

Insights into blood biochemistry and serum malondialdehyde levels following benzene and 1,3-butadiene exposure among four occupations around the Map Ta Phut industrial estate

Chan Pattama Polyong^{1*}, Anamai Thetkathuek², Marissa Kongsombatsuk³, Teeranun Nakyai²

¹Occupational Health and Safety Program, Bansomdejchaopraya Rajabhat University, Bangkok, Thailand

²Department of Industrial Hygiene and Safety, Burapha University, Mueang Chonburi City, Thailand

³Department of Occupational and Environmental Medicine, Rayong Hospital in Honor of Her Royal Highness Princess Maha Chakri Sirindhorn, Mueang Rayong City, Thailand

Abstract

Background: In Map Ta Phut, Rayong Province, Thailand, the concentrations of benzene (BZ) and 1,3-butadiene (BD) in ambient air exceeds the standards set by the US Environmental Protection Agency (EPA). Therefore, health surveillance of exposure pathways and target organs in exposed individuals is important.

Methods: This cross-sectional study aimed to provide insights into blood biochemistry and serum malondialdehyde from BZ and 1,3-BD exposure among outdoor workers working in the Map Ta Phut industrial estate, Thailand. The study sample consisted of 200 people from four occupations: local fishers, street vendors, bus drivers, and traffic police.

Results: The local fishers group had higher levels of 1,2-DNB compared with the other groups ($P < 0.05$). Regarding health effects, the bus drivers group had higher white blood cell counts than the other groups ($P < 0.05$), particularly showing elevated neutrophil-to-lymphocyte ratio (NLR), monocyte-to-lymphocyte ratio (MLR), basophil-to-lymphocyte ratio (BLR), and eosinophil-to-lymphocyte ratio (ELR) ($P < 0.05$). Malondialdehyde (MDA) levels were higher in the traffic police group than in the other groups ($P < 0.05$). The workers in the red zone (where 1,3-butadiene (BD) in the air exceeded the standard) had different blood cell parameters compared with workers in other color zones ($P < 0.05$).

Conclusion: Workers in the red zone area had lower red blood cell counts than those in other areas. Therefore, red blood cell count parameters should be used as indicators of health surveillance. Workers should also wear masks during outdoor work and monitor their health in response to air quality reports.

Keywords: S-phenylmercapturic acid (S-PMA), 1,2-Dihydroxy-4-(N-Acetyl)butane, Blood biochemical, Malondialdehyde, Outdoor workers

Citation: Polyong CP, Thetkathuek A, Kongsombatsuk M, Nakyai T. Insights into blood biochemistry and serum malondialdehyde levels following benzene and 1,3-butadiene exposure among four occupations around the Map Ta Phut industrial estate. Environmental Health Engineering and Management Journal. 2025;12:1540. doi: 10.34172/EHEM.1540.

Article History:

Received: 1 February 2025

Revised: 15 April 2025

Accepted: 12 May 2025

ePublished: 5 November 2025

*Correspondence to:

Chan Pattama Polyong,

Email: chan.bsru@gmail.com

Introduction

The Pollution Control Department reports several important chemicals contaminating the air in Map Ta Phut, Rayong Province, Thailand, at levels exceeding the standards set by the US Environmental Protection Agency (EPA). For example, benzene and 1,3-butadiene had 24-hour average concentrations exceeding the standard at all monitoring stations, with a tendency to increase (1). Based on empirical evidence, Map Ta Phut and nearby areas have been declared a pollution control zone since 2010 (2). The government and private agencies have jointly sought ways to reduce contamination. In 2023, the levels of some of these substances had decreased,

reaching the regulatory standards; however, benzene and 1,3-butadiene were still above the standard. For example, the monitoring station at Muang Mai, Map Ta Phut, reported an annual average benzene level of $2.10 \mu\text{g}/\text{m}^3$ (standard: $1.7 \mu\text{g}/\text{m}^3$) and a 1,3-butadiene level of $2.13 \mu\text{g}/\text{m}^3$ (standard: $0.33 \mu\text{g}/\text{m}^3$) (1). Both substances have been designated by the International Agency for Research on Cancer as Group 1 human carcinogens, specifically causing leukemia (3).

People who work and live in such polluted areas can be exposed to benzene and 1,3-butadiene through three routes: respiration, skin, and ingestion. Benzene and 1,3-butadiene are organic compounds that can easily



evaporate into the air at normal temperatures. Therefore, breathing is the main route of exposure, and the absorbed chemicals are distributed throughout the body by the bloodstream. The excretion mechanism of benzene and 1,3-butadiene requires a metabolic process using the liver enzyme CYP2E1 as the main factor to be broken down into water-soluble substances for excretion in the urine (4). Substances that enter the body can be degraded into various substances depending on the phase of degradation and the enzymes that react with them. For example, the American Conference of Governmental Industrial Hygienists (ACGIH) (5) recommends that benzene be measured using urinary t,t-MA, and S-phenylmercapturic acid (S-PMA) levels. However, S-PMA is a more suitable marker than t,t-MA, as it controls for confounding variables including smoking and dietary sorbic acid (6). Regarding 1,3-butadiene, the ACGIH recommends 1,2-dihydroxy-4-(N-acetyl)butane (1,2-DNB). In this study, S-PMA and 1,2-DNB markers were used to assess exposure to benzene and 1,3-butadiene. In case a person is exposed to more than they can excrete, it may result in toxicity.

The toxic effects of benzene and 1,3-butadiene can result from both the pathway and the target organs. For example, the liver is responsible for breaking down benzene. If the liver is overworked, it can result in inflammation (7). A study in the fuel industry found that exposure to benzene affects serum glutamic oxaloacetic transaminase (SGOT) and serum glutamate pyruvate transaminase (SGPT), which are markers of liver function tests (8). In addition, organs involved in metabolic transformation or chemical excretion, which contain abundant capillaries, may also be damaged. A study found that petrochemical industry workers had abnormal creatinine levels associated with the chemicals in fuels (9). There is also concern regarding benzene and 1,3-butadiene, as both can cause cancer (3). In the initial stage, the substance causes inflammation in the body, causing the number of white blood cells to change (10). In the long term, it will interfere with the production of blood cells in the bone marrow, decreasing the number of blood cells, causing anemia (11). In addition, benzene and 1,3-butadiene are free radicals that can damage cell walls, which leads to the creation of malondialdehyde (MDA), causing DNA mutation (12). Previous studies have reported a statistically significant association between 1,3-butadiene exposure and lymphocyte levels (13). Therefore, health surveillance of pathways and target organs in exposed individuals is crucial.

Occupational groups at risk include those working around contaminated industries. The primary sources of benzene and 1,3-butadiene are industries that use these chemicals, especially fuel-related industries, and high-traffic areas. In Map Ta Phut, people at risk include street vendors, public transport drivers, traffic police, and local fishermen who are present near industrial areas full-time.

A study of fuel tank workers in Map Ta Phut found that 37% were exposed to t,t-MA, a decomposition product of benzene, at levels exceeding the ACGIH threshold (14). Furthermore, these occupations are outside of Thailand's labor protection laws. While factory workers, who have social security benefits, must undergo health checks based on occupational risk factors, the general public or non-official workers do not enjoy such benefits (15).

