



# Experimental campaigns in Nepal: main results and conclusions

## UEF/IEOH

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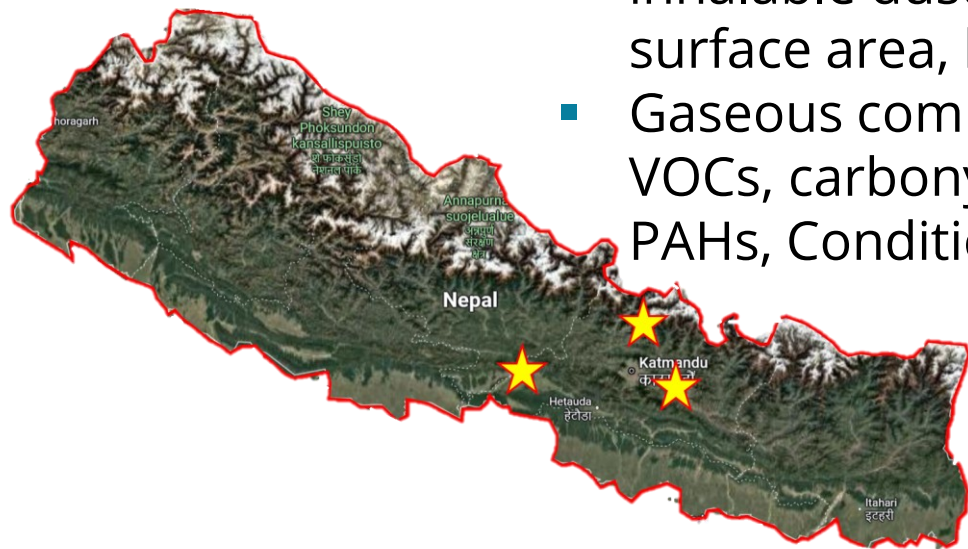
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11/10/2025 Marko Hyttinen



# Measurement campaigns in Nepal

- 3 different districts
  - Chitwan (Terai)
  - Rasuwa (Mountains)
  - Kavre (Mid Hills)
- Measuring during cooking (indoor and outdoors (background levels))
  - Particulate matter (mass, number, inhalable dust, lung-deposited surface area, black carbon )
  - Gaseous compounds ( $\text{CO}_2$ ,  $\text{CO}$ , VOCs, carbonyls (formaldehyde)), PAHs, Conditions (T, RH)





# Measurement campaign in Chitwan Post-monsoon

Rice harvest season, with straw burning  
in the area

- IAP Campaign 1. Chitwan,  
8 households 21th October to 28th  
October, 2024
- 2081 BS – Kartik 1–8

# Measurement campaign in Rasuwa

## Dry late-winter period

- IAP Campaign 2.  
Rasuwa,  
7 households 2nd March  
to 8th March, 2025
- 2081 BS – Falgun 19–25

