Health risk assessment for benzene-exposure in oil refineries

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Alexandria city has multiple refineries and petrochemical plants. The worker’s exposure to benzene was evaluated in three selected sites with reference to international guidelines and Egyptian regulations. Health risk assessment due to human exposure to benzene was also investigated. Air samples were collected for each site for proving the exposure levels. Urine samples were collected and analyzed for phenol, using NOISH method for its assay. Risk perception was also performed among workers of the study sites. Data revealed that the workers at the three sites were exposed to benzene with varying degrees. HQ was >1 at site one and site two and reduced by adopting better control measures, at site three where it was ≥1. The highest cancer risk was at site-one with an average of 1100 per 10^6 (one in thousand) followed by site-three with an average of 247 per 10^6 and site-two with an average cancer risk of 185 per 10^6. The results revealed that site-two had the best control measures due to modern engineering and inherent safer design with the implementation of national and international regulations for benzene risk management. The underlying study highlight on the possible potential health risk posed by benzene exposure that may occur among workers of oil refineries, and the importance of related interventions and protective measurements in order to preserve workers’ health.

Keywords: Benzene exposure, Benzene risk perception, Benzene health risk assessment, Benzene hazard quotient and cancer risk.

INTRODUCTION

Exposure science studies the transfer of hazardous agents from the workplace and general environment into human bodies, through measurement of environmental concentrations of hazardous agents, and length and duration of contact with these hazards. Exposure science also seeks to mitigate the adverse effects of contact with hazardous agents, by elucidating critical pathways of exposure, and directed interventions to interrupt or minimize the exposure pathways (Williams et al., 2008).

Alexandria (northern Egypt) is a significant industrial center for Egyptian petroleum industry with multiple petroleum refineries and petrochemical plants. Petroleum refineries and petrochemical plants are major sources of volatile aromatic hydrocarbons (VAHs) in the environment (Rao et al., 2007). Benzene is a major VAH emitted during petroleum refinery and petrochemical operations (Mirkova et al., 1999). Benzene has been classified as a human carcinogen by the International Agency for Research on Cancer, National Toxicology Program Report on carcinogens and the American Conference of Governmental Industrial Hygienist, ACGIH, (ACGIH 1997). Epidemiological studies have shown the occurrence of acute and chronic leukemia, even with low concentrations (Rinsky et al., 1987).

Benzene is metabolized in the human body to
phe- nols, which can be detected in the urine of exposed workers (Rothman et al., 1998). Acute exposure to benzene can cause dizziness, euphoria, giddiness, headache, nausea, staggering gait, weakness, drowsiness, respiratory and gastrointestinal irritation, pulmonary edema and pneumonia, convulsions and paralysis (Robert Schnatter et al., 2010; U.S. Department of Health and Human Services, 1988). Benzene can also cause irritation to the skin, eyes and mucous membranes. Moreover, chronic exposure to benzene can cause fatigue, nervousness, irritability, blurred vision, and labored breathing. Repeated skin contact can cause redness, blistering, and scaly dermatitis (Robert Schnatter et al., 2010). Recent studies showed significant hematological disorders, chromosomal aberrations as well as relatively high concentration of phenol in 24-hour urine samples due to exposure to benzene in chemical industry workers. Furthermore, blood disorders may lead to anemia and other diseases causing a significant reduction in working capacity and activity of workers, loss of working hours, and the increase in the costs of medical care of the affected workers (Mohamed et al., 2013). Occupational benzene exposure mainly occurs via inhalation (Tompa et al., 2005). Workers in petroleum refineries and petrochemical plants, including those involved in loading and transportation of petroleum products may have some levels of exposure to benzene (Lin et al., 2004). Exposure standards show the ambient concentration of a particular substance or mixture that must not be exceeded (Farshad et al., 2013; Falzone et al., 2016). Occupational exposure limits (OELs) have been introduced by various organizations for the management of benzene exposure. The occupational exposure limits (OEL) of benzene have been reduced and made stringent over time in recognition of its health hazards. ACGIH’s recommended threshold limit value-time weighted average (TLV-TWA) for benzene has been reduced from 100 ppm in 1946 to the current value of 0.5 ppm, which was adopted in 1997. A short-term exposure limit (STEL) of 2.5 ppm also has been adopted (ACGIH 1997). Basso et al. 2011, had reported that benzene concentrations in modern refineries should be less than 1 ppm.