Addressing benzene and 1,3-butadiene contamination has been a collaborative effort between the government, the private sector, and educational agencies. Air quality monitoring stations have been set up around the Map Ta Phut industrial estate. For health monitoring, government agencies have allocated budgets for general health examinations of people in the surrounding areas. However, there is still a lack of a clear connection between exposure and health effects related to risk factors. In the past, monitoring at stations was not suitable for assessing individual exposure. Importantly, the non-official workers in the vicinity of the Map Ta Phut industrial estate, who are high-risk groups, remain unaddressed by health-related agencies. In addition, there are uncertainties regarding 1,3-butadiene's effects on hematological parameters (16). This study aimed to provide insights into blood biochemistry and serum malondialdehyde from benzene and 1,3-butadiene exposure among outdoor workers at the petrochemical Map Ta Phut industrial estate to provide health status information and identify high-risk groups that need to be prioritized for disease prevention. These findings are valuable for the fields of occupational health, community medicine, and preventive care.

Materials and Methods

Participants

The population consisted of 200 outdoor workers from four occupational groups around the Map Ta Phut industrial pollution control area in Rayong Province: local fishermen, street vendors, bus drivers, and traffic police, 50 people per group. The multistage random sampling method was used, beginning with simple random sampling according to the work points. The next step included using cluster random sampling to cover the working area. The inclusion criteria were: working in the Map Ta Phut area for at least six months, being over 18 years old, not having a diagnosed blood disease, and being willing to participate in the research. The exclusion criterion was absence from work on the day of sample collection.

This study selected subjects with more than six months of experience, consistent with previous studies (17,18). Studies conducted on mice have reported that exposure to 100 ppm benzene, toluene, ethylbenzene, and xylenes (BTEX) for six months caused statistically significant changes in hematology indices. Therefore, this study used six months as the long-term exposure period, considered

to have the potential to affect blood cells.

This study collected samples from areas surrounding large industrial estates (highlighted in purple) in Thailand (19). The sample groups were determined based on location and are represented by different colors. For example, the red color represents the local fisherman group, with samples collected at the fishing village, while the blue color represents the traffic police group, with samples collected from three locations (Points 1, 2, and 3), totaling 10, 20, and 20 participants, respectively (Figure 1).

Research Tools and Data Collection

1. Interview form: The interview form consisted of four items collecting sociodemographic and health-behavioral information: gender, age, smoking, and alcohol consumption. The interviews were conducted by the research team. Interviews were conducted during breaks at convenient locations for each occupation, including community halls, public bus stops, and police stations.
2. Chemicals in the air: Data on benzene (BZ) and 1,3-butadiene (BD) in the environment were obtained from eight monitoring stations of the Pollution Control Department located around the Map Ta Phut industrial estate. Interpretation was done based on US EPA criteria, dividing the map into color zones according to %OEL: red for very high risk ($>100\%$ OEL), yellow for medium risk ($50\text{--}100\%$ OEL), and green for low risk ($<50\%$ OEL).
3. Equipment for collecting urine samples: The equipment used for collecting urine samples included plastic cups and 50-mL polyethylene containers. Urine samples were collected to assess benzene and 1,3-butadiene levels in urine. The research team explained that urine samples should be collected at the end of the participants' work shift. Participants were advised to collect mid-stream urine in a plastic cup and then pour at least 50 mL or half of the urine container into a polyethylene container. Each urine sample was collected after work, and each participant took approximately five minutes to complete the collection. When the researchers received the urine sample, they immediately packed it in a box at a temperature below 4°C and sent it to the laboratory for BZ and BD in urine analysis.
4. Equipment for blood sampling: Materials used for blood sampling included alcohol, cotton balls, gauze, rubber gloves, tourniquets, a blood sampling set with needle No. 22, and EDTA-, anticoagulant-, and heparin-coated blood sampling tubes (5 or 10 mL). The purpose of data collection was to assess

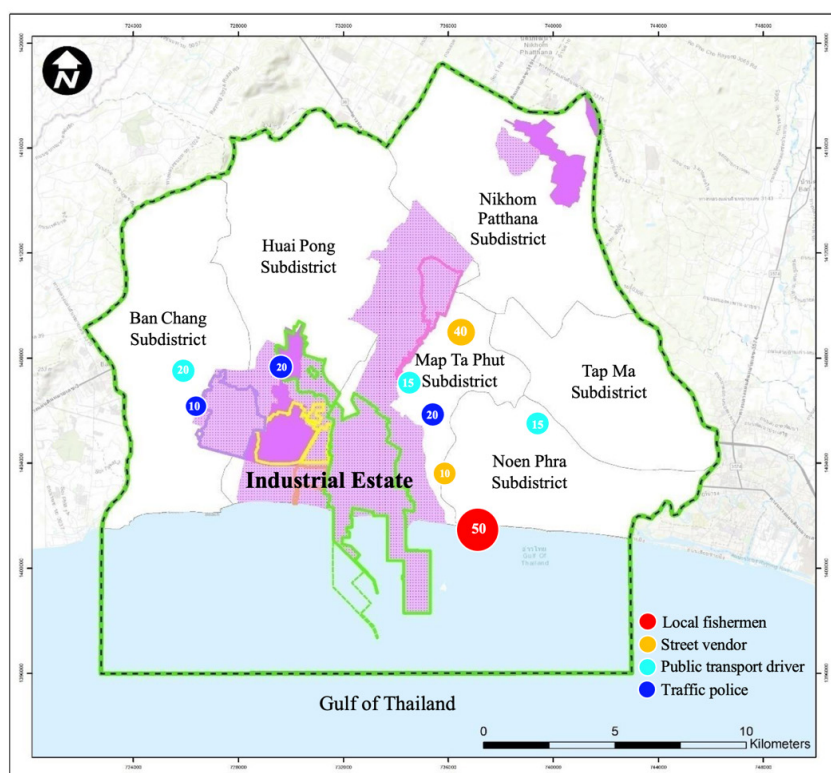


Figure 1. Samples collected from areas surrounding the industrial estates

blood biochemical values, including complete blood counts and liver and kidney function, with the interpretation based on the criteria of the Thai Society of Hematology. Blood samples were collected after work, corresponding to the urine sampling period, at the same interview site but at a different time from the interview. Blood was drawn from a vein in the inner elbow using a vacuum tube with a volume of 8 mL. For complete blood count analysis, the sample was placed in an EDTA tube, and for biochemical analysis, it was placed in an anticoagulant tube. After obtaining the blood sample, the researcher quickly packed it in a box at a temperature below 4 °C and sent it to the laboratory for the serum to be analyzed for biochemical values, including blood count and liver and kidney function, after verifying the number of collected blood and urine samples, they were immediately transported to the laboratory.

Important Variables

The study measured key markers of toxicity along the pathway, including the markers of exposure and the markers of health effects, as follows:

- I. The biomarkers of exposure included metabolites, including S-PMA for benzene ($\mu\text{g/g Cr}$) and 1,2-DNB for 1,3-butadiene (mg/L).
- II. The biomarkers of health effects included the markers of the pathway and target organs, including SGOT and SGPT enzymes for liver function, blood urea nitrogen (BUN) and Cr enzyme for kidney function, MDA for DNA damage, and complete blood counts for bone marrow function.