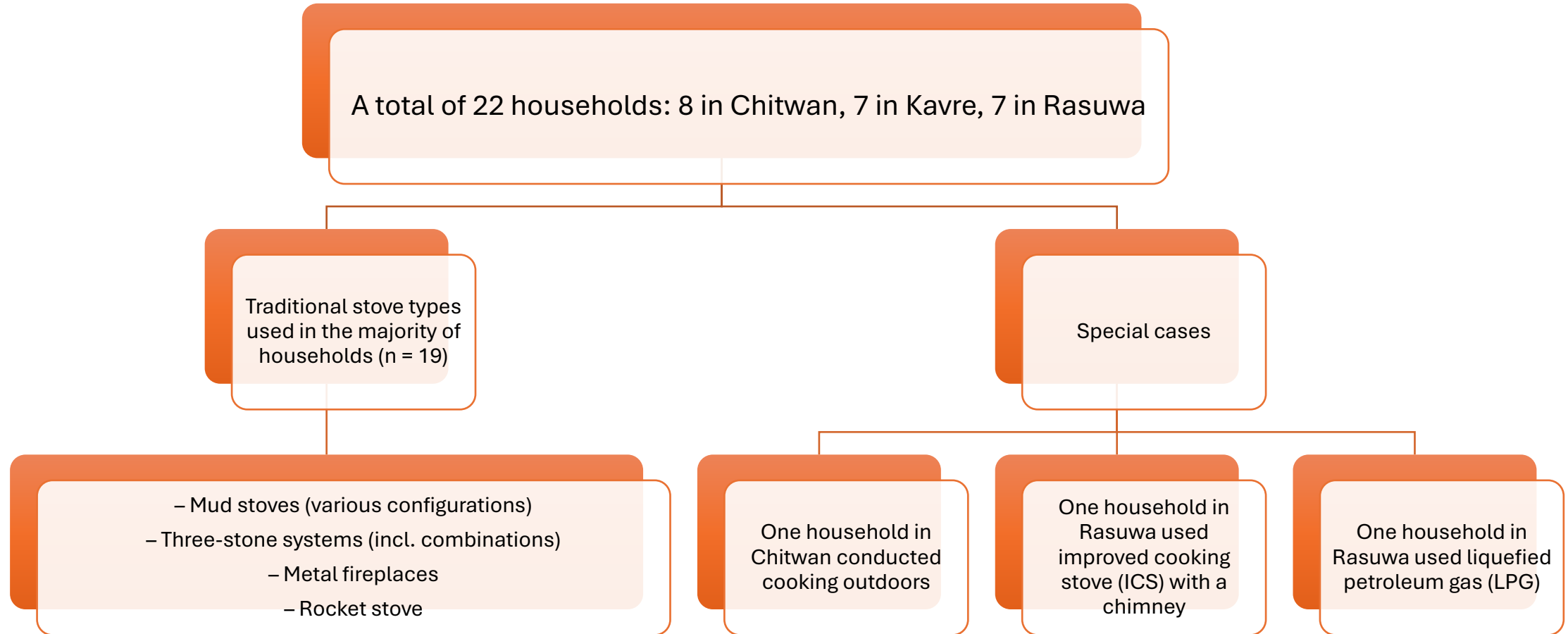




Measurement campaign in Kavre  
Dry late-winter period  
(sometimes with poor air quality)

- IAP Campaign 2. Kavre,  
7 households 10th March to 16th March,  
2025
- 2081 BS — Falgun 27 → Chaitra 3

# Overview of Cooking Setups in the Measurement Campaigns





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# Measurement Methods and Instrumentation

## Indoor and Outdoor Monitoring

Real-time measurements near the fireplace (morning/evening)  
Simultaneous outdoor background sampling

### On-line Instruments:

Ultrafine particles (PN<sub>0.3</sub>) – Partector  
PM<sub>2.5</sub> – DustTrak  
Temp, CO & CO<sub>2</sub> – IAQ-Calc  
Black Carbon – MicroAethalometer

