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RESEARCH ARTICLE

Chemical Characterization of Whiteboard Marker Inks Available in Nepal and Health Awareness among High School Teachers

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Abstract

Whiteboard markers are widely used in educational and professional environments due to their convenience and cleanliness compared with traditional chalk. This study evaluates the quality, compositional characteristics, and potential health risks associated with commercially available whiteboard marker inks from different brands. Elemental composition of the ink was determined using Energy-Dispersive X-ray Fluorescence (EDXRF), while Fourier Transform Infrared (FTIR) spectroscopy was employed to identify functional groups and solvent components. Gravimetric analysis was conducted to quantify solid and liquid components. In addition, a survey of 209 teachers was carried out to assess user awareness and reported health effects. The survey results revealed that a substantial proportion of teachers experienced health-related symptoms, including nasal irritation (34%) and eye irritation (18%), while 52.6% reported no prior awareness of the chemical constituents present in marker inks. Elemental analysis identified several metals, including copper (up to 3.8%), sulphur, silicon, and potassium, with certain brands also containing chromium or zinc, which may pose potential risks upon skin contact. FTIR analysis indicated that alcohol-based solvents, most consistent with ethyl and isopropyl alcohol. Gravimetric analysis further demonstrated notable variability in non-volatile material content across different brands. The combined analytical and survey findings highlight potential health concerns associated with exposure to volatile organic compounds and metal constituents in commonly used whiteboard marker inks. These results emphasize the need for safer ink formulations and increased awareness among users regarding potential chemical exposure.

Keywords: Volatile organic compounds (VOCs); Heavy metals; Whiteboard marker ink; Chemical composition; Health effects.

Introduction

Over the past few decades, educational institutions and workplaces have progressively transitioned from traditional blackboards and chalk to whiteboards and marker inks [1, 2, 3]. This shift has been driven mainly by the cleaner appearance, ease of use, and perceived health benefits of whiteboards compared with chalk-based systems [4]. Chalk dust is known to contribute to respiratory discomfort and the deterioration of indoor air quality, making whiteboards a preferred dust-free alternative in indoor environments [5]. With the widespread adoption of whiteboards, manufacturers have developed specialized inks tailored for whiteboard markers. These inks are typically formulated as liquids or pastes containing colorants for writing, printing, and drawing applications [6].

Whiteboard marker inks are specifically designed for smooth, non-porous surfaces and are expected to exhibit key performance characteristics, including easy erasability, minimal shrinkage during drying, and negligible residual deposition. Ceramic and plastic-based marker boards, in particular, require inks with enhanced performance compared with traditional chalk-based systems [7, 8, 9]. Despite these functional advantages, commercially available whiteboard marker inks are often expensive and may contain hazardous chemicals. Conventional formulations frequently incorporate organic solvents such as xylene and toluene, along with other volatile organic compounds (VOCs) [10, 11]. Although these solvents facilitate rapid drying and smooth writing performance, they raise significant public health concerns. Among these compounds, BTEX chemicals-benzene, toluene, ethylbenzene, and xylene are of particular concern due to their known toxicological properties [12]. Benzene is classified by the International Agency for Research on Cancer (IARC) as Group 1, carcinogenic to humans, while ethylbenzene is classified as Group 2B, indicating possible carcinogenicity [13, 14]. Inhalation is the primary route of exposure to these compounds, thereby increasing potential health risks for teachers, students, and other occupants of indoor educational environments [15, 16]. Furthermore, many Safety Data Sheets for commercial whiteboard marker inks are incomplete or lack sufficient detail, and a majority of users have limited training in safe chemical handling practices. Previous studies have investigated various aspects of ink composition, particularly in forensic science. Analytical techniques such as Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (SEM-EDS) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) have been employed to examine the elemental composition of printing inks [17, 18]. In addition, Fourier Transform Infrared (FTIR) spectroscopy, Raman spectroscopy, and X-ray Fluorescence (XRF) analysis have been widely used to identify organic and inorganic ink constituents [19, 20]. Gravimetric analysis has also been applied to quantify the volatile and non-volatile components of inks [21]. However, these studies focused primarily on individual analytical techniques for chemical characterization and have not established a direct link between laboratory findings and user experiences. In particular, previous studies have not integrated chemical composition data analysis with teachers' perceptions of marker performance, smell, and safety. This lack of integration reveals a critical research gap and demonstrates the need for a comprehensive evaluation that links laboratory-based chemical analysis with user feedback to improve the composition and practical use of commercial whiteboard marker inks. Addressing this gap is essential for enhancing both the formulation and sensible use of commercial whiteboard marker inks.