Statistics

The distribution of important variables, including biomarkers of exposure and health effects, was also analyzed using the Kolmogorov-Smirnov test. The statistical analysis was divided into two parts:

(I) descriptive statistics, which analyzed numbers, percentages, means, and standard deviations, and (II) inferential statistics, which analyzed the following objectives of the analysis: (a) analysis of the relationship between S-PMA and 1,2-DNB in urine using Pearson's correlation, (b) comparison of biomarkers of exposure and effects between four occupational groups using one-way ANOVA, (c) comparison of biomarkers of effects between three groups based on work period (≤ 5 , 6–10, and > 10 years) using one-way ANOVA, (d) comparison of biomarkers of effects between two distances (≤ 5 and > 5 km) using the student's *t*-test, (e) comparison of biomarkers of effects separated by workplace risk area (red, yellow, and green) using one-way ANOVA, and (f) the relationship between MDA and blood biochemistry using Pearson's correlation. Statistical significance was defined as $P < 0.05$.

Results

Demographic Characteristics

The sample group consisted of 200 people working around the petrochemical Map Ta Phut industrial estate in four occupational groups, 50 participants each, including local fishers, street vendors, bus drivers, and traffic police. The study population was 66.0% male, with an average age of 47.44 ± 13.86 years and an average body mass index of 25.28 ± 4.49 kg/m^2 ; 30% were smokers, and 59% consumed alcohol. Most participants had worked in the Map Ta Phut industrial estate for more than ten years (55.0%), and their workplace was ≤ 5 km away from the Map Ta Phut industrial estate border (67.0%).

Relationship Between S-PMA and 1,2-DNB in Urine

Analysis of the relationship between S-PMA and 1,2-DNB in urine showed that both substances had a positive correlation ($P < 0.05$), meaning that increased S-PMA levels were associated with increased 1,2-DNB levels (Figure 2).

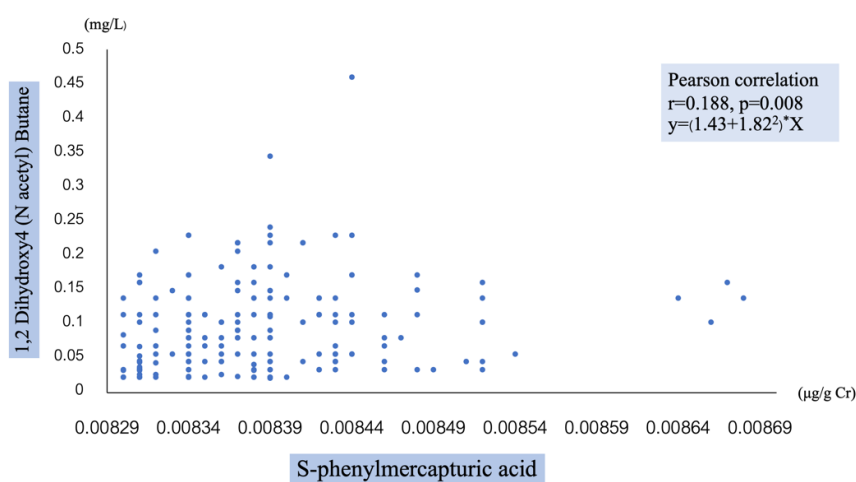


Figure 2. Relationship between S-PMA and 1,2-DNB in urine

Biomarkers of Exposure, Blood Biochemistry, and MDA by Occupational Groups

The sample group's S-PMA and 1,2-DNB levels in urine were within the standard criteria of the ACGIH biological exposure indices (BEIs). Comparison of the exposure showed that the local fishers had significantly higher 1,2-DNB levels than other groups ($P < 0.05$). Regarding health effects, it was found that the bus drivers had significantly higher white blood cell counts than other groups ($P < 0.05$), especially higher neutrophil-to-lymphocyte (NLR), monocyte-to-lymphocyte (MLR), basophil-to-

lymphocyte (BLR), and eosinophil-to-lymphocyte (ELR) ratios. However, the local fishers had lower red blood cell counts (RBC) than other groups ($P < 0.05$), especially hemoglobin (HGB), hematocrit (HCT), and mean corpuscular hemoglobin concentration (MCHC). As for the amount of MDA, it was found to be higher in the traffic police than in the other groups ($P < 0.05$) (Table 1).

Blood Biochemistry and MDA by Work Experience and Distance from the Industrial Area

The results showed that workers who had worked in the

Table 1. Comparison of biomarkers of exposure and health effects by occupational groups

Parameters	Occupation groups				Total	P
	Local fishers	Street vendors	Bus drivers	Traffic police		
n=	(50)	(50)	(50)	(50)	(200)	
Mean ± SD						
Biomarkers of exposure						
S-PMA (µg/g Cr)	0.00835±0.00003	0.00833±0.00003	0.00846±0.00008	0.00838±0.00004	0.00838±0.00007	0.000*
1,2-DNB (mg/L)	0.129±0.074	0.035±0.018	0.104±0.072	0.103±0.042	0.093±0.066	0.000*
Biomarkers of health effects						
Hematologic						
WBCs (10 ³ /uL)	7.29±1.89	7.42±2	7.40±1.69	6.74±1.48	7.21±1.78	0.18
NE (%)	49.18±9.58	54.16±7.68	51.84±9.1	50.22±6.15	51.35±8.39	0.017*
MO (%)	2.4±1.26	3.7±1.18	3.6±1.96	5.6±1.95	3.92±1.86	0.000*
EO (%)	4.58±3.76	3.62±2.6	5.1±4.33	3.72±2.53	4.26±3.42	0.092
BA (%)	0.82±0.48	0.80±0.45	0.88±0.43	0.46±0.5	0.74±0.49	0.000*
LY (%)	43.02±8.77	37.72±9.91	36.58±8.28	41.68±6	39.75±7.98	0.000*
NLR	1.26±0.7	1.52±0.54	1.56±0.72	1.25±0.34	1.4±0.61	0.01*
MLR	0.05±0.03	0.1±0.03	0.16±0.06	0.09±0.04	0.1±0.06	0.000*
BLR	0.02±0.01	0.02±0.01	0.03±0.01	0.01±0.01	0.02±0.01	0.000*
ELR	0.11±0.1	0.09±0.07	0.17±0.16	0.09±0.06	0.11±0.11	0.019*
RBC (10 ⁶ /uL)	4.5±0.73	4.8±0.58	4.87±0.65	5.05±0.46	4.8±0.64	0.165
HGB (g/dL)	13.14±1.53	13.67±1.63	14.39±1.79	14.72±1.05	13.98±1.64	0.034*
HCT (%)	39.48±4.67	39.86±4.77	42.26±5.02	43.06±2.81	41.17±4.63	0.008*
MCV (fL)	88.05±8.36	83.47±8.94	86.99±7.66	85.45±6.21	85.99±7.99	0.213
MCH (pg)	29.54±3.26	28.68±3.34	29.75±3.26	29.27±2.41	29.31±3.09	0.27
MCHC (g/dL)	33.52±1.29	34.32±0.86	34.09±1.51	34.24±0.89	34.04±1.21	0.008*
RDW (%)	13.7±0.89	13.96±1.23	13.64±0.97	13.48±0.75	13.7±0.98	0.062
PLT (10 ³ /uL)	267.6±94.08	262.78±64.72	240.58±70.11	242.68±62.77	253.41±74.39	0.012*
Liver enzymes						
SGOT (U/L)	31.26±17.21	23.36±7.58	30.94±16.14	26.96±13.68	28.13±14.45	0.007*
SGPT (U/L)	31.3±17.66	30.74±28	44.52±31.89	38.96±35.12	36.38±29.27	0.193
Kidney enzymes						
BUN (mg/dl)	14.12±5.07	13.18±4.02	14.18±4.55	12.92±3.07	13.6±4.25	0.053
Cr (mg/dl)	0.8±0.21	0.77±0.14	0.86±0.26	0.93±0.16	0.84±0.2	0.085
MDA (nmol/L)	80.34±21.61	88.34±15.67	89.98±30	97.58±28.11	89.06±25.09	0.022*