The study was planned to comparatively assess the health risk due to exposure to benzene at three oil refinery workplaces in order to evaluate the possible adverse health effects and cancer risk. A risk perception tool was utilized to evaluate the hazard awareness among workers at the study sites and analyzing the level of control measures.

MATERIALS AND METHOD

Description of the study area

Alexandria is located on the Mediterranean Sea at latitude 31° 12’ 32” N and longitude 29° 54’ 33” E. It is the second largest city and a major financial centre in Egypt with total area of 2679 km², extending over 32 km along the coast of the Mediterranean Sea in the north central part of the country (http://www.alexandria.gov.eg). Three refinery study sites were selected to represent locations of the petroleum industry; two modern refineries and one old refinery.

Risk Perception

150 exposed persons from the three refineries were asked to fill out a pre-designed risk perception tool posing questions assessing safe benzene guidelines based on OSHA and COSHH beside Egyptian regulations, PPE and qualitative risk assessment by Kinney and Fine method. The tool was used as a way for benzene exposure assessment, analyzing levels of the control measures and levels of awareness to evaluate the benzene risk management in each site.

The study samples from the three sites were asked to conduct a risk assessment for benzene exposure in order to measure the employees’ risk perception towards hazards of benzene. They were asked to quantify the benzene risk based on Kinney and Fine method by using three variable risk calculator;

\[
\text{Risk} = \text{Exposure} \times \text{Probability} \times \text{Consequence}
\]

The method was adopted in risk assessment in work sites as previously described (Marhavilas et al., 2011; Stankovic and Stankovic, 2013; Oturakci et al., 2015). The method is widely used by petroleum companies in the task of risk assessment.

Ambient benzene measurements

Air samples were collected during the study period; two years, from each site. Samples were based on personal breathing zone samples. Personal air samplers were used (flow rate, 100 ml/min) and connected to pumps. Air sampling was carried out throughout the entire 8h working shift. Personal exposure monitoring of benzene was done with a low volume personal sampler (MSA part No.456058, USA) fitted with a charcoal sorbent tube that was attached to the waist of the worker. On each event, personal air sampling was started with a work shift in each site.

The tube held in a low flow holder was clipped to the attire of worker close to the personal breathing zone. The air was drawn at a rate of 100 ml/min from 6 am to 2 pm (for a full work shift of 8h) or through two charcoal sorbent tubes (tube source) for four hours’ periods.

The charcoal was desorbed in 1 ml of carbon disulfide (CS₂) for 1–1.5h and analyzed for benzene.
Quantification was done on a gas chromatograph equipped with a flame ionization detector. The analysis was done by a certified analytical service third party, as per Egyptian law.

Biological Monitoring

Urine samples were collected from all participants for assay of Phenol. The samples were taken after 4 days off at the end of the first working shift (refinery workers work for 12hr four days on duty and 4 days off duty)

Urine specimens were collected 50 to 100 mL in polyethylene screw-cap bottle containing preservative at the end of a work shift (Ong et al., 1996). The urine samples were kept in dry ice in the insulated container; samples can be stable for 4 days at 25°C and for 3 months at 4°C. Phenol analysis was done by gas chromatography, FID, by acid hydrolysis extraction, as described by NOISH Method 8305.

Statistical analysis

After data were collected it was revised, coded and fed to statistical software IBM SPSS version 21. The graphs were constructed using Microsoft excel software. Numeric data analysis was performed by one-way and repeated measures ANOVA. Analysis of categorical data was conducted by Mont Carlo exact test and Fishers exact test.

Risk characterization

Health Risk Assessment

The benzene concentrations were converted from μg/m³ to μg/kg/day in terms of Lifetime Average Daily Dose (LADD) using values summarized in Table 1. The LADD and the values of USEPA Inhalation Reference Dose (RfD) and Slope Factor (SF) were used for estimating the HQ and CR (Edokpolo et al. 2015).

The Lifetime Average Daily Doses (LADD) (μg/kg/day) for exposure to benzene concentrations were calculated using the default values in Table 1 with Equation (1):

\[ \text{LADD} = \frac{[C_{\text{exp}} \times IR \times EL \times ED]}{[BW \times LT]} \] ……………… (1)

where

- \( C_{\text{exp}} \) is exposure concentration (μg/m³);
- IR, Inhalation Rate (m³/day);
- EL, Exposure Length (day/day);
- ED, the Exposure Duration (days);
- BW, Body Weight (kg);
- LT, Lifetime (days).