## Active and Passive Sampling:

Inhalable dust (<100 μm) – IOM samplers (mass + PAHs)

VOCs – Tenax tubes → TD-GC-MS

Carbonyls – UMEX passive samplers → LC-MS

PAHs (gas + particle phases) – Tenax + IOM → GC-MS

Contextual data: household structure, fuel, stove type, cooking practices, ventilation.



# Examples of IAP Measurements in Kitchens During Cooking



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# Additional examples



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# Active and passive sampling on (ambient, outdoor level measurements)



Image source: Hyttinen, M. (2025)

# Results and findings

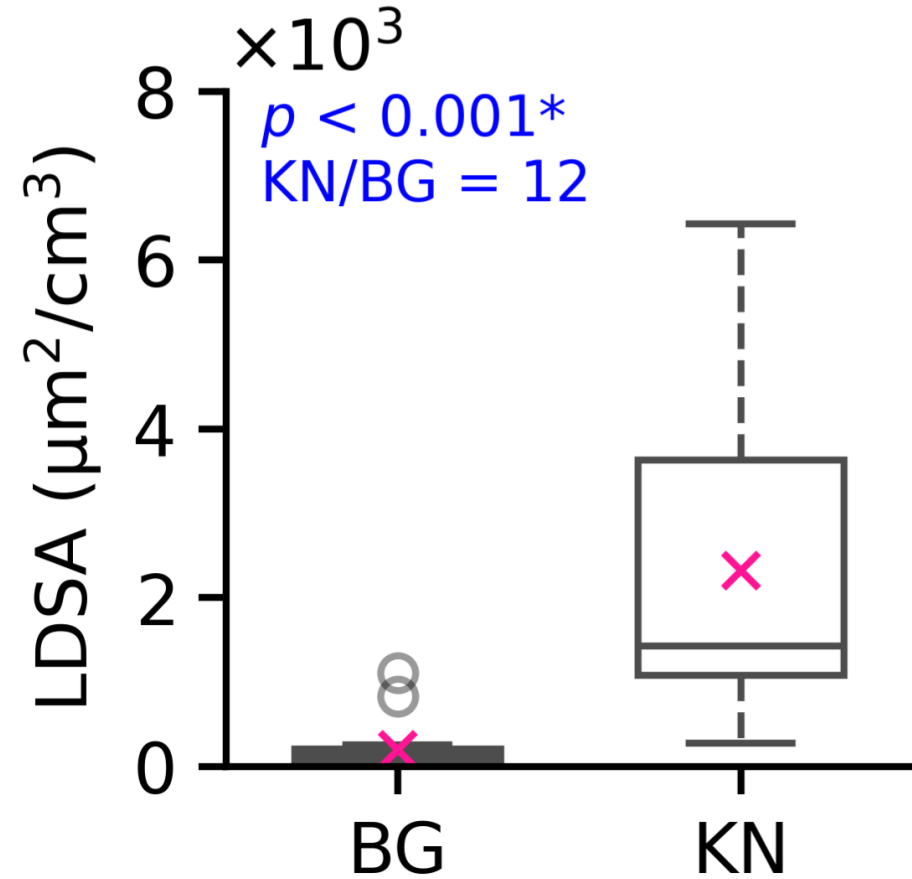
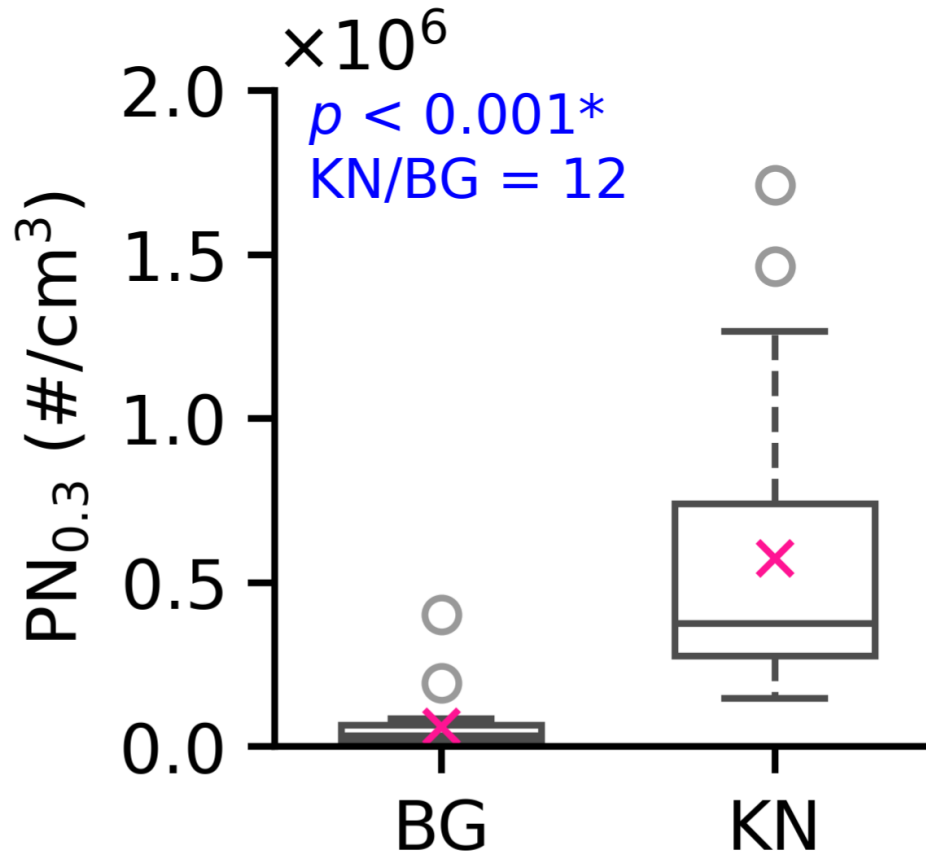
In the following, I will present results on:

