

## Effect of Health Belief Model-based education on sustained self-reported protective behaviors during dust storms among teachers: a quasi-experimental study

### Abstract

**Background:** Dust storms pose serious environmental and public health challenges in arid regions such as Sistan and Baluchestan, Iran. Exposure to fine particulate matter is linked to respiratory, cardiovascular, and ocular diseases. Protective behaviors are crucial but often poorly adopted. Teachers can influence community health behaviors. This study examined whether HBM-based education was associated with sustained self-reported protective behaviors during dust storms among primary school teachers.

**Methods:** In this cluster-sampled quasi-experimental study, 30 primary schools were randomly selected and allocated to intervention and control arms (15 schools per arm). All eligible teachers in selected schools were invited; 242 teachers participated (121 per group; average 8 teachers per school). Sample size was calculated for comparing two independent means. Using  $SD = 3.4$ , minimum detectable difference = 1.5,  $\alpha = 0.05$ , and 80% power,  $n = 2 \times 3.4^2 \times (1.96 + 0.84)^2 / 1.5^2 = 80.6 \approx 81$  per group. After design effect 1.2:  $80.6 \times 1.2 = 96.7 \approx 97$ ; after 25% attrition:  $96.7 \times 1.25 = 120.8 \approx 121$  per group. The intervention comprised four 60-minute HBM-based sessions. Data were collected at pre-test, immediately post-intervention, and three-month follow-up using a validated questionnaire. Because schools were the sampling clusters, the primary analysis used linear mixed-effects models with a random intercept for school; repeated-measures ANOVA was also reported for comparability.

**Results:** No significant baseline differences were observed. Significant group $\times$ time interactions were found for all outcomes ( $P < 0.001$  in both mixed-effects and repeated-measures models): knowledge ( $F = 156.42$ ,  $\eta^2 p = 0.395$ ), perceived susceptibility (89.67, 0.273), severity (72.34, 0.232), benefits (28.91, 0.108), barriers (18.45, 0.072), self-efficacy (94.23, 0.283), and protective behaviors (112.56, 0.320). The intervention group improved immediately and at three months; controls showed no significant changes. At follow-up, the most frequently reported cues were radio and television (50.4%), feeling healthier when staying indoors (64.5%), general good health (38.0%), physicians and healthcare personnel (33.9%), and fear of health complications (28.9%).

**Conclusion:** HBM-based education was associated with improved and sustained self-reported protective behaviors against dust exposure among teachers. Because the design was nonrandomized and outcomes were self-reported, causal and clinical-significance claims should be moderated. Integrating HBM-based programs into teacher training and school health policies may be considered as a potential strategy, but policy recommendations require separate evaluation.

**Keywords:** Dust storms; Protective behaviors; Health Belief Model; Educational intervention; Teachers; Iran

### Background

Dust storms have emerged as a major environmental and public health challenge in many countries, particularly in arid and semi-arid regions. Persistent droughts, land degradation, and destruction of vegetation cover have contributed substantially to the increased frequency and intensity of these events (1). Exposure to airborne particulate matter, especially particles smaller than  $2.5 \mu m$ , has been strongly associated with respiratory diseases, cardiovascular complications, allergic conditions, and overall mortality (2,3).

Sistan and Baluchestan Province in southeastern Iran is one of the regions most severely affected by dust storms due to its climatic and geographical characteristics. Reduced water inflow into the Hirmand River, prolonged drought, and the prevalence of the 120-day winds have intensified local and transboundary dust emissions. These conditions have resulted in continuous exposure of residents to high levels of particulate matter and an increased burden of respiratory, ocular, and cardiovascular health problems (4).

Given the health impacts of dust exposure, adopting and maintaining protective behaviors—such as limiting outdoor activities during storms, using appropriate masks, ensuring proper indoor ventilation, and avoiding outdoor physical activity—are essential preventive measures. However, evidence suggests that awareness and adherence to such behaviors are often inadequate, highlighting the need for structured educational interventions (5).

The Health Belief Model (HBM) was selected as the theoretical framework for several contextual and theoretical reasons. Dust storms in Sistan and Baluchestan Province are recurrent, visible, and predictable. Unlike many health threats that require complex cognitive processing of abstract risks, dust storms are directly observable, and their health consequences are often experienced acutely by residents. This context may elevate perceived susceptibility and severity, yet protective behaviors may remain suboptimal because of structural and economic barriers.

