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ORIGINAL ARTICLE

BENZENE HEALTH RISK ASSESSMENT FOR NEUROLOGICAL DISORDERS OF GAS STATION EMPLOYEES IN RAYONG PROVINCE, THAILAND

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ABSTRACT

Background. The main job of employees working in the area of fuel service stations is to provide refueling services to customers. Therefore, operators at petrol stations may be exposed to chemicals for long periods, potentially affecting their health in nervous system.

Objectives. This study aims to assess the risk of benzene exposure to the nervous system in gas station operators. Data were collected from 100 fuel service personnel working at fuel dispensers and 100 employees working outside fuel dispensers, accounting to 200 cases.

Material and methods. Data were collected using interview questionnaires. Urine samples were used for the analysis of t,t-muconic acid.

Results. The results showed that t,t-muconic acid concentration is 431.23 ± 233.69 µg/g.cr (449.28 ± 213.32 µg/g.cr at fuel dispensers vs 413.18 ± 252.20 µg/g.cr outside fuel dispensers). The risk characterization results showed that most of the risks were at level 1 (low risk), as observed in 108 people (54.0%). The results of the analysis of the relationship between t,t-muconic acid concentrations classified by 3 levels of percentile and neurological disorders of the study group, the results showed that there was a statistically significant relationship (p-value <0.05).

Conclusion. Therefore, the benzene neurotoxic risk assessment model could be utilized in field practice.

Key words: *health risk assessment, benzene, petrol station, worker, Rayong province, Thailand*

INTRODUCTION

Employees working in gas stations are one of the personnel that contributes to the development of a country. However, employees working at a gas station do not only work as refueling service employees but also perform various services, which include working in grocery stores, restaurants, coffee shops, sanitary facilities, engine repairs, or car washes [1, 2]. Rayong province is one of the provinces with investment in transportation expansion of the industry, agriculture, and marine tourism. As a result, there are more businesses to support the economic growth of a country [3].

The main job of employees working in the area of fuel service stations is to provide refueling services to customers. However, there are also other occupations operating in these areas, with employees normally working for more than 8 h per day [1]. Therefore, these employees are more likely to be exposed to latent occupational hazards [4, 5]. Operators at petrol stations may be exposed to chemicals for long periods, potentially affecting their health in many systems [6]. The main effect is in the nervous system, which is now attracting concern [7, 8]. If employees are exposed to excessive amounts of benzene, this can damage the central nervous system (CNS), until they abnormal symptoms such as depression [8], resulting in cognitive and behavioral disorders [9]. It is very important that benzene is classified as a carcinogen and can be harmful to health, causing leukemia [9, 10] even after long-term exposure to low benzene concentrations [11].

Health surveillance for high-risk groups exposed to benzene while working in the gas station was achieved by assessing the biomarker of exposure in

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the urinary benzene in the form of t,t-muconic acid, or S-phenyl mercapturic acid [12]. In addition, health impact assessments, including changes in biochemical indicators [13] are also gaining interest. In addition, symptoms of various system disorders can be assessed, especially assessment of neurological disorders by using a neurological disorder questionnaire such as the modified EURO QUEST questionnaire [14] and using neurobehavioral system tests [15] to assess the neurological health of at-risk groups, etc.

Therefore, health risk assessment of benzene in gas stations for health is very important. In this case, health risk assessment for toxic pollutants including the low dose of benzene must be carried out to determine the possible adverse effects of exposure to this substance [16]. Particularly, benzene is a carcinogen and is highly toxic to the body [9]. In Thailand, there are health risk assessment guidelines according to the TIS 2012 standard, which is used for the assessment of chemical health risks. It will be helpful to figure out how to manage to avoid exposure to benzene at the source [17].

Previous studies have examined the risks of exposure to low concentrations of benzene, to the health of workers in China [7]. Health risk assessments of various chemicals, including benzene, take many models, such as the model of the United States Environmental Protection Agency [16, 18] and the biomatrix of health risk assessment model, which recommends the use of t,t-MA [1]. No previous studies have been conducted to assess the risk of benzene on neurological symptoms which will be useful as a guideline for health surveillance among employees working at fuel stations that currently do not have annual health checks based on risk factors like in the industry which appears only in research studies [19, 20]. Therefore, the researcher is interested in studying to assess the risk of benzene in the nervous system of employees working at a fuel service station in Rayong province. This study is expected to be useful as a tool for screening health risks to prevent the risk of benzene on the nervous system in the at-risk group.

