Impact of Indoor Air Pollutant Concentration Levels on the Health of Press Operators of Printing Facilities in Zaria Metropolis, Nigeria

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Long-term exposure to air pollutants in printing facilities is detrimental to the health, well-being, and productivity of press users. This study investigated the concentrations of indoor air pollutants in 22 printing facilities in Zaria, Nigeria, as well as their interactions with press operators' perceptions of feeling Sick Building Syndrome (SBS) symptoms. The study employed quantitative methods. The concentrations of indoor air pollutants (CO_2, CO, TVOC, HCHO, $PM_{2.5}$, and PM_{10}) were monitored with air quality multifunction devices in the different printing facilities. Questionnaires were also administered to assess press operators' health and perceptions of feeling SBS symptoms in the printing facility. The results showed that indoor air pollutant concentrations vary in the different printing facilities, with pollutant concentration values in the range of 0.323–9.999 mg/m^3, 0.030–0.078 mg/m^3, 21.33–426.67 µg/m^3, and 28.0–568 µg/m^3 for TVOCs, HCHO, $PM_{2.5}$ and $PM_{10,}$ respectively and same exceeding the NESREA standard values. Findings also show that press operators rarely felt 14 SBS symptoms in the printing facility. The questionnaire results suggest that health-related problems experienced by press operators may worsen if operators continue to have long-term exposure to these pollutants. From this study, press operators need to be cautious of the adverse health impacts associated with long-term exposure to indoor air pollutants. Indoor air quality (IAQ) monitoring equipment and indoor air pollutant capture systems should be installed in all printing environments to minimize the adverse impacts of indoor air pollutant concentrations. The findings of this study advance the knowledge of the health impacts of prolonged indoor air pollutant exposure in printing facilities and the connections between elevated concentrations and adverse effects on press operators. Implications include the need for enhanced occupational health practices, regulatory compliance, awareness training, and infrastructure investment to safeguard press workers' well-being and productivity in printing facilities.

Keywords: Indoor Air Pollution (IAP), Pollutant, Printing Facility, Sick Building Syndrome (SBS), Press Operator's Health

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INTRODUCTION

Indoor air pollution (IAP) is the term used to describe the physical, chemical, and biological contamination of indoor air. It is the presence of foreign substances in the atmosphere that are outside of the norm or a significant change in the proportion of its components that are perceived as harmful or have a direct or indirect effect on health (Pecingina & Popa, 2014; Idemudia *et al.,* 2022; Rawat & Kumar, 2023). According to the World Health Organization (WHO) (2021), about 3.2 million people die annually due to household exposure to air pollution. Achieving good indoor air quality (IAQ) is still a recurring issue in the built environment. Poor IAQ continues to be associated with increased death, reduced workers' productivity, and increased dermatological and respiratory problems in the indoor environment (Omole *et al*., 2020; Sun *et al.,* 2022). In recent times, issues of IAP remain a large environmental and health concern in low-income countries.

According to WHO (2016), IAP is one of the world's largest environmental problems and a leading risk factor for several causes of premature death in poor nations around the globe. Data have also shown that death rates are higher across Sub-Saharan Africa where Nigeria belongs (Ritchie & Roser, 2022). According to Liqun and Yanqun (2011), IAP can cause dermatological disorders and respiratory diseases in humans. In addition to these health concerns, poor IAQ can result in low productivity in the indoor space (Air-Specialty, 2017). According to Spiru and Simona (2017) and Kiurski *et al.* (2013), the likely sources of IAP in the built environment are heating and cooling systems, infiltration of pollutants from the outdoor space, human occupancy, consumer products, construction materials, combustion sources, coatings, furniture, humidification, and dehumidification devices amongst others. As asserted by Pona *et al.* (2021), IAP is one of the challenges the nation of Nigeria is currently facing amidst other social, environmental, and economic challenges beclouding the country such as insufficient electric power supply, poor waste management, wind erosion, desertification, deforestation, lead exposures, water pollution, noise pollution, and unemployment.

Different studies have assessed the IAQ of different indoor microenvironments and their related issues in kindergartens, office buildings, residential buildings, health clubs, and eateries. According to Slezakova (2018), Abdullah *et al*. (2019), and Rahim *et al.,* (2022), the major causes of IAQ problems in these microenvironments are attributed to improper ventilation, deficiencies in a ventilation system, overcrowding of the indoor space, high temperature and humidity in the indoor environment, infiltration of outdoor polluted, and air pollutant sources. In addition to these microenvironments, pollutants emitted from printing facilities having printing equipment and machines have become a major concern (Kiurski *et al.,* 2017). According to Kiurski *et al*. (2017), during printing production processes, harmful substances are released into the indoor environment which impacts the immediate environment and technical personnel who serve these processes directly. It was further mentioned, that, a printing environment's indoor air that is contaminated can be linked to health problems experienced by its employees and users.

