
  - Type of fuel used
  - Cooking technology
  - User practices (Bond et al., 2013)

Photo: Project Team, 2025

# OBJECTIVES

- Monitor indoor concentrations of $PM_{2.5}$, CO, and analyze $NO_2$ based on types of cook stoves
- Assess potential health risks associated with exposure to these air pollutants
- Identify the emission variations across the three ecological regions (Terai, Hill and Mountain)



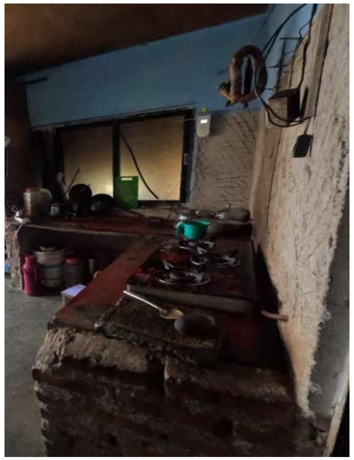



Photo: Project Team, 2025

# Study Area

- 3 distinct physiographic regions in Bagmati Province, Nepal
  - ❖ Chitwan (Terai)
  - ❖ Kavre (Mid-hills)
  - ❖ Rasuwa (Mountains)

# METHODOLOGY

## Part I (Air Quality Monitoring)

## Research Design

- Comparative cross-sectional field design (Benyon et al., 2025; Munyao et al., 2022)
- Combined real-time air quality monitoring with contextual data collection in selected households
- Sampling strategy: Purposive sampling
- Sample Size (N) = 21 households (7 per each District)

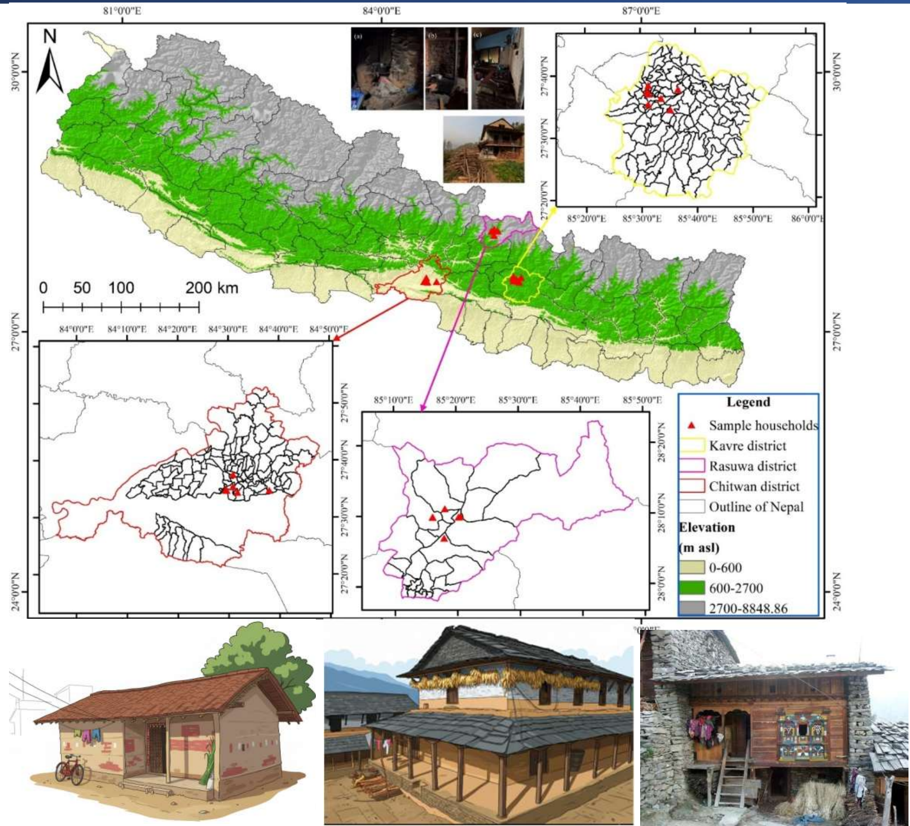



Fig: Map of the study area along with the major household types representation

Note: Locations selected based on availability for air quality monitoring and logistical feasibility

# Methodology

## Air Quality Monitoring

- Parameters: $PM_{2.5}$ (Indoor & Outdoor), CO & $NO_2$ (Indoor)

| S.N | Parameters | Instrument |
|---|---|---|
| 1 | $PM_{2.5}$ | Air Visual Pro (Monitoring: 8-10 hour/day/per HH) |
| 2 | CO | Aeroqual Series 500 (Monitoring: 8-10 hour/day/per HH) |
| 3 | $NO_2$ | Envirotech Handy Sampler (APM 821). Integrated ~4-hour active sampling + Impinger with absorbing solution (Saltzman, 1954; WHO, 1977) + laboratory analysis (Spectrophotometry) |

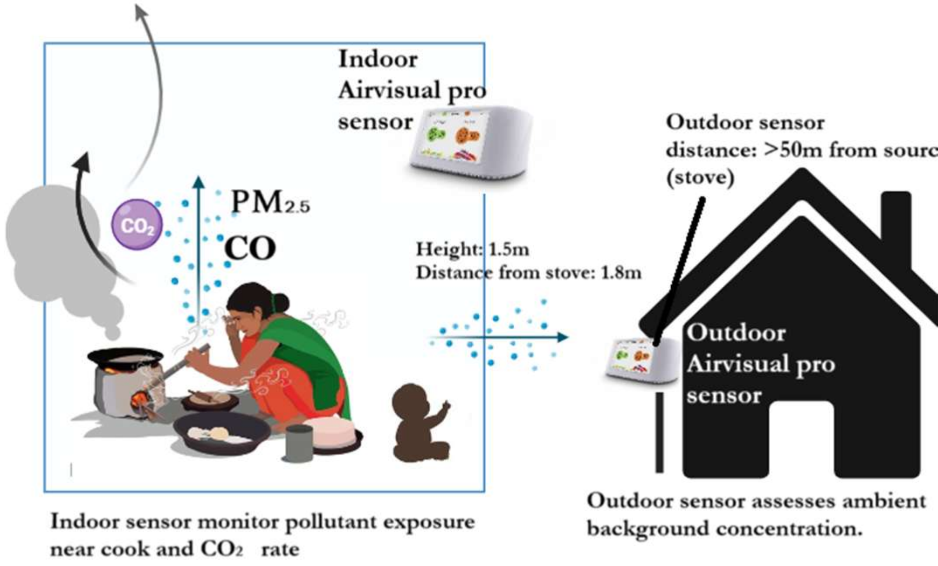



Fig: Conceptual figure for the placement of sensors in the study

### Instrument's Position

- Indoor: In the occupant breathing zone (1-1.5m high, 1-2m from stove) (ASHRAE, 2013; WHO, 2009)
- Outdoor: Sensor distance >50m from the source (stove)

# Methodology

## Health Risk Assessment

$$\text{Exposure concentration } (EC) = \frac{C_{air}+ET+EF+ED}{AT_n} \text{....... (iii)}$$

Table: Exposure assumptions for the study (Abidin et al., 2023; Moradpour et al., 2023; NRCCP, 1994)

| Parameter | Value | Description |
|---|---|---|
| ET | 2.5 hours/day | Exposure time: Average daily time spent in the kitchen |
| EF | 350 days/year | Exposure frequency: Annual frequency of exposure |
| ED | 30 years | Exposure duration: Chronic exposure duration |
| $AT_n$ | 262,800 hours | Averaging time for non-carcinogens: ED × 365 days × 24 hours |