MATERIAL AND MEDTHODS

Study site and population

The study population consists of employees of gas stations in Rayong province. Initially, the researcher coordinated with the municipality for public relations and chose a fuel service station adjacent to the main road of Rayong. A simple random sampling was then performed for the selection of employees. The researchers randomly selected a group (cluster random sampling), i.e., refueling service workers, according to the inclusion criteria by selecting everyone voluntarily at each gas station. If the number of samples was insufficient, employees in the next gas station were chosen.

Sample size calculation

In a sample of 200 cases, calculated from a previous study by *Chaiklieng* and *Nantanuch* [21], 83.7% of workers who had worked at gas stations experienced adverse reactions (P = 0.837), with a 5% error (e = 0.05) 95% CI (Z = 1.96). The sample size was 200 cases, which are classified as the exposure group of 100 people who work in a gas station with a duty to provide fuel services and the control group (non-exposure group) of 100 employees who work in a fuel service station without having to directly service the fuel. The inclusion criteria included fuel service station employees aged between 18 and 60 years, able to read, listen, and write Thai consent to participate in the research, and able to work on the data collection day for 8 h. The exclusion criterion included employees who cannot complete 8 h of work and are unable to participate in research activities.

Research ethics

This study is conducted in consideration of human research ethics from the Human Research Committee of Burapha University (Research Project Code No. HS 031/2020, certified on July 22, 2020, completed before data collection).

Data collection tools

Step 1. **Data collection: demographic information, work history, symptoms of nervous system disorders, and t,t-muconic acid in urine.**

The instruments and data collection in this study is divided into two parts, i.e., the interview form and the urine sample collection device.

Interview questionnaires: The research tool and data collection were interview questionnaires, divided into 3 parts, totaling 30 items, scored by selecting answers and filling in the words.

Part 1 - includes ten personal data, such as gender, age, body mass index, marital status, education level, and history of smoking and consumption of alcohol.

Part 2 - includes the work history of five items such as work experience (years), the number of hours worked in a day (hours), the number of days worked per week (days), overtime (hours/week), and sleep time per night (hours).

Part 3 - includes 15 neurological symptoms, i.e., (1) Vertigo, (2) headache, (3) dizziness, (4) nausea and vomiting, (5) fatigue/easy fatigue, (6) more drowsy than usual, (7) lack of concentration and poor memory, (8) stressed and easily irritated, (9) lack of smell, (10) taste changes, (11) numbness of the hands and feet, (12) facial numbness, (13) limb weakness, (14) hand tremor, and (15) decreased sexual sensation. These neurological symptoms are classified into five levels: (1) 0–2 symptoms with a score of 1, (2) 3–5 symptoms with a score of 2, (3) 6–8 symptoms with a score of 3, and (4) 9–11 symptoms with a score of 4 points, and (5) 12–15 or more symptoms with a score of 5.

Quality test of the questionnaires: A quality test of the interview questionnaire by considering the content validity, structure, and objectives of the research including the appropriateness of the language. The reliability was checked by finding *Cronbach's* alpha coefficient equal to 0.88.

Urine sampling: The equipment used for the biological samples is a delivery slip, plastic jar, and polyethylene tubes intended for urine collection. The levels of t,t-muconic acid are assessed based on the interpretation criteria recommended by the American Conference of Governmental Industrial Hygienists [22].

Data collection

Collecting data from interview questionnaires: Data collection by interview questionnaires starts with the researcher explaining to the research assistants to understand the question line accordingly. Later, the researchers met with managers again at each gas station's appointment and started collecting research data by interviewing each individual at each gas station. The interview time was 10–15 min at the office area of each gas station.

Urine sample collection: The employees were informed to collect a mid-stream urine sample in the plastic cup provided. At least 50 ml of this sample was placed into cold storage immediately. The urine specimen collections were sent to the laboratory each day and stored at -20 C to analyze the t,t-MA concentration for benzene. The urine samples were analyzed using HPLC following the method described in these studies [23, 24].

Step 2. Assessing the risk of benzene on the nervous system

Hazard identification: In this first step, the researcher uses the information collected from personal data, work history (i.e., exposure frequency (EF), exposure duration, the amount of substance, t,t-muconic acid in the urine of the sample consisted of the refueling service department, cashier, loading petrol, car washing, car repair, selling in convenience stores, raw materials to identify the hazards of benzene in the work area. The researchers search, collect and study the chemical information (Safety Data Sheet, SDS) of benzene, benzene exposure, and health effect information.