Although previous studies have reported the chemical composition and VOC content of inks, they mainly focused on laboratory analysis and did not relate these findings to real classroom exposure and user health effects. In this study, FTIR, EDXRF, and gravimetric analyses revealed clear differences in solvent content, metal-based components, and formulation among commercially available whiteboard marker inks, and these results were directly linked with a large scale teacher survey on odor, awareness, handling practices, and self-reported health symptoms. This integrated approach provides a more realistic assessment of potential exposure risks in educational environments. Therefore, the novelty of this work lies in connecting chemical composition with user experience to improve the safety evaluation of whiteboard marker inks.

Materials and Methods

Study Area and Survey Methodology

The survey was conducted using a questionnaire created in Google Forms. The questionnaire was reviewed by experts, and their feedback was incorporated to ensure clarity, relevance, and completeness. It was then distributed primarily via digital platforms, including Facebook, WhatsApp, and email. This online approach enabled broad geographic coverage and facilitated efficient data collection. A total of 209 valid responses were obtained from teachers representing 33 districts across Nepal, as illustrated in the corresponding study area map in **Figure. 1**. In addition to domestic participation, responses were also received from educators based in India, Pakistan, the United States, Germany, and South Korea, thereby incorporating an international perspective. Participants represented a range of teaching levels, including primary, secondary, and higher education.

The questionnaire was designed to collect information on teachers' patterns of whiteboard marker use, perceptions of ink performance characteristics (such as color intensity and odor), and awareness of the chemical composition of whiteboard marker inks. The survey also aimed to assess users' general understanding of potential health and safety concerns associated with prolonged marker use in indoor environments. Responses were collected anonymously to encourage honest reporting and reduce response bias. The compiled survey data were subsequently analyzed to identify trends in usage behavior, perception, and awareness, and to complement the laboratory-based chemical analyses presented in this study. The survey questionnaire is provided in supporting information.

Sample Collection

Six commercially available whiteboard marker brands were selected based on their availability in local retail outlets and their common use in educational settings. The samples were randomly purchased to represent products that are readily accessible to users and therefore reflect realistic exposure conditions. Although the number of samples is limited, they were chosen to capture the diversity of commercially available markers in terms of brand, formulation, and price, which provides a representative overview of products commonly used in Nepalese classrooms. Ink samples were extracted directly from the ink bottles under controlled laboratory conditions and stored in clean, airtight containers prior to analysis. All samples were handled using standard laboratory safety procedures.

Physico-Chemical Analysis

In addition to the survey-based assessment, laboratory-based analytical techniques were employed to characterize the physico-chemical properties of commercially available whiteboard marker inks.

Elemental Analysis by EDXRF

The elemental composition of the ink samples was determined using Energy-Dispersive X-ray Fluorescence (EDXRF) spectroscopy with an EDX-8000 spectrometer (Shimadzu). Small aliquots of liquid ink were prepared and placed in appropriate sample holders. Samples were irradiated with X-rays under controlled operating conditions using a rhodium anode X-ray tube, with tube voltages ranging from 15 to 50 kV, tube currents from 282 to 1000 μA, and live acquisition times of 20–60 s, depending on the elemental range analysed. Measurements were performed in air using a 5- mm and 10-mm collimator. The emitted characteristic X-ray spectra were analyzed to identify inorganic elements, particularly metal-based pigments, and to estimate their relative concentrations.