- Ultrafine particles ( $PN_{0.3}$ )
- Lung Deposited Surface Area (LDSA) concentrations
- $PM_{2.5}$
- Inhalable dust
- VOCs (TVOC, benzene, naphthalene)
- Formaldehyde
- PAHs





# Ultra-fine particle concentrations and LDSA



# Ultra-fine particles (UFPs)

**Extremely high maximum concentrations during the cooking!**

Average number concentrations ranged during cooking between **400 000 – 800 000 #/cm<sup>3</sup>**

LPG: 160 000 #/cm<sup>3</sup>

ICS w. chimney 190 000 #/cm<sup>3</sup>

Outdoor cooking 150 000 #/cm<sup>3</sup>

Outdoor ambient 10 000 – 62 000 #/cm<sup>3</sup>

## Reference values:

**Low particle concentration:**  
**< 1 000 #/cm<sup>3</sup>** (24-hour mean)

**High particle number concentration:**

- **10 000 #/cm<sup>3</sup>** (24-hour mean)  
**or > 20 000 #/cm<sup>3</sup>** (1-hour mean)

*Occasional high peaks in outdoor background particle number concentrations were observed, most likely related to nearby biomass burning or neighborhood cooking activities.*



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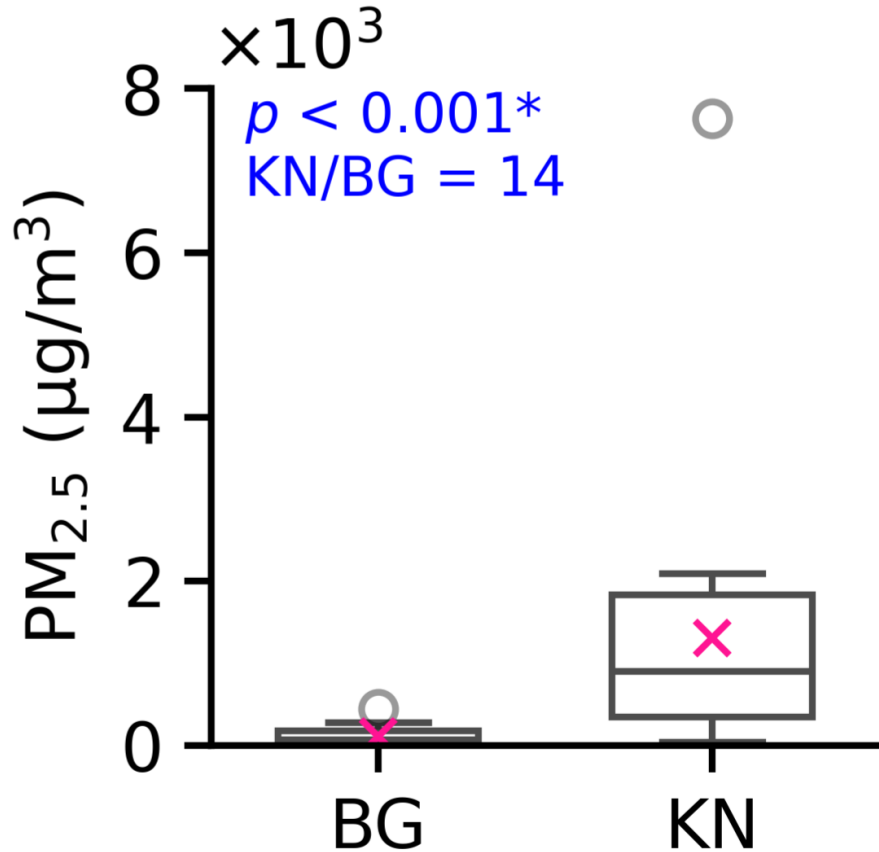
	AM	MAX
HH_Chitwan	<b>412000</b>	<b>5.4 million</b>
HH_Chitwan_out_cooking	<b>147000</b>	2.5 million
Chitwan_outdoor_bg	<b>62000</b>	1.4 million
HH_Rasuwa	<b>817000</b>	<b>5.6 million</b>
Rasuwa_outdoor_bg	<b>10000</b>	0.24 million
HH_Rasuwa_LPG	<b>157000</b>	0.9 million
HH_Rasuwa_ICS	190000	2.1 million
HH_Kavre	<b>680000</b>	<b>3.5 million</b>
Kavre_outdoor_bg	<b>26000</b>	0.7 million

# Typical Lung-Deposited Surface Area (LDSA) Concentrations in Different Environments

- Kitchen LDSA concentrations were typically an order of magnitude higher than background levels, indicating substantially increased respiratory particle exposure during cooking.

Environment	LDSA $\mu\text{m}^2/\text{cm}^3$
Clean background / rural	20–100
Urban background	100–300
Indoor, no strong sources	100–300
Indoor with combustion (cooking, biomass)	<b>500–3 000+</b>
Occupational / extreme	> 3 000
<b>Our study (Kitchen)</b>	<b>1000-3000 (peaks up to 6000-7000!)</b>
<b>Background (outdoors)</b>	<b>100-300</b>