Notes: S-PMA: S-phenylmercapturic acid; 1,2-DNB: 1,2-dihydroxy-4-(N-acetyl)butane; WBC: white blood cell; NE: neutrophil; MO: monocyte; EO: eosinophil; BA: basophil; LY: lymphocyte; NLR: neutrophil-lymphocyte ratio; MLR: monocyte-lymphocyte ratio; BLR: basophil-lymphocyte ratio; ELR: eosinophil-lymphocyte ratio; RBC: red blood cell; HGB: hemoglobin; HCT: hematocrit; MCV: mean cell volume; MCH: mean cell hemoglobin; MCHC: mean cell hemoglobin concentration; RDW: red blood cell distribution width; PLT: platelet; SGOT: serum glutamic oxaloacetic transaminase; SGPT: serum glutamic pyruvic transaminase; BUN: blood urea nitrogen; Cr: creatinine; MDA: malondialdehyde; * $P < 0.05$.

Map Ta Phut area for more than ten years had higher percentages of basophils (BA%), lymphocytes (LY%), and blood urea nitrogen (BUN) than workers who had less than ten years of experience ($P < 0.05$). In addition, workers who worked within a radius of 5 km or less from the industrial area's border had lower RBC, HGB, and MCHC than workers who worked more than 5 km away ($P < 0.05$) (Table 2).

Blood Biochemistry and MDA in the Work Risk Area

The environmental work risk area was obtained from air quality measurement data from Pollution Control Department stations in communities. The locations of the stations were selected to be as close to the workers as possible. All outdoor workers worked in areas where benzene concentrations in the air were measured at $< 50\%$

OEL. Regarding 1,3-butadiene, 40% of outdoor workers worked in red areas (Table 3). The color area results led to further comparative analysis regarding health effects.

Blood Biochemistry and MDA in the Work Risk Area

The results of the study on white blood cells revealed that

Table 3. Number of outdoor workers classified by work location according to color area

Color area	Risk levels	OEL	Benzene <i>n</i> =200	1,3-butadiene <i>n</i> =200
Red	Very high risk	$> 100\%$ OEL	-	80 (40%)
Yellow	Medium risk	50 to 100% OEL	-	54 (27%)
Green	Low risk	$< 50\%$ OEL	200 (100%)	66 (33%)

Notes: The 24-hour OEL of benzene was $7.6 \mu\text{g}/\text{m}^3$, and the OEL of 1,3-butadiene was $5.3 \mu\text{g}/\text{m}^3$.

Table 2. Comparison of biomarkers of exposure and health effects by work experience and distance from the petrochemical Map Ta Phut industrial estate

Parameters	Work experience (years)			<i>P</i>	Distance (kilometers)		<i>P</i>
	≤5	6–10	>10		≤5	>5	
<i>n</i> =	(46)	(44)	(110)		(134)	(66)	
	Mean±SD				Mean±SD		
Hematologic							
WBCs (10 ³ /uL)	7.46±2.07	7.21±1.78	7.11±1.66	0.468	7.37±1.88	6.9±1.52	0.083
NE (%)	52.5±7.58	51.84±7.81	50.67±8.92	0.598	52.24±8.72	49.55±7.42	0.033*
MO (%)	4.07±1.65	3.59±1.43	3.96±2.08	0.096	3.45±1.72	4.83±1.78	0.000*
EO (%)	3.83±2.74	4.16±3.16	4.47±3.77	0.213	4.06±3.24	4.65±3.76	0.252
BA (%)	0.65±0.52	0.73±0.54	0.78±0.45	0.018*	0.76±0.47	0.7±0.52	0.388
LY (%)	38.96±7.22	39.68±7.58	40.11±8.46	0.008*	39.49±8.32	40.27±7.27	0.517
NLR	1.44±0.63	1.4±0.53	1.38±0.63	0.292	1.44±0.64	1.31±0.52	0.159
MLR	0.11±0.06	0.09±0.04	0.1±0.06	0.719	0.09±0.06	0.12±0.05	0.000*
BLR	0.02±0.02	0.02±0.02	0.02±0.01	0.247	0.02±0.01	0.01±0.01	0.461
ELR	0.1±0.07	0.11±0.12	0.12±0.12	0.067	0.11±0.1	0.12±0.12	0.369
RBC (10 ⁶ /uL)	5.04±0.59	4.8±0.61	4.71±0.65	0.833	4.72±0.65	4.97±0.59	0.009*
HGB (g/dL)	14.51±1.69	14.11±1.58	13.7±1.59	0.825	13.67±1.57	14.61±1.58	0.000*
HCT (%)	42.52±4.92	41.57±4.34	40.44±4.51	0.976	40.47±4.55	42.58±4.51	0.002
MCV (fL)	84.43±6.91	86.7±7.7	86.35±8.49	0.938	86.09±8.47	85.78±6.97	0.795
MCH (pg)	28.93±2.89	29.56±2.91	29.37±3.25	0.788	29.19±3.16	29.55±2.97	0.435
MCHC (g/dL)	34.15±1.05	34.08±1.24	33.98±1.25	0.292	33.88±1.21	34.36±1.14	0.008*
RDW (%)	13.68±1.01	13.68±0.91	13.7±1.01	0.968	13.76±1.01	13.56±0.91	0.172
PLT (10 ³ /uL)	248.54±65.82	269.09±81.18	249.17±74.75	0.545	262.81±75.99	234.32±67.63	0.011*
Liver enzymes							
SGOT	26.96±15.76	28.16±14.02	28.61±14.15	0.982	27.66±13.26	29.09±16.67	0.511
SGPT	37.74±34.17	38.34±25.81	35.03±28.55	0.211	34.25±25.33	40.7±35.81	0.144
Kidney enzymes							
BUN (mg/dl)	12.67±2.93	13.75±5.15	13.93±4.3	0.006*	13.51±4.2	13.77±4.37	0.688
Cr (mg/dl)	0.85±0.18	0.82±0.22	0.84±0.21	0.671	0.8±0.17	0.92±0.23	0.000*
MDA (nmol/L)	92.73±25.36	87.84±23.08	88.01±25.09	0.738	88.07±22.47	91.06±29.78	0.43

Notes: WBC: white blood cell; NE: neutrophil; MO: monocyte; EO: eosinophil; BA: basophil; LY: lymphocyte; NLR: neutrophil-lymphocyte ratio; MLR: monocyte-lymphocyte ratio; BLR: basophil-lymphocyte ratio; ELR: eosinophil-lymphocyte ratio; RBC: red blood cell; HGB: hemoglobin; HCT: hematocrit; MCV: mean cell volume; MCH: mean cell hemoglobin; MCHC: mean cell hemoglobin concentration; RDW: red blood cell distribution width; PLT: platelet; SGOT: serum glutamic oxaloacetic transaminase; SGPT: serum glutamic pyruvic transaminase; BUN: blood urea nitrogen; Cr: creatinine; MDA: malondialdehyde; * $P < 0.05$.

workers in the red zone had a higher LY% than those in other zones. Workers in the yellow zone had a higher percentage of neutrophils (NE%) and NLR than those in other zones. Workers in the green zone had a higher percentage of monocytes (MO%) than those in other zones ($P<0.05$). The data showed that the total white blood cell count did not indicate a consistent trend. Both the types and counts of white blood cells were elevated and observed in all zones. Regarding red blood cells, it was found that workers in the red zone had lower RBC, HGB, HCT, and MCHC and a higher platelet count (PLT) than those in other zones ($P<0.05$), showing consistent directions of data (Table 4).