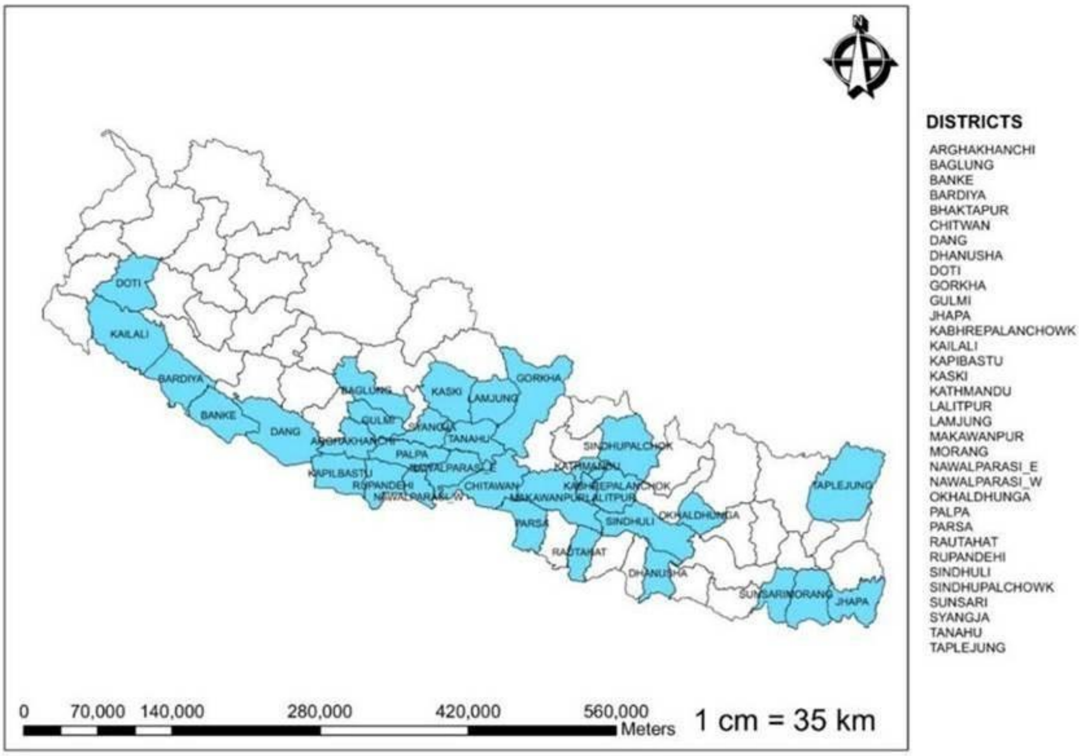

Figure. 1: Geographic map of Nepal showing the survey area and the districts from which participating respondents provided responses.

Fourier Transform Infrared (FTIR) Spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify functional groups and organic components present in both liquid inks and dried residues. Analyses were performed using an FTIR spectrometer at the Central Department of Chemistry, Tribhuvan University, Kathmandu, Nepal, employing an IRPrestige-21 spectrometer (Shimadzu, Singapore). The recorded spectra were baseline-corrected and normalized using the instrument software prior to interpretation. Characteristic absorption bands were assigned based on standard group frequency correlation charts and were further verified by comparison with reference spectra of ethyl alcohol and isopropyl alcohol measured under similar conditions. Characteristic absorption bands were interpreted to identify solvents, binders, and other organic constituents commonly used in marker ink formulations.

Gravimetric analysis

Gravimetric analysis was used to measure the concentration of each ink sample. First, 1 mL of liquid ink was placed in a pre-weighed Petri dish, and the starting mass was noted. The sample was then dried in an oven at 60 °C for 1.5 h to ensure evaporation of volatile components. After drying, the Petri dish and solid residue were weighed again. The change in mass before and after drying showed the amount of non-volatile (solid) content. The concentration was expressed using both mass percent (m/m) and mass–volume percent (m/v) as,

$$\text{Mass percent (m/m)} = \frac{\text{mass of solid residue (g)}}{\text{mass of solution (g)}} \times 100\% \quad \ldots\ldots. (1)$$

$$\text{Mass–volume percent (m/v)} = \frac{\text{mass of solid residue (g)}}{\text{volume of solution (mL)}} \times 100\% \quad \ldots\ldots\ldots..(2)$$

Data Integration and Analysis

Results from physico-chemical analyses were integrated with survey findings to establish relationships between ink composition and user-reported perceptions, including odor intensity, writing performance, and potential health concerns. This combined analytical and perception-based approach enabled a comprehensive evaluation of commercial whiteboard marker inks from both chemical and user-experience perspectives.