Health effect assessment: Assessment of the effects of benzene on the nervous system as health effect rating (HER) is classified using the results collected from the first step of the assessment of 15 neurological disorders classified into 5 levels: 1) 0–2 symptoms = 1 point, 2) 3–5 symptoms = 2 points, 3) 6–8 symptoms = 3 points, 4) 9–11 symptoms = 4 points, 5) 12–15 or more symptoms = 5 points

Exposure assessment: Exposure assessment of benzene was calculated using data from exposure frequency and urinary t,t-muconic acid levels as follows:

(a) Exposure frequency (EF) consisted of five levels: (1) the frequency of exposure once a year, (2) exposure 2–3 times a year, (3) exposure 2–3 times a month, (4) exposure for 2–4 h consecutively in one shift, and (5) exposure throughout the shift, respectively.

(b) Concentration rating (CR): Urinary t,t-muconic acid levels are calculated by comparing t,t-muconic acid levels with the biological exposure index (BEI) [22] resulting in the chemical concentrations as (Concentration rating, CR) which are classified into 5 levels: Level 1 (Below BEI 10%), level 2 (Below 50%), level 3 (Below 75%), level 4 (75–100), and level 5 (Above 100%), respectively [17].

(c) Exposure assessment score: EAS is calculated by multiplying EF (level 1–5) and CR (level 1–5) as (EAS) = [EF × CR]. EAS was classified into five exposure rating (ER) groups as follows: Level 1: Acceptable (1–3 points), Level 2: Low (4–9 points), Level 3: Moderate (10–16 points), Level 4: High (17–20 points), Level 5: Very high (21–25 points) [17].

Risk characterization

Risk characterization is calculated by multiplying the ER and the HER as [hazard characterization = ER × HER]. The multiplied scores of ER and HER were then used to classify the 5 levels of risk characteristics as follows: Level 1: 1–3 points = acceptable or no significance, Level 2: 4–9 points = low, Level 3: 10–16 points = medium, Level 4: 17–20 points = high, Level 5: 21–25 points = very high [17].

Statistics analysis

The statistics used in the study were descriptive statistics, including frequency, percentage, mean, standard deviation, and range (minimum/maximum). *Chi*-square statistics were used to analyze the data to determine the relationship between t,t-muconic acid of BEI levels and neurologic disorder symptoms.

RESULTS

Part 1. Demographic information, work history, and neurological disorders

This study found the number of males and females is similar amount of which 68.5% were females more than males. The mean age was 30.25 ± 11.105 years, and the average body mass index is 23.63 ± 5.26 kg/sqm classified as at the fuel dispenser at 32.0% and outside the fuel dispenser at 10%, drinking alcoholic beverages at 49.0% at the fuel dispenser 49% and outside the fuel dispenser 42.0%.

Work history: The results of this study found that working experience is 2.44 ± 4.06 years (1.61 ± 2.85 years at the fuel dispensers vs 3.81 ± 5.27 years outside the fuel dispensers), hours worked are 9.05 ± 1.57 h/day (9.09 ± 1.54 h/day at the fuel dispensers vs 8.98 ± 1.63 h/day outside the fuel dispensers), the number of days worked is 6.31 ± 2 day/week (6.32 ± 0.49 years at the fuel dispensers vs 6.30 ± 0.46 years outside the fuel dispensers), operation overtime is 6.42 ± 4.87 h/week (4.94 ± 2.61 h/week at the fuel dispensers vs 5.44 ± 2.60 h/week outside the fuel dispensers). Table 1 presents the details.

Table 1. Work history at fuel dispenser and outside the fuel dispenser

Work history	Fuel dispenser area	Outside fuel dispenser area	Total
Work experience (years), Mean±SD	1.61±2.848	3.81±5.266	2.44±4.063
Working hours per day, Mean±SD	9.09±1.535	8.98±1.628	9.05±1.568
Workdays per week, Mean±SD	6.32±0.489	6.30±0.460	6.31±0.477
Overtime work hours/week, Mean±SD	6.53±4.777	6.23±5.145	6.42±4.871

Table 2. Number (percentage) of neurological disorders among workers in gas station workers