Table 4. Comparison of biomarkers of health effects by workplace risk area

Parameters	Workplace risk area			P
	Red	Yellow	Green	
	(80)	(54)	(66)	
n=	Mean±SD			
Hematologic				
WBCs (10 ³ /uL)	7.16±1.85	7.68±1.19	6.9±1.52	0.057
NE (%)	50.83±8.94	54.33±8.02	49.55±7.42	0.006*
MO (%)	2.79±1.34	4.43±1.77	4.83±1.78	0.000*
EO (%)	4.33±3.63	3.67±2.52	4.65±3.76	0.286
BA (%)	0.74±0.49	0.8±0.45	0.7±0.52	0.549
LY (%)	41.33±8.25	36.78±7.72	40.27±7.27	0.004*
NLR	1.33±0.61	1.6±0.66	1.31±0.52	0.015*
MLR	0.07±0.04	0.13±0.06	0.13±0.05	0.000*
BLR	0.02±0.01	0.02±0.01	0.02±0.02	0.217
ELR	0.11±0.09	0.1±0.11	0.12±0.12	0.668
RBC (10 ⁶ /uL)	4.68±0.71	4.78±0.54	4.97±0.59	0.023*
HGB (g/dL)	13.63±1.55	13.72±1.63	14.61±1.58	0.000*
HCT (%)	40.55±4.52	42.58±4.51	42.58±4.51	0.01*
MCV (fL)	87.06±8.10	84.65±8.86	85.78±6.97	0.224
MCH (pg)	29.4±2.98	28.88±3.41	29.56±2.97	0.466
MCHC (g/dL)	33.76±1.17	34.07±1.26	34.36±1.14	0.01*
RDW (%)	13.67±0.9	13.91±1.15	13.56±0.91	0.149
PLT (10 ³ /uL)	264.06±82.28	260.96±66.3	234.32±67.63	0.037*
Liver enzymes				
SGOT (U/L)	29.1±14.39	25.52±11.18	29.09±16.67	0.3
SGPT (U/L)	33.34±20.61	35.61±31.2	40.7±35.81	0.312
Kidney enzymes				
BUN (mg/dl)	14.16±4.63	12.56±3.29	13.77±4.37	0.092
Cr (mg/dl)	0.83±0.19	0.77±0.14	0.92±0.23	0.000*
MDA (nmol/L)	89.21±26.07	86.38±15.8	91.06±29.78	0.598

Notes: WBC: white blood cell; NE: neutrophil; MO: monocyte; EO: eosinophil; BA: basophil; LY: lymphocyte; NLR: neutrophil-lymphocyte ratio; MLR: monocyte-lymphocyte ratio; BLR: basophil-lymphocyte ratio; ELR: eosinophil-lymphocyte ratio; RBC: red blood cell; HGB: hemoglobin; HCT: hematocrit; MCV: mean cell volume; MCH: mean cell hemoglobin; MCHC: mean cell hemoglobin concentration; RDW: red blood cell distribution width; PLT: platelet; SGOT: serum glutamic oxaloacetic transaminase; SGPT: serum glutamic pyruvic transaminase; BUN: blood urea nitrogen; Cr: creatinine; MDA: malondialdehyde; * $P<0.05$.

MDA Related to Blood Biochemistry

Pairwise correlation analysis between MDA and blood biochemistry showed that MDA had a statistically significant relationship with the SGPT enzyme ($P<0.05$). However, there was no statistically significant relationship between MDA and kidney enzymes (Table 5). This study further examined the relationship between potential confounding variables – specifically age and years of exposure – and the concentration of malondialdehyde. The analysis found no significant correlation (age: $r=0.025$, $P=0.729$; years of exposure: $r=0.044$, $P=0.539$).

Discussion

The biomarkers of exposure, S-PMA and 1,2-DNB, were within the standard limits in urine at levels within the biological exposure index (BEI) standards set by

Table 5. Correlation between serum MDA and blood biochemical test

Parameters	MDA	
	r	P
Hematologic		
WBCs ($10^3/\mu\text{L}$)	0.063	0.378
NE (%)	0.056	0.434
MO (%)	-0.014	0.84
EO (%)	0.022	0.757
BA (%)	-0.026	0.711
LY (%)	-0.063	0.375
NLR	0.016	0.822
MLR	-0.017	0.129
BLR	-0.027	0.702
ELR	0.02	0.777
RBC ($10^6/\mu\text{L}$)	0.125	0.077
HGB (g/dL)	0.087	0.223
HCT (%)	0.066	0.351
MCV (fL)	-0.118	0.096
MCH (pg)	-0.064	0.368
MCHC (g/dL)	0.12	0.09
RDW (%)	-0.018	0.796
PLT ($10^3/\mu\text{L}$)	0.042	0.557
Liver enzymes		
SGOT (U/L)	0.104	0.141
SGPT (U/L)	0.212	0.003*
Kidney enzymes		
BUN (mg/dl)	0.129	0.069
Cr (mg/dl)	0.018	0.315

Notes: WBC: white blood cell; NE: neutrophil; MO: monocyte; EO: eosinophil; BA: basophil; LY: lymphocyte; NLR: neutrophil-lymphocyte ratio; MLR: monocyte-lymphocyte ratio; BLR: basophil-lymphocyte ratio; ELR: eosinophil-lymphocyte ratio; RBC: red blood cell; HGB: hemoglobin; HCT: hematocrit; MCV: mean cell volume; MCH: mean cell hemoglobin; MCHC: mean cell hemoglobin concentration; RDW: red blood cell distribution width; PLT: platelet; SGOT: serum glutamic oxaloacetic transaminase; SGPT: serum glutamic pyruvic transaminase; BUN: blood urea nitrogen; Cr: creatinine; * $P<0.05$.

the American Conference of Governmental Industrial Hygienists (ACGIH). There was a positive relationship between S-PMA and 1,2-DNB, indicating that outdoor workers were exposed to the same substances. This study found a statistically significant relationship between S-PMA and 1,2-DNB ($P < 0.05$); however, the strength of the association was weak, as indicated by the correlation coefficient ($r = 0.188$). The presence of various sources of exposure across different locations may explain this weak correlation. For example, people with certain occupations, such as fishermen, may work downwind of industrial areas, while others, such as drivers or traffic police, may be exposed to emissions from road traffic. If the exposure originated solely from a single industrial source, a stronger correlation would be expected. Therefore, it is possible that workers were exposed to pollutants from multiple sources. Reports have indicated that the Map Ta Phut pollution control area contains airborne chemical contaminants originating from both industrial activities and traffic emissions, each contributing significantly to workers' potential exposure risks (20). Hence, future studies should consider assessing exposure from multiple sources simultaneously.