# Methodology

## Health Risk Assessment

Hazard Quotient $(HQ) = \frac{EC}{RfC},$ HQ > 1 → possible adverse effects

Hazard Index $(HI) = \sum HQ = HQ_{PM_{2.5}} + HQ_{CO} + HQ_{NO_2}$

HI ≤ 1 → unlikely risk, HI > 1 → potential combined health risk

Table: RfC values and source for current study (Ababio et al., 2023)

| Pollutant | RfC Value | Unit | Source |
|---|---|---|---|
| $PM_{2.5}$ | 5 | µg/m³ | WHO air quality guideline (2021) |
| CO | 0.7 | ppm | U.S. EPA reference concentration |
| $NO_2$ | 0.053 | ppm | U.S. EPA reference concentration |

# Methodology

## Part II (Emission Characteristics)

Combined three-stage stratified-quota-random sampling method (Huy et al. , 2021):

- Each district divided into three strata: Urban, Peri-urban and Rural
- Quota sampling: Select specific wards for in-depth surveys
- Systematic random sampling: Select HHs (every fifth household in densely populated areas and third household in less densely one (Das et al., 2018)

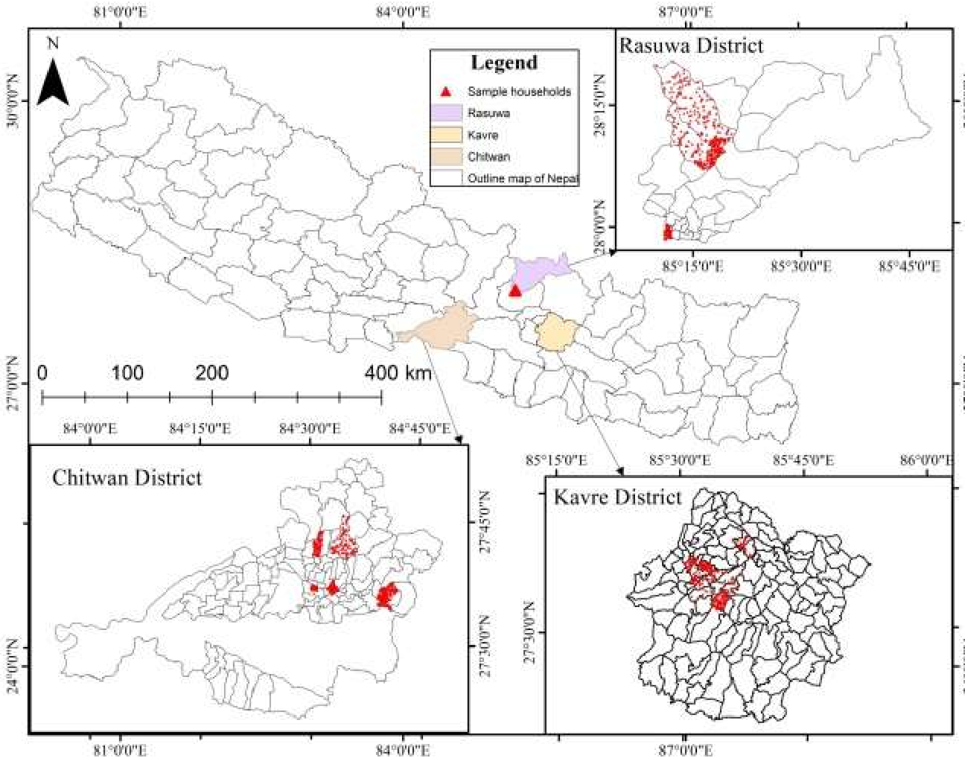


Fig: Map of the study area for emission characteristics

# Methodology

| District | Strata | Total No of Households | Sample Size | Selected Study Area | Final Sample Size |
|---|---|---|---|---|---|
| Rasuwa | Urban | 3101 | 93.18 | Uttargaya Rural Municipality - 5 | 93 |
| | Rural | 8030 | 94.92 | Aamachhodingmo Rural Municipality - 2, 3, 4, 5 | 95 |
| Kavre | Urban | 25525 | 95.68 | Banepa Municipality - 7, 11 | 96 |
| | | | | Dhulikhel Municipality - 4, 6, 7 | |
| | | | | Panauti Municipality - 6 | |
| | Peri-Urban | 37195 | 95.8 | Dhulikhel Municipality - 9, 11 | 96 |
| | | | | Panauti Municipality - 5, 9, 10 | |
| | | | | Panchkhal Municipality - 3, 4, 7 | |
| | | | | Namobudhha Municipality - 1 | |
| | Rural | 54475 | 95.87 | Namobuddha Municipality - 11 | 96 |
| Chitwan | Urban | 63406 | 95.9 | Khairahani, Ratnanagar Municipality - 1 | 96 |
| | Peri-Urban | 89681 | 95.94 | Kalika Municipality - 4 | 96 |
| | | | | Rapti Municipality - 3, 4 | |
| | Rural | 26080 | 95.69 | Kalika Municipality - 8 | 96 |
| **Total sample size** | | | | | **764** |

- Population and Household data of three Districts in the urban, peri- urban and rural area (CBS, 2021)
- Sample size was calculated as using Cochran's formula (1977) with an allowable error 10%
- Emission factor: compiled from multiple studies

## Collection and compilation of Activity Data

- Activity data - Comprehensive questionnaires designed to address socioeconomic conditions, types of cooking fuel, and fuel consumption rates
- Fuel wood consumed for cooking - Spring Balance in the households

# Results (Part-I)

## Environmental calibration of instruments

### Colocation and Value correction

- All six low-cost sensors showed a strong positive correlation with the reference-grade monitor ($R^2 = 0.91$).
- A generalized correction equation was developed to enhance data accuracy:

$$\textit{Corrected } PM_{2.5} = 1.20 \times \textit{Raw } PM_{2.5} - 13.42$$

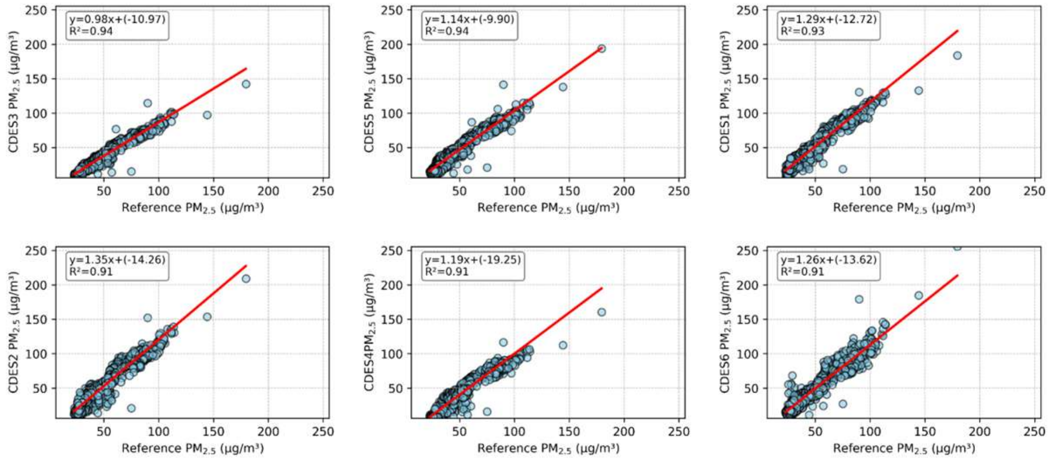



Fig: Scatter plots of $PM_{2.5}$ concentrations from seven Air visual pro sensors (renamed as CDES(1-7) versus the reference Grimm monitor