Amongst the few research efforts channeled in this regard in assessing the quality of the indoor air in a printing environment is the evaluation and investigation of IAQ in a digital printing facility by Adamovic *et al*. (2018) and screen-printing environment by Kiurski *et al*. (2013). However, in the Nigeria context, there is still a paucity of information on the IAQ of printing presses or facilities and associated health impacts on users or operators as research into IAQ of this environment is still considerably low (Ayeni *et al.*, 2023). Moreover, the rapid demand and expanding market for print media and products in the form of newspapers, magazines, journals, books, posters, banners, leaflets, and clothes, from printing presses in recent times is on the rise. As a result, many businesses have sprung up in the country to meet this increasing demand in the print industry. Hence, the birth of many printing facilities that are not designed for such purposes. In addition to this, as reported by Atarodi *et al*. (2018), many owners, workers, and users of printing facilities in the built environment are still unaware to an extent, of the potential hazards of having poor indoor air in their indoor working environment. This makes users in these facilities prone and vulnerable to respiratory and dermatological problems. There is now a big concern that exposure to chemical contaminations from a printing press could result in adverse health effects which may in turn result in death if workers and users that are exposed to such pollutants are sensitive and allergic or perhaps if the pollutant level and exposure limits are sufficiently high.

It is imperative to assess the quality of the indoor air of printing presses or facilities in Nigeria as most of the printing press operations in the country might have been taking place in buildings or facilities not designed for such purposes. In addition, press operators and users who work for long hours in these presses may have been exposed to a wide range of health hazards such as lung cancer, allergies, and asthma amongst others from pollutants emanating from various printing emission sources which in turn may lead to adverse health problems if not given due attention (Adamovic *et al*., 2018; Sun *et al.*, 2022). An assessment of the quality of the indoor air of printing facilities in Zaria metropolis, the health risk exposure levels of users, compliance level with national air quality standards, key IAQ challenges, and control strategies for mitigating adverse effects of poor IAQ may, in turn, improve the quality of life and productivity in this built space. The goal of evaluating the indoor air pollutant concentration levels and their effects on press operators in the investigated printing presses was to gather quantitative data on the current state of IAQ in this setting.

LITERATURE REVIEW

Indoor Air Quality (IAQ) Parameters

The acceptability of IAQ in an indoor environment is often subject to measurement of IAQ parameters and comparison with acceptable limits and thresholds as set and specified by standards and legislations such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), World Health Organization (WHO), and National Environmental Standards and Regulations Enforcement Agency (NESREA) (ASHRAE, 2010; NESREA, 2021; WHO, 2016). At a global level, parameters that determine the quality of air in the indoor space are temperature, humidity, and chemical species (air pollutants) present in the air and seen to be harmful to human health such as Particulate Matter ($PM_{2.5}$ and PM_{10}), Total Volatile Organic Compounds (TVOCs: acetone, arsine, glycerin, styrene, formaldehyde, hydrogen sulfide, methylene chloride, nitric oxide, benzene, ethylene, xylene, toluene, tetrachloroethylene), Carbon dioxide (CO_2), Carbon monoxide (CO), Ozone (O_3) and Radon (Rn). According to Ismail *et al.* (2010), these pollutants in the indoor space are either allergenic, irritants, carcinogenic, immunotoxic, neurotoxic, or sick building syndrome (SBS) indicative. In addition to these air pollutants, the contributions of bacteria and fungi are also assessed at the microbiological level (Colella *et al.* 2022). According to NESREA (2021), an excellent class category of IAQ parameter should not exceed 20–25.5 ^{0}C, 40–70%, 1.7 ppm, 800 ppm, 0.200 mg/m^3, 0.030 mg/m^3, 15 µg/m^3, and 20 µg/m^3 for temperature, relative humidity, CO, CO_2, TVOC, HCHO, $PM_{2.5}$, and PM_{10} respectively. The levels of these parameters in the indoor environment are often influenced by factors such as the indoor pollutant source emission rate, concentration of outdoor pollutants, ventilation rate, rate of removal of harmful chemical species, and associated rate of transformation of pollutants. At low levels, these parameters in the indoor environment can cause discomfort, headache, mucous membrane irritation, or fatigue (Atarodi *et al*., 2018).

Health-related Issues of Indoor Air Pollution

According to Levesque *et al.* (2018), exposure to indoor air pollutants can have a wide variety of negative health impacts, from mild to fatal, uncommon to prevalent, including symptoms of SBS and building-related illness (BRI). Building Related Illness (BRI) is an illness or disease caused by exposure to airborne building contaminants. Common BRIs includes legionnaire's disease, Pontiac fever, hypersensitivity pneumonitis, humidifier fever, and lung cancer from radon (Johnson, 2019; Puri & Wittman, 2023). The factors that contribute to BRI may include poor building design, structure deterioration, and interior finishes (Fan & Ding, 2022). Generally, avoidance of further exposure to BRI is often recommended by taking appropriate measures. SBS on the other hand is not a disease in itself but refers to certain sets of symptoms, that users of an indoor space experience which tend to abate when they leave a particular building (Gladyszewska-Fiedoruk, 2019). It is a condition that makes occupants of a building uncomfortable, irritated, or ill (Runeson-Broberg & Norbäck, 2013). Elevated prevalence of the symptoms in a building is considered a piece of evidence that the building is responsible for causing the problems (Nezis *et al.*, 2022). In most cases, SBS occurs only in certain types of buildings that have automated heating, air-conditioning, and systems ventilation (Niza *et al.*, 2023). It may also occur and prevail in public buildings and spaces such as hospitals, schools, apartment buildings, and educational institutes (Nag, 2018). Researchers in the built environment consider only symptoms that abate when occupants leave the building to be SBS symptoms (Nakayama *et al.*, 2019). These symptoms include the following: fatigue, headache, nausea, dizziness, difficulties in concentrating, itching, burning, or irritation of the eyes; irritated, stuffy, or runny nose, hoarse or dry throat; and cough, dryness, itching, burning, tightness, or stinging of facial skin, erythema (reddening of the skin); scaling, itching scalp or ears; or, dryness or itching of the hands (Kamaruzzaman & Sabrini, 2011; Ha *et al.*, 2020). Gladyszewska-Fiedoruk (2019) conducted a survey in an office building with 200 employees for possible complaints of SBS, 68% of the respondents experienced one or more of the several symptoms typical of SBS. A building in which 30% of its users experience various ailments while in the internal environment where the discomfort disappears in a short time upon leaving the building is a "sick building" (Johnson *et al.*, 2018). Hence, the examined office building was concluded to be "sick."

