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INDOOR AIR QUALITY MONITORING AMONG A POPULATION WITH KNOWN RESPIRATORY HEALTH STATUS: A CASE STUDY OF NAVOIY CITY

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ABSTRACT

Indoor air quality (IAQ) is a critical public health determinant, yet its relationship with pediatric respiratory morbidity in heavy-industrial, arid regions remains understudied. This paper introduces the methodological framework and preliminary validation results of the Navoiy Community Asthma Project (NaHAL), which evaluates the impacts of indoor chemical and biological pollutants on children with known asthma status in Navoiy City, Uzbekistan. A 2.5-year matched case-control study (n = 500 children; 250 asthmatics, 250 healthy controls) was established across residential sectors of Navoiy. Environmental monitoring was deployed for 5 continuous days in living rooms and bedrooms using a double-blind approach. Gaseous pollutants (NO_2, HCHO, VOCs) were captured via passive diffusion tubes, while respirable suspended particulates ($PM_{2.5}$) were measured via active gravimetric sampling. Dust samples were vacuum-extracted from carpets and mattresses to analyze endotoxins and dust mite allergens (Der p1).

Keywords. Indoor air quality (IAQ), pediatric asthma, respiratory health, $PM_{2.5}$, respirable suspended particulates (RSP), nitrogen dioxide (NO_2), formaldehyde (HCHO), volatile organic compounds (VOCs), indoor pollutants, bioaerosols, endotoxins, dust mite allergens, Der p1, environmental monitoring, passive diffusion sampling, gravimetric analysis, ELISA, case-control study, double-blind study, indoor exposure assessment, residential environment, industrial pollution, children's health, epidemiological risk assessment, microclimate.

1. INTRODUCTION

Previous research findings indicate that indoor air pollution constitutes one of the top five environmental risk factors threatening public health [1]. Evidence suggests that individual exposure levels to indoor air pollutants are typically 2 to 5 times—and in certain extreme cases up to 100 times—higher than corresponding outdoor ambient levels.

In recent years, the Republic of Uzbekistan, particularly the industrial center of Navoiy City, has witnessed a rapid expansion of modern, airtight, energy-efficient residential high-rises. However, the reduced ventilation rates inherent in these sealed structures, coupled with the widespread utilization of synthetic materials in modern interior design and construction, have led to an increased accumulation of hazardous compounds within indoor microenvironments.

The population of Navoiy City, especially young children, spends approximately 85–90% of their daily time indoors due to the region's arid, continental desert climate and extreme summer temperatures, which necessitate the continuous operation of closed-circuit air conditioning and split-systems [2]. From a physiological standpoint, children inhale a higher volume of air relative to their body weight compared to adults, thereby increasing the net toxic pulmonary load. While Navoiy City hosts major chemical and metallurgical industrial conglomerates—such as "Navoiyazot" JSC and "Navoiy Mining and Metallurgical Combinat"

(NMMC) JSC—which actively affect ambient air quality, the indoor air quality (IAQ) of residential sectors in this region has historically lacked systematic evaluation.

Epidemiological studies [3-4] demonstrate that pediatric respiratory health can deteriorate even at pollutant exposure levels well below established maximum allowable concentrations (MAC). This degradation is primarily attributed to the synergistic pathogenetic effects of nitrogen oxides (NO_x), industrial and mineral particulate matter ($PM_{2.5}$), and other co-pollutants.

The dry desert climate of Navoiy, combined with industrial dust fallout, shapes a unique indoor microenvironment. Indoor dust, microclimate dynamics (temperature and relative humidity), and volatile organic compounds (VOCs) act as potent triggers for asthmatic children [5]. Furthermore, unvented natural gas combustion from domestic cookstoves, inadequate air exchange rates, and indoor biological allergens heavily contribute to respiratory morbidity [6–9].

Although the propagation of house dust mites (Dermatophagoides spp.) is constrained by the local low-humidity regime, accumulated mineral and organic dust within household carpets and upholstered furniture acts synergistically to exacerbate asthma symptoms [10].

1.1. Community-Based Research Initiative: The Navoiy Community Asthma Project (NaHAL)

To address these gaps, the Navoiy Community Asthma Project (NaHAL) established a comprehensive screening database tracking childhood asthma incidence in cooperation with local municipal health clinics and community leaders.