Neurological disorders	n (%) of neurological disorders								
	Fuel dispenser area			Outside fuel dispenser area			Total		
	No	Sometimes	Frequent	No	Sometimes	Frequent	No	Sometimes	Frequent
1 Vertigo	58 (58.0)	40 (40.0)	2 (2.0)	57 (57.0)	38 (38.0)	5 (5.0)	115 (57.5)	78 (39.0)	7 (3.5)
2 Headache	53 (53.0)	44 (44.0)	5 (5.0)	49 (49.0)	41 (41.0)	10 (10.0)	102 (51)	83 (41.5)	15 (41.5)
3 Dizziness	64 (64.0)	34 (34.0)	2 (2.0)	62 (62.0)	33 (33.0)	5 (5.0)	126 (63.0)	67 (33.5)	7 (3.5)
4. Nausea/vomiting	82 (82.0)	18 (18.0)	0 (0.0)	85 (85.0)	14 (14.0)	1 (1.0)	167 (83.5)	32 (16.0)	1 (5.0)
5. Tired, easily tired	70 (70)	29 (29)	1 (1)	71 (71.0)	25 (25.0)	4 (4.0)	141 (70.5)	54 (27.0)	5 (2.5)
6. More drowsy than usual	78 (78.0)	20 (20.0)	2 (2.0)	77 (77.0)	21 (21.0)	2 (2.0)	155 (77.5)	41 (20.5)	4 (2.0)
7.Lack of concentration and poor memory	79 (79.0)	21 (21.0)	0 (0.0)	74 (74.0)	24 (24.0)	2 (2.0)	153 (76.5)	45 (22.5)	2 (1.0)
8. Stressed, easily irritated	68 (68.0)	29 (29.0)	3 (3.0)	55 (55.0)	37 (37.0)	8 (8.0)	123 (61.5)	66 (33.0)	11 (5.5)
9. lack of smell	91 (91)	8 (8.0)	1 (1.0)	92 (92.0)	7 (7.0)	1 (1.0)	183 (91.5)	15 (7.5)	2 (1.0)
10. Taste changes	93 (93.0)	7 (7.0)	0 (0.0)	95 (95.0)	5 (5.0)	0 (0.0)	188 (94.0)	12 (6.0)	0 (0.0)
11. Numbness of the hands and feet	81 (81.0)	16 (16.0)	3 (3.0)	74 (74.0)	20 (20.0)	6 (6.0)	155 (77.5)	36 (18.0)	9 (95.5)
12. Facial numbness	97 (97.0)	3 (3.0)	0 (0.0)	98 (98.0)	2 (2.0)	0 (0.0)	195 (97.5)	5 (2.5)	0 (0)
13. Weak limbs	86 (86.0)	12 (12.0)	2 (2.0)	87 (87.0)	10 (10.0)	3 (3.0)	173 (86.5)	22 (11.0)	5
14. Hand tremor	89 (89.0)	11 (11.0)	0 (0.0)	81 (81.0)	14 (14.0)	5 (5.0)	170 (85.0)	25 (12.5)	5 (2.5)
15. Decreased sexual sensation	94 (94.0)	4 (4.0)	2 (2.0)	88 (88.0)	11 (11.0)	1 (1.0)	182 (91.0)	15 (7.5)	3 (1.5)

Neurological disorders in employees working at and outside the fuel dispensers were observed during the past 3 months to the present, which sometimes include headaches (44.0% at the fuel dispensers vs 41.0% outside the fuel dispensers) and dizziness (40.0% at the fuel dispensers vs 38.0% outside the fuel dispensers), as presented in Table 2.

Part 2. Assessment of neurological risk from benzene exposure

Exposure assessment

The results of the analysis of t,t-muconic acid levels showed the mean ± SD of the t,t-muconic acid concentration was 431.23 ± 233.69 µg/g.cr (449.28 ± 213.32 µg/g.cr at fuel dispensers vs 413.18 ± 252.20 µg/g.cr outside the fuel dispensers), and the range(min, max) is 393.40 (59.71–1482.46 µg /g.cr) classified as at fuel dispensers area 428.23 (95.58 - .1202.56 µg /g.cr and outside the fuel dispensers 375.57 (59.71–1,482.46), as presented in Table 3.

The results showed that urinary t,t-muconic acid levels compared to BEI as exposure concentration (EC) were mostly EC levels >100% of BEI (500 µg/g.cr) in 59 cases (29.5%) and EF level of benzene exposure continuously throughout the shift of 200 cases (100%), the details of which are shown in Table 4.

The result showed that the majority of ER were moderate or level 3 as observed in 92 cases (46.0%), followed by very high or level 5 as observed in 59 cases (29.5%), as presented in Table 5.