Hazard Quotient (HQ)

The HQ method of risk characterization was used to estimate the potential adverse health effects or non-cancer effects for exposure to benzene. The USEPA Reference Dose (RfD) derived from benzene was used to estimate the HQ using Equation (2)

\[ \text{HQ} = \frac{\text{LADD}}{\text{RfD}} \] ……………… (2)

Where

- LADD, lifetime average daily dose (μg/kg/day)
- RfD, reference dose which equal to 8.5 (μg/kg/day)

If the value of HQ is less than 1, then the exposed local population (consumers) is said to be safe, if HQ is equal to or higher than 1, is considered as not safe for human health, therefore potential health risk occurred, and related interventions and protective measurements should be taken (USEPA, 2013).

Cancer Risk

The cancer risks were calculated by the mathematical equations to determine the number of individuals that are likely to acquire cancers due to their exposure to benzene (Yan et al., 2015) from inhalation intake. Cancer risk is expressed as the excess risk of developing cancer over a lifetime of exposure (70 years). The USEPA inhalation slope factor derived from benzene was used to quantitatively estimate the excess cancer risk in terms of lifetime exposure (LADD) by using Equation (3):

\[ \text{Cancer Risk} = \frac{\text{LADD} \times \text{SF}}{\text{RfD}} \times (\text{μg/kg/day}) \] ……………… (3)

Where

- LADD, lifetime average daily dose (μg/kg/day)
- SF, Slope factor which equals to 27.3 (μg/kg/day)

according to USEPA (Edokpolo et al., 2015).

RESULTS

Analysis of risk perception using Kinney and Fine risk assessment method showed that 31.3% of the study group reported that benzene exposure has no risk at all, 36.7% reported the low degree of risk, 14% reported medium risk degree, 7.3% reported high risk and 10.7% reported very high risk. Figure 1 illustrates the workers’ perception to benzene risk.

Benzene risk management and risk perception levels among workers of the study refinery sites, using OSHA and COSHH guidelines, are shown in Figure 2. As shown, the good level of workers’ perception for benzene risk management strategies was in 51% of workers at site-two. 39.6% at site-one and 26.9% at site-three. Site-two showed the highest workers’ level of
Table 1. USPEA benzene default exposure factors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (LT)</td>
<td>70</td>
<td>Years</td>
</tr>
<tr>
<td>Body Wight (BW)</td>
<td>70</td>
<td>Kg</td>
</tr>
<tr>
<td>Exposure Length (EL)</td>
<td>0.33 (8h/day)</td>
<td>Day/day</td>
</tr>
<tr>
<td>Exposure Duration (ED)</td>
<td>25</td>
<td>Years</td>
</tr>
<tr>
<td>Inhalation Rate (IR)</td>
<td>20</td>
<td>m³/day</td>
</tr>
<tr>
<td>Inhalation Reference Dose (RfD)</td>
<td>0.0085</td>
<td>mg/kg/day</td>
</tr>
<tr>
<td>Slope Factor</td>
<td>0.0273</td>
<td>(mg/kg/day)⁻¹</td>
</tr>
</tbody>
</table>

Figure 1. Workers’ perception of benzene risk, using risk calculator of Kinney and Fine method.

Figure 2. Benzene risk management and risk perception levels among workers of the study refinery sites, using OSHA and COSHH guidelines.
awareness compared to other study sites, indicating its best control measures.

Analysis of phenol in urine samples of workers at the three study sites is illustrated in Table 2. Mean values were 57.5, 48.7 and 55.5 mg/gm Creatinine, at site one, site two, and site three, respectively. ANOVA showed significant reduction, with standard deviation with significant reduction, of study site one, site two, and site three, respectively. The results revealed that site two was significantly different at p=0.006.

Table 3 shows the average benzene daily exposure among workers at site-one oil refinery through analysis in multiple working locations. The highest benzene exposure was at LAB complex area with an average of 3717 µg/m². LADD was 82.5 µg/kg/day, HQ = 9.7 and cancer risk was 2253 per 10⁶. At pump station area, the average benzene exposure was 1779 µg/m³, LADD was 39.5 µg/kg/day, HQ = 4.6 and cancer risk was 1078.5 per 10⁶. At tank farm, the average benzene exposure was 1373 µg/m³, LADD was 30.5 µg/kg/day, HQ = 3.6 and cancer risk was 832.3 per 10⁶. Neir compressor station, the average benzene exposure was 1280 µg/m³, LADD was 28.4 µg/kg/day, HQ = 3.3 and cancer risk was 775.6 per 10⁶. Near utility area, the average benzene exposure was 930 µg/m³, LADD was 20.6 µg/kg/day, HQ = 2.4 and cancer risk was 564 per 10⁶. The whole site average benzene exposure was 1815.8 µg/m³, LADD was 40.3 µg/kg/day, HQ = 4.72 and cancer risk was 1100.68 per 10⁶. As illustrated, HQ was above one for all locations within site one, indicating health risk for working subjects.