Because Navoiy City's macro-ambient air quality is uniformly influenced by large-scale industrial emissions, baseline outdoor pollutant parameters are continuously cross-referenced using automated monitoring stations operated by the Centre of Hydrometeorological Service (O‘zgidromet).

Asthma diagnoses within the cohort were verified through standardized screening questionnaires, supplemented by clinical diagnostic markers, including skin prick testing (SPT) and spirometric evaluation of pulmonary function. The research framework is interdisciplinary: investigators from the Navoiy State University of Mining and Technologies oversee the quantification of **chemical indoor pollutants** (gaseous and organic compounds), while pulmonologists from the Regional Medical Centre handle the isolation and analysis of **biological indoor agents** (endotoxins, allergens, and fungal spores).

2. METHODOLOGY

This 2.5-year longitudinal study comprises four operational phases. Phases 1 and 2 involved cohort selection from the NaHAL database and the methodological validation of sampling protocols across selected residential units in Navoiy City. Environmental monitoring was deployed across diverse domestic layouts to evaluate seasonal and structural microclimate influences.

Phase 3 implements a rigorous "blind study" sampling matrix: field researchers and laboratory technicians remain completely blinded to the clinical status of the households (asthmatic vs. healthy control). Phase 4 runs parallel to data acquisition, focusing on multivariate statistical modeling, epidemiological risk assessment, and the formulation of public health recommendations.

2.1. Study Population and Sampling Protocol

The target cohort was recruited from pediatric populations registered across two major Family Polyclinics (OP) in Navoiy City. The experimental framework utilizes a matched case-control design (n = 500 candidates: 250 verified asthmatic children forming the case group, and 250 healthy children forming the control group). Adjusting for attrition and non-response rates, a final sample size of approximately 400 households is anticipated, which provides sufficient statistical power to determine the relative risk odds ratios for individual indoor pollutants.

Cases and controls were tightly matched based on age, biological sex, and socioeconomic background. During the baseline home visit, two monitoring arrays are deployed for a continuous duration of 5 days: one in the primary communal area (living room) and another directly in the child's bedroom.

Upon completion of the 5-day cycle, field teams recover the instruments and extract dust samples using standardized vacuum protocols from three distinct matrices: the living room carpet, the child's mattress, and the bedroom floor carpet.

2.1.1. Respirable Suspended Particulates (RSP/$PM_{2.5}$)

Gravimetric determination of indoor $PM_{2.5}$ mass concentrations is conducted via active air sampling utilizing calibrated Vortex Timer pumps (Casella, UK) operating at fixed flow rates over the 5-day cycle. Particulate concentrations are calculated based on the net mass of aerodynamic particles smaller than 2.5 micrometers captured on the filter media.

2.1.2. Volatile Organic Compounds (VOCs), NOx, and Formaldehyde

Speciation of volatile organic compounds (VOCs) is performed via passive adsorption on stainless steel diffusion tubes packed with Carbopak B sorbent, followed by thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) analysis [11].

Indoor nitrogen dioxide (NO_2) exposure is assessed via passive molecular diffusion tubes, with colorimetric quantification executed through UV-Vis spectrophotometry at an absorbance wavelength of 540 nm [12]. Airborne formaldehyde (HCHO) concentrations are captured using silica gel cartridges coated with 2,4-dinitrophenylhydrazine (DNPH) and analyzed via HPLC-UV according to standardized toxicological guidelines [13].

2.1.3. Microclimate and Bioaerosol Analysis

Ambient temperature and relative humidity are logged continuously at 10-minute intervals using Tinytalk data loggers. Structural dampness is verified using electronic moisture meters alongside visual inspection of external-facing indoor walls.

Collected dust fractions are sieved, weighed, and subjected to phosphate-buffered saline (PBS) extraction. The extracts are analyzed via Enzyme-Linked Immunosorbent Assay (ELISA) to determine concentrations of the dust mite allergen Der p1 and specific fungal antigens. Endotoxin content is determined from pyrogen-free water extracts via kinetic turbidimetric Limulus Amebocyte Lysate (LAL 5000E) assays.