Regarding S-PMA and 1,2-DNB, it should be noted that there are no standard criteria for outdoor workers. Therefore, in this study, comparisons were made using similar criteria for industrial workers. This study's results were consistent with previous studies in similar contexts. A study on S-PMA in the general population in central Italy collected urine samples from 780 people in four groups: employed, unemployed, homemakers, and retired; the geometric means were 0.061, 0.080, 0.077, and 0.080 $\mu\text{g/g Cr}$, respectively (21). However, industrial workers may have higher exposure than outdoor workers. A study on industrial shoe workers reported a 95% CI for S-PMA of 15.59–36.55 $\mu\text{g/g Cr}$ (22). In addition, a study on petrochemical workers reported a mean S-PMA of 0.37 $\mu\text{g/g Cr}$ (23). It can be observed that previous studies on industrial workers found higher exposure compared to outdoor workers. In addition, the occupation groups around the industrial estate in this study were those who worked outdoors with natural ventilation. The study area was located next to the sea, resulting in regular sea breezes. This may have caused the study's results on the exposure to both substances in urine to be lower than those of workers in closed industrial buildings.

This study measured benzene and 1,3-butadiene metabolites in accordance with ACGIH recommendations. However, these criteria are designed for occupational settings involving exposure durations of 8 hours per day or 40 hours per week, which differs from the continuous exposure experienced by the general population or outdoor workers. According to the ATSDR (24), there are no established reference values for these metabolites in the general population. Previous studies have attempted

to address this gap. For instance, a study in Italy measured urinary S-PMA levels in non-smoking individuals from the general population and reported a median value of 0.097 micrograms per gram of creatinine (21), which is consistent with the findings of the present study. The US Health and Nutrition Examination Survey investigated 1,3-butadiene exposure but did not establish a standard reference value. It was noted, however, that cigarette smoking significantly influences metabolite levels of 1,3-butadiene (25). Despite these efforts, there remains a gap in research on metabolite levels in the general population.

This study was conducted among individuals in outdoor occupations, who may experience longer exposure durations compared to industrial workers; however, their exposure may be lower compared to the exposure of those in industrial settings. Currently, there is no standard reference value for chemical exposure in the general population. Although this study referenced occupational exposure limits established by ACGIH, the results were discussed in comparison with findings from studies on the general population. As such, this research serves as a pilot study on occupational and environmental exposure. Future studies should be conducted on a larger scale and include more rigorous control of confounding variables.

The biomarkers of effects for white and red blood cells were found to be different in each occupational group. The bus drivers had higher NLR, MLR, BLR, and ELR than other groups. In this study, the white blood cell proportions were analyzed because they provide specific proportions and indicate inflammation in the body, which can help determine the prognosis of cancer-related diseases. Therefore, this parameter has been included in the consideration of disease progression and prognosis of various types of cancer (26). The white blood cell proportion in bus drivers was found to be high, possibly because almost all of them were male (98.0%) and had higher-risk health behaviors than females, including drinking alcohol and smoking. In addition, bus drivers had longer working hours than other groups, starting at 5:00 a.m. and finishing at approximately 9:00 p.m.; long working hours are associated with exposure to traffic-related chemicals (27). In addition, Ali et al (28) reported that long driving hours among bus drivers are a risk factor for musculoskeletal disorders (MSDs). All of these factors may cause inflammation in the body and raise the proportion of white blood cells.

The comparison among occupational groups showed that local fishers had lower HGB, HCT, and MCHC than other occupational groups. When the participants' work locations were analyzed by color zones, considering the amount of 1,3-butadiene in the air, which exceeded the standard, it was found that the local fishers worked in the red zone, and they had lower levels of several types

of red blood cells than workers in other color zones. The study's results indicated that the local fishers, who lived in a fishing village, were the occupational group closest to the petrochemical plant's border, with a distance of 3.29 km. Therefore, their workplace and residence were in the same area, where the amount of 1,3-butadiene in the air exceeded the standard. Therefore, the local fishers were exposed to more 1,2-DNB than the workers in other areas. There is evidence that 1,3-butadiene affects human red blood cells (3). Therefore, it may interfere with bone marrow making blood cells. Another factor is the work conditions of local fishers. As they have to leave for work early in the morning, there may be a lack of food or insufficient nutrients for blood cell production. A study in a neighboring country (Cambodia) found that low meat consumption is associated with iron deficiency, which causes anemia (29). This may be the cause of lower-than-normal red blood cell counts. Therefore, implementing preventive measures to reduce exposure to 1,3-butadiene and promoting health among fishermen are important considerations.

Workers who had worked in the Map Ta Phut area for more than ten years had higher BA%, LY%, and BUN than those who had worked in the area for less than ten years. This study applied a ten-year cutoff period based on environmental monitoring data from the Map Ta Phut area, which indicated that airborne BZ and 1,3-BD contaminants have exceeded standard limits over the past decade. Therefore, this research aimed to examine the relationship between long-term exposure to excessive volatile organic compounds and workers' health outcomes. This finding is consistent with a previous study on VOC exposure among workers in the Map Ta Phut Pollution Control Area, which reported that the behavior of using personal protective equipment had a statistically significant effect on changes in BA% (11). In addition, a research report compiled from the database of the University of Alabama at Birmingham stated that exposure to 1,3-butadiene increases the risk of cancer, particularly leukemia, with a higher likelihood of developing chronic lymphocytic leukemia (13). Elevated LY% may indicate viral infection, but it is also more common in patients with leukemia. Therefore, people who have lived in Map Ta Phut for a long time should monitor their health by regularly checking their white blood cell count.

The results of the classification of the research area into red, yellow, and green zones according to the amount of 1,3-butadiene in the air (the amount of benzene in the air at the time of sample collection was low and within the standard range) showed that workers in the red zone (1,3-butadiene exceeding the standard) had a higher LY% than those in the yellow and green zones, and workers in the yellow zone had a higher NE% and NLR than those in the other color zones. The data indicate consistency, where people who had lived near industrial

estates for a long time had changes in white blood cells, especially LY%. However, in the other zones, the type and number of white blood cells showed inconsistency and fluctuation. White blood cells may function to destroy pathogens and foreign substances that enter the body by direct phagocytosis or by producing antibodies, which are proteins that can fight foreign substances. The fluctuations are associated with inflammation or infection in the body. Therefore, their secretion occurs quickly (10). As a result, across all color zones where samples were collected, changes were observed in both the type and number of white blood cells.

Regarding the type and number of red blood cells, it was found that workers in the red zone had a lower RBC and higher PLT than those in other color zones. This is consistent with a study of 1,3-butadiene exposure in petrochemical workers in Italy, which concluded that occupational 1,3-butadiene exposure caused oxidative stress, resulting in reduced damage to glutathione transferase in red blood cells (30). In addition, chronic exposure to low doses of benzene also resulted in changes in red blood cells. The toxicology of benzene can suppress bone marrow function, causing anemia (11). In addition, the study found a higher platelet count, indicating factors that stimulate the production of more platelets, including inflammation, infection, blood loss, red blood cell rupture, etc. (31). Exposure to these two substances may change the completeness of blood cells. Therefore, the people who work near the border of the petrochemical industrial estate should be prioritized in health monitoring by hematological assessment.