Results and Discussion

Survey Analysis

A total of 209 completed questionnaires were collected from teachers representing 33 of Nepal's 77 districts, including Arghakhanchi, Baglung, Banke, Bardiya, Bhaktapur, Chitwan, Dang, Dhanusha, Doti, Gorkha, Gulmi, Jhapa, Kabhrepalanchok, Kailali, Kapilvastu, Kaski, Kathmandu, Lalitpur, Lamjung, Makawanpur, Morang, Nawalparasi, Okhaldhunga, Palpa, Parsa, Rautahat, Rupandehi, Sindhuli, Sindupalchowk, Sunsari, Syangja, Tanahu, and Taplejung. Additional respondents were received from educators based in India, Pakistan, the United States, Germany, and South Korea. The respondents pool encompassed a range of educational levels, from lower primary to campus level. Survey results are summarized in **Figure. 2 (A)-(C)**.
Among the 209 respondents, approximately 45% (95/209) reported 1-5 years of teaching experience, while 21% (43/209) had more than 10 years of experience. Teachers with less than 1 year and 5-10 years of experience accounted for 18% (38/209), and 16% (33/209) of respondents respectively **(Figure. 2(A))**. In terms of teaching load, 62% (130/209) reported teaching fewer than 20 classes per week, whereas 38% (79/209) taught more than 20 classes weekly, with the number of classes ranging from 8 to 66 per week **(Figure. 2B)**. Nearly all respondents (98%, 206/209) reported using markers during instruction.
Health-related findings indicated that 42% of teachers reported no noticeable health effects, 34% experienced nasal irritation, 18% reported eye irritation, and 6% experienced respiratory problems **(Figure. 2(C))**. Seasonal preferences for marker use showed that a majority of respondents (54%, 113/209) found marker use easier in summer months, whereas the remaining preferred winter conditions. Regarding board-cleaning practices, most teachers (65%, 136/209) reported using a brush to erase whiteboards, followed by paper use (11%, 24/209), with the remainder employing other types of dusters.

Figure. 3 summarizes teachers' responses to three questions concerning whiteboard marker use and hygiene practices. Approximately 71% of respondents reported using their hands to erase the whiteboard, while 29% indicated they did not. A larger proportion, 79.6%, reported washing their hands after using markers, reflecting generally good hygiene practices. Notably, only 52.6% of respondents reported being aware of the chemical composition of whiteboard marker inks, including the presence of organic solvents and dyes, whereas 47.4% indicated a lack of such knowledge. Among respondents who reported using their hands to erase whiteboards, 39% (73/189) experienced itching, 20% (38/189) reported burning sensations, and 7% (13/189) reported other adverse effects, including rashes, coughing, or skin-related problems, while 34% (65/189) reported no noticeable reaction. Although the majority of participants considered whiteboard markers to be easier and more convenient than traditional chalk, several concerns were expressed regarding unpleasant odors, eye and nasal irritation, and potential health risks associated with prolonged exposure.

To mitigate these risks, respondents suggested alternatives and preventive measures to mitigate these risks including the adoption of digital teaching tools such as smart boards, projectors, and multimedia-based instruction, as well as traditional options such as dustless chalk and green boards. Additional recommendations included the use of safer marker ink formulations, wearing gloves during board cleaning, and reducing the frequency of marker usage. Overall, respondents expressed a preference for incorporating technology and safer materials to reduce health hazards associated with whiteboard marker use.