According to WHO estimates, 30% of all newly built or remodeled buildings (offices, schools, banks, eateries, presses, etc.) are victims of SBS (Ogaji *et al.*, 2022; Azizi *et al.*, 2023). Studies are often carried out to determine the building, environmental, and personal factors associated with elevated rates of SBS symptoms (Hoang *et al.*, 2020; Igwe *et al.*, 2023). Such studies do not determine whether the symptoms are caused by the building, or whether they are simply present in the general population. However, in a situation where strong associations exist between risk factors and SBS symptom prevalence, factors should be addressed. Problems frequently associated with elevated SBS prevalence include the following: low ventilation rates (< 20 cfm/p), ventilation operations (<10 hours/day)**,** insufficient materials control**,** fleecy (high surface area) materials**,** carpets, air-conditioning, high temperature**,** high humidity**,** low relative humidity**,** volatile hydrocarbons**,** microbial volatile organic compounds, dust, high occupant density and photocopiers present and perception of "dry air" (Azuma *et al.,* 2017; Gladyszewska-Fiedoruk, 2019). These factors represent "risk factors" for SBS. The "cause" of SBS symptoms is multi-factorial although one or a few factors may dominate in any particular problem building or portion of a building (Igwe *et al.*, 2023). In general, it seems logical that addressing or controlling these factors will reduce the incidence of SBS symptoms in a building and also reduce the risk of BRI.

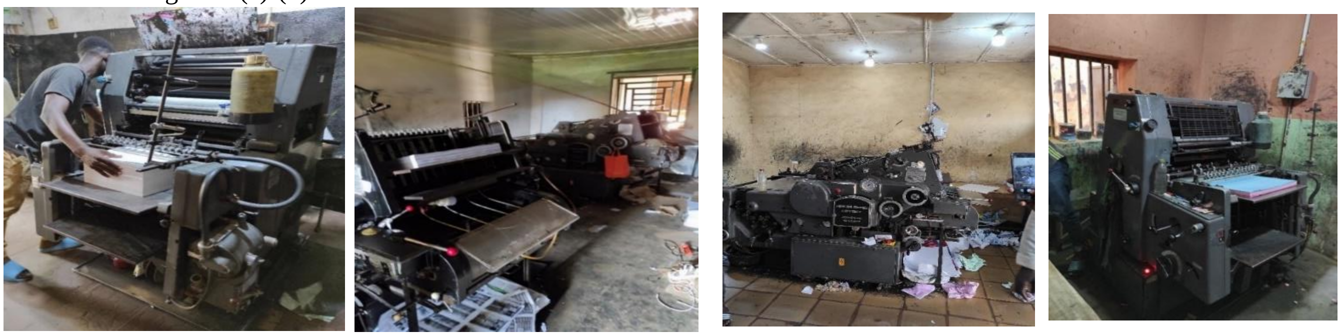
MATERIALS AND METHODS

Study Area

The research was conducted in Zaria, a bustling metropolis in Kaduna, Nigeria. It is situated in the northern region of Nigeria, between the coordinates of 11° 02' 00" and 11° 12' 00" in the north and 7° 36' 00" and 7° 46' 00" in the east. It has a land area of 300 km^2 and is 500-700 meters above mean sea level. The study region serves as the hub for education in Nigeria's northern states. Zaria has a tropical savanna climate with warm temperatures all year long, a wet season from April to September, a dry season from October to March, monthly mean temperatures varying from 140 °C to 390 °C, and 1092.8 mm of annual rainfall. Major printing operations are concentrated in this city's "Printing Cluster."

Sampling Sites

The sampling sites include all operational printing facilities in the study region that use at least one offset printing machine: Multilith, Kord, GTO, or Sordz. A total of 22 sampling sites with operational printing facilities were identified. For the sake of anonymity, the printing facilities in the respective sampling sites have been represented by the letters of the alphabet (P1-P22). Images of some of the assessed printing facilities are shown in Figure 1 (a)-(d).



(a) **(b)** **(c)** **(d)**

Figure 1 (a)-(d): Selected images of printing presses/facilities investigated.

Data Collection and Procedure

As this study is quantitative, data for the study was collected through a checklist, measuring equipment, and a questionnaire. A well-structured checklist was used to obtain relevant information specific to each printing press's indoor location. A walkthrough survey of each printing press was performed to collect data relating to air circulation/conditioning systems, the number installed, and their functionality (Table 1).