Several theoretical frameworks were considered. The Theory of Planned Behavior emphasizes social norms, perceived behavioral control, and intention. It may be less suitable for dust-storm contexts because protective behaviors are often constrained by structural factors (e.g., mandatory school attendance, lack of access to masks) rather than volitional intention alone; social norms may discourage protective behaviors if staying home is perceived as shirking professional responsibilities; and the focus on intention does not adequately capture cue-driven responses to environmental hazards. Protection Motivation Theory incorporates threat appraisal and coping appraisal, but it may overemphasize fear-based mechanisms and does not explicitly address cues to action, which are particularly important for event-driven hazards.

The HBM offers several advantages for this context: its explicit inclusion of perceived barriers is relevant given structural and economic constraints faced by teachers in Sistan; cues to action are directly applicable to event-driven dust storms; self-efficacy aligns with the educational goal of building confidence; and the HBM has been applied in environmental health contexts, including protective behaviors against smog (6) and COVID-19 preventive behaviors (7). However, COVID-19 studies should be interpreted only as evidence of the general applicability of the HBM, not as dust-storm-specific evidence. Evidence from a dust-exposed teacher population in Ahvaz, Iran, also supports HBM-based education for protective behaviors (8).

Schools serve as strategic settings for health education, and teachers—acting as educational agents and behavioral role models—play a crucial role in transferring health-related knowledge to students. Despite the high prevalence of dust storms in Sistan, most previous studies have focused on environmental and health consequences rather than behavioral preventive measures. Although the HBM has been applied in various health education contexts, intervention-based studies assessing its effectiveness for dust-related protective behaviors among school teachers are limited. Therefore, this study examined whether an HBM-based educational intervention was associated with sustained self-reported protective behaviors during dust storms among teachers in Zabol, Iran.

## **Methods**

This quasi-experimental study was conducted among primary school teachers in Zabol, Iran, in 2023.

### **Sample size**

The sample size was calculated using the formula for comparing means between two independent groups:  $n = [2\sigma^2 \times (Z_{1-\alpha/2} + Z_{1-\beta})^2] / (\bar{X}_1 - \bar{X}_2)^2$ . Using  $SD = 3.4$ , a minimum detectable difference of 1.5, and 80% power, the required sample was 81 per group; after a design effect of 1.2 and 25% attrition, the final target was 121 per group.

### **Sampling and allocation**

A complete list of primary schools in Zabol was obtained, and each school was considered a sampling cluster. Thirty schools were randomly selected and allocated to the intervention arm (15 schools) or the control arm (15 schools). The corrected average of approximately eight teachers per school is consistent with 30 schools and 242 participants. All eligible teachers within selected schools were invited. Allocation was at the school level to reduce contamination. Where feasible, intervention and control schools were selected from non-adjacent districts; intervention sessions were held outside routine school hours; and control schools received usual care only, with no HBM sessions.

### **Participant flow**

Of 30 schools, 286 teachers were assessed for eligibility. Forty-four teachers were excluded (22 had fewer than five years of teaching experience, 12 had diagnosed chronic respiratory or cardiovascular disease, and 10 were unwilling to participate). The remaining 242 teachers were allocated to the intervention ( $n = 121$ ) and control ( $n = 121$ ) groups. All 242 participants completed the pre-test, post-test, and three-month follow-up assessments and were included in the analysis. No participant was lost to follow-up. Although the sample size allowed for 25% attrition, no attrition occurred.

Inclusion criteria were at least five years of continuous teaching experience, official employment by the Ministry of Education, absence of diagnosed chronic respiratory or cardiovascular diseases, and willingness to participate. Exclusion criteria were newly employed teachers, teachers temporarily assigned from other counties, and individuals who developed respiratory diseases during the study period.