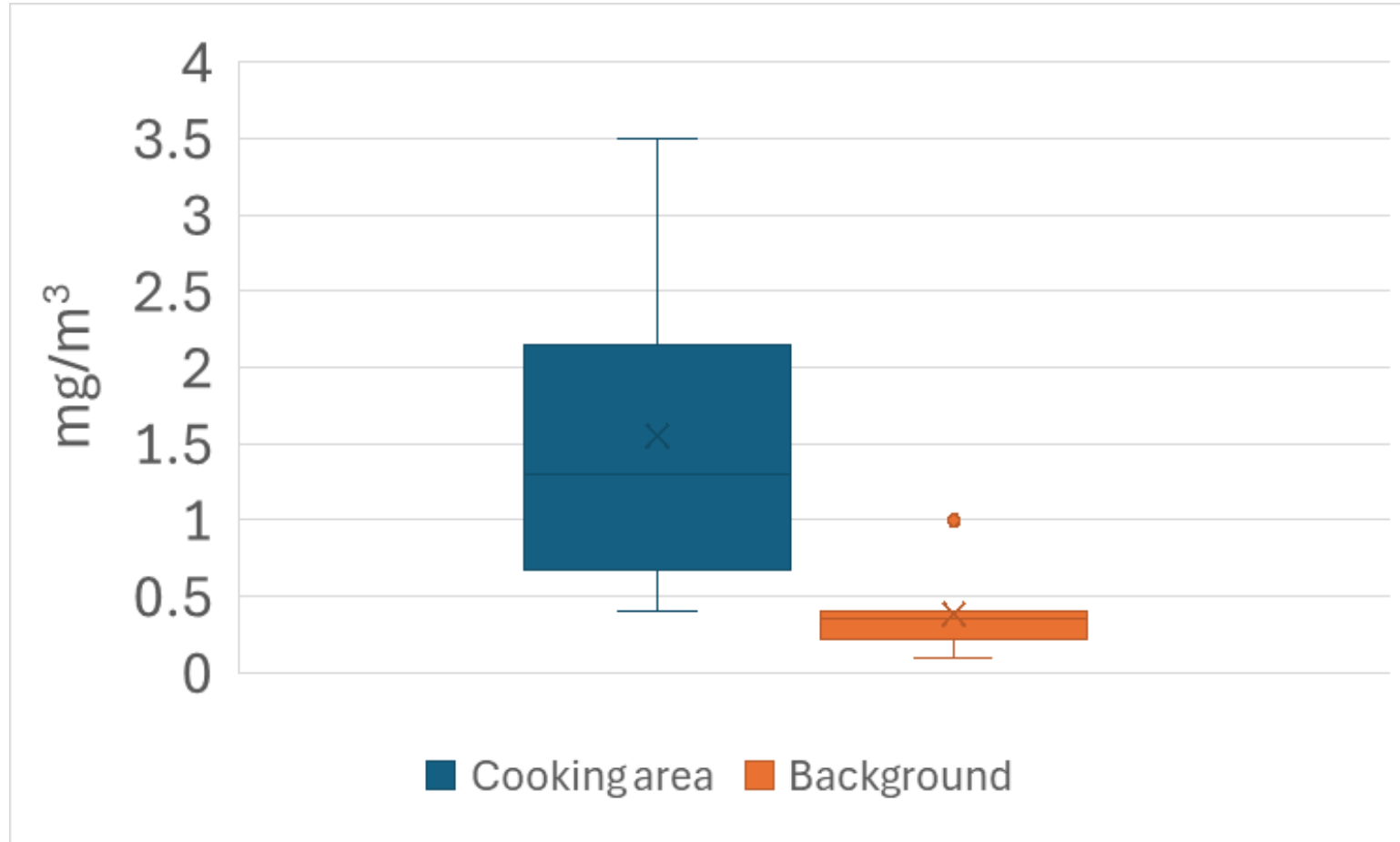
# PM<sub>2.5</sub> concentrations



- Mass concentrations varied during the cooking: 700-1800 µg/m<sup>3</sup>
- Outdoor cooking: 350 µg/m<sup>3</sup>
- Cooking w. ICS + chimney: 100 µg/m<sup>3</sup>
- LPG: 40 µg/m<sup>3</sup>
- Outdoor background: 30-120 µg/m<sup>3</sup>
- **AirQualityGuideline**: 15 µg/m<sup>3</sup> (24-hour mean) WHO
- There is no 1-hour mean for PM<sub>2.5</sub>



# Inhalable dust (<math><100\mu\text{m}</math>) near the cooking area and background (outdoor) concentration

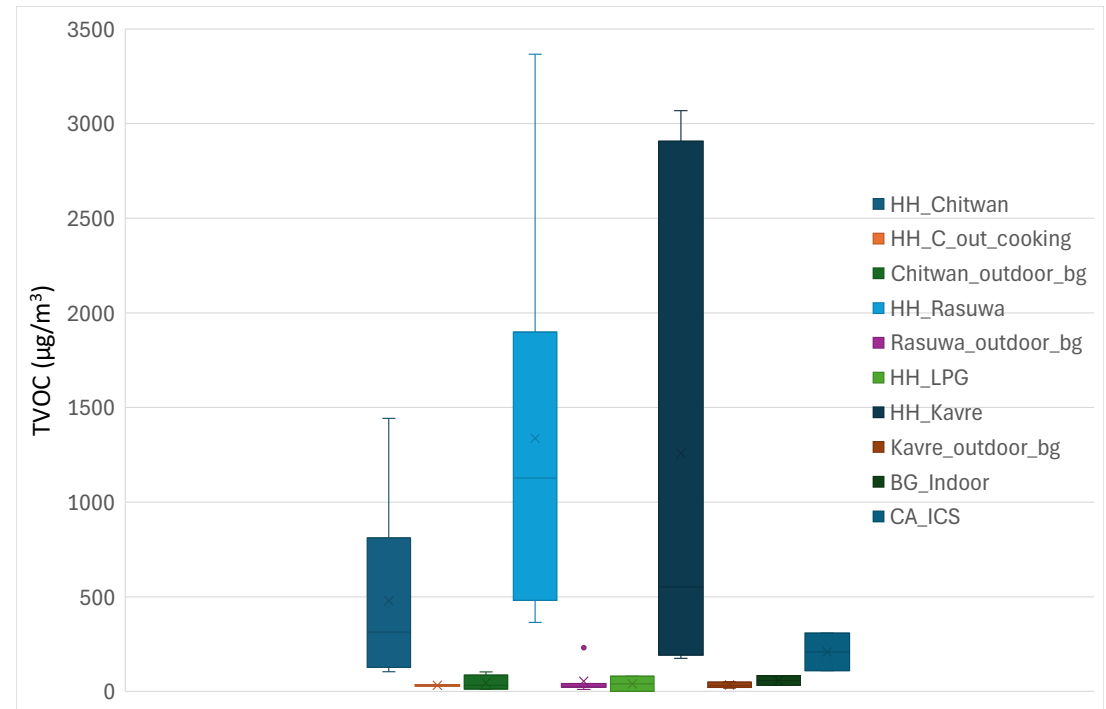


Reference values for inhalable dust are mainly occupational (OEL). In Finland, the occupational exposure limit (OEL<sub>8h</sub>) for organic inhalable dust is 5  $\text{mg}/\text{m}^3$

In indoor biomass combustion,  $\text{PM}_{2.5}$  and ultrafine particles are more relevant for exposure and health effects.