Air sampling

Using the following equipment: Air Quality Monitor (TUYA WIFI), Carbon Monoxide Meter (AS8700A), and Ozone Concentration Meter (DM502-03), measurements of IAQ parameters including temperature, relative humidity, carbon dioxide (CO_2), carbon monoxide (CO), the total volatile organic compound (TVOC), formaldehyde (HCHO), particulate matter 2.5 and 10 microns ($PM_{2.5}$, PM_{10}), and ozone (O_3) were made in the selected printing facilities. The TUYA WIFI air quality monitor measures temperature in the range of -10 to 50°C, relative humidity in the range of 20 to 85% RH, CO_2 in the range of 400–5,000 ppm, TVOC in the range of 0.000–9.999 mg/m3, HCHO in the range of 0.000–1.999 mg/m3, and $PM_{2.5}$/PM_{10} in the range of 0-999 µg/m3. The quantity of CO in the printing presses under investigation was measured using the carbon monoxide meter (AS8700A). The CO meter measures CO in the range of 0–999 ppm. On the other hand, the amount of O_3 concentration in the study area was monitored using the ozone concentration meter (DM502-O3). The instrument measures ozone concentrations between 0 and 5 ppm. By following specific testing protocols, data on IAQ parameters were gathered. Data for the study were collected using a similar protocol employed by Omole *et al.* (2020) in assessing the indoor air quality (IAQ) of a microenvironment. First, a sampling spot within the printing presses' interior space was chosen. For the duration of the evaluation, a 1 m distance from the printing equipment was deemed appropriate. The concentration of IAQ parameters is anticipated to be highest within this distance, where the majority of press operators conduct printing activities. Following manufacturer-recommended calibration, the air quality monitor (TUYA WiFi), carbon monoxide meter, and ozone concentration meter were held 1 m away from the printing apparatus, and IAQ measurements were made. The different handheld devices were held at a height of 1.5 m above the ground during the air pollutant measurements (Omole *et al.*, 2020). Pollutant content measurements were made between 9:00 am and 6:00 pm. Each sampling session of the printing process included at least three (3) measurements. The findings were read from the instrument's screen and entered into a sampling form. Before beginning any new measurement, all measuring equipment was recalibrated to ensure that the findings were accurate and followed the manufacturer's instructions. Measurements were taken during the wet season of the year.

Assessment of the impact of IAQ on press operators

For the subjective part of the study, a well-structured questionnaire was used as an instrument to assess the impact of IAQ on the health of printing press operators. The questionnaires were used to determine whether press operators suffer from specific health-related issues such as cardiovascular diseases (CVDs), pulmonary diseases, acute respiratory infections, and building-associated illnesses (SBS and BRI), which may be exacerbated by poor IAQ in the printing indoor space. The questionnaire was structured into four sections (1, 2, 3, and 4). Section 1 requires that the respondents (press operators) tick appropriate details that include: gender, age range, number of years working in the printing press, and the average length of time spent daily in the printing press. Section 2 of the questionnaire addresses the perceived SBS symptoms that press operators frequently encounter while working in the printing press on a 5-point Likert scale (5-always, 4-often, 3-sometimes, 2-rarely, 1-never). Section 3 of the questionnaire lists some health-related issues linked with IAQ and asks respondents to mark any that are peculiar to them. The final section (Section 4) asks respondents to fill out some personal measures they take to reduce the impact of IAQ problems on their health. A total of 22 questionnaires were self-administered to the operators of the printing press equipment, with one questionnaire assigned for each printing facility.

Statistical analysis

Statistical Product and Service Solution (SPSS 25) was used for the statistical analysis. Descriptive analysis was conducted by comparing the mean of the concentrations of air pollutants. One-way ANOVA was used to compare the differences in concentrations of air pollutants across the printing press. A p-value of 0.05 was used.

RESULTS AND DISCUSSION

Air Circulation/Conditioning and Ventilation System of Printing Facility

Table 1 shows the quantity of installed air circulation and ventilation systems and the functionality of the system in the printing facilities. An air circulation or ventilation system may generally impact the airflow and CO_2 levels in the printing press. It is noticeable that 6 printing presses (P6, P7, P11, P14, P15, and P17) were without any installed air circulation/air conditioning system(s). In these presses, air pollutant concentration buildup may be experienced as there is no exchange of the indoor air with the outdoor. On the other hand, 6 printing presses (P1, P3, P8, P19, P21, P22) have at least an installed air conditioning (AC) unit that is functional. In addition, about 11 printing presses have at least a functional air circulation system (fan) installed in the facility to facilitate air circulation within the space, especially during printing operations. Worthy to note also is the number of installed and functional air circulation/conditioning systems in the printing press P22. This press recorded the highest number of air circulation/conditioning systems (N=11). This may be attributed to the volume of space and the need to ensure adequate airflow within this printing press. In general, none of the printing facilities has any installed exhaust system.

Table 1: Air circulation/conditioning and ventilation system of the printing press

Printing Press	Floor Area (m^2)	Volume of Space (m^3)	Air Circulation System Installed	Air Conditioning System Installed	Exhaust System Installed	Total Installed System	Total Functional System
P1	14	44.8	0	1	0	1	1
P2	18	54	1	0	0	1	1
P3	21.4	60	0	1	0	1	1
P4	8	24	1	0	0	1	1
P5	7.2	16.6	1	0	0	1	1
P6	6.1	13	0	0	0	0	0
P7	7.5	18.8	0	0	0	0	0
P8	22.1	60.87	0	1	0	1	1
P9	5.4	12.96	1	0	0	1	1
P10	8.3	26.21	1	0	0	1	1
P11	10.5	31.5	0	0	0	0	0
P12	25.2	75.6	1	0	0	1	1
P13	7	21	1	0	0	1	1
P14	8.64	21.6	0	0	0	0	0
P15	17.5	52.5	0	0	0	0	0
P16	18	45	1	0	0	1	1
P17	11.88	35.64	0	0	0	0	0
P18	31.5	94.5	2	0	0	2	2
P19	19.5	58.5	2	1	0	3	3
P20	108	324	10	0	0	10	10
P21	72	252	3	1	0	4	4
P22	168	1,008	9	2	0	11	11