Fig: Colocation of Airvisual pro sensors with reference GRIMM sensor at ICIMOD

# Results (Part-I)…

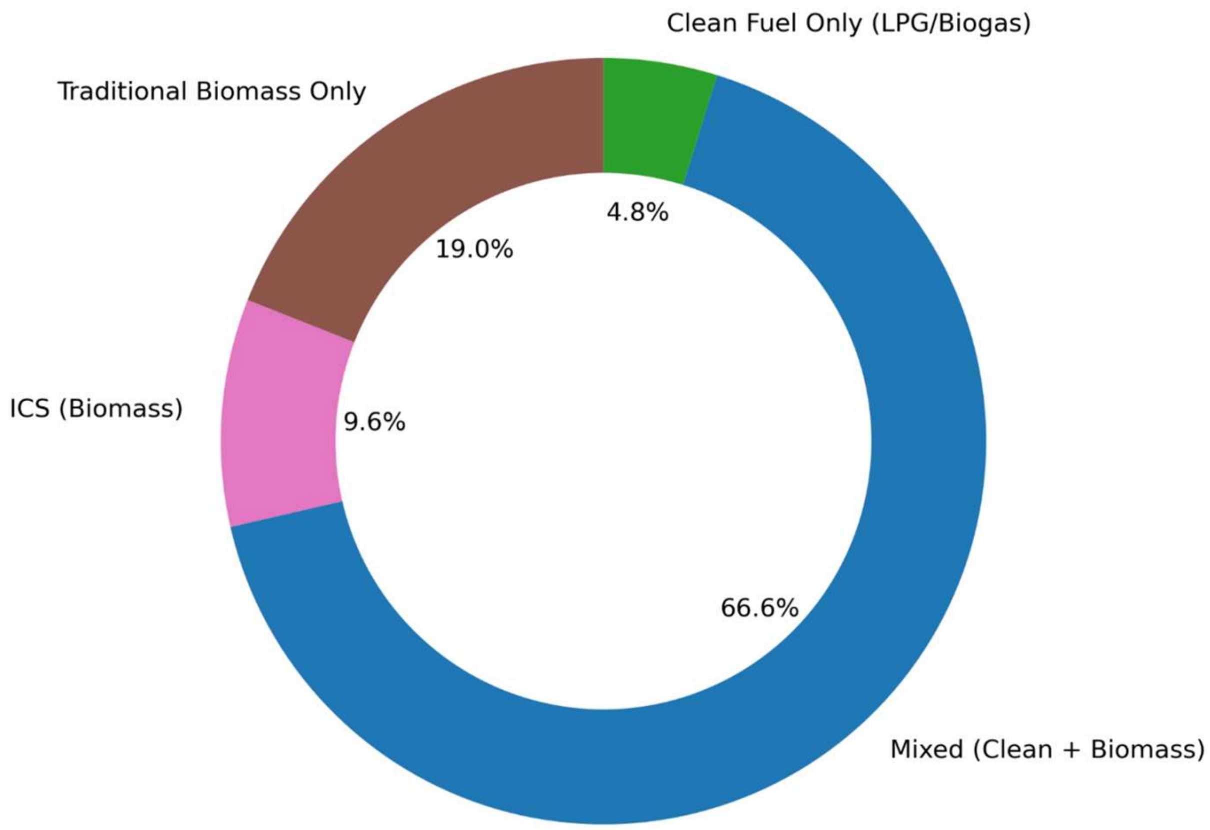



Fig: Distribution of cookstove types across the 21-household sample (n = 21).
Mixed use (clean + biomass) dominates at 66.6%.

# Results (Part-I)…

## Stove Performance

- TCS produced the **highest** $PM_{2.5}$ peaks due to inefficient combustion; common ICS underperformed, while metallic stoves improved but still exceeded WHO limits (Smith et al., 2000; Pokhrel et al., 2015; Kar et al., 2012; Ochieng et al., 2013).

- LPG stoves emitted near-zero $PM_{2.5}$, showing that only a switch to clean fuels can achieve safe indoor air (Heltberg, 2004; WHO, 2022; Rosenthal et al., 2018).

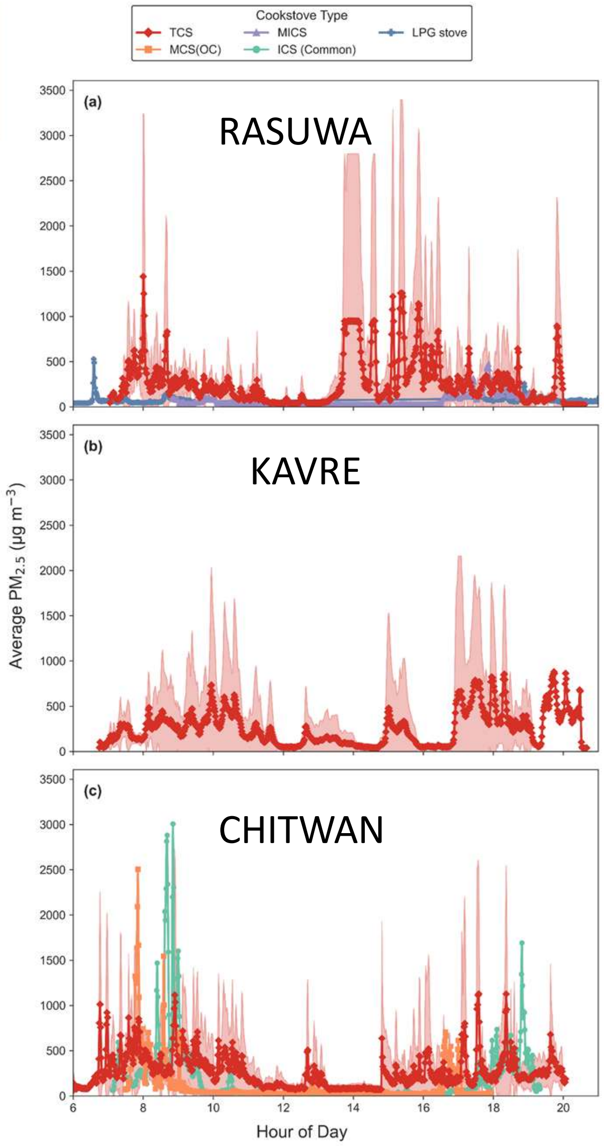



Fig: Average diurnal $PM_{2.5}$ concentration profiles (μg/m³) by cookstove type for (from top to bottom) (a) Chitwan, (b) Kavre, and (c) Rasuwa districts.

# Results (Part-I)...

## Average $PM_{2.5}$ concentration by stove types

- Traditional Cookstove (TCS): 260 µg/m³
- Improved Cookstove (MICS): 68µg/m³ → ~74% reduction to TCS
- LPG Stove: 62 µg/m³ → ~76% reduction to TCS
- Both MICS and LPG stoves substantially reduce $PM_{2.5}$ compared to TCS.