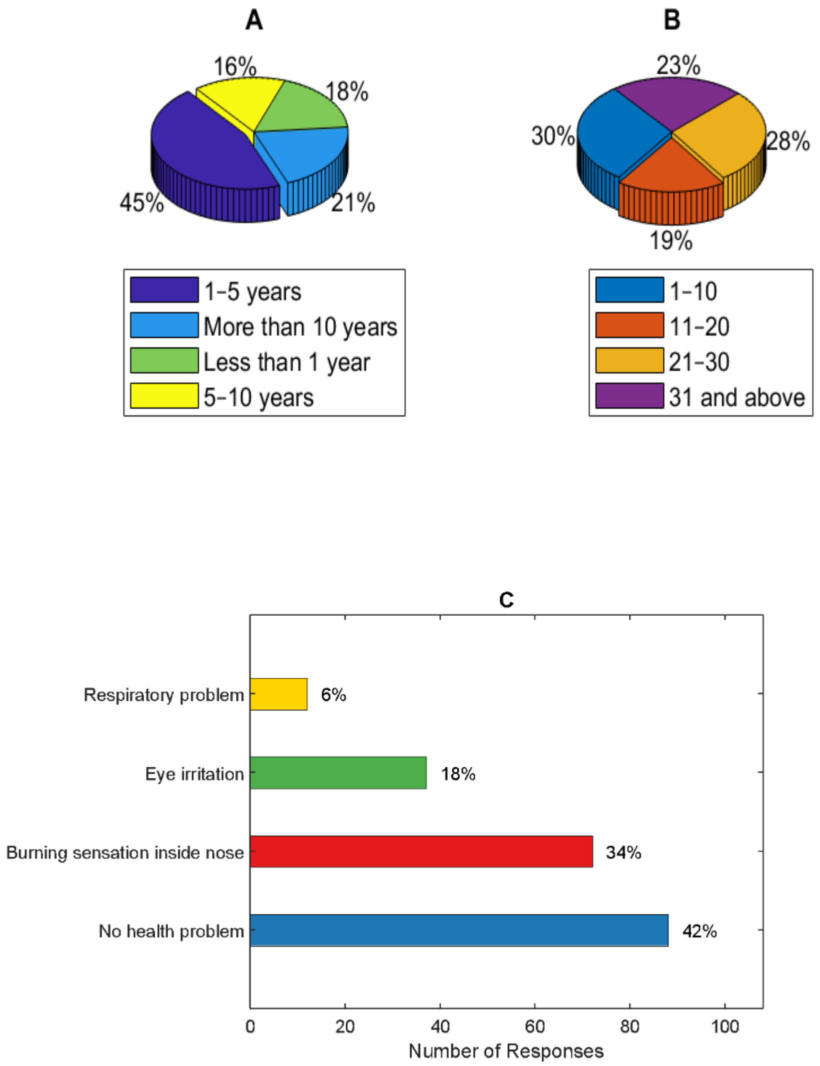

Figure. 2: Summary of survey results: (A) weekly teaching load (classes per week), (B) distribution of respondents by teaching experience, and (C) self-reported health symptoms during teaching

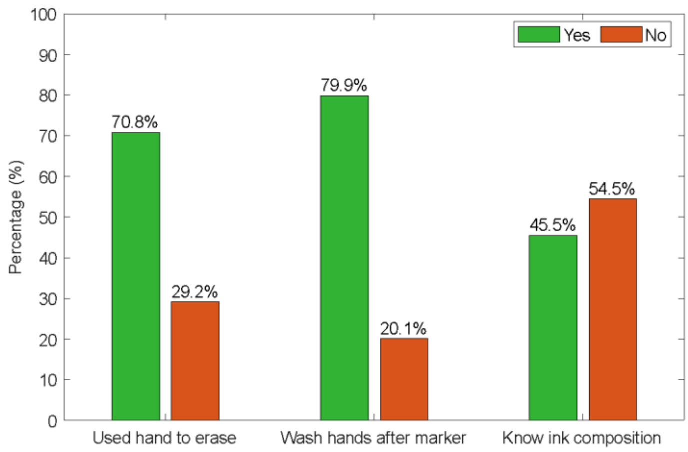

Figure. 3: Respondents' whiteboard marker handling practices and awareness of ink composition