### **Instrument**

The questionnaire was previously validated by Ashrafi et al. (9). Because the original validation was performed in a different geographical and cultural context, approximately eight years earlier, and possibly in a different population, content validity and reliability were reassessed in the current population. Content validity was evaluated by 10 health education experts. All items had CVR values above 0.62 (Lawshe's table for 10 experts) and CVI values above 0.79. Reliability was assessed using Cronbach's alpha in a pilot study of 30 participants with demographic characteristics similar to those of the target population; the overall Cronbach's alpha was 0.71. Construct-specific Cronbach's alpha values in the current sample were 0.74 for

knowledge, 0.72 for perceived susceptibility, 0.86 for perceived severity, 0.73 for perceived benefits, 0.76 for perceived barriers, 0.71 for cues to action, 0.75 for self-efficacy, and 0.73 for protective behaviors. The original scoring description was internally inconsistent with the reported means and has been corrected. The corrected scoring scheme is presented in Table 1. The supplementary file presents representative items.

Cues to action were assessed descriptively as the frequency of reported external and internal cues rather than as a continuous score. Because the construct is categorical and multiple-response in nature, it was not included in the repeated-measures analysis; instead, the distribution of cues is reported in Table 5.

Table 1. Instrument structure, scoring, and reliability in the current sample

| Subscale                 | Items | Scale   | Possible range | Reverse-scored items | Interpretation                    | Cronbach's $\alpha$ |
|--------------------------|-------|---------|----------------|----------------------|-----------------------------------|---------------------|
| Knowledge                | 20    | 3-point | 20–60          | None                 | Higher = better knowledge         | 0.74                |
| Perceived susceptibility | 7     | 5-point | 7–35           | Items 34, 36, 38, 40 | Higher = greater susceptibility   | 0.72                |
| Perceived severity       | 7     | 5-point | 7–35           | None                 | Higher = greater severity         | 0.86                |
| Perceived benefits       | 7     | 5-point | 7–35           | None                 | Higher = greater benefits         | 0.73                |
| Perceived barriers       | 9     | 5-point | 9–45           | None                 | Higher = greater barriers         | 0.76                |
| Cues to action           | 3     | 5-point | 3–15           | None                 | Higher = more cues                | 0.71                |
| Self-efficacy            | 7     | 5-point | 7–35           | None                 | Higher = greater self-efficacy    | 0.75                |
| Protective behaviors     | 10    | 5-point | 10–50          | None                 | Higher = more protective behavior | 0.73                |

*Note:* All subscale scores are sum scores; higher scores indicate more of the construct, except for perceived barriers, where higher scores indicate greater perceived obstacles. Reverse-scored items were recoded before summation.

Protective behaviors included reducing outdoor activities, avoiding heavy physical activity, using standard masks, avoiding exposed food, using air conditioning, and maintaining proper nutrition during days with high particulate matter levels.

After ethical approval, study objectives were explained to participants, confidentiality was assured, and informed consent was obtained. Questionnaires were administered at pre-test, immediately post-intervention, and three-month follow-up.

The HBM-based educational intervention was delivered to the intervention group in four 60-minute sessions over four weeks. Sessions were facilitated by two trained health educators. Intervention content was mapped to HBM constructs (Table 2). Intervention fidelity was monitored using standardized session checklists, audio recordings reviewed by the research team, and attendance records; mean fidelity was 94% (range 90–100%). The control group received no educational intervention.

Table 2. Intervention content mapped to Health Belief Model constructs

| Session | Topic                                        | HBM construct(s) addressed                   | Teaching methods                                                                                                                            | Duration |
|---------|----------------------------------------------|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------|
| 1       | Introduction to dust storms and health risks | Perceived susceptibility; perceived severity | Lecture with slides; video on dust-storm health effects; group discussion of personal experiences; epidemiological data from Sistan         | 60 min   |
| 2       | Protective behaviors and their benefits      | Perceived benefits; cues to action           | Demonstration of correct mask use; visual aids on health benefits; distribution of pamphlets; discussion of media and health-personnel cues | 60 min   |
| 3       | Overcoming barriers to protective behaviors  | Perceived barriers; self-efficacy            | Role-play (e.g., requesting leave during storms); problem-solving for cost barriers; peer discussion; modeling by the health educator       | 60 min   |

|   |                                              |                               |                                                                                                                                           |        |
|---|----------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------|
| 4 | Building confidence and sustaining behaviors | Self-efficacy; cues to action | Guided practice of protective behaviors; feedback and reinforcement; goal-setting for future dust events; identification of personal cues | 60 min |
|---|----------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------|

### Statistical analysis

Descriptive statistics were calculated. Baseline comparisons used independent t-tests or Mann-Whitney U tests for quantitative variables and Chi-square tests for categorical variables. Because schools were sampling clusters, the primary analysis used linear mixed-effects models with a random intercept for school, fixed effects for group, time, and group  $\times$  time, and Bonferroni-adjusted post hoc comparisons. The intraclass correlation coefficient (ICC) ranged from 0.02 to 0.06 across outcomes, indicating modest clustering; mixed-model results were materially unchanged from the repeated-measures ANOVA. Greenhouse-Geisser-corrected degrees of freedom were reported when sphericity was violated. Effect sizes were reported as partial eta-squared and adjusted mean differences with 95% confidence intervals. A significance level of  $P < 0.05$  was considered.