Thermal Parameters in the Printing Facilities

Table 2 shows the temperature and relative humidity values of the various printing presses investigated during inactive and active printing operations. The high-temperature values recorded in the press facilities assessed may be attributed to the mean radiant heat gains into the indoor space of the presses, improper mixing of air by ventilation systems installed in the various presses, and heat generation or release from the various printing equipment. As a result of these high-temperature values, press users may witness some sort of discomfort while carrying out press activities. This may in turn affect their productivity levels. A different scenario was however observed for the relative humidity thermal parameter. It was shown that during inactive printing times, only 4 printing presses (P10, P13, P14, and P17) failed to meet the specified range of 40-70% while 13 others did not meet the range during active printing times. These high RH values in these presses can promote the development or growth of molds (Spiru & Simona, 2017). As measurements of IAQ parameters were taken during the wet season, it might have contributed to these high RH values.

Table 2: Mean levels of thermal parameters

Printing Press	**Temp. (^{0}C)**		**RH (%)**	
	I	**A**	**I**	**A**
P1	28.67	30.33	59.67	62.33
P2	29.67	32.33	67.67	69.67
P3	31.33	32.67	62.33	64.67
P4	30.67	32.00	60.33	62.33
P5	30.33	32.00	63.00	66.67
P6	28.00	33.00	69.00	74.00
P7	26.67	29.00	61.00	62.67
P8	30.33	32.33	67.33	71.67
P9	27.67	29.67	69.67	71.00
P10	27.33	30.33	71.00	80.00
P11	30.33	31.33	63.33	67.67
P12	23.67	25.67	67.67	77.00
P13	25.67	26.67	80.67	83.67
P14	25.33	28.33	75.33	79.33
P15	30.67	32.67	65.33	69.67
P16	30.33	33.67	68.67	73.33
P17	27.33	31.33	74.67	85.00
P18	29.33	32.00	70.00	77.33
P19	29.00	30.00	69.00	84.00
P20	30.00	31.33	68.67	71.33
P21	27.00	28.00	61.67	74.67
P22	30.00	30.67	52.33	56.33
P-value	0.000	0.000	0.000	0.000

I – Inactive printing times, A – Active printing times.
NESREA Standard for excellent class IAQ: Temp. (20-25.5^{o}C), RH (40-70%).

Air Pollutant Concentration Levels in the Printing Facilities

Table 3 reveals the mean concentration levels of all the indoor air pollutants sampled in the 22 printing presses during the inactive and active printing press activity times. Higher concentration levels of indoor air pollutants were observed during active printing time compared to inactive time. This was expected as printing operations often release harmful substances into the indoor space, which in turn may raise the mass concentration levels of IAQ parameters. Before printing activities, some indoor air pollutants like TVOCs, $PM_{2.5,}$ and PM_{10} recorded concentration values exceeding the NESREA's excellent class concentration limits of 0.200 mg/m^3, 15 µg/m^3, and 20 µg/m^3 in most of the printing press, respectively. The highest mean CO (10.33 ppm), CO_2 (823 ppm), TVOC (6.034 mg/m^3), HCHO (0.030 mg/m^3), $PM_{2.5}$ (124.33 µg/m^3), and PM_{10} (138.67 µg/m^3) were recorded in presses P3, P13, P6, P21, P9, P18, P14, and P14 in that order. During active printing activities, the mean concentration of IAQ pollutants like TVOCs, HCHO, $PM_{2.5,}$ and PM_{10} was found to exceed the standard values designated by NESREA's excellent class concentration limits in about 60% of the printing presses assessed.

Interestingly, during inactive printing times, CO is detected in press P6 only. The observed mean value of the CO in this press is 10.33 ppm. This may be associated with carbon monoxide from generating sets from the outdoor space. On the other hand, 7 printing facilities have their mean concentration values exceeding the stipulated threshold during the active printing times. Due to the relatively unstable electrical power supply in the study area, some of these printing presses had to use alternative power sources like generators for their operation. Some of these generators were found to be close to door and window openings. This might have been the source of the CO generation in the printing facilities. As press users become exposed to these CO concentrations in the presses, they may likely experience fatigue, chest pains, angina, and/or heart problems (Kiurski, *et al.* 2013). For the mean concentration of the CO_2 IAQ parameter, unlike the CO, only 1 printing press (P21) for the inactive printing times and 3 others for the active printing times have their measured values exceeding the standard value of 800 ppm. This high value of CO_2 recorded may be attributed to inadequate ventilation systems in the printing press. It was observed that all the windows in this press were closed. The impact of this CO_2 may result in health effects such as dizziness, restlessness, headaches, difficulty breathing, tiredness, sweating, and increased heart rate amongst other presses (WHO, 2016). Furthermore, it was observed that 12 presses (inactive printing times) and 20 presses (active printing times) had their TVOCs not meeting with stipulated limits (0.20 mg/m^3) of the NESREA standard. Perhaps due to the low solubility of these compounds in water and high vapor pressure, they may have evaporated into the indoor air space from potential TVOC sources in the printing presses. Due to these concentration levels within the press facilities, press operators are prone to health risks that include headaches, fatigue, dizziness, throat/nose/eye irritations, and skin problems among others (BCA, 2010).