Table 4 shows the average benzene daily exposure among workers at site-two oil refinery through analysis in multiple working locations. The highest benzene exposure was at tank farm area with an average of 420.5 µg/m³, LADD was 9.33 µg/kg/day, HQ = 1.1 and cancer risk was 255 per 10⁶. At PACOL unit, the average benzene exposure was 394 µg/m³, LADD was 8.75 µg/kg/day, HQ = 1 and cancer risk was 239 per 10⁶. At Sulfoline unit, the average benzene exposure was 315 µg/m³, LADD was 7 µg/kg/day, HQ = 0.8 and cancer risk was 190 per 10⁶. At laboratories, the average benzene exposure was 92 µg/m³, LADD was 2 µg/kg/day, HQ = 0.23 and cancer risk was 55.7 per 10⁶. The whole site average benzene exposure was 305.4 µg/m³, LADD was 6.77 µg/kg/day, HQ = 0.78 and cancer risk was 185 per 10⁶. As illustrated, HQ is less than 1, then the exposed local population is safe.

Table 5 shows the average benzene daily exposure among workers at site-three oil refinery through analysis in multiple working locations. The highest benzene exposure was at CCR unit with an average of 545 µg/m³, LADD was 12.1 µg/kg/day, HQ = 1.4 and cancer risk was 330 per 10⁶. At isomerization area, the average benzene exposure was 427 µg/m³, LADD was 9.5 µg/kg/day, HQ = 1.1 and cancer risk was 259 per 10⁶. The whole site average benzene exposure was 395 µg/m³, LADD was 9 µg/kg/day, HQ = 1 and cancer risk was 247 per 10⁶. HQ is less than 1, then the exposed local population is safe and when HQ is equal to or higher than 1, is considered as not safe for human health, therefore related interventions and protective measurements should be taken.

**DISCUSSION**

**Risk perception**

Benzene risk perception at the three studied sites revealed a lack in benzene risk management and the guidelines of OSHA or COSHH besides the Egyptian laws for exposure control were not fulfilled all times, especially for benzene hazard communication, which was reflected as a low level of awareness. Oleinick (2014) reported that Health Communication Standard, HCS, was associated with significant reduction in chemical events including; acute injuries/illnesses and chemical carcinogen exposures.

The selection of the suitable breathing apparatus to work in areas containing benzene is not well regulated as half of the study sample reported that they have no idea about the selection criteria and are not sure about the validity of breathing accessories (filters, cartridge...etc.). Kirkeleit et al. (2006) reported that the efficiency of half-mask respirator for organic solvents is affected by several factors, such as the fitting of the respirator, face piece and the frequency of cartridge exchange.

The three sites have periodic medical monitoring program as the majority of study sample reported that they submitted to periodic medical surveillance program to check benzene exposure, but the majority of study samples reported that they are not notified of the medical check results. They also are not aware of the biological exposure index for benzene BEI. The majority of samples reported that their company does not take the appropriate action in case of confirmed over exposure or exceeding BEI or they ignore what company do in such occasions. The results are in consistence with the findings of Williams, 2014, study when he analyzed the violation of OSHA benzene standards.

It was shown that most of the study workers reported that benzene exposure has no risk at all or have a low degree of risk, only 14% reported medium risk, 7.3% reported high risk and 10.7% reported very high risk. Site-two gave the best results for risk perception tool. The samples risk calculation was not in line with results of Falzon et al. (2016) who reported that exposure to
Table 2. Analysis of phenol in the urine of workers of oil refineries.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SD</th>
<th>F (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>57.5</td>
<td>35.0</td>
<td>100.0</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>Site 2</td>
<td>48.7</td>
<td>30.0</td>
<td>76.0</td>
<td>12.4</td>
<td>5.2 (0.006) *</td>
</tr>
<tr>
<td>Site 3</td>
<td>55.5</td>
<td>28.0</td>
<td>77.0</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54.2</td>
<td>28.0</td>
<td>100.0</td>
<td>14.2</td>
<td></td>
</tr>
</tbody>
</table>

F: One Way ANOVA  d: Significantly different group  * P < 0.05 (significant)

Table 3. Health risk assessment at Site-one.