Table 3. Concentration of t,t-muconic acid in the urine of workers working at the fuel dispenser and outside the fuel

Benzene exposure indicators	Fuel dispenser area n=100		Outside fuel dispenser area n=100		Total (n=200)	
	n	%	n	%	n	%
t,t-Muconic acid in the urine (µg/g.cr)						
<500	67	67.0	74	74.0	141	70.5
≥500	33	33.0	26	26.0	59	29.5
Mean±SD	449.284±213.323		413.179±252.200		431.232±233.686	
Median Min-max	428.23 95.58-1202.56		375.57 59.71-1482.46		393.40 59.71-1482.46	
Percentile of t,t-muconic acid in urine (µg/g.cr)						
25					274.59	
50					393.62	
75					519.17	

Table 4. Number and percentage of urinary t,t-muconic acid levels classify groups by comparing with BEI values, EC, and BEF

Level of exposure concentration (µg/g.cr)	Urinary t,t-muconic acid levels classify groups by comparing with BEI values	n (%)
1 (<25)	<10% of BEI (500 µg/g.cr)	0 (0.0)
2 (<250)	<50% of BEI (500 µg/g.cr)	40 (20.0)
3 (<375)	<75% of BEI (500 µg/g.cr)	52 (26.0)
4 (375-500)	<75-100% of BEI (500 ug/dl)	49 (24.5)
5(>500)	>100% of BEI (500 µg/g.cr)	59 (29.5)
Level of the frequency of exposure to benzene (1–5)	The frequency of exposure to benzene	
1	Infrequently	0 (0.0)
2	2-3 times a year	0 (0.0)
3	2-3 times a month	0 (0.0)
4	2-4 h per shift	0 (0.0)
5	Continuous exposure throughout the shift	200 (100.0)

BE – biological exposure index, EC – exposure concentration, BEF – benzene exposure frequency

Classification of effects on the nervous system (HER)

The results of the study on the classification of effects on the nervous system (HER) showed that most of the severity belonged to level 1 (no impact), as observed in 101 cases (40%), followed by level 2 (low impact) in 48 cases (24%), respectively, as presented in Table 6.

Risk characterization rating

Regarding risk characterization, the results found that most of them are at level 1 (low level), as observed in 108 cases (54.0%), followed by level 0 (acceptable) in 45 cases (22.5%), as presented in Table 7.

Table 5. Number and percentage of urinary benzene exposure rating (ER)

EF	t,t-muconic acid of BEI					Exposure rating (ER)		n	%
	1	2	3	4	5	EAS	Classification		
1	1	2	3	4	5	1-3	1=Acceptable	0	0.0
2	2	4	6	8	10	4-6	2=Low	0	0.0
3	3	6	9	13	15	10-16	3=Moderate	92	46.0
4	4	8	12	16	20	17-20	4=High	49	24.5
5	5	10	15	20	25	21-25	5=Very high	59	29.5

EF – Exposure frequency, EAS - Exposure assessment score

Table 6. Number and percentage of the severity of neurological symptoms

Level	Adverse symptom level	Nervous system disorders (symptoms)	n	%
1	Non-symptomatic	1 (0-2)	101	50.5
2	Low	2 (3-5)	48	24.0
3	Moderate	3 (6-8)	27	13.5
4	High	4 (9-11)	14	7.0
5	Very high	5 (12-15)	10	5.0

Table 7. Number and percentage of risk level calculated from exposure rating (ER) × severe health effect rating (HER)

Risk level			n	%
Score range (1-3/4-9)	Level	Level		
1-3	Acceptable	0	45	22.5
4-9	Low	1	108	54.0
10-16	Moderate	2	34	17.0
17-20	High	3	10	5.0
21-25	Very high	4	3	1.5
Total			200	100

Table 8. Relationship between urinary benzene concentrations and neurological disorders among employees in the fuel dispenser worker group and those outside the fuel dispenser worker group

Neurological disorder (Symptoms)	t,t-muconic acid in the urine (µg/g.cr)			Total, n (%)	P-value
	Percentile 25 (274.59 µg/g.cr), n (%)	Percentile 50 (293.62 µg/g.cr), n (%)	Percentile 75 (519.17 µg/g.cr), n (%)		
Classification of symptoms					
1 (0-2)	27 (54.0)	22 (44.0)	52 (52)	101 (50.5)	0.030*
2 (3-5)	11 (22.0)	12 (24.0)	25 (25.0)	48 (24.0)	
3 (6-8)	6 (12.0)	14 (28.0)	7 (7.0)	27 (13.5)	
4 (9-11)	4 (8.0)	2 (4.0)	8 (8.0)	14 (7.0)	
5 (12-15)	2 (4.0)	0 (0)	100 (100)	10 (5.0.03)	

Part 3. Examining the relationship between urinary benzene concentrations and neurological disorders

Assessment of the relationship between t,t-muconic acid, was classified according to 3 levels of percentile, 25, 50, and 75, with neurological disorders of the workers in the fuel dispenser area and the workers outside the fuel dispenser. The results showed that there was a statistically significant relationship (p-value <.05), as presented in Table 8.