Concerning the HCHO levels of the printing presses investigated, it can be observed that only one printing press (P18) slightly exceeded the standard for HCHO specified by NESREA (0.03 mg/m^3) when printing activities are not being carried out. All the recorded values of HCHO in the printing facilities may be attributed to emission sources such as building materials, adhesives, and glues. Since about 95% of the presses have their HCHO values within the NESREA limit of 0.30 mg/m^3 during inactive printing times, press users may likely not suffer sensory irritation, concentration distraction, lachrymation, or coughs during inactive printing times presses (EPA, 2016). However, the increased levels of HCHO observed in 59% of the presses during the active printing times may be linked to emission sources such as printing equipment glues, adhesives, and construction materials. As a result, press users may experience some SBS symptoms such as sensory irritation, difficulty concentrating, and cough.

For the mass concentrations of $PM_{2.5}$ and PM_{10} in all the 22 printing presses, it is evident from the data presented that all the printing facilities have values exceeding the respective limits of NESREA both for the inactive and active printing times. $PM_{2.5}$ particles are inhalable and capable of being deposited on the larger airways or deeper parts of the lungs. The implication of this is that press users are at high risk of developing respiratory symptoms, asthma attacks, and heart and lung problems while those with chronic heart or lung diseases may suffer premature death (Liu, Box, & Kalman, 2008). On the other hand, PM_{10} particles may aggravate the pre-existing conditions of asthma and chronic bronchitis. These PM particles may have originated from the outdoors of the printing facilities and entered the indoor space via door and window openings while others may be due to visible dust, dirt, and complex reactions in the built space of the printing press. For the ozone concentration, the NESREA standard stipulates 25 ppm as the concentration level of the excellent class of this pollutant. Interestingly, the mean concentration levels of O_3 across the whole printing facility were found to be within the stipulated standard level. This indicates that during inactive and active printing times, press operators or users may likely not experience cough, scratchy or sore throat, difficulty breathing, or inflammation of the airways (Nazaroff, 2004). Press operators must ensure that these values are monitored continuously and kept within the expected range.

In general, as shown in Table 3, for the inactive and active printing times, there were statistically significant differences between mean concentration levels of the IAQ parameters CO_2, TVOC, HCHO, $PM_{2.5,}$ and PM_{10} in the 22 printing presses as determined by one-way ANOVA. The respectively obtained *p*-values were all seen to be less than the alpha value (0.05). Ozone, on the other hand, could not be tested as the mean values were constant all through the presses.

Table 3: Mean concentration of chemical pollutants in printing facilities

Printing Press	Chemical Pollutants													
	CO (ppm)		CO_2 (ppm)		TVOC (mg/m^3)		HCHO (mg/m^3)		$PM_{2.5}$ ($\mu g/m^3$)		PM_{10} ($\mu g/m^3$)		O_3 (ppm)	
	I	A	I	A	I	A	I	A	I	A	I	A	I	A
P1	0.00	5.00	458.33	758.33	0.182	0.323	0.022	0.027	24.00	84.67	28.00	113.00	0.00	0.01
P2	0.00	0.00	530.33	658.33	0.097	0.113	0.027	0.031	31.67	42.00	40.00	46.00	0.00	0.00
P3	0.00	0.00	553.33	638.33	0.111	0.115	0.022	0.030	27.67	37.33	35.00	38.33	0.00	0.01
P4	0.00	0.00	656.33	661.00	0.437	0.788	0.021	0.034	26.67	29.00	34.00	36.33	0.00	0.00
P5	0.00	0.00	609.67	732.67	2.401	9.999	0.021	0.042	30.00	32.67	39.33	40.33	0.00	0.02
P6	10.33	19.00	578.00	746.33	0.017	4.707	0.018	0.050	55.33	78.33	81.00	92.67	0.00	0.00
P7	0.00	20.33	520.33	548.00	0.257	4.526	0.017	0.029	26.33	29.00	34.67	37.00	0.00	0.02
P8	0.00	31.00	508.67	558.33	0.607	9.999	0.018	0.028	30.67	36.67	35.33	41.33	0.00	0.03
P9	0.00	10.00	517.33	811.00	6.034	9.999	0.018	0.031	30.33	42.33	35.67	72.67	0.00	0.00
P10	0.00	0.00	540.67	603.33	0.089	0.551	0.015	0.025	28.33	31.00	38.67	43.67	0.00	0.00
P11	0.00	5.67	524.67	1425.33	2.078	9.999	0.020	0.033	44.00	50.67	59.67	63.67	0.00	0.02
P12	0.00	6.00	560.00	699.00	0.350	9.999	0.016	0.023	28.33	46.67	32.00	56.33	0.00	0.00
P13	0.00	0.00	534.33	630.33	0.272	6.831	0.012	0.023	25.67	58.33	33.00	53.67	0.00	0.00
P14	0.00	5.33	606.00	739.33	0.133	4.467	0.015	0.036	124.33	181.00	138.67	174.67	0.00	0.00
P15	0.00	0.00	469.33	540.33	0.103	2.454	0.014	0.036	19.00	43.33	22.33	37.00	0.00	0.05
P16	0.00	0.00	563.00	603.00	0.783	4.516	0.019	0.037	26.00	36.67	29.00	36.67	0.00	0.04
P17	0.00	0.00	483.67	586.67	0.202	9.999	0.012	0.015	23.00	25.33	30.00	32.67	0.00	0.00
P18	0.00	0.00	545.67	756.67	0.389	0.608	0.030	0.039	70.00	568.33	81.67	568.33	0.00	0.01
P19	0.00	0.00	460.67	646.67	0.090	0.564	0.011	0.031	20.67	92.67	28.00	92.67	0.00	0.03
P20	0.00	0.00	536.33	574.67	0.118	0.467	0.024	0.032	40.00	63.00	52.67	63.00	0.00	0.00
P21	0.00	0.00	823.00	840.00	0.651	0.741	0.023	0.029	18.67	44.67	26.00	44.67	0.00	0.01
P22	0.00	0.00	434.00	533.67	0.123	9.999	0.028	0.078	18.67	28.00	23.33	28.00	0.00	0.04
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-	0.000