<table>
<thead>
<tr>
<th>Location</th>
<th>Conc. µg/m3</th>
<th>LADD µg/kg/day</th>
<th>HQ</th>
<th>CR per 10⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Farm</td>
<td>1373</td>
<td>30.5</td>
<td>3.6</td>
<td>832.3</td>
</tr>
<tr>
<td>Pump station</td>
<td>1779</td>
<td>39.5</td>
<td>4.6</td>
<td>1078.5</td>
</tr>
<tr>
<td>Comp. station</td>
<td>1280</td>
<td>28.4</td>
<td>3.3</td>
<td>775.6</td>
</tr>
<tr>
<td>LAB complex</td>
<td>3717</td>
<td>82.5</td>
<td>9.7</td>
<td>2253</td>
</tr>
<tr>
<td>Utility</td>
<td>930</td>
<td>20.6</td>
<td>2.4</td>
<td>564</td>
</tr>
<tr>
<td>Site-1 Average</td>
<td>1815.8</td>
<td>40.3</td>
<td>4.72</td>
<td>1100.68</td>
</tr>
</tbody>
</table>

Table 4. Health risk assessment at Site-two.

<table>
<thead>
<tr>
<th>Location</th>
<th>Conc. µg/m3</th>
<th>LADD µg/kg/day</th>
<th>HQ</th>
<th>CR per 10⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Farm</td>
<td>420.5</td>
<td>9.33</td>
<td>1.1</td>
<td>255</td>
</tr>
<tr>
<td>PACOL unit</td>
<td>394</td>
<td>8.75</td>
<td>1</td>
<td>239</td>
</tr>
<tr>
<td>Sulpholane</td>
<td>315</td>
<td>7</td>
<td>0.8</td>
<td>190</td>
</tr>
<tr>
<td>LAB</td>
<td>92</td>
<td>2</td>
<td>0.23</td>
<td>55.7</td>
</tr>
<tr>
<td>Site-2 Average</td>
<td>305.4</td>
<td>6.77</td>
<td>0.78</td>
<td>185</td>
</tr>
</tbody>
</table>

Table 5. Health risk assessment at Site-three.

<table>
<thead>
<tr>
<th>Location</th>
<th>Conc. µg/m3</th>
<th>LADD µg/kg/day</th>
<th>HQ</th>
<th>CR per 10⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank farm</td>
<td>411</td>
<td>9.1</td>
<td>1</td>
<td>249</td>
</tr>
<tr>
<td>CDU</td>
<td>377.5</td>
<td>8.4</td>
<td>1</td>
<td>229</td>
</tr>
<tr>
<td>CCR</td>
<td>545</td>
<td>12.1</td>
<td>1.4</td>
<td>330</td>
</tr>
<tr>
<td>Reform.</td>
<td>349</td>
<td>7.8</td>
<td>0.9</td>
<td>211</td>
</tr>
<tr>
<td>Iso.</td>
<td>427</td>
<td>9.5</td>
<td>1.1</td>
<td>259</td>
</tr>
<tr>
<td>HCK</td>
<td>350.5</td>
<td>7.8</td>
<td>0.9</td>
<td>212</td>
</tr>
<tr>
<td>VDU</td>
<td>314.7</td>
<td>9.2</td>
<td>1</td>
<td>250</td>
</tr>
<tr>
<td>NHT</td>
<td>387</td>
<td>8.6</td>
<td>1</td>
<td>234</td>
</tr>
<tr>
<td>Site-3 Average</td>
<td>395</td>
<td>9</td>
<td>1</td>
<td>247</td>
</tr>
</tbody>
</table>

benzene is the most important cancer risk factors during work activities.

Ambient benzene measurements

The data in site-one showed the average concentration is 0.55 ppm exceeds the Egyptian law but comply with OSHA benzene standard. Sites-two and three had average benzene concentration of 0.1 ppm. Increasing levels more than 1 ppm benzene as per OSHA can result in overexposures as well as for 0.5 ppm benzene TWA (Verna et al., 2001). The results are in agreement with those obtained by Kreider et al. (2010) at ExxonMobil Joliet refinery study and Gaffney et al. (2011 and 2010) at ExxonMobil Baytown refinery and ExxonMobil Beaumont refinery. Panko et al. (2009) study on Baton Rouge refinery showed better results with 0.097 ppm average benzene concentration and confirmed the findings of Williams et al. (2008) and
Kawai et al. (1990) findings in Japanese petroleum refinery.