FTIR Analysis

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the functional groups present in the selected commercially available whiteboard marker ink samples, as each chemical bond exhibits characteristic absorption bands in the infrared region. The liquid ink sample was directly subjected to FTIR analysis, and the resulting spectrum for S1 is shown in **Figure. 4A**. The spectra for other samples (S2-S6) are provided in supporting information. Based on standard group frequency assignments for organic compounds [22], the frequency range between 3570-3200 cm^{-1} (broad) is attributed to O-H stretching vibrations associated with intermolecular hydrogen-bonded alcohols, with variable intensity. A sharp absorption peak at approximately 2920.22 cm^{-1}, within the 2950-2850 cm^{-1} region, corresponds to C-H stretching vibrations of aliphatic hydrocarbons. In addition, the absorption band observed in the range of 1690-1760 cm^{-1} indicates the presence of carbonyl (C=O) functional groups, which may arise from aldehydes, ketones, or carboxylic acids. The sharp peak at 1093.43 cm^{-1} is assigned to C-O stretching vibrations, commonly associated with alcohols, ethers, esters, or carboxylic acids. To further evaluate the contribution of volatile components, the ink samples were dried at approximately 70 °C for 1.5 h to remove volatile organic compounds prior to FTIR analysis. The FTIR spectrum of the dried ink residue is shown in **Figure. 4B**.

In the residue spectrum, the sharp absorption band in the 2950-2850 cm^{-1} range confirms the presence of an alkanes group, as this peak arises from C-H stretching. Also, the peak observed at frequency 1734.33 cm^{-1} is attributed to C=O stretching vibrations. Notably, when comparing the FTIR spectra of the liquid ink sample with those of the corresponding residue, the characteristic absorption bands observed in the ranges of 2950-2850 cm^{-1} and 1000-1300 cm^{-1} in the liquid ink were absent in the residue spectra. This observation suggests the removal or transformation of functional groups associated with volatile solvent components during drying. The observed frequencies, combined with spectral pattern matching against reference FTIR spectra of pure ethyl alcohol and isopropyl alcohol, indicate that alcohol-based VOCs are the most likely solvents present in the whiteboard marker ink samples.

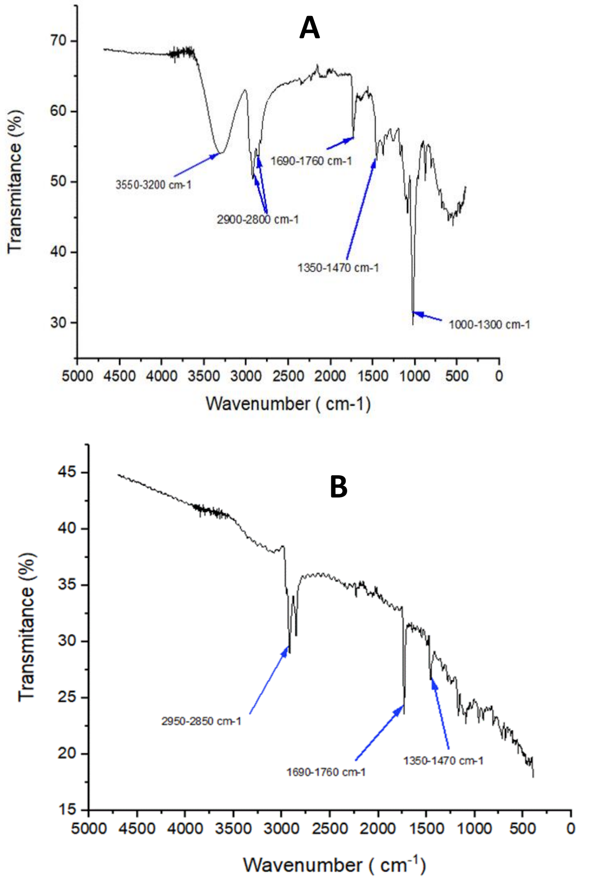

Figure. 4: FTIR spectra of the ink sample S1. (A) Ink liquid and (B) ink residue.

Energy Dispersive X-ray Analysis

Energy-dispersive X-ray Fluorescence (EDXRF) spectroscopy was employed for semi-quantitative elemental analysis of various whiteboard marker ink samples. The EDXRF analysis (**Figure. 5 and Table S1**) revealed significant variations in elemental composition across the analyzed samples, with copper (Cu) showing the notable variation. Sample SN3 exhibited the highest copper concentration, reaching approximately 3.8%, which notably surpasses previously reported values of ~1%