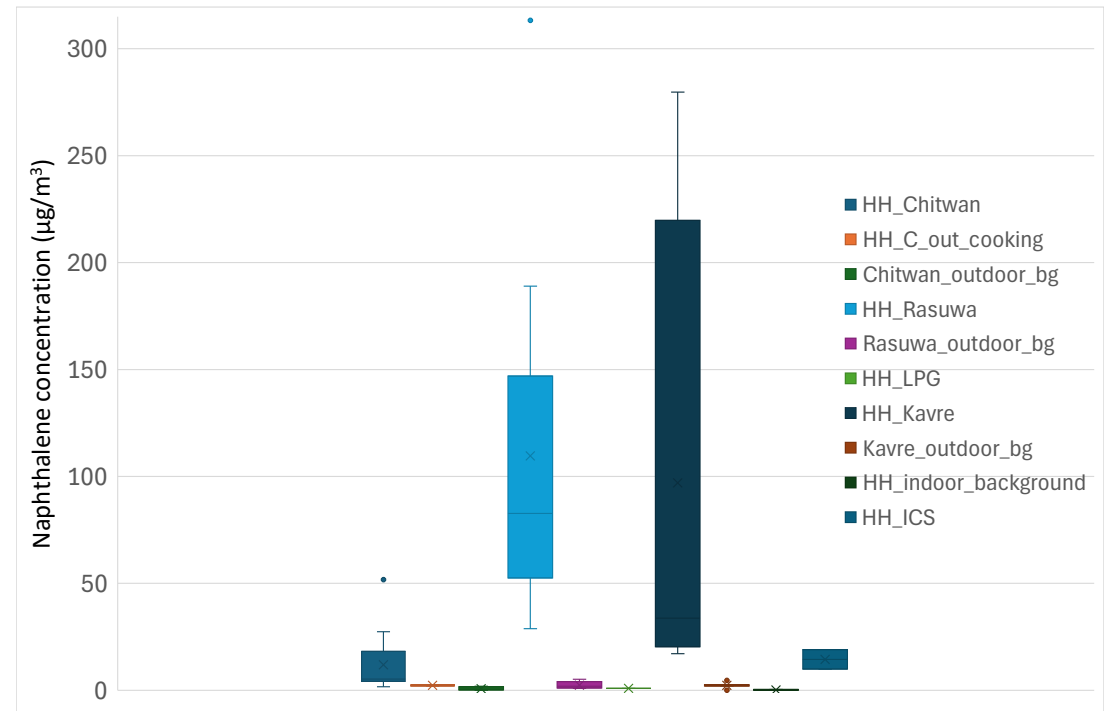
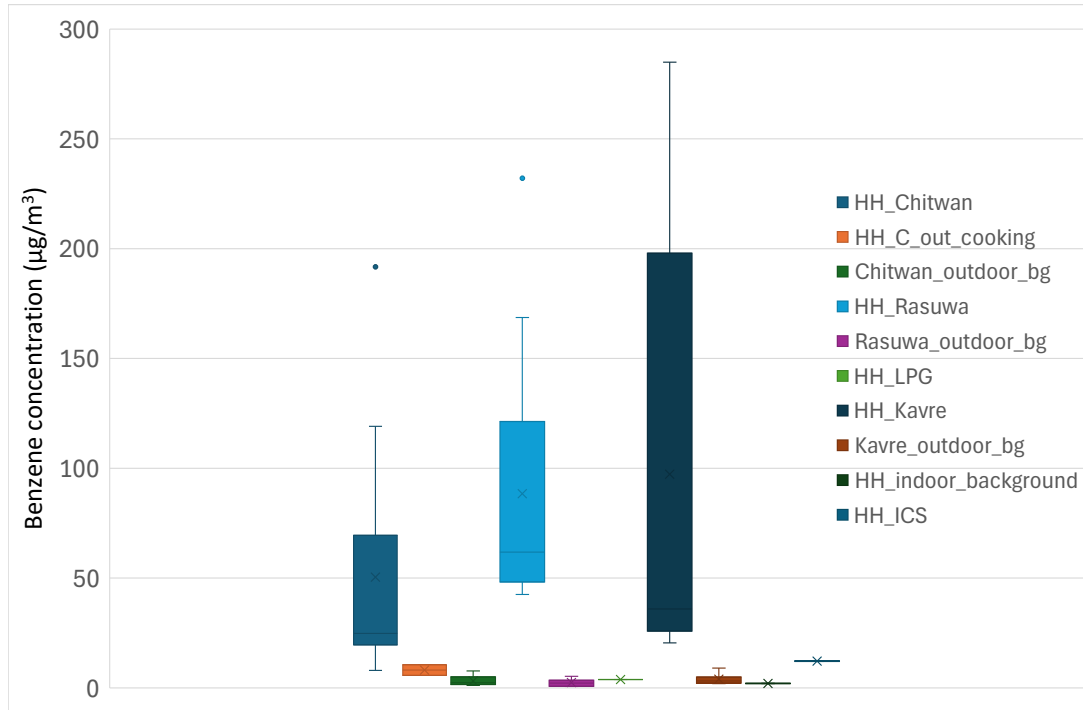
# Total concentrations of volatile organic compounds (TVOC)

- Mean TVOC indoors 480-1340 $\mu\text{g}/\text{m}^3$ . Ambient outdoor air level 30-50 $\mu\text{g}/\text{m}^3$ .
- Indoor air background (no fire) 60 $\mu\text{g}/\text{m}^3$ .
- The main important VOCs in indoors during cooking were benzene and naphthalene. (and other aromatic compounds)