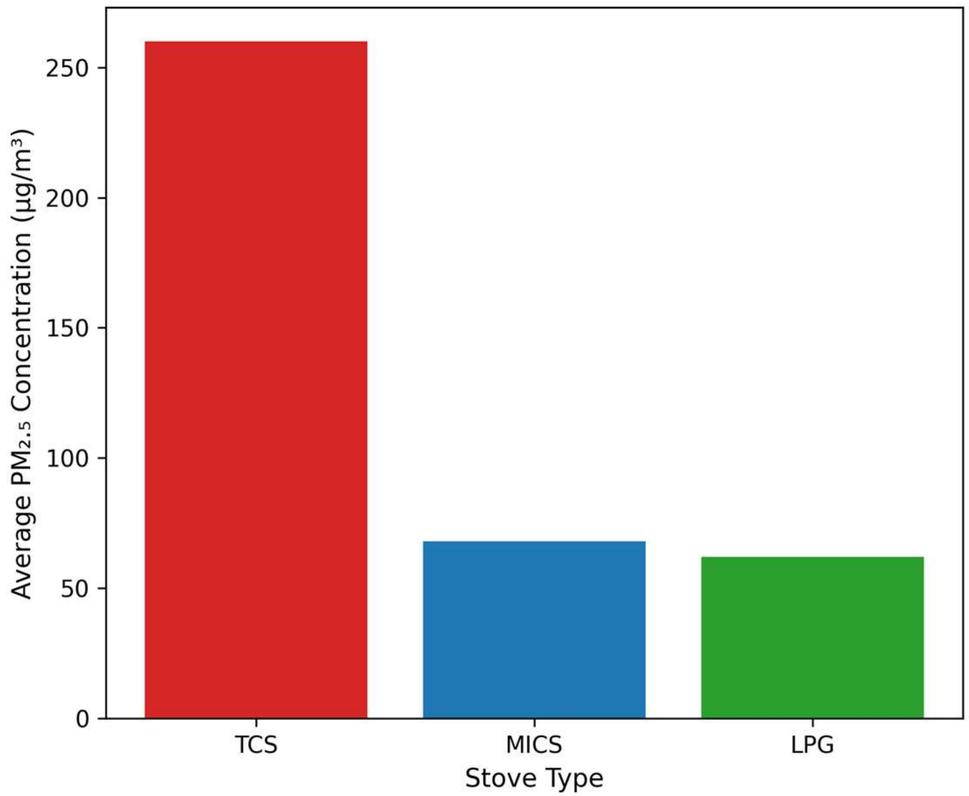



Fig: Average $PM_{2.5}$ concentration variation according to the stove types

# Results (Part-I)...

## Regional variation of CO and $NO_2$ concentration

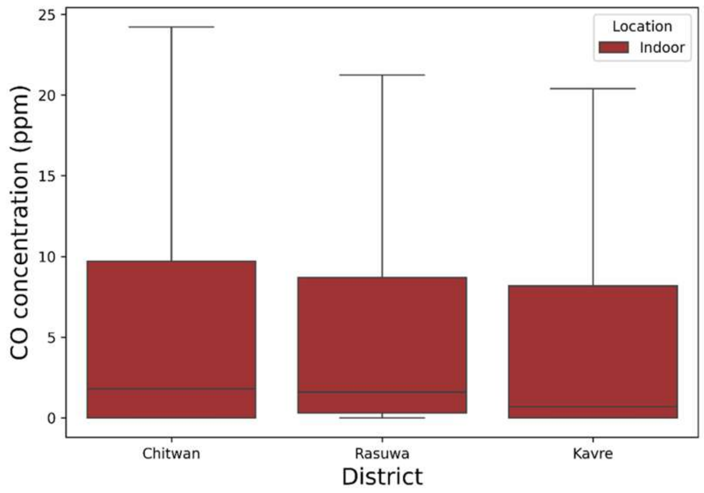



Fig: Average CO concentration variations among sampled districts

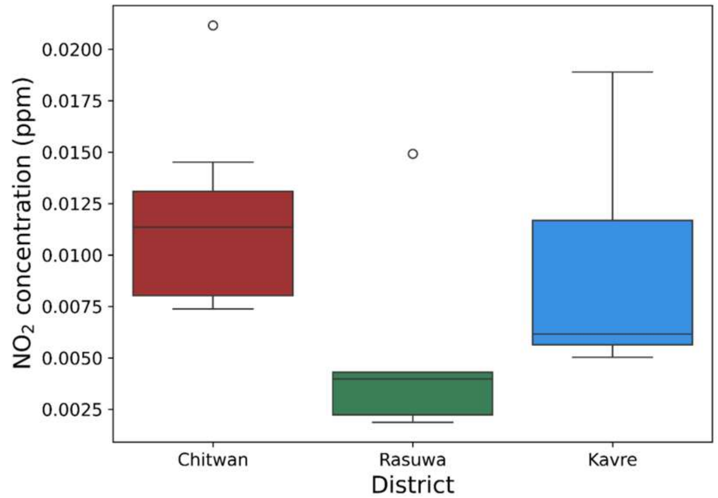



Fig: $NO_2$ concentration variations among the districts

Table: Summary of statistical test of indoor $PM_{2.5}$ and CO concentration variations among sampled districts.

| Test | Test Statistic | df | p-value |
|---|---|---|---|
| Kruskal-Wallis($PM_{2.5}$ Indoor) | | | 0.107 |
| Kruskal-Wallis(CO Indoor) | | | 0.956 |
| Wilcoxon Signed-Rank (paired)($PM_{2.5}$ (In vs Out)) | | | <0.00001 |

Table: Summary of statistical test of $NO_2$ concentration variations among the districts

| Test | Statistic | p-value | Significance |
|---|---|---|---|
| Kruskal-Wallis | $\chi^2$ | 0.007 | ** |
| Dunn's Post-hoc Comparisons | Z | | |
| Chitwan - Rasuwa | | 0.005 | ** |
| Chitwan - Kavre | | 0.634 | NS |
| Kavre - Rasuwa | | 0.174 | NS |

NS = Not Significant (p> 0.05), ** = Significant (p < 0.01)

# Results (Part-I)…

## Regional variation of Indoor and outdoor $PM_{2.5}$ concentration

In all three districts, indoor $PM_{2.5}$ concentrations were consistently and significantly higher than outdoor levels, a difference confirmed by the Wilcoxon Signed-Rank Test ($p < 0.00001$).