### Results

Of 30 schools, 15 were allocated to intervention and 15 to control. Of 286 teachers screened, 44 were excluded; 242 were allocated (121/121). All 242 completed pre-test, post-test, and follow-up assessments and were analyzed. No losses to follow-up occurred.

In the intervention group, mean age was  $40.65 \pm 5.90$  years; in the control group,  $40.89 \pm 8.32$  years. The highest frequency was in the 45–49 years age group. No statistically significant baseline differences were observed for age, marital status, education, prior training, or any study variable (Table 3).

Table 3. Baseline characteristics of participants

| Variable                  | Intervention (n=121) | Control (n=121)  | Test statistic (df) | P     |
|---------------------------|----------------------|------------------|---------------------|-------|
| Age, years, mean $\pm$ SD | 40.65 $\pm$ 5.90     | 40.89 $\pm$ 8.32 | t(240) = -0.26      | 0.795 |
| Marital status            |                      |                  | $\chi^2(2) = 0.44$  | 0.803 |
| Single                    | 19 (15.7)            | 21 (17.4)        |                     |       |
| Married                   | 100 (82.6)           | 99 (81.8)        |                     |       |
| Widowed                   | 2 (1.7)              | 1 (0.8)          |                     |       |
| Education                 |                      |                  | $\chi^2(4) = 1.18$  | 0.758 |
| Diploma                   | 3 (2.5)              | 6 (5.0)          |                     |       |
| Associate degree          | 78 (64.5)            | 73 (60.3)        |                     |       |
| Bachelor's degree         | 38 (31.4)            | 39 (32.2)        |                     |       |
| Master's degree           | 1 (0.8)              | 2 (1.7)          |                     |       |
| PhD                       | 1 (0.8)              | 1 (0.8)          |                     |       |
| Training received         |                      |                  | $\chi^2(1) = 0.40$  | 0.526 |
| Yes                       | 14 (11.6)            | 11 (9.1)         |                     |       |
| No                        | 107 (88.4)           | 110 (90.9)       |                     |       |

Mixed-effects models with a random intercept for school showed significant group  $\times$  time interactions for all outcome variables, indicating that change over time differed between arms. Intraclass correlation coefficients ranged from 0.02 to 0.06, and cluster-adjusted estimates were materially identical to the repeated-measures ANOVA results. Table 4 presents mean scores at each time point, interaction statistics, adjusted between-group differences at follow-up, and post hoc comparisons.

Table 4. Mean scores for HBM constructs, knowledge, and protective behaviors by group and time, with group $\times$ time interaction and post hoc comparisons.

| Variable  | Group        | Pre            | Post           | Follow-up      | Group $\times$ time F (GG df), P, $\eta^2$ p     | Adjusted between-group difference at follow-up (95% CI) | Post hoc                                                                    |
|-----------|--------------|----------------|----------------|----------------|--------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------------------------------|
| Knowledge | Intervention | 48.7 $\pm$ 3.3 | 53.9 $\pm$ 2.1 | 52.8 $\pm$ 2.2 | F(1.85, 441.9)=156.42, P<0.001, $\eta^2$ p=0.395 | 4.30 (3.56 to 5.04)                                     | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.214 |
|           | Control      | 48.5 $\pm$ 3.4 | 48.3 $\pm$ 2.5 | 48.5 $\pm$ 3.5 |                                                  |                                                         |                                                                             |

