Study Protocol

Using Real-Time $PM_{2.5}$ Information Feedback to Reduce Household Indoor Air Pollution: A Randomized Controlled Trial

1. Title

Using Real-Time $PM_{2.5}$ Information Feedback to Reduce Household Indoor Air Pollution: Protocol for a Randomized Controlled Trial

2. Background and Rationale

Indoor air pollution remains an important health risk in many households, particularly where cooking, heating, and ventilation practices may lead to sustained exposure to fine particulate matter ($PM_{2.5}$). Although households are often exposed to harmful levels of indoor air pollution, many may not be fully aware of when pollution occurs, how severe it is, or what actions can effectively reduce exposure in daily life.

Providing households with real-time air quality information may improve awareness and enable behavioral adjustment. Immediate feedback through visible pollution readings and warning signals may help users recognize pollution episodes as they occur. Complementary informational materials may further support understanding of the health risks of indoor air pollution and practical ways to reduce exposure. However, causal evidence on whether such interventions can reduce indoor $PM_{2.5}$ exposure in household settings remains limited.

This study evaluates whether providing households with real-time $PM_{2.5}$ feedback, threshold-based warning alerts, and an informational leaflet can reduce indoor air pollution exposure relative to a control condition without access to these tools.

3. Study Objectives

The primary objective of this study is to estimate the causal effect of a real-time indoor air quality information intervention on household indoor $PM_{2.5}$ exposure.

The secondary objective is to assess whether providing explanatory information on indoor air pollution and mitigation actions, alongside real-time monitoring, is associated with changes in exposure patterns over the intervention period.

4. Study Design

This study is a two-arm randomized controlled trial conducted at the household level.

Participants are assigned to one of two study arms:

- **Treatment group**: households receive access to real-time $PM_{2.5}$ monitoring with on-device display, a red alarm when $PM_{2.5}$ exceeds a predefined threshold, and an informational leaflet on indoor air pollution and exposure reduction.

- **Control group**: households do not receive access to real-time $PM_{2.5}$ information display, alarm signals, or the informational leaflet during the study period.

The total study duration for each household is **two months**, consisting of:

- **Two-week baseline period** before the intervention
- **Six-week treatment period**

Outcome data are collected continuously throughout both periods.

5. Study Setting

The study is conducted among households in rural areas. Indoor air quality is monitored using $PM_{2.5}$ sensors placed inside participating households. The intervention is implemented in natural household settings under real-life daily living conditions.

6. Participants

6.1 Eligibility Criteria

Households are eligible to participate if they:

- reside in the selected study area;
- agree to have an indoor $PM_{2.5}$ sensor installed for the study period;
- provide informed consent for participation.

Households may be excluded if they:

- are unable or unwilling to complete the study procedures;
- experience equipment installation constraints that prevent reliable monitoring.

7. Interventions

7.1 Treatment Arm

Households assigned to the treatment arm receive a $PM_{2.5}$ sensor with **real-time display** of indoor air quality readings. The device provides immediate visual feedback to household members and activates a **red alarm** when indoor $PM_{2.5}$ concentrations exceed **60 $\mu g/m^3$**.

In addition, treatment households receive an **information leaflet** that explains:

- what indoor air pollution is;
- why $PM_{2.5}$ is harmful to health;
- common household sources of indoor air pollution; and

- practical actions to reduce indoor air pollution exposure, such as improving ventilation and modifying household behaviors during pollution episodes.

The intervention is delivered continuously during the six-week treatment period.

7.2 Control Arm

Households assigned to the control arm do not receive access to real-time $PM_{2.5}$ readings, threshold-based alarms, or the informational leaflet during the study period. $PM_{2.5}$ is still measured for research purposes, but no active feedback is provided to participants.

8. Randomisation

Participants are randomly allocated to the treatment or control group using a **pure computer-based randomisation process** implemented in **Stata** through an online workflow. Allocation is conducted without manual interference.

Where relevant, randomisation may be conducted after baseline recruitment and sensor setup to ensure comparable pre-intervention monitoring across groups. The assignment sequence is generated electronically, and households are allocated according to the computer-generated randomisation results.

9. Blinding

Because the intervention involves visible real-time display and alarm functions, participants cannot be blinded to treatment assignment. Field implementation staff may also be aware of treatment status during device setup and communication. However, outcome measurement is based on sensor-recorded $PM_{2.5}$ data, which reduces the scope for subjective reporting bias in the primary outcome.

10. Outcome Measures

10.1 Primary Outcome

The primary outcome is **indoor $PM_{2.5}$ concentration**, measured continuously using installed air quality sensors.

Possible summary measures include:

- average $PM_{2.5}$ concentration over the observation period;
- daily average $PM_{2.5}$ concentration;
- number or share of observation periods exceeding the threshold;
- changes in $PM_{2.5}$ levels from baseline to treatment period.

10.2 Secondary Outcomes

Secondary outcomes may include:

- frequency of high-pollution episodes;
- duration of time spent above the $PM_{2.5}$ threshold;
- temporal changes in household exposure patterns over the six-week treatment period.

11. Data Collection

$PM_{2.5}$ data are collected using indoor sensors installed in participant households. Monitoring begins during the two-week baseline period and continues throughout the six-week intervention period.

Treatment households receive active feedback during the treatment phase, while control households do not receive real-time feedback. Additional study data may include basic household background information collected at enrollment.

12. Timeline

For each household, the study timeline is as follows:

- **Week 0 to Week 2**: baseline monitoring period
- **Week 3 to Week 8**: intervention period

The full observation window is two months for both study arms.

13. Sample Size

The final sample size will be determined based on recruitment feasibility, statistical power considerations, and available study resources. Households are allocated across the two arms in approximately equal proportions.

14. Statistical Analysis

The primary analysis will compare indoor $PM_{2.5}$ outcomes between treatment and control households over the intervention period, using an intention-to-treat framework.

Baseline $PM_{2.5}$ observations collected during the two-week pre-intervention period will be used to describe pre-treatment comparability and may be incorporated to improve precision. Depending on the final data structure, analysis may be conducted at the household, day, or finer temporal level, with appropriate adjustment for repeated observations and baseline values.

Pre-specified subgroup or heterogeneity analyses may be conducted where sample size permits.

15. Ethical Considerations

Participation in the study is voluntary. Informed consent is obtained from all participating households prior to enrollment. Data are collected for research purposes and handled confidentially. Participants may withdraw from the study at any time.

The intervention is low risk and consists of information provision and feedback on indoor air quality conditions. No invasive procedures are involved.

16. Risks and Benefits

Risks to participants are minimal and primarily relate to the inconvenience of sensor placement and study participation. Potential benefits include improved awareness of indoor air pollution and possible reductions in exposure among households receiving the intervention.

17. Data Management and Confidentiality

All study data are stored securely and used only for research purposes. Household identifiers are separated from analytic data where feasible. Only authorized study personnel have access to identifiable information.

18. Dissemination

Findings from the study will be disseminated through academic publications, research presentations, and project reports. Results may also inform future interventions aimed at reducing household exposure to indoor air pollution.

19. Limitations

Several limitations should be noted. First, participants in the treatment group may change behavior because they are aware of being monitored and alerted, making it difficult to fully separate informational effects from monitoring effects. Second, because participants cannot be blinded, behavioral responses may partly reflect awareness of treatment assignment. Third, the six-week intervention period allows evaluation of short-run effects, but it may not be sufficient to determine whether any behavioral changes and exposure reductions persist over a longer time horizon.

20. Trial Status

At the time of protocol preparation, the study is in the pilot/implementation stage, with monitoring devices prepared and intervention procedures established.