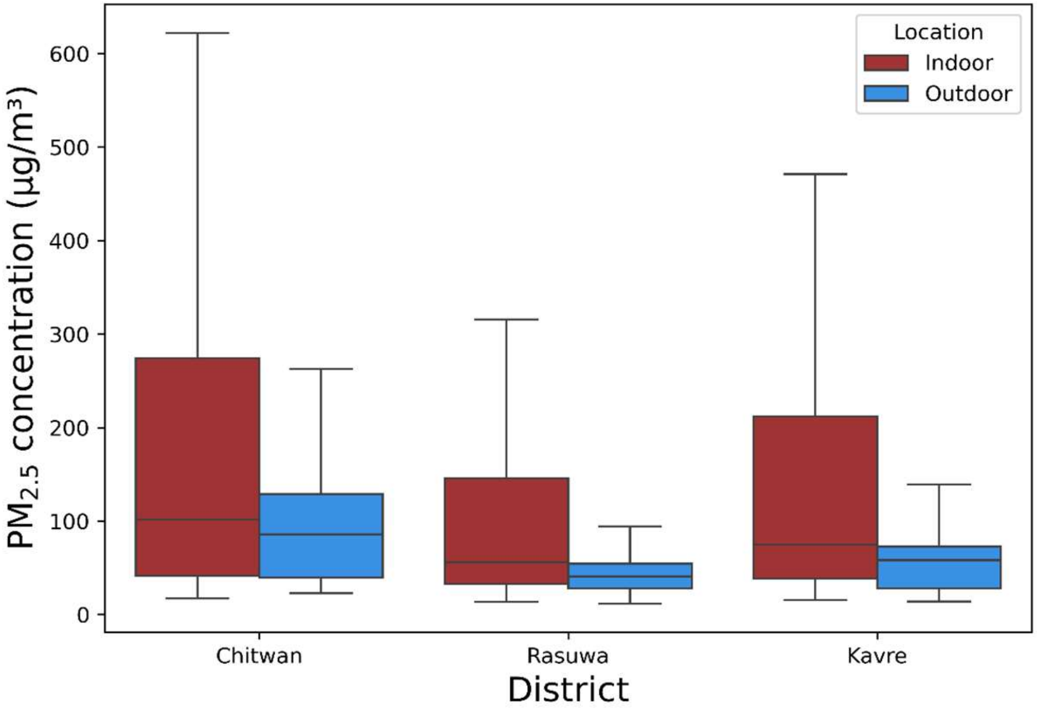



Fig: Boxplot comparison of indoor and outdoor $PM_{2.5}$ concentrations across the Chitwan, Rasuwa, and Kavre districts.

## Hazard Index (HI)

- 100% of the 21 sampled households showed a HI greater than the safety threshold of 1, with values ranging from 1.46 to an alarming 18.75.

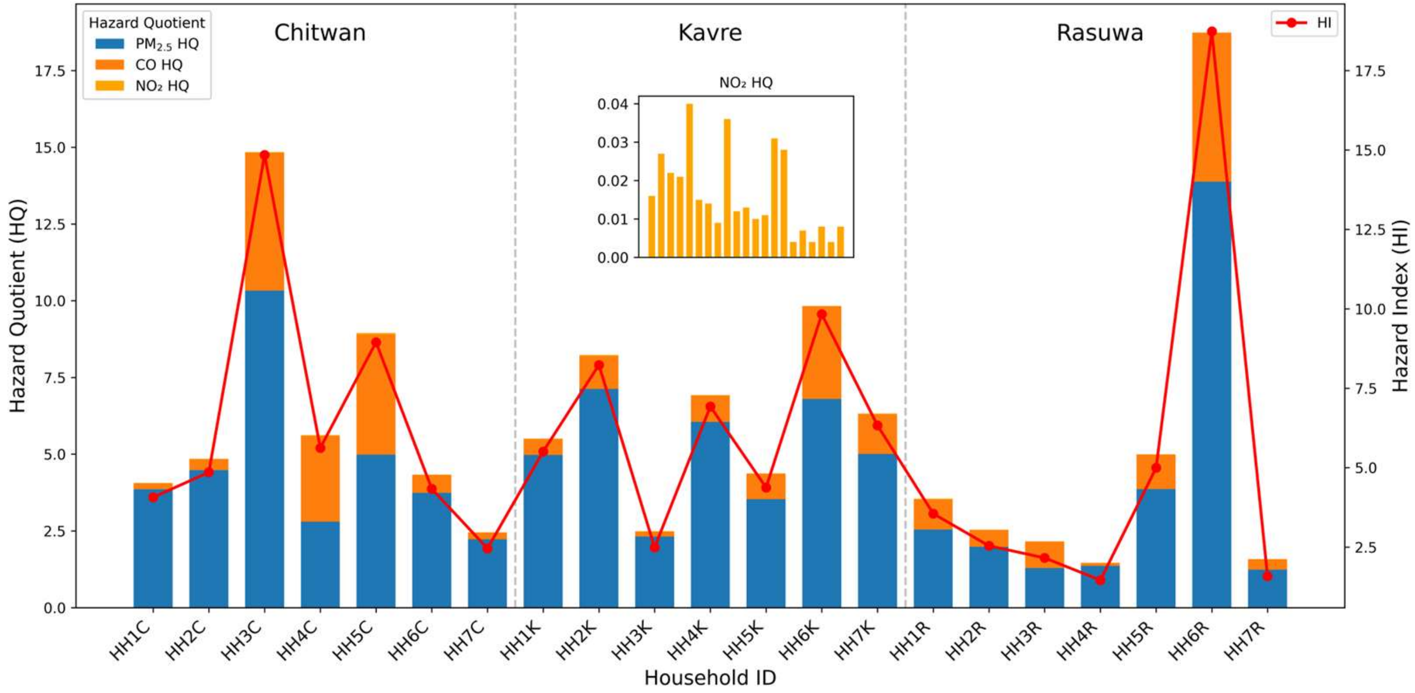



Fig: Household health risk assessment. The stacked bars represent the individual HQ for $PM_{2.5}$ ,CO, $NO_2$ (left axis) for each household, grouped by district. The red line plot indicates the cumulative HI (right axis)

# Results (Part-I)...

## Firewood species and weight of firewood used

- *Alnus nepalensis* (Uttis) is the most common species in Kavre and Rasuwa. In contrast, Chitwan households utilize a wider range of species, with *Melia azedarach* and *Shorea robusta* being prominent.

- The median weight of firewood used is very similar for both morning (about 2.2 kg) and evening ( about 2.1 kg) cooking events.

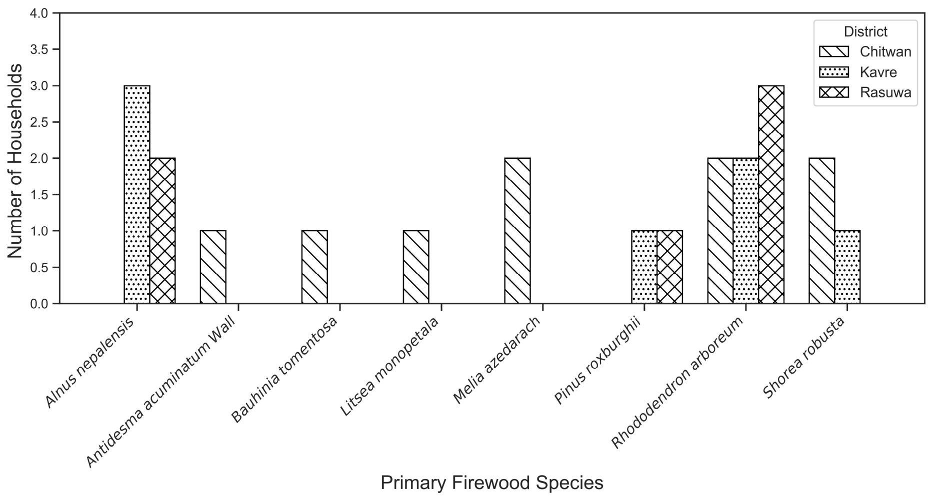



Fig: Number of households using different primary firewood species, categorized by district (Chitwan, Kavre, and Rasuwa).