**Biological monitoring**

Human biomonitoring provides an efficient and cost-effective mean of measuring human exposure to occupational and environmental chemicals. It considers all sources of exposure and all routes of uptake proving in most cases to be an excellent instrument for risk assessment and risk management (Carriera et al., 2010). Benzene biomonitoring was performed for the three refineries by measuring phenol in urine as a standard biomarker for benzene exposure (Wiwanitkit et al., 2004). The main metabolite of benzene, phenol, is by far the most widely investigated and well-documented variable for biological monitoring of benzene (Ong et al., 1996). Measurement of urinary phenol levels has historically been the standard bioassay for benzene exposure, despite the well-described limitations of this test. Selecting the phenol as a biomarker was traditional routine in Egyptian petroleum industry and was advised by site occupational physicians. The study investigated all study samples from the three sites, the presence of phenol in post-shift urine were considered as a proof of occupational exposure (Bogadi-Sare et al., 1996). The mean concentration of phenol for all sites was 54.2 mg/g Creatinine urinary and site-two showed the least concentration with a mean value of 48.7 mg/g Creatinine, within the limit of ACGIH-BEI value. Site-one workers had the highest mean value; 57.5 mg/g Creatinine and site-three 55.5 mg/g Creatinine. The biomonitoring results were also consistent with ambient benzene concentration measurements. The results were in line with findings of Kim et al. (2006), who found that the urine concentration of phenol was consistently elevated when the group’s median benzene exposure was at or above 0.5 ppm air concentrations. The results of Kim et al. (2006) and Mohamed et al. (2013) showed that despite low benzene exposure in the work atmosphere and the use of personal protective equipment to a varying degree, the site’s personnel had a significant uptake of benzene that correlated highly with benzene exposure probably due to an extended work schedule of 12h and physical strain during work or other confounding factors. Control measures should be improved for processes, which impose a potential for increased absorption of benzene upon the workers (Kirkeleit et al., 2006).

**Health Risk Assessment**

In this study, both cancer and non-cancer risk were estimated. The cancer risks were calculated by the mathematical equations to determine the number of individuals likely to acquire cancers due to their exposure to benzene from inhalation uptake (Yan et al., 2015). Health risk assessment was calculated for the three sites by mathematical equations in agreement with the study conducted by Hazrati et al. 2016, Edokpolo et al. 2015, and Yan et al. 2015. Benzene concentrations were converted from ppm to μg/m³ to μg/kg/day in terms of Lifetime Average Daily Dose (LADD) which in turn were used in calculating the Hazard quotient (HQ) and cancer risk (CR) by using the values of USEPA Inhalation Reference Dose (RFD) and Slope Factor (SF). The HQ method of risk characterization was used to estimate the adverse health effects and non-cancer risks for exposure to benzene (Majumdar et al., 2008). Cancer risk is expressed as the excess risk of developing cancer over a lifetime of exposure (70 years) (Edokpolo et al., 2015). HQ values for site-one were always the highest values and >1, which mean that site-one exposed personnel are likely to have adverse health effects more than the other sites (Edokpolo et al., 2015). Which means that their non-cancer risk was at the level of definite concern. Compared with site one, site two registered good and safe values especially after 2010 results as always the HQ <1, site three values were closer and similar to site two values and clearly better than the site one but the average of HQ is equal to 1 indicating that they were usually at the level of concern (Yan et al., 2015).

Similarly, site-one showed the maximum cancer potential risk compared to the other studied sites with a value of 1100 per 10⁶, and exceed OSHA 1993 probability of cancer risk with PEL exposure (Majumdar et al., 2008). Site-two had the lowest cancer risk values among the three sites with an average of 185 per 10⁶. Site-three had an average of 247 per 10⁶ cancer risks. The results were in line with the findings of Hazrati et al. (2016) and Edokpolo et al. (2015) and Yan et al. (2015).

**CONCLUSION**

Conclusively, the underlying study highlight the importance of health risk assessment to evaluate the daily occupational benzene exposure rates which simultaneous can result in sub threshold exposures that could result in adverse health effects. Thus intentional attempts should be directed to preserve the public health regarding this type of work-related pollution.

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