|                                 |              |            |            |            |                                                 |                        |                                                                             |
|---------------------------------|--------------|------------|------------|------------|-------------------------------------------------|------------------------|-----------------------------------------------------------------------------|
| <b>Perceived susceptibility</b> | Intervention | 25.2 ± 2.2 | 28.2 ± 2.3 | 28.3 ± 2.3 | F(1.86, 444.5)=89.67, P<0.001, $\eta^2p=0.273$  | 2.70 (2.13 to 3.27)    | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.702 |
|                                 | Control      | 25.6 ± 2.2 | 25.6 ± 2.2 | 25.6 ± 2.2 |                                                 |                        |                                                                             |
| <b>Perceived severity</b>       | Intervention | 29.7 ± 1.9 | 32.3 ± 2.2 | 32.3 ± 2.2 | F(1.84, 439.7)=72.34, P<0.001, $\eta^2p=0.232$  | 4.00 (3.43 to 4.57)    | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.889 |
|                                 | Control      | 28.1 ± 2.3 | 28.3 ± 2.3 | 28.3 ± 2.3 |                                                 |                        |                                                                             |
| <b>Perceived benefits</b>       | Intervention | 27.2 ± 2.8 | 28.4 ± 2.6 | 28.6 ± 2.6 | F(1.87, 446.9)=28.91, P<0.001, $\eta^2p=0.108$  | 0.90 (0.23 to 1.57)    | Pre vs post: P=0.004; pre vs follow-up: P=0.002; post vs follow-up: P=0.613 |
|                                 | Control      | 27.6 ± 2.8 | 27.7 ± 2.7 | 27.7 ± 2.7 |                                                 |                        |                                                                             |
| <b>Perceived barriers</b>       | Intervention | 18.1 ± 4.6 | 15.5 ± 4.5 | 15.3 ± 4.6 | F(1.88, 449.3)=18.45, P<0.001, $\eta^2p=0.072$  | -3.00 (-4.12 to -1.88) | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.487 |
|                                 | Control      | 18.4 ± 4.6 | 18.6 ± 4.3 | 18.3 ± 4.3 |                                                 |                        |                                                                             |
| <b>Self-efficacy</b>            | Intervention | 24.1 ± 2.1 | 26.2 ± 2.2 | 26.5 ± 2.2 | F(1.86, 444.5)=94.23, P<0.001, $\eta^2p=0.283$  | 1.90 (1.33 to 2.47)    | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.319 |
|                                 | Control      | 24.5 ± 2.3 | 24.7 ± 2.4 | 24.6 ± 2.3 |                                                 |                        |                                                                             |
| <b>Protective behavior</b>      | Intervention | 32.4 ± 4.3 | 36.6 ± 3.9 | 37.3 ± 3.8 | F(1.85, 441.9)=112.56, P<0.001, $\eta^2p=0.320$ | 4.00 (2.98 to 5.02)    | Pre vs post: P<0.001; pre vs follow-up: P<0.001; post vs follow-up: P=0.106 |
|                                 | Control      | 33.1 ± 4.5 | 33.2 ± 4.3 | 33.3 ± 4.3 |                                                 |                        |                                                                             |

*Note: F statistics are from repeated-measures ANOVA with Greenhouse–Geisser correction and are reported for comparability; mixed-effects model results were materially identical.  $\eta^2p$  = partial eta-squared. In the intervention group, all pairwise post hoc comparisons were significant except post vs follow-up, indicating that gains were maintained at three months. In the control group, no within-group change was significant (all  $P > 0.05$ ).*

At the three-month follow-up, all 121 intervention-group teachers provided complete responses to the cues section. Because respondents could select more than one cue, percentages sum to more than 100% and do not represent mutually exclusive categories (Table 5).

Table 5. External and internal cues to action regarding dust exposure reported by intervention-group teachers at the three-month follow-up (n = 121; multiple responses allowed).

| Cue type        | Cue                                               | n  | % of 121 respondents |
|-----------------|---------------------------------------------------|----|----------------------|
| <b>External</b> | Books and booklets                                | 16 | 13.2                 |
|                 | Radio and television                              | 61 | 50.4                 |
|                 | Physicians and healthcare personnel               | 41 | 33.9                 |
|                 | School health colleagues                          | 34 | 28.1                 |
|                 | Family and acquaintances                          | 27 | 22.3                 |
| <b>Internal</b> | Fear of health complications due to dust exposure | 35 | 28.9                 |

|                                                        |    |      |
|--------------------------------------------------------|----|------|
| Feeling healthier by staying indoors during dusty days | 78 | 64.5 |
| Lack of belief in dust and its consequences            | 19 | 15.7 |
| General good health                                    | 46 | 38.0 |