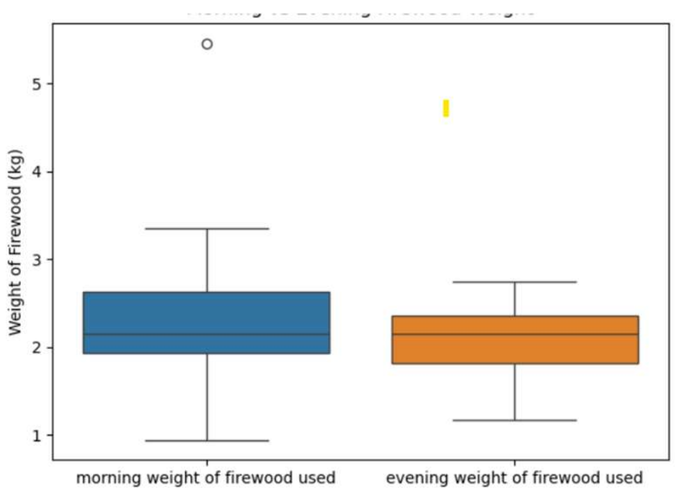



Fig: Boxplot of weight of firewood used in morning and evening

# Results (Part-II)

## Overview of Activity Data

- Fuelwood dominates all three districts, but reliance is most extreme in Rasuwa.
- LPG shows clear urban bias across districts, reflecting affordability and accessibility.
- Crop residues contribute modestly, mainly in rural areas, as supplementary fuel.
- Biogas remains minimal in Rasuwa and Kavre but shows meaningful penetration in Chitwan, indicating greater potential for clean energy adoption.

Annual fuel consumption (tonnes/year)

| Types of fuel | Rasuwa | Kavre | Chitwan |
|---|---|---|---|
| Fuel Wood | 32,187.99 | 153,448.29 | 198,497.19 |
| LPG | 766.74 | 7,218.21 | 19,574.22 |
| Residues/Crop | 291.43 | 1,250.32 | 2,786.40 |

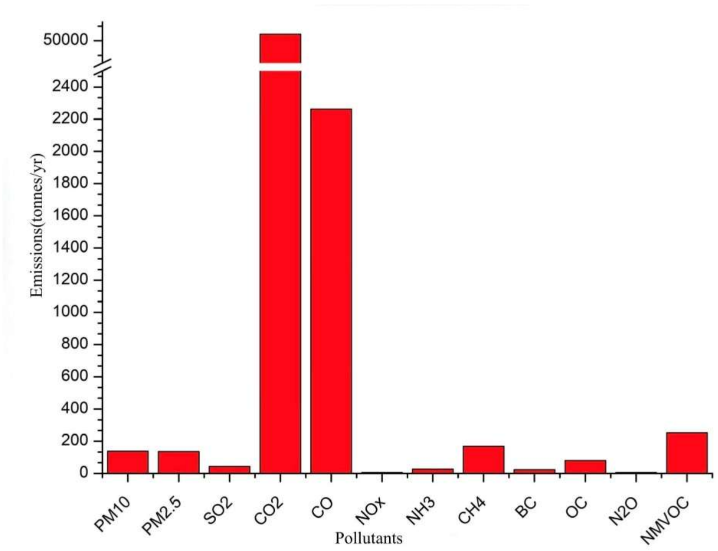
Annual consumption of different fuel types (kg/capita/year)

| Ecological Region | Urban | Urban | Peri Urban | Rural |
|---|---|---|---|---|
| Rasuwa | Fuel wood | 410.41 | | 820.91 |
| | LPG | 25.33 | | 13.64 |
| | Crop Residues | 5.59 | | 6.72 |
| | Bio Gas | 2.59 | | 2.64 |
| Kavre | Fuel wood | 196.83 | 429.13 | 552.67 |
| | LPG | 26.56 | 19.49 | 16.91 |
| | Crop Residues | 0 | 2.88 | 4.09 |
| | Bio Gas | | 0.88 | 4.09 |
| Chitwan | Fuel wood | 180.61 | 261.75 | 545.41 |
| | LPG | 35.98 | 24.51 | 19.33 |
| | Crop Residues | 2.59 | 3.53 | 8.01 |
| | Bio Gas | 4.94 | 3.27 | 4.74 |

# Results (Part-II)

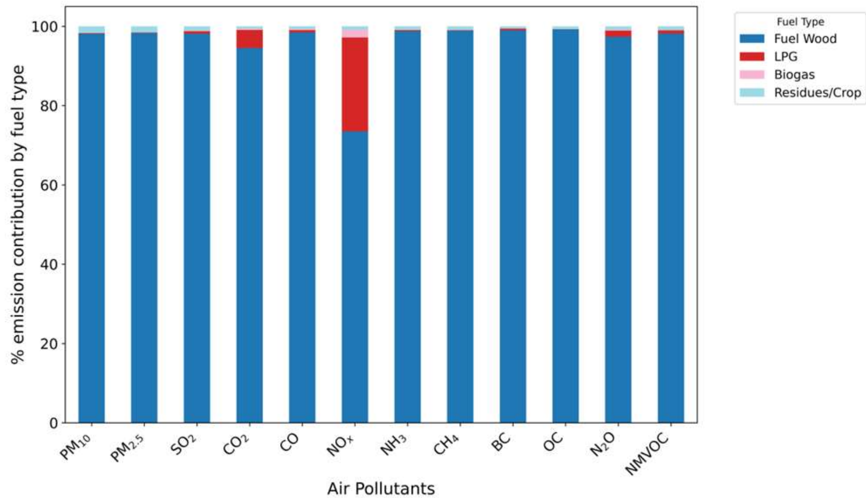
## Total Annual Emissions (tonnes/year) in Rasuwa district

- **$CO_2$ dominates** at 52,266.79 tonnes /yr, far higher than all other pollutants.
- Other major emissions: CO (2,262.58), NMVOC (252.46), $CH_4$ (167.97).
- **Moderate pollutants:** $PM_{10}$ (137.78), $PM_{2.5}$ (135.89), OC (80.15), $NH_3$ (27.38), BC (23.73).




Fuel contribution:

- **Firewood :** >98% of most pollutants, 94.5% of $CO_2$, 73.5% of $NO_X$.
- **LPG :** noticeable only in NOx (23.7%), small $CO_2$ share (4.5%), negligible elsewhere.
- **Biogas :** minimal (0.3% $CO_2$, 1.9% $NO_X$, near zero for others).
- **Crop residues :** modest (~1%), slightly higher in particulates and $CH_4$.



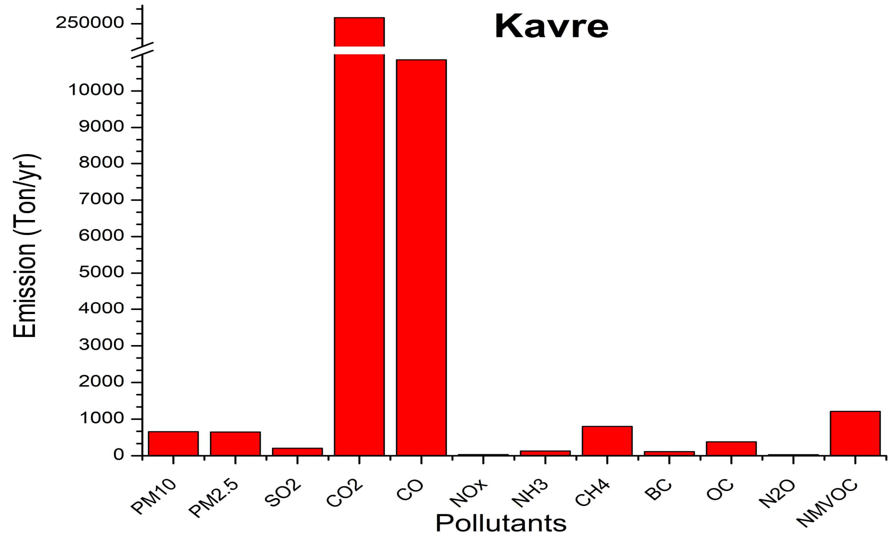
# Results (Part-II)