Zones of gasoline stations and areas of work about the likelihood of exposure levels, adverse effects, and risk characterization are shown in Table 9

DISCUSSION

This study aims to assess the risk of benzene exposure to the nervous system among fuel service providers according to a health risk assessment model applied from the notification of the Ministry of Industry, Chemical Risk Assessment B.E. 2012 [17]. The results found that the mean age was 30.25 (±11.015) years, considered to be the working age consistent with the results of studies in Indonesia, indicating that the average age of employees working at gas stations was 29.90 years [25] as well as in Brazil with an average age of 30-year-old employees [26]. This study reported more female (68.5%) than male (36.5%) subjects, consistent with the 2021 National Statistical Report, indicating that the population is classified by labor status and sex. Throughout the kingdom, there are more female workers than males [27]. However, this study was not consistent with the study of *Tunsaringkasm* et al. [13] who studied the characteristics of employees at a gas station, in which most subjects were male.

Regarding the evidence of studies in humans, gender-specific differences appear to be variables of interest when considering benzene exposure and health effects. Previous research suggests the likelihood of a particular risk of health consequences for women [28]. Epidemiological evidence shows that women are involved greater in the effects of benzene exposure on health than males [29]. Finally, evidence that emerged about a different rate of metabolization of benzene in women rather than in men calls for further biochemical surveys to understand how this difference could lead to toxicologically relevant effects [30].

Assessing the risk of benzene on neurological disorders

The results of this study showed that the researcher applied a model of chemical health risk assessment according to the guidelines of the Ministry of Industry [17] with the following criteria: frequency of exposure, chemical concentration, and the severity of health symptoms. In this research, the focus was on

Table 9. Zones of gasoline stations and areas of working with the likelihood of exposure levels, adverse effects, and risk characterization (n=200)

Parameters	Likelihood of exposure levels					Adverse health effects					Risk characterization				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Zone															
Control zone 1	0(0.0)	0(0.0)	61(66.3)	33(67.3)	42(72.9)	75(74.3)	29(60.4)	17(63.0)	12(85.7)	4(40.0)	30(66.7)	77(71.3)	23(67.6)	5(50.0)	2(66.7)
Control zone 2	0(0.0)	0(0.0)	31(33.7)	16(32.7)	16(27.1)	26(25.7)	19(39.6)	10(37.0)	2(14.3)	6(60.0)	15(33.3)	31(28.7)	11(32.4)	5(50.0)	1(33.3)
Work area															
Oil distribution	0(0.0)	0(0.0)	42(45.7)	26(53.1)	32(54.2)	52(51.5)	27(56.3)	13(48.1)	5(37.5)	3(30.0)	18(40.0)	62(57.4)	16(47.1)	3(30.0)	1(33.3)
Outside oil distribution	0(0.0)	0(0.0)	50(54.3)	23(46.9)	27(45.8)	49(48.5)	21(43.8)	14(51.9)	9(64.3)	7(70.0)	27(60.0)	46(42.6)	18(52.9)	7(70.0)	2(66.7)

Control zone 1 – Control zone inside the pollution; Control zone 2 – control zone outside the pollution neurological symptoms, which were found to be the main effect of benzene exposure on health. Especially, employees working at gas stations exposed to a wide range of low levels of chemicals should be a concern as well. This requires modern strategies for risk assessment and management of chemical health risks [31].

Exposure to low concentrations of benzene in the workplace can pose a health risk. Therefore, benzene exposure should be assessed even at substandard concentrations [7]. In addition, the level of risk varies by job type and exposure to specific chemicals [32] as well as the type of health risk assessment [16, 18, 19]. The benefits of chemical risk assessment are for health monitoring of employees exposed to benzene [1] and for formulating control measures to reduce workers' exposure to chemicals [7, 33]. Health risk assessment is an intuitive and attractive method because it can be used even where information is limited and does not require specialization. It also shows a quick way to recognize the problem of risk, the severity of danger, and frequency/probability [34].