*Note: Data were collected only from the intervention group at the three-month follow-up; the control group was not surveyed for cues. The denominator is the 121 intervention-group teachers who provided complete responses to the cues section. Because multiple responses were permitted, percentages sum to more than 100% and do not represent mutually exclusive categories.*

## Discussion

This cluster-sampled quasi-experimental study found that HBM-based education was associated with improvements in knowledge, all HBM constructs, and self-reported protective behaviors among primary school teachers in Zabol, with gains maintained at three months. Because allocation was at the school level and outcomes were self-reported, these findings should be interpreted as intervention-associated improvements rather than verified causal effects on behavior.

The improvement in knowledge was consistent with previous HBM-based educational studies (9,10). However, knowledge alone is generally insufficient for sustained behavior change (11). In this study, knowledge gains were accompanied by changes in HBM constructs and in protective behavior, which is consistent with the interpretation that the intervention supported the translation of knowledge into motivational and behavioral change. The use of multiple teaching methods—lecture, video, group discussion, and visual aids—and the direct relevance of content to participants' daily experience probably contributed to this finding (9).

Increases in perceived susceptibility and perceived severity are consistent with HBM-based studies in other populations (7,12–14). COVID-19 studies support the general applicability of the HBM but are not dust-storm-specific evidence; the most directly relevant prior evidence comes from an HBM-based intervention among dust-exposed teachers in Ahvaz, Iran (8). Baseline susceptibility was already relatively high ( $25.2 \pm 2.2$  in the intervention group and  $25.6 \pm 2.2$  in the control group), plausibly reflecting direct experience of recurrent dust events, which may have limited the magnitude of achievable change. The persistence of gains at three months suggests that the intervention reinforced, rather than merely temporarily raised, threat appraisal.

Perceived benefits showed the smallest effect size among the threat and benefit constructs. The modest change is consistent with HBM-based educational interventions in which some belief constructs show smaller gains than knowledge or self-efficacy (15), and it reflects high baseline levels in both groups ( $27.2 \pm 2.8$  and  $27.6 \pm 2.8$ ) and a ceiling effect. The adjusted between-group difference at follow-up was small but statistically significant (0.90, 95% CI 0.23 to 1.57), indicating that the intervention produced a measurable but modest improvement in perceived benefits.

Perceived barriers showed the smallest effect size of all constructs. This is important because structural barriers—such as mask cost, mandatory school attendance, and lack of leave policies—may not be overcome by education alone. Perceived barriers and self-efficacy have been shown to predict protective behavior in air-pollution contexts (16), and perceived barriers have been identified as a key predictor of preventive behavior (17). The relatively small reduction in perceived barriers (from  $18.1 \pm 4.6$  to  $15.3 \pm 4.6$ ) suggests that education alone may have limited reach against structural constraints and that complementary environmental or policy measures would be needed to address them.

Self-efficacy improved substantially, consistent with evidence that self-efficacy is a key predictor of preventive behavior in the HBM (18) and with HBM-based educational studies reporting increases in self-efficacy (19). The step-by-step training, practical exercises, feedback, role-play, and goal-setting components of the intervention likely contributed to this improvement. Because self-efficacy is a proximal predictor of behavior, its improvement may have mediated part of the observed behavioral change, although formal mediation analysis was not performed.

Protective behaviors improved and were maintained at three months, consistent with previous HBM-based studies of dust-exposed teachers (8,9) and with HBM-based interventions for other preventive behaviors (19–21). Given the well-documented respiratory, cardiovascular, and ocular health consequences of desert dust exposure (22), these behavioral improvements may be clinically meaningful, although this study did not measure health outcomes and cannot establish clinical benefit. However, the behavioral scale used static, non-time-bound items and did not objectively verify frequency or enactment during specific dust events; the findings therefore reflect sustained self-reported protective behaviors, not objectively verified behavioral persistence. Recurrent dust events may have acted as natural external cues reinforcing protective practice, and this cannot be separated from intervention effects in the present design.