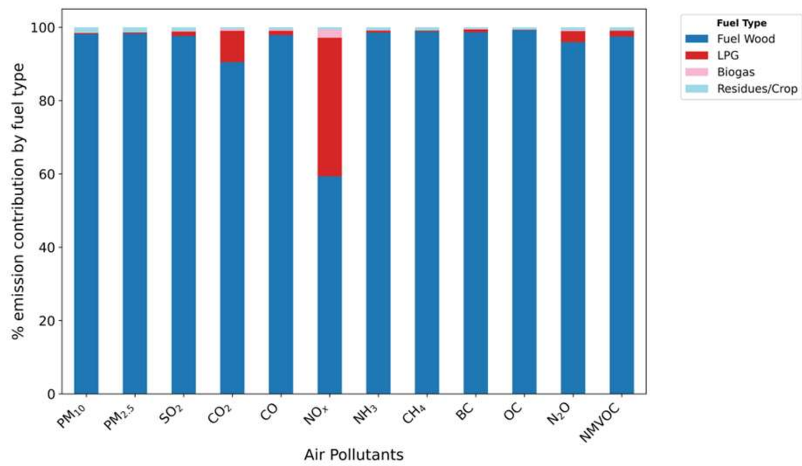
Total Annual Emissions (tonnes/year) in Kavre district

- Major emissions in Kavre: $CO_2$ = 260,349 t/yr, CO = 10,852, NMVOC = 1,212, $CH_4$ = 801, $PM_{10}$ = 657, $PM_{2.5}$ = 648, $SO_2$ = 206, BC = 114, OC = 382.

Fuel contribution:

- Fuel wood dominates: >95% of particulates, CO, $CH_4$, BC, OC, and ~90% of $CO_2$.
- LPG contributes 8.6% of $CO_2$, but its major role is in $NO_x$ (37.8%), far higher than any other fuel after firewood.
- Biogas negligible: ~0.45% of $CO_2$, ~2.2% of $NO_X$, near zero elsewhere.
- Crop residues minor: ~1-2% for particulates, $SO_2$, $CH_4$, NMVOC.
- Kavre's emissions are overwhelmingly from fuel wood, LPG is only significant in $NO_X$, and biogas/residues are minimal.



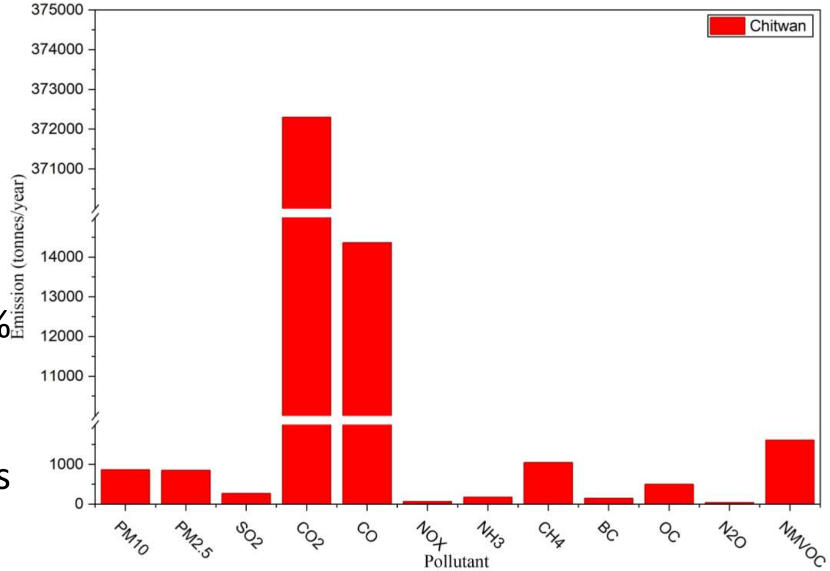



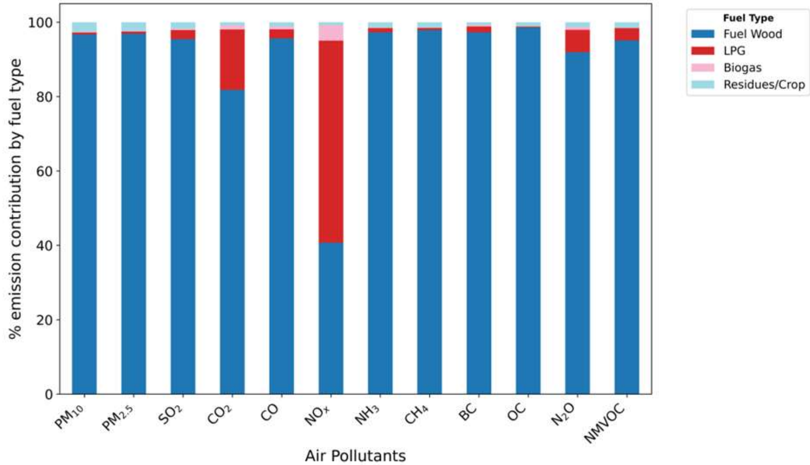
# Results (Part-II)

Total Annual Emissions (tonnes/year) in Chitwan district

- **Major emissions in Chitwan**: $CO_2$ = 372,302 tonnes/yr, CO = 14,362, NMVOC = 1,607, $CH_4$ = 1,046, $PM_{10}$ = 862, $PM_{2.5}$ = 850, $SO_2$= 272, BC = 149, OC = 497.
- **Fuel wood** dominates: >95% of most pollutants, 82% of $CO_2$, 96-98% of particulates, CO, $CH_4$, BC, OC, $NH_3$, NMVOC, and ~92% of $N_2O$.
- **LPG** second-largest: 16.2% of $CO_2$, 54.4% of $NO_X$ , ~2-3% in particulates and $SO_2$, <3% elsewhere.
- **Biogas** minor: ~1.1% of $CO_2$, 4.2% of $NO_X$, < 1% of most pollutants.
- **Crop residues** small: ~2-3% of particulates, ~1% of $CO_2$, CO, $CH_4$, NMVOC.