This study found that MDA had a positive relationship with SGPT enzyme activity. However, the correlation was weak, with an *r* value of 0.212, suggesting that other factors may also have affected liver function. Therefore, further studies are recommended to confirm these findings. The MDA was associated with SGPT, which is consistent with previous studies that found an association between MDA and the occurrence of non-alcoholic fatty liver disease (NAFLD) and steatohepatitis (NASH). The results showed that high serum MDA values were associated with a risk of NAFLD and NASH (OR=2.59, 95% CI=1.33–5.07, *P*=0.005; OR=2.04, 95% CI=1.02–4.06, *P*=0.043, respectively) (12). This chemical is an important factor that promotes the production of numerous free radicals (32). When there is an imbalance between free radicals and the process of protecting against free radical damage (antioxidants) in cells (33), the body experiences oxidative stress within cells and tissues, resulting in processes including lipid peroxidation, cytokine activation, and excessive reactive oxygen and nitrogen species (ROS/RNS), which are mechanisms that can cause liver dysfunction. Chronicity can result in NASH pathogenesis (34). Therefore, this study supports academic data on the MDA indicator and increased liver function, which may

result from air pollutants that cause an imbalance of free radicals in the body.

This study accounted for variables that may affect health outcomes. Other factors that may affect the liver, based on the literature review (35,36), were assessed in the interview for preliminary analysis. These included liver and kidney-related diseases (viral hepatitis, liver cancer, non-alcoholic fatty liver disease, and jaundice), chronic diseases that require regular medication, alcohol consumption, etc. The results showed that these factors were not associated with the liver enzyme.

Conclusion

In conclusion, workers around the petrochemical industrial estate had low exposure to S-PMA and 1,2-DNB. However, on the day of sample collection, the level of 1,3-butadiene in the air exceeded the standard, especially in the local fishers' working area. Regarding health effects, it was found that the bus drivers had higher white blood cell counts than other groups. Workers in the red zone had different blood cell values compared with workers in the other color zones, namely, higher LY% and PLT. On the other hand, RBC, HGB, HCT, and MCHC were found to be lower than in the other color zones. In addition, MDA was found to be associated with liver function.

The benefits of this research included supporting the screening of groups at risk of chemical exposure and related health effects. In addition, the research team provided personalized guidance on appropriate preventive measures. Additionally, they have collaborated with local public health agencies to refer at-risk individuals to the environmental pollution clinic system, consistent with the Ministry of Public Health's policy to establish such clinics in hospitals with adequate resources.

A limitation of this study was that information on exposure to other chemical groups, particularly volatile organic compounds (VOCs) and heavy metals, was collected to establish exclusion criteria. Examples include spraying pesticides, certain hobbies (e.g., working in laundry services), the use of household chemicals (e.g., insecticides or mosquito repellents), and grilling food. However, the study may not fully account for all possible exposures, including inhalation of vehicle exhaust fumes containing beta- α -pyrene, which is challenging to assess. Therefore, the findings should be interpreted in the context of similar environments, such as industrial communities or areas with high traffic density. To control for dietary variables that may influence the concentration of malondialdehyde and its metabolites, this study only qualitatively assessed whether participants consumed certain foods. As a result, recall bias may be present. Future studies should address this limitation by employing a larger sample size and incorporating more rigorous statistical analysis techniques.

Acknowledgments

The authors hereby express their gratitude to the staff of Memorial Hospital Sirindhorn for their assistance in data collection in the area, and the owners and station managers for their cooperation. Finally, the authors acknowledge everyone who volunteered to join this research, particularly the research participants. Burapha University funded this research.

Authors' contributions

Conceptualization: Chan Pattama Polyong, Anamai Thetkathuek, Teeranun Nakyai.

Data curation: Chan Pattama Polyong, Marissa Kongsombatsuk, Teeranun Nakyai.

Formal analysis: Chan Pattama Polyong, Anamai Thetkathuek, Teeranun Nakyai.

Funding acquisition: Anamai Thetkathuek.

Investigation: Anamai Thetkathuek.

Methodology: Chan Pattama Polyong, Anamai Thetkathuek, Teeranun Nakyai.

Project administration: Anamai Thetkathuek.

Resources: Chan Pattama Polyong, Anamai Thetkathuek, Marissa Kongsombatsuk.

Software: Chan Pattama Polyong, Anamai Thetkathuek.

Supervision: Anamai Thetkathuek.

Validation: Anamai Thetkathuek, Marissa Kongsombatsuk, Teeranun Nakyai.

Visualization: Anamai Thetkathuek, Teeranun Nakyai.

Writing—original draft: Chan Pattama Polyong.

Writing—review & editing: Chan Pattama Polyong, Anamai Thetkathuek, Marissa Kongsombatsuk, Teeranun Nakyai.

Competing interests

The authors declare the following financial interests/personal relationships, which may be considered as potential competing interests.

Ethical issues

The study protocol was reviewed and approved by the Human Ethics Committee of Burapha University (approval number HS 096/2023) prior to data collection. All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and national research committees and with the 1964 Helsinki Declaration and its later amendments.

Funding

This study was supported in part by the Fundamental Fund of National Science Research and Innovation Fund (NSRF) via Burapha University (grant number 52/2024).

References

1. Pollution Control Department. Summary Report on Volatile Organic Compounds in the Atmosphere (VOCs). 2023. Available from: <https://shorturl.asia/p1Kq3>. Accessed December 3, 2023. [Thai].