External cues (radio and television, 50.4%; physicians and healthcare personnel, 33.9%; school health colleagues, 28.1%) and internal cues (feeling healthier when staying indoors, 64.5%; general good health,

38.0%; fear of health complications, 28.9%) were both reported by intervention-group teachers. These descriptive findings suggest that interventions might usefully engage multiple cue channels, but the cues data describe the intervention arm only and should not be generalized to the full sample or used to infer causal mechanisms.

The effect size for perceived barriers in this study was smaller than that reported by Walrave et al. (17), who found perceived barriers to influence adoption of a contact tracing app during COVID-19. This difference may reflect the different nature of the health threat (COVID-19 vs dust storms) and the different population (general public vs teachers). In the context of dust storms, structural barriers such as mandatory school attendance and lack of leave policies may be more difficult to overcome through education alone. Similarly, the effect size for perceived benefits was smaller than in some previous studies, possibly because participants already recognized the benefits of protective behaviors at baseline.

This study has several limitations. First, outcomes were self-reported, which may introduce reporting and social-desirability bias and may overestimate adherence; no objective or observational behavioral measures were used. Second, the study was conducted among primary school teachers in one city, limiting generalizability to other populations, regions, and age groups. Third, follow-up was limited to three months, so long-term sustainability is unknown. Fourth, selection bias cannot be excluded: schools rather than individuals were allocated, and although allocation was random at the school level, unmeasured school-level characteristics (e.g., administrative support, staffing, building quality) may have differed between arms. Fifth, although allocation at the school level and delivery of sessions off-site reduced the risk of contamination, residual contamination through social interaction between teachers in different schools cannot be fully excluded; any such contamination would most likely bias estimates toward the null.

Sixth, clustering within schools may have affected standard errors; ICCs were low (0.02–0.06) and cluster-adjusted estimates were consistent with the unadjusted results, but the study was not powered for formal cluster-level inference. Seventh, dust-storm frequency and intensity varied during the study period, and exposure to other information sources may have influenced participants' perceptions and behaviors independently of the intervention. Eighth, although fidelity was monitored (mean 94%, range 90–100%), facilitator characteristics and participant reactivity cannot be fully ruled out. Ninth, the use of verbal consent, while approved by the ethics committee in the context of the COVID-19 pandemic, may have limited verification of participants' understanding of study procedures. Tenth, formal mediation analysis was not performed, so the extent to which self-efficacy mediated behavioral change remains uncertain.

The findings support further evaluation, rather than immediate adoption, of HBM-based education for teachers in dust-prone areas. The following are potential implications that require separate testing: incorporating HBM-based content into pre-service and in-service teacher training; coordinating timely dust-storm alerts through mass media and school health personnel as cues to action; and examining, in implementation research with objective behavioral and exposure outcomes, whether school-level measures such as mask availability, explicit leave provisions for severe dust events, and affordable mask alternatives are feasible, acceptable, and effective. This study was not designed to evaluate these measures, and their effectiveness, cost, and unintended consequences remain untested. Future studies should use cluster-randomized designs, objective behavioral endpoints (e.g., observational or sensor-based measures), episode-specific recall or ecological momentary assessment, longer follow-up, and formal mediation analysis to clarify mechanisms.

## **Conclusion**

This cluster-sampled quasi-experimental study found that HBM-based education was associated with improvements in knowledge, HBM constructs, and sustained self-reported protective behaviors among primary school teachers during dust storms, with gains maintained at three months. Because allocation was nonrandomized and outcomes were self-reported, these findings should be interpreted as intervention-associated improvements rather than verified causal effects.

The findings support further evaluation, rather than immediate adoption, of HBM-based education for teachers in dust-prone areas. HBM-based content may be considered for teacher training and school health programs, but the effectiveness and feasibility of policy-level measures require assessment in future cluster-randomized trials with objective behavioral and exposure endpoints and longer follow-up.

## **Declarations**

**Ethics approval and consent to participate:** Ethical considerations were meticulously observed throughout the study. Ethical approval was obtained from the Ethics Committee of Zabol University of Medical Sciences (IR.ZBMU.REC.1399.081). The ethics code was assigned in the Iranian year 1399 (2020–2021) when the study protocol was initially submitted and reviewed. Due to the COVID-19 pandemic and related restrictions on school access and in-person research activities, data collection was postponed until 2023. The ethics committee was informed of this delay and confirmed that the original approval remained valid, as the study protocol had not changed. All procedures performed in this study involving human