Exposure assessment

There is a way to start the framework of chemical risk assessment for human health, which is to consider exposure to external chemicals or infer endogenous chemical exposure from exogenous concentration measurements by modeling. However, some uncertainties may be characteristic of this exposure assessment method because it is possible that an overestimation may occur or may be too low [7]. Bioassays have been used to assess benzene exposure [19]. The biomarker should be as specific as possible to the chemical and highly sensitive to detect chemicals even at low levels [7]. The results of this study assessed biological exposure by evaluating urinary t,t-muconic acid in fuel service workers at the end of shift, as recommended by ACGIH [22] as BEI.

Analysis results showed that the concentration at the fuel dispenser was higher than outside the fuel dispenser area. In this study, the concentration of t,t-muconic acid was found to be higher than the level seen in the study of *Geraldino* [4], which is consistent with the study of *Fakhrinnur* et al. [25]. The urinary t,t-MA level of the exposure group was 480.74. (219.65) µg/g creatinine, which was significantly higher compared to 229.96 (127.80) µg/g creatinine in office workers.

It is important to keep in mind that benzene is a carcinogen [9], so airborne benzene levels must not exceed the chemical limit. Especially, for BEI, t,t-MA levels should be below 500 µg/g of creatinine. However, levels of benzene below the standard may present a health risk [7]. In operations at a gas station, employees working at and outside the fuel dispensers are both likely exposed to benzene because it is a vapor and can easily spread from the source to different areas [4]. Therefore, *in vivo* exposure to benzene should be assessed to predict benzene internal exposure. Examination of benzene in the blood is a reliable biomarker of exposure; however, many researchers have used urinary benzene to quantify exposure [35]. In this study, the urinary exposure of benzene in the form of t,t-muconic acid was assessed, comparing the t,t-muconic acid concentration with the BEI. It was found that most of the EC were >100% of the BEI (500 µg/g.cr) [22] of 59 cases (29.5%), inconsistent with the study by *Chaiklieng* [1], who found that the t,t-MA metabolite was detected in 77 workers (32.8%) and 16 workers (6.8%) with the highest level of more than 500 µg/g.cr (13 fueling workers and 3 cashiers).

In terms of operating frequency, most of the employees who work in gas stations have several working days per week were 6.31 ± 2.48 days. It can be seen that most employees have more than 40 h of work per week, which exceeds the law of the Labor Protection Act B.E. 1998 set in section [36]. Therefore, employees should focus on adequate bedtime to reduce the risk of benzene, therefore, employees have the opportunity to be exposed to benzene in the body throughout the working period due to 100% of employees with continuous operating frequency throughout the shift, this allows being exposed to benzene throughout the working period. This study found that the majority of ER results were moderate, as observed in 92 cases (46%). More attention is still needed to occupational health risks exposure to benzene, toluene, and xylenes lower than OEL [7].

Classification of adverse health effects

Regarding adverse health effects or health effect rating (HER) results of this study, most were at level 1 (no impact), as observed in 101 (40%) subjects. It can be seen that this model for categorizing the severity of benzene from neurodegenerative disorders is convenient for use in assessing neurologic risk. However, the benzene severity classification scheme differs from the Dick FD [37] categorization of neurologic symptoms, categorized into four stages: Type (1), symptoms only (symptoms); Type (2A), sustained personality or mood change; Type (2B), impairment in intellectual function; and Type (3), dementia: cognitive impairment.

In addition, the severity of symptoms in this study differed from the study by *Chaiklieng* et al. [1], which classified the severity of benzene as having an impact on health classified according to the severity of the symptoms, including all systems of the whole body. Therefore, those with related duties must be aware that gas station operators are exposed to low levels of benzene. Employees also have the opportunity to be exposed to benzene, which can affect the nervous system and other systems [7, 38].

Benzene is known to be one of the major constituents of BTEX as a neurotoxic constituent of fuel. Gasoline-induced neurotoxicity increased mood disorders, as reported in past studies that describe a link between exposure to benzene in fuel and risk of neurological symptoms after benzene exposure [8, 9]. A good understanding of the mode of action for benzene for the benefit of deciding the severity of neurotoxic effects can influence health risk assessments for benzene [38].