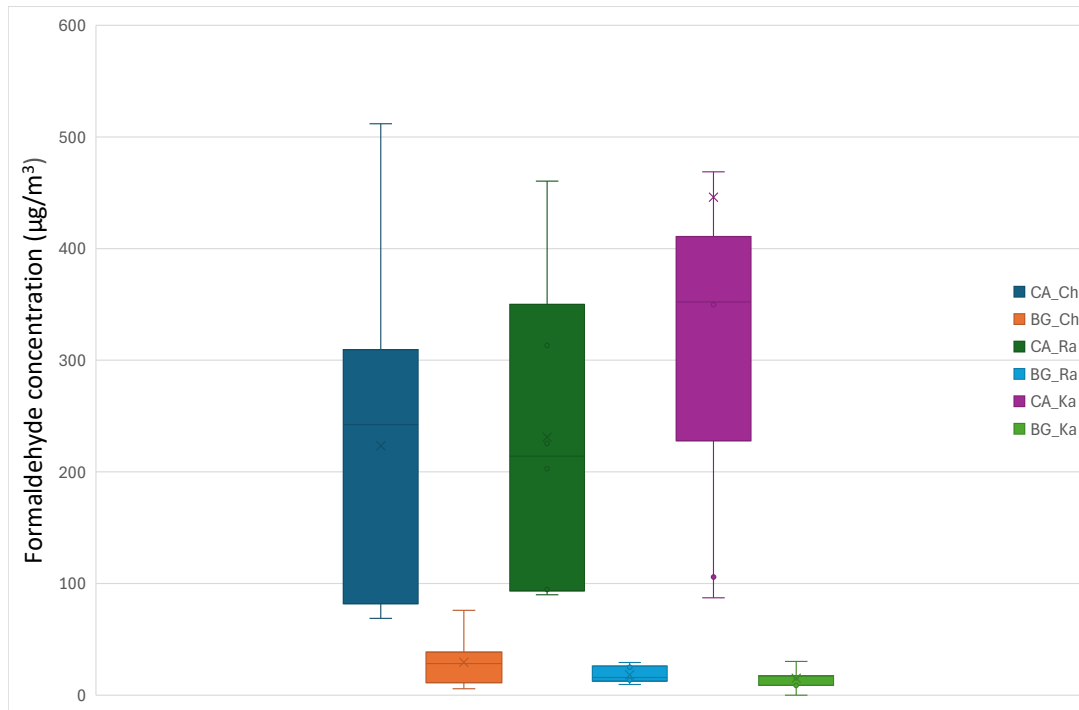
# Benzene and naphthalene



Indoor biomass cooking: benzene and naphthalene  $\sim 20\text{--}200 \mu\text{g}/\text{m}^3$  (peaks  $>300 \mu\text{g}/\text{m}^3$ ), with naphthalene exceeding the WHO guideline by  $\sim 10\text{--}25\times$ ; benzene has no safe threshold.



# Formaldehyde



Indoor cooking generated substantially elevated formaldehyde concentrations, typically in the range of 200–400  $\mu\text{g}/\text{m}^3$ , varying by location. Background levels (outdoors) were an order of magnitude lower (20–60  $\mu\text{g}/\text{m}^3$ ).

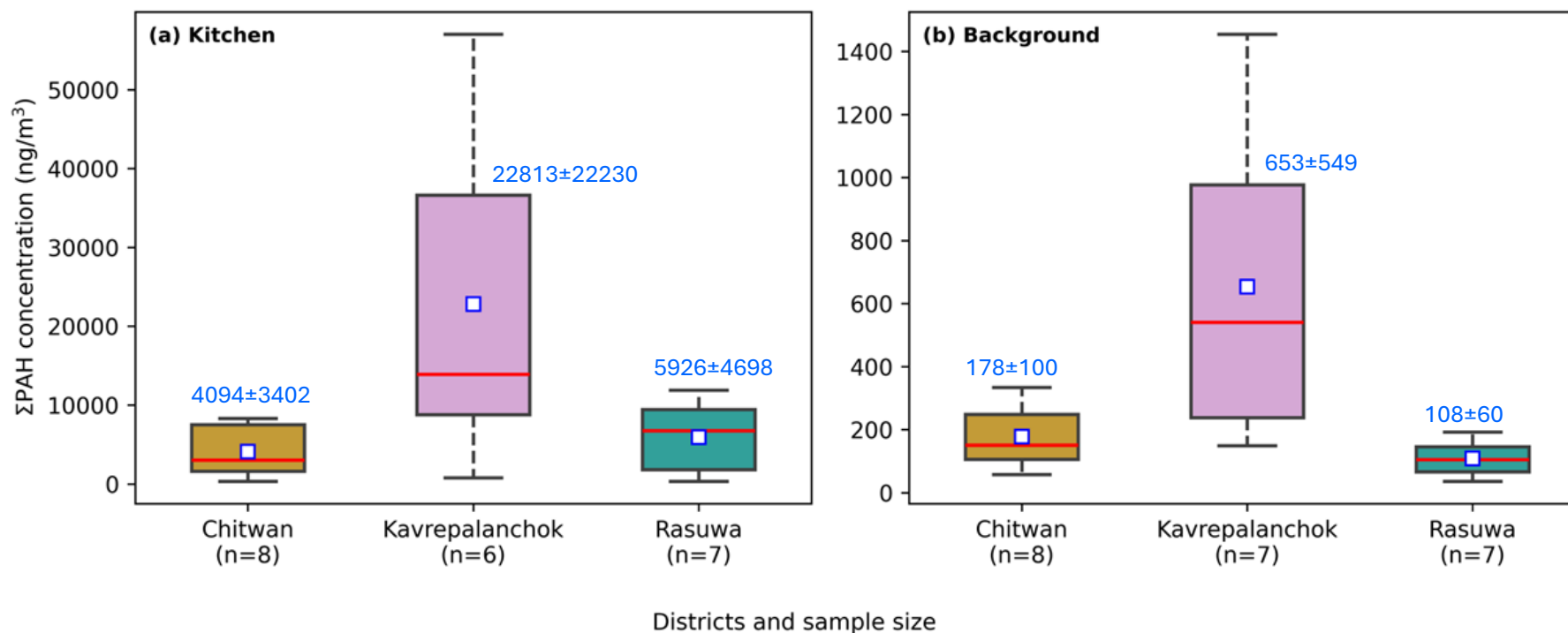
Guidevalue for formaldehyde 100  $\mu\text{g}/\text{m}^3$  (30 min exposure, WHO 2010). Mean Indoor levels were 220–450  $\mu\text{g}/\text{m}^3$ , ambient background levels 15–45  $\mu\text{g}/\text{m}^3$ . When using LPG indoors 20  $\mu\text{g}/\text{m}^3$