I – Inactive printing times, A – Active printing times.

NESREA Standard for excellent class IAQ: CO (<1.7 ppm), CO_2 (< 800 ppm), TVOC (< 0.20 mg/m^3), HCHO (< 0.030 mg/m^3), $PM_{2.5}$ (< 15 $\mu g/m^3$), PM_{10} (< 20 $\mu g/m^3$), O_3 (< 25 ppm).

Impact of Indoor Air Quality (IAQ) on the Health of Printing Press Operators

Profile of press operators

Table 4 shows the profile of the 22 printing press operators surveyed in the study. It can be observed that 22 (100%) of the press operators are male. This is not surprising, as printing press operations are often male-dominated. It is also evident that 3 (13.6%) of these operators are within the age range of 15–20 years, while others—6 (27.3%), 7 (31.8%), 5 (22.7%), and 1 (4.5%), have ages in the range of 21–30 years, 31–40 years, 41–50 years, and above 50 years, respectively. This suggests that the vast majority of press operators are in their prime age. In terms of the working experience of the press operators, only 1 (4.5%) has worked less than a year in a printing press, while 3 (13.6%), 5 (22.7%), and 7 (31.8%) of the operators have press working experience in the range of 1–5 years, 6–10 years, and 11–15 years, respectively. Operators with press working experience greater than 15 were only six (27.3%). This shows that several press operators (more than 50%) have spent a remarkable number of years (11 years and beyond) in a printing press. Also, this level of working experience invariably translates into a reliable response. It can also be seen in Table 4 that none of the sites have average daily working hours of less than 3 hours. However, 2 (9.1%) of these press operators spend an average of 4-6 hours daily working in their respective presses, while 9 (40.9%) have average daily press working hours of 7-8 hours. It is also clear that 11 (50%) spend more than 8 hours in the indoor environment of the press. These considerably high average daily working hours of press operators may be attributed to the nature of press activities. Hence, press operators' average working hours may suggest high exposure times to indoor air pollutants in the presses.

Table 4: Profile of printing press operators

Variables	Frequency (No)	Percentage (%)
Gender		
Male	22	100
Female	0	0
Total	**22**	**100**
Age		
15-20 years	3	13.6
21-30 years	6	27.3
31-40 years	7	31.8
41-50years	5	22.7
Above 50	1	4.5
Total	**22**	**100.0**
Working experience in press		
less than 1 year	1	4.5
1-5 years	3	13.6
6-10 years	5	22.7
11-15 years	7	31.8
greater than 15 years	6	27.3
Total	**22**	**100**
Average daily working hour		
Less than 1 hour	0	0
1-3 hours	0	0
4-6 hours	2	9.1
7-8 hours	9	40.9
more than 8 hours	11	50.0
Total	**22**	**100.0**

Health-related problems of press operators

Table 5 shows the result of some most common health-related problems that may likely worsen if press operators have short or long exposure time to indoor air pollutants that exceed the limits as stipulated by standards. It can be observed from Table 5 that only 1 (4.5%) of the press operators is asthmatic, 4 (18.2%) have sight issues, 1 (4.5%) have breathing difficulties and 4 (18.2%) suffer from migraine. Thus, press operators suffering from one or a combination of these health-related problems may need to monitor or pay close attention to their health or retire from press operations as not all IAQ parameters as measured in the printing presses are within mass concentration limits as stated in the relevant standard used for assessment (Tables 3). Interestingly, no press operator (0%)

associated their health status with health problems such as cardiovascular disease (CVD), lung cancer, pneumonitis, or influenza. Perhaps, this kind of response may be due to press operators' unwillingness to reveal their true state of health for trust and confidentiality reasons or they are not aware. A medical examination may however be needed to ascertain that press operators are free of these health-related problems as reported. Furthermore, relevant professional bodies who regulate printing press activities may need to request a medical check from press operators quarterly to ensure they have no serious health conditions.