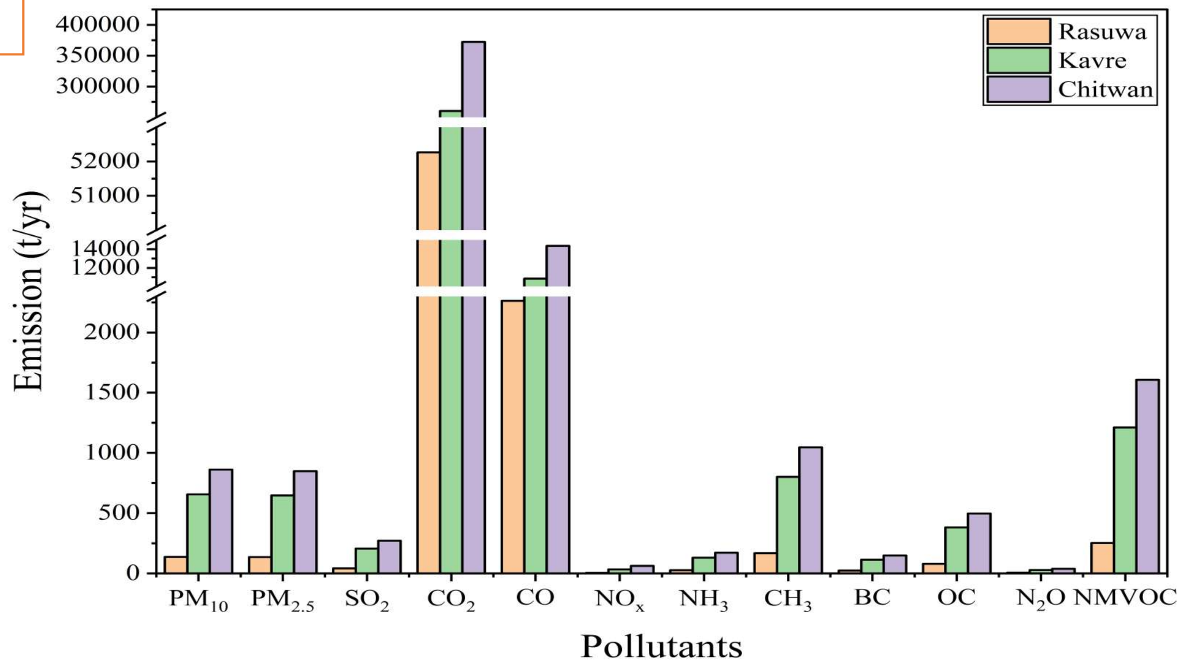
Emissions from Chitwan are overwhelmingly from fuel wood, while LPG stands out as a key $NO_X$ source. Biogas and residues contribute little overall.



# Results (Part-II)

Total Annual Emissions (tonnes/year) in three(3) districts




Rasuwa: Lowest overall emissions, small contribution from each pollutant.

Kavre: Larger emissions, especially $CO_2$ and particulates, but still less than Chitwan.

Chitwan: Dominates in all pollutants, showing highest total emissions.

Gradient effect: Emissions increase from mountain (Rasuwa) → mid-hill (Kavre) → terai (Chitwan).

Dominant sources: $CO_2$ and CO are the largest contributors in all districts, highlighting biomass and fossil combustion.

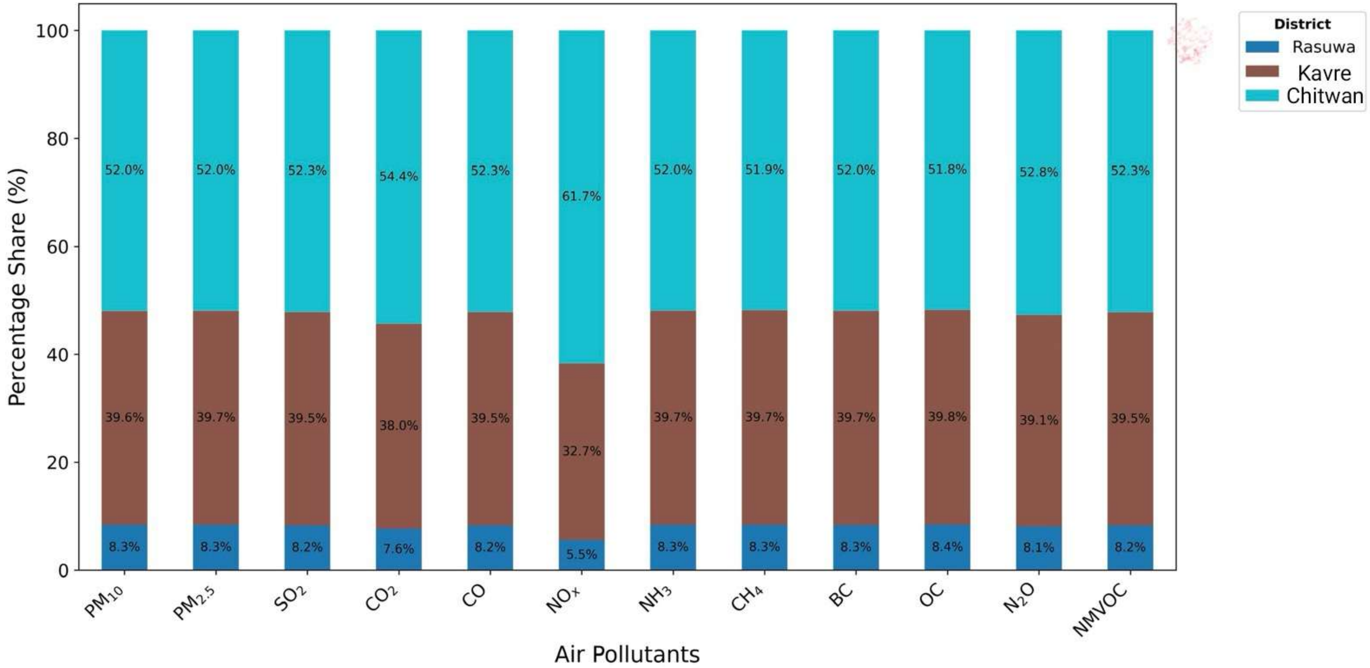
Air quality risks: $PM_{2.5}$ and $PM_{10}$ are most severe in Chitwan, followed by Kavre.

Climate impact: Methane ($CH_4$), Black carbon (BC), and $N_2O$ are highest in Chitwan, reinforcing its role as both a health and climate hotspot.

Relative role of population: The higher emissions in Chitwan and Kavre are strongly linked to larger populations and energy demand, while Rasuwa contributes far less in absolute terms.

# Results (Part-II)

Percentage share of emissions in three(3) districts




- Chitwan is the dominant emitter across all pollutants.
- Kavre is the second major contributor, close to 40%.
- Rasuwa has only a minor contribution (~8%), meaning emissions are much lower there.
- NOx stands out as the pollutant most skewed towards Chitwan, showing significant regional variation..

Chitwan

- Consistently has the highest share of emissions across all pollutants.
- Contribution ranges from 51.8% (OC) to 61.7% (NOx).
- On average, Chitwan contributes around 52–54% of most pollutants.

Kavre

- Second highest contributor for most pollutants.
- Share ranges between 32.7% (NOx) and 39.8% (OC).
- Typically contributes 38–40% across pollutants.

Rasuwa

- Has the lowest contribution for all pollutants.
- Values range from 5.5% (NOx) to 8.4% (OC).
- Generally contributes about 7–8%.

# Conclusion

- Biomass cooking causes high $PM_{2.5}$ and CO
- LPG/MICS reduce $PM_{2.5}$ by ~ 74–76% but remained unhealthy
- Health Index >1 in all biomass households ($PM_{2.5}$ primary driver)
- Clear urbanization-infrastructure gradient:

Rasuwa (fuelwood) → Kavre (mixed) → Chitwan (diversified: LPG/biogas/electricity)

- Chitwan - highest total emissions , Kavre moderate levels. and Rasuwa has lower total emissions.
- Urbanization raises total emissions, but cleaner tech has reduced emissions at the per-capita level.
- 83% households prefer cleaner stoves

# THANK YOU !

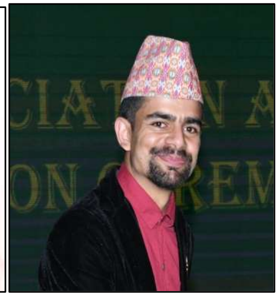
SmokeFree Homes NEPAL

## Team CDES-TU

- Rejina Maskey Byanju
- Ramesh Prasad Sapkota
- Bhupendra Das
- Enna Mool
- Charan Bhattarai (M.Sc Student)
- Balkrishna Paudel (M.Sc. Student)





## Team UEF

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## Team KU

## Funding Agency

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