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# PAHs in indoor and ambient air



$\Sigma\text{PAH}_{28}$  is substantially higher in kitchen air than in background

- Chitwan: 23x
- Kavrepalanchok: 35x
- Rasuwa: 55x

$\Sigma\text{PAH}_{28}$  across three districts: (a) Kitchen, (b) Ambient



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## Outdoor cooking

During outdoor cooking, the biomass fuel and combustion activity were similar to indoor cooking.

Measured pollutant concentrations were nevertheless clearly lower outdoors. The reduced concentrations are explained by rapid dilution and dispersion in open air. In Chitwan, outdoor cooking  $PM_{2.5}$  averaged  $\sim 350 \mu\text{g}/\text{m}^3$ , while indoor cooking reached  $\sim 1200 \mu\text{g}/\text{m}^3$ .



# LPG

During LPG use, ultrafine particles ( $PM_{0.3}$ ) were generated, but  $PM_{2.5}$  concentrations remained low, at outdoor background levels. The levels of other pollutants (e.g., VOCs, inhalable dust etc.) also stayed close to background values.



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# Improved cooking stove with chimney

- Pollutant concentrations were generally lower than during indoor open-fire cooking but remained elevated compared with LPG use.
- $PM_{2.5}$  averaged  $\sim 0.1\text{--}0.4\text{ mg/m}^3$  (peaks up to  $\sim 2\text{ mg/m}^3$ ),  $PN_{0.3}$   $\sim 190\,000\ \#/cm^3$  (peaks  $>2\,000\,000\ \#/cm^3$ ), and LDSA  $\sim 600\text{ nm}^2/cm^3$  (max  $\sim 3\,300$ ).
- VOCs and PAHs (TVOC  $\sim 100\text{--}300\ \mu\text{g/m}^3$ ; benzene  $\sim 12\ \mu\text{g/m}^3$ ; naphthalene  $\sim 10\text{--}19\ \mu\text{g/m}^3$ ) were lower than in many other indoor cooking sites.
- However, exposure was influenced by nearby indoor open-fire use in an adjacent household, and the ICS did not appear to operate efficiently at all times. And fuel consumption was also reported to be high.





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# Indoor Cooking as a Major Source of Exposure



Indoor air pollution levels ( $PN_{0.3}$ ,  $PM_{2.5}$ , PAHs, VOCs, and carbonyls) were high during cooking, even though the instruments were placed at some distance from the open fire.

Smoke often accumulated and lingered indoors, and small children were sometimes present.

These **repeated daily exposure peaks** pose significant health risks; if major changes are not possible, reducing exposure duration is critical.

# Open Fires and Inefficient Stoves without Chimneys Increase Indoor Air Pollution



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# Summary



- Indoor biomass cooking produced the highest concentrations of particles, PAHs, VOCs and formaldehyde, all far above WHO guideline values.
- PAHs increased 23–55× compared with background air.
- Indoor TVOC levels during cooking reached several hundred to over 1000  $\mu\text{g}/\text{m}^3$ , with benzene and naphthalene as key compounds.
- Formaldehyde concentrations during cooking commonly exceeded 200  $\mu\text{g}/\text{m}^3$ .
- Outdoor cooking resulted lower exposures due to rapid dilution.
- LPG produced the lowest pollution levels across all pollutants.

## Key messages:

- **Exposure Time Matters — Repeated daily peaks drive cumulative health risks.**
- **Stove type, user practices, and ventilation jointly determine indoor air quality.**
- **Significant reductions require integrated solutions – combining improved stove technology, effective ventilation, and culturally appropriate practices.**

# Thank you



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