Table 5: Health-related problems of printing press operators

	Health problems	YES		NO	
		Frequency (No)	Percentage (%)	Frequency (No)	Percentage (%)
1	Asthma	1	4.5	21	95.5
2	cardiovascular disease (CVD)	0	0	22	100
3	Eye problem	4	18.2	18	81.8
4	Lung cancer	0	0	22	100
5	Breathing difficulty	1	4.5	21	95.5
6	Migraine	4	18.2	18	81.8
7	Pneumonitis	0	0	22	100
8	Influenza	0	0	22	100

Perceived frequency of press operators feeling sick building syndrome (SBS) symptoms

Table 6 presents the result of press operators' perceived frequency of feeling sick building syndrome (SBS) symptoms in the indoor space of their respective printing facilities. Based on the perceived frequency of feeling the SBS symptoms shown in Table 6, it can be seen that Fatigue (M=2.32) which is a general SBS symptom, ranks 1st and is perceived to be rarely experienced by press operators in the printing press. In addition, under this category of SBS symptoms, dizziness (M=2.27) and headache (M=2.23) rank 2nd and 3rd respectively. On the other hand, irritated nose (M=2.18), cough (M=2.09), and irritation of the eyes (M=2.05) which are all mucous membrane SBS symptoms ranked 1st, 2nd, and 3rd in that order. As it relates to the skin SBS symptoms experienced by press operators while working in the press, dryness of the hands (M=2.00) ranks 1st, dry facial skin (M=1.95) ranks 2^{nd,} and scaling ears (M=1.91) ranks 3rd. Surprisingly, the findings of the mean concentration levels of the IAQ parameter as shown in Table 3 reveal high concentration values for some parameters but in general, press operators expressed that they rarely experience any discomfort, irritation, or become ill when they are within the indoor space of the printing press or when they engage in press operations and activities. Though this is the current situation, the operators in these printing presses/facilities may still need to be cautious of the adverse health impacts associated with short or long-term exposure to IAQ pollutants. The high prevalence of SBS symptoms in any built space may be due to building factors, building environmental factors, building use/occupancy factors, or occupant factors, however, the availability of at least a functional installed ventilation system in about 73% of the printing presses (Table 1), and considerably, CO, CO_2, HCHO, and O_3 levels within acceptable limits in most presses' spaces during the inactive and active printing times (Tables 3), might be the reason for the rarely perceived feeling of SBS symptoms in the printing presses' indoor built spaces (Levesque *et al.,* 2018). The result as seen in Table 6 may suggest that the perceived impact of IAQ on the health of printing press operators is generally minimal or negligible although the results of Table 3 reveal some IAQ parameters exceeding expected concentration limits. Furthermore, according to the result obtained in Table 5, which is more of health risk factors, press operators may develop or show fewer concerns for the highlighted health-related problems linked with poor IAQ in a built space due to their perception of rarely feeling SBS symptoms in Table 6.

Table 6: Perceived frequency of feeling SBS symptoms in the printing press

S/No	SBS Symptoms	Mean	SD	Rank	Remarks
A	**General Symptom**				
1	Fatigue	2.32	0.477	1st	Rarely
2	Dizziness	2.27	0.631	2nd	Rarely
3	Headache	2.23	0.528	3rd	Rarely
4	Chest pain	2.05	0.375	4th	Rarely
5	Difficulty in concentration	2.00	0.000	5th	Rarely
6	Breathing Difficulty	2.00	0.309	6th	Rarely
7	Nausea	1.95	0.375	7th	Rarely
B	**Mucous membrane symptoms**				
1	Irritated nose	2.18	0.588	1st	Rarely
2	Cough	2.09	0.426	2nd	Rarely
3	Irritation of the eyes	2.05	0.213	3rd	Rarely
4	Dry throat	2.00	0.309	4th	Rarely
C	**Skin symptoms**				
1	Dryness of the hands	2.00	0.309	1st	Rarely
2	Dry facial skin	1.95	0.213	2nd	Rarely
3	Scaling ears	1.91	0.294	3rd	Rarely

5- always, 4-often 3- sometimes, 2- rarely, 1-never

CONCLUSION

This research examined the level of indoor air pollutants in 22 printing facilities and how they affected press operators in Zaria, Kaduna, Nigeria. According to the research, the IAQ parameters TVOCs, HCHO, PM2.5, and PM10 are the ones causing IAQ issues in the evaluated printing presses because the mean concentration of these IAQ pollutants was found to be higher than the NESREA-designated excellent class concentration limits in most of the printing facilities during active printing times. In all the 22 printing presses examined for IAQ, particulate matters ($PM_{2.5}$ and PM_{10}) did not meet the limits for both active and inactive printing times, which necessitates their control. In this study, press operators rarely experienced SBS symptoms in the printing facilities which may likely cause them to experience discomfort, irritation, or become ill when they are within the indoor space of the printing press or when they engage in press operations and activities. However, the impact of IAQ parameters like HCHO, $PM_{2.5,}$ and PM_{10} on their health may become significant if exposure continues. In this study, only readily available and well-calibrated IAQ handheld measuring devices were used to obtain data on the concentration levels of IAQ parameters. To obtain real-time statistics on the levels of indoor air pollution and to properly manage IAQ parameters in the investigated printing facilities, printing press owners should install an indoor air quality monitoring system. In addition, the researcher was unable to conduct medical examination tests to ascertain the true health status of respondents. The health-related results in this study were only based on the reported health state of press operators. Press operators should undergo routine medical examinations at least once a year, and those with working experience of 10 years or more should have a respiratory system test to determine the real condition of their systems. The findings of this study contribute to the understanding of the health consequences of extended IAP exposure in printing facilities, as well as the relationships between high concentrations and detrimental effects on press operators. To protect press workers' health and productivity in printing facilities, some implications call for improved occupational health practices, regulatory compliance, awareness training, and infrastructure investment.

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