Cu in other ink studies. In contrast, all other samples contained less than 0.001% Cu. Across the majority of ink samples, sulfur (S), silicon (Si), potassium (K), and copper (Cu) were consistently detected. Chromium (Cr) was uniquely identified in sample SN1, while zinc (Zn) was detected exclusively in sample SN6. Iron (Fe) was observed only in samples SN1, SN2, and SN3, indicating a relatively low ferrous content overall. This observation is favorable, as elevated Fe^{2+} concentrations are known to accelerate material degradation through oxidative and acid-catalyzed pathways [23]. The presence of sulfur, especially with metals like Cu and Zn, strongly suggests the use of metal sulfide pigments, which are commonly employed in black ink formulations[24, 25]. However, the co-occurrence of heavy metals such as Cu, Cr, and Zn, particularly in sulfide forms, raises human health concerns through dermal exposure during frequent skin contact. These findings reinforce the need for further toxicological evaluation and improved formulation strategies to minimize potential health risks associated with prolonged marker use [26, 27].

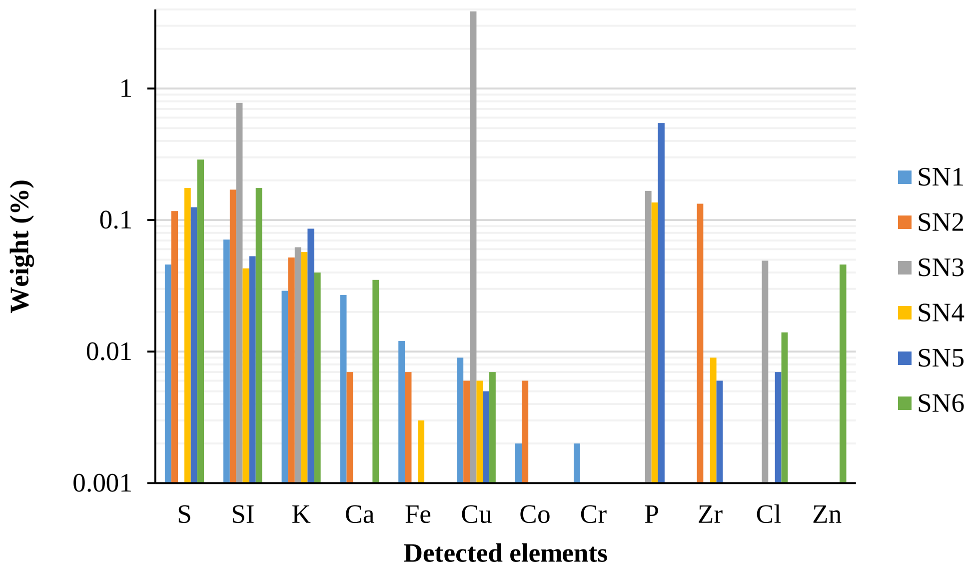

Figure. 5: EDXRF graph of different ink samples SN1-SN6.

Gravimetric determination of VOC in ink samples

Commercial whiteboard marker inks do not share uniform chemical compositions, although most products are labeled as 'non-toxic' to consumers. Organic solvents are commonly incorporated into marker ink formulations to facilitate rapid drying during use [28]. While the detailed chemical composition of individual ink samples was not fully characterized in the present study, information from Material Safety Data Sheets (MSDS) of commercially available markers, particularly those marketed for back-to-school use, indicates the presence of various volatile organic compounds (VOCs). These commonly include butanol, ethanol, methanol, and isopropanol across most brands. Although only tiny amounts of chemicals are present in marker pen ink, these chemicals still have adverse health effects. For example, butanol, ethanol, methanol, and isopropanol are the common chemicals found in almost all brands of board marker pen. These chemicals cause eye irritation, skin problems, throat problems, blurred vision, headache, vomiting, central nervous system depression, etc. It is generally assumed that inks with higher solvent content may pose greater health risks due to increased VOC evaporation during use. Therefore, in this study, the solvent mass, mass percentage (m/m), and mass-volume percentage (m/v) of different commercial marker ink samples were calculated to comparatively assess potential toxicity among randomly selected products available in the market.

Table 1: Different weights of liquid and dried ink samples for concentration measurement.