3. RESULTS AND DISCUSSION

Methodological validation trials confirmed that a **5-day sampling window** is optimal for the Navoiy microenvironment. Initial 7-day trials led to analyte overloading on the collection media, exceeding the upper linear calibration limits of the chromatographic systems. Shortening the cycle eliminated the need for extract dilution steps, thereby minimizing experimental error propagation.

The analytical reproducibility of the active sampling pumps was high, demonstrating a standard deviation below 0.02 across all preliminary test sites. In terms of engineering performance, the heavy mineral dust loads characteristic of Navoiy's outdoor air required modifying the sampler enclosures with auxiliary exhaust channels to prevent pump motor overheating and automatic shut-off errors.

Preliminary baseline data from the active monitoring phase shows that residential $PM_{2.5}$ (RSP) concentrations range between **14 and 64 µg/m³**.

According to national and international ambient air quality guidelines, the target 24-hour average exposure limit for fine particulate matter ($PM_{2.5}$) is established at **50 µg/m³**.

Table 1: Residential $PM_{2.5}$ Mass Concentrations Across Monitored Households (µg/m³)

Household ID	Living Room	Child's Bedroom
Household 1	22	14
Household 2	64	23
Household 3	34	27
Household 4	27	16

Data Analysis:

The maximum indoor $PM_{2.5}$ value was recorded in the living room of Household 2 (64 µg/m³), noticeably exceeding the 50 µg/m³ health advisory limit. Across all monitored properties, living room particulate concentrations consistently outpaced bedroom levels. In the context of Navoiy City, this spatial gradient is driven by indoor tracking of outdoor industrial/crustal dust, domestic cooking emissions, and localized indoor human activity.

Nitrogen Dioxide (NO_2) Exposure Profiles

Gaseous NO_2 concentrations across the residential matrix fluctuated between **7 and 44 ppb**. Elevated levels were strongly correlated with properties utilizing unvented natural gas appliances or localized heating systems. The data demonstrates that the accumulation of indoor NO_2 is predominantly driven by localized kitchen activities rather than generic background infiltration.

Table 2: Spatial Distribution of Gaseous Indoor NO_2 Concentrations (ppb)

Household ID	Living Room	Child's Bedroom
Household 1	44	12
Household 2	23	17
Household 3	17	19
Household 4	9	9

Data Analysis:

The highest gaseous NO_2 burden was measured in the living room of Household 1 (44 ppb), linked directly to intensive kitchen gas stove operation and low structural air exchange rates. Conversely, Household 4 exhibited low background levels (9 ppb) in both rooms.

Formaldehyde (HCHO) Concentrations

Formaldehyde concentrations across all checked households were universally low, mapping tightly within a narrow range of **2 to 5 ppb**. These trace levels are toxicologically negligible and indicate that indoor formaldehyde emission from building materials is not currently a primary risk factor in the surveyed buildings.

Table 3: Indoor Formaldehyde (HCHO) Exposure Levels (ppb)

Household ID	Living Room	Child's Bedroom
Household 1	5	4
Household 2	3	2
Household 3	2	2
Household 4	2	3

Biological Contaminant Dynamics and the "Survivor Effect"

Due to the regional arid climate, indoor relative humidity levels remain structurally low. Interestingly, preliminary pilot data revealed that healthy control households occasionally displayed higher absolute endotoxin loads and moisture levels than households inhabited by asthmatic children.

This paradox is explained by the **"survivor effect"**—an epidemiological behavioral shift where families with a diagnosed asthmatic child implement rigorous, frequent wet-cleaning regimens and allergen-reduction steps, effectively altering the baseline bioaerosol profile. The final large-scale case-control dataset will allow us to statistically decouple these behavioral adaptations from primary environmental risks.

4. CONCLUSION

The environmental monitoring methodology developed for this study has been successfully validated for the unique industrial and climatic conditions of Navoiy City. A 5-day continuous exposure matrix provides an optimal balance between analytical sensitivity and sample integrity.

By executing sample collection and laboratory analysis under strict double-blind conditions, the study design successfully eliminates observer and selection bias. Selecting cohorts from socioeconomically homogeneous residential microrayons within Navoiy effectively controls for macro-level confounding variables.

Upon completion, this project will yield critical, definitive epidemiological data regarding the exact etiological roles that chemical and biological indoor air pollutants play in pediatric respiratory health within arid, heavy-industrial zones.

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