The case of benzene toxicity on the nervous system as neurotoxins may damage the CNS and cause depression, facial flushing, ataxia, vertigo, mental confusion, dizziness, giddiness, nausea, weakness, and headache if exposed to low benzene concentrations. It can also cause abnormal symptoms [7]. Therefore, continuous surveillance for neurological symptoms should be undertaken.

Risk characterization

The results of this study were able to identify the risk characterization. It was found that the majority were at level 1 (low risk. Risk characterization by pollution control area and outside pollution control area and the operating area around and outside the fuel dispenser showed that the level of risk characteristics was similar. However, although the majority of employees are at a low level of neurotoxicity with benzene, they should not be ignored even in the very high-risk group of only 10 cases (5%). Therefore, the health of employees' nervous systems should be monitored on an ongoing basis [7].

The neurotoxicity risk assessment of benzene, although using the same health risk assessment model as the other studies, is conducted (likelihood on exposure × severity) [1]. This has different educational contexts such as study methods, sample groups, and study areas, among others. Importantly, the area studied in this study is in Rayong province which is an area developed in industry, transportation, and tourism and has a very high economic growth [39]. In addition, this study examined the group of workers in the fuel service station that covers operators outside the fuel dispenser, who can also be exposed to benzene, such as the food and beverage trade group, convenience store groups, and others.

Urinary benzene concentrations and neurological symptoms

The urinary t,t-muconic acid levels were classified according to three levels of percentile and neurological abnormalities of the subjects. The results showed that there was a statistically significant relationship (p-value <.05). The association results of this study support the results of assessing the risk of benzene exposure to neurological disorders. However, the effects of benzene on the nervous system may be influenced by several factors. Therefore, it is advisable to take proactive measures to measure chemicals in the working environment. Measures to enable labor to reduce benzene exposure should be instituted together with biochemical blood assessments for high-risk individuals [7, 9]. The study found that the risk of benzene level 5 was in 10 (5%) people, benzene may have a disturbing effect on the nervous system. Therefore, surveillance for nervous system disorders by assessing acetylcholinesterase enzyme, which may be an appropriate parameter [13].

The highlight of this study was that it assessed the risk of benzene on the nervous system covering a sample of people working at gas stations, both around and outside fuel dispensers. Both of these groups have the potential to be exposed to and be harmed by benzene. In addition, the health risks of employees operating at gas stations within and outside the pollution control area were also described. The weak point in this study was that severity in the nervous system is not assessed through a diagnosis by a specialist, and the severity was not ranked according to the severity of the symptoms but was rather assessed according to the number of neurological symptoms. However, the neurological symptom assessment passed the quality assessment from three qualified persons who are occupational medicine physicians. Therefore, this assessment tool is considered a quality tool and is convenient for use in screening neurological disorders in field areas. The present study also assessed the relationship between urinary benzene concentrations, t,t-muconic acid, and neurological disorders. The results of the study found that a statistically significant correlation would support and confirm the appropriateness of the risk assessment model to continue to assess the risk of benzene on the nervous system in the field.

CONCLUSION AND RECOMMENDATIONS

The results of identifying the risk characterization of benzene on the nervous system showed that most of the risks were at level 1 (low risk), as observed in 108 subjects (54.0%), followed by level 0 (acceptable) in 45 subjects (22.5%). The correlation between t,t-muconic acid concentrations classified by 3 Percentile levels and neurological symptoms of the study subjects were found to be statistically correlated (p-value <0.05. Therefore, the benzene neurotoxic risk assessment model was useful for implementation. However, the researchers suggest that more studies be conducted in larger samples and a manual be created for assessing the risk of benzene on the nervous system, which includes creating an application and evaluating the effectiveness of the application to assess the risk of benzene on the nervous system in the real area.

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Authors' contributions

Anamai Thetkathuek and Chan Pattama Polyong initiated the idea to conduct the study and collect data. Anamai Thetkathuek wrote the first draft of the manuscript and planned the design of the study. Wanlop Jaidee helped with the research methodology. All authors read and approved the final manuscript.

Disclosure statement

All authors declare no conflicts of interest.

Abbreviations

ACGIH: American Conference of Governmental Industrial Hygienists, BEF: Benzene exposure frequency, BEI: Biological Exposure Index, CNS: Central nervous system, CR: Concentration rating, EAS: Exposure assessment score, EEC: Eastern Economic Corridor, ER: Exposure ratings, HER: Health effect rating, IARC: The International Agency for Research on Cancer, OEL: Occupational exposure limits, t,t-MA: t,t-muconic acid, SDS: Safety Data Sheet.

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