Sample ID	Weight of solution (g)	Weight of residue (g)	Weight of solvent	Mass %	Mass-volume %
SN1	0.76	0.14	0.62	18.42	14
SN2	0.77	0.15	0.62	19.48	15
SN3	0.76	0.14	0.62	18.42	14
SN4	0.74	0.11	0.63	14.86	11
SN5	0.78	0.16	0.62	20.51	16
SN6	0.76	0.15	0.60	19.74	15

An evaporation-based gravimetric method was employed to determine the volatile and non-volatile fractions of the ink samples. By quantifying the mass loss upon controlled drying, the relative solvent content of each ink was estimated, providing insight into formulation variability and potential exposure risks associated with routine marker use. Among the six samples analyzed, the mass of the non-volatile residue ranged from 0.11 g (SN4) to 0.16 g (SN5), reflecting the differences in the concentrations of non-volatile substances such as pigments, binders, and additives. The mass percent (m/m) values followed the same trend, with SN4 showing the lowest value (14.86%), indicating the most dilute formulation, while SN6 exhibited the highest value (19.74%), suggesting the most concentrated ink. The mass-volume percent ranges from 11 % (SN4) to 16 % (SN5), indicating variation in the concentration of residues per mL of ink. Samples SN1 and SN3 displayed identical solution and residue masses, indicating similar formulations or potentially originating from the same manufacturer. SN5 and SN6 showed the highest residue content, indicating a thicker or more pigmented ink that could deliver darker prints or longer-lasting marks. Conversely, sample SN4, characterized by the lowest residue content and highest solvent proportion, represents the most dilute formulation, which may result in lighter coloration or faster drying during use.

Overall, the observed variation in residue mass and mass percentages shows that the ink samples are not formulated with a consistent solute-to-solvent ratio. These findings highlight substantial differences in formulation strategies among commercially available whiteboard marker inks, likely reflecting variations in brand quality, intended performance characteristics, or manufacturing practices.

Conclusions

This comprehensive investigation of the selected commercially available whiteboard marker inks offers critical insights into chemical composition, formulation variability, and associated user-reported health effects. Despite their widespread use of whiteboard markers and their practical advantages in educational settings, a substantial proportion of users reported adverse health symptoms, including nasal and eye irritation, alongside limited awareness of the chemical constituents present in marker inks. Laboratory-based analyses revealed considerable variability in elemental composition, including the presence of heavy metals, organic solvents, and differences in non-volatile residue content among brands. The combined survey and analytical findings suggest a clear association between ink composition, particularly the presence of volatile organic compounds and metal-based components and reported health concerns among users. These results highlight potential exposure risks arising from prolonged or repeated use of whiteboard markers in indoor environments. Overall, the study underscores the need for re-evaluation of existing ink formulations, improved disclosure of chemical constituents, and the development of safer, low-toxicity alternatives to enhance user safety and minimize health risks in educational and occupational settings.

However, the semi quantitative nature of EDXRF and FTIR analyses, the lack of VOC speciation, and potential biases in the online survey (self-selection and recall bias) limit the generalizability of the findings. Despite these constraints, the combined chemical and user-based data indicate potential exposure risks from prolonged marker use in indoor environments. Future studies using higher-sensitivity techniques (e.g., GC–MS for VOCs, ICP-MS for metals) and direct air monitoring in classrooms are recommended to provide quantitative exposure and risk assessment. Overall, these results emphasize the need for safer marker formulations, improved disclosure of chemical constituents, and increased user awareness to minimize health hazards in educational and occupational settings.

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Author's contribution statement

S. Sharma: Performed the experiments, Analyzed and interpreted the data, Wrote the first draft**; M. Kharel & B. Chalise:** Formal analysis, review & editing; **D. Gewali:** Contributed reagents, materials, analysis tools or data; **K. R. Sharma:** Contributed reagents, materials and data analysis; **H. Paudyal:** Analysed and interpreted the data; contributed reagents, materials, analysis tools or data; **B. B. Neupane:** Conceived and designed the experiments, analysed and interpreted the data, supervision; Contributed reagents, materials, analysis tools or data, review and editing.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

The data used to construct Figures and tables are available in the supplementary material, and additional data can be provided by the corresponding author upon reasonable request.

Supplementary Materials (available as separate file)

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