2. Announcement of the Thai National Environment Board. Regarding designating the areas of Map Ta Phut Subdistrict, Huai Pong Subdistrict, Noen Phra Subdistrict, and Thap Ma Subdistrict, Mueang Rayong District, Rayong Province, both subdistricts, Map Kha Subdistrict, Nikhom Phatthana District, Rayong Province, and Subdistrict and Ban Chang Subdistrict, Ban Chang District, Rayong Province, the Entire Subdistrict, Including the Sea Area Within the Boundaries it is a Pollution Control Area. Royal Gazette; 2009.
3. International Agency for Research on Cancer. Agents Classified by the IARC Monographs, Volumes 1-139. 2024. Available from: <https://monographs.iarc.who.int/agents-classified-by-the-iarc/>. Accessed December 3, 2023.
4. Carbonari D, Chiarella P, Mansi A, Pigni D, Iavicoli S, Tranfo G. Biomarkers of susceptibility following benzene exposure: influence of genetic polymorphisms on benzene metabolism and health effects. *Biomark Med*. 2016;10(2):145-63. doi: [10.2217/bmm.15.106](https://doi.org/10.2217/bmm.15.106).
5. American Conference of Governmental Industrial Hygienists (ACGIH). TLVs and BEIs. Threshold Limit Values for Chemical Substances and Physical Agents: Biological Exposure Indices. Kemper Meadow Drive, Cincinnati, OH: ACGIH; 2023.
6. Carbonari D, Proietto A, Fioretti M, Tranfo G, Paci E, Papacchini M, et al. Influence of genetic polymorphism on t,t-MA/S-PMA ratio in 301 benzene exposed subjects. *Toxicol Lett*. 2014;231(2):205-12. doi: [10.1016/j.toxlet.2014.06.029](https://doi.org/10.1016/j.toxlet.2014.06.029).
7. Ruchirawat M, Navasumrit P, Settachan D. Exposure to benzene in various susceptible populations: co-exposures to 1,3-butadiene and PAHs and implications for carcinogenic risk. *Chem Biol Interact*. 2010;184(1-2):67-76. doi: [10.1016/j.cbi.2009.12.026](https://doi.org/10.1016/j.cbi.2009.12.026).
8. Ahmed AA, Alsalmi W, Elhadi AA, Almarabet MM. Adverse effects of benzene exposure on hematological and hepatic biochemical parameters of petrol filling workers in Wadi Al-Hayah, Libya. *Eur J Pharm Med Res*. 2022;9(12):40-5.
9. Yuan TH, Ke DY, Wang JE, Chan CC. Associations between renal functions and exposure of arsenic and polycyclic aromatic hydrocarbon in adults living near a petrochemical complex. *Environ Pollut*. 2020;256:113457. doi: [10.1016/j.envpol.2019.113457](https://doi.org/10.1016/j.envpol.2019.113457).
10. Tigner A, Ibrahim SA, Murray I. Histology, White Blood Cell. 2024. Available from: <https://europepmc.org/article/NBK/nbk563148>. Accessed December 12, 2023.
11. Polyong CP, Thetkathuek A. Factors influencing the hematological parameters among laborers at a gas service station in Rayong province, Thailand. *J Public Health Dev*. 2022;20(3):47-53. doi: [10.55131/jphd/2022/200304](https://doi.org/10.55131/jphd/2022/200304).
12. Zelber-Sagi S, Ivancovsky-Wajcman D, Fliss-Isakov N, Hahn M, Webb M, Shibolet O, et al. Serum malondialdehyde is associated with non-alcoholic fatty liver and related liver damage differentially in men and women. *Antioxidants (Basel)*. 2020;9(7):578. doi: [10.3390/antiox9070578](https://doi.org/10.3390/antiox9070578).
13. Sielken RL Jr, Valdez-Flores C. A comprehensive review of occupational and general population cancer risk: 1,3-butadiene exposure-response modeling for all leukemia, acute myelogenous leukemia, chronic lymphocytic leukemia, chronic myelogenous leukemia, myeloid neoplasm and lymphoid neoplasm. *Chem Biol Interact*. 2015;241:50-8. doi: [10.1016/j.cbi.2015.06.009](https://doi.org/10.1016/j.cbi.2015.06.009).
14. Polyong CP, Roytrakul S, Sirivarasai J, Yingratanasuk T, Thetkathuek A. Novel serum proteomes expressed from benzene exposure among gasoline station attendants. *Biomark Insights*. 2024;19:11772719241259604. doi: [10.1177/11772719241259604](https://doi.org/10.1177/11772719241259604).
15. Labor Protection Law. Social Security Act. Royal Gazette; 2024. Available from: <https://shorturl.asia/RMBLQ>. Accessed December 12, 2023.
16. Tsai SP, Ahmed FS, Ransdell JD, Wendt JK, Donnelly RP. A hematology surveillance study of petrochemical workers exposed to 1,3 butadiene. *J Occup Environ Hyg*. 2005;2(10):508-15. doi: [10.1080/15459620500280960](https://doi.org/10.1080/15459620500280960).
17. Teklu G, Negash M, Asefaw T, Tesfay F, Gebremariam G, Teklehaimanot G, et al. Effect of gasoline exposure on hematological parameters of gas station workers in Mekelle city, Tigray region, Northern Ethiopia. *J Blood Med*. 2021;12:839-47. doi: [10.2147/jbm.S286743](https://doi.org/10.2147/jbm.S286743).
18. Sipayung LP, Suryanto D, Megawati ER. Correlation between benzene exposure and complete blood count of employees in X and Y gas stations. *Media Kesehatan Masyarakat Indonesia*. 2016;12(2):81-90. doi: [10.30597/mkmi.v12i2.924](https://doi.org/10.30597/mkmi.v12i2.924).
19. Office of the Eastern Economic Corridor Policy Committee. A Study Report on the Status of Air Pollution Management in the Map Ta Phut Industrial Area and the Potential for Industrial Expansion According to the Area's Air Quality Support Potential, and Policy Recommendations for Sustainable Industrial Development in the Map Ta Phut Area. 2020. Available from: <http://eec-mtp.onep.go.th/report/airpollutioncarryingcapacity-2020.pdf>. Accessed April 12, 2025. [Thai].
20. Holland R, Khan MAH, Matthews JC, Bonifacio S, Walters R, Koria P, et al. Investigating the variation of benzene and 1,3-butadiene in the UK during 2000-2020. *Int J Environ Res Public Health*. 2022;19(19):11904. doi: [10.3390/ijerph191911904](https://doi.org/10.3390/ijerph191911904).
21. Tranfo G, Pigni D, Paci E, Bauleo L, Forastiere F, Ancona C. Biomonitoring of urinary benzene metabolite SPMA in the general population in Central Italy. *Toxics*. 2018;6(3):37. doi: [10.3390/toxics6030037](https://doi.org/10.3390/toxics6030037).
22. Wulandari P, Wispriyono B, Fitria L, Kusnopranto H, Arrazy S, Sanjaya BR. Urinary S-phenylmercapturic acid (S-PMA) level as biomarkers of exposure to benzene in informal shoes industrial workers, Cibaduyut Bandung. *KnE Life Sci*. 2018;4(1):84-92. doi: [10.18502/kls.v4i1.1369](https://doi.org/10.18502/kls.v4i1.1369).
23. Zhang X, Deng Q, He Z, Li J, Ma X, Zhang Z, et al. Influence of benzene exposure, fat content, and their interactions on erythroid-related hematologic parameters in petrochemical workers: a cross-sectional study. *BMC Public Health*. 2020;20(1):382. doi: [10.1186/s12889-020-08493-z](https://doi.org/10.1186/s12889-020-08493-z).
24. Agency for Toxic Substances and Disease Registry. Interaction Profile for: Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX). 2004. Available from: <https://www.atsdr.cdc.gov/interaction-profiles/media/pdfs/ip05.pdf>. Accessed April 12, 2025.
25. Nieto A, Zhang L, Bhandari D, Zhu W, Blount BC, De Jesús VR. Exposure to 1,3-butadiene in the US population: National Health and Nutrition Examination Survey 2011-2016. *Biomarkers*. 2021;26(4):371-83. doi: [10.1080/1354750x.2021.1904000](https://doi.org/10.1080/1354750x.2021.1904000).
26. Areerattanavet K, Kaewkangsan V, Asanprakit W, Satthaporn S, Vassanasiri W. Evaluation of pre-treatment neutrophil to lymphocyte ratio (NLR) in prediction of

- disease-free survival (DFS) in patients with operable breast cancers. *Royal Thai Army Med J*. 2017;70(3):119-26.
27. Khreis H, Warsow KM, Verlinghieri E, Guzman A, Pellecuer L, Ferreira A, et al. The health impacts of traffic-related exposures in urban areas: understanding real effects, underlying driving forces and co-producing future directions. *J Transp Health*. 2016;3(3):249-67. doi: [10.1016/j.jth.2016.07.002](https://doi.org/10.1016/j.jth.2016.07.002).
 28. Ali AM, Alam MM, Sufyaan M, Ahmad I, Zarrin S. Prevalence of work-related musculoskeletal disorders among professional rickshaw drivers in Aligarh, Uttar Pradesh, India. *Work*. 2023;76(3):1239-53. doi: [10.3233/wor-220621](https://doi.org/10.3233/wor-220621).
 29. Charles CV, Dewey CE, Hall A, Hak C, Channary S, Summerlee AJ. Anemia in Cambodia: a cross-sectional study of anemia, socioeconomic status and other associated risk factors in rural women. *Asia Pac J Clin Nutr*. 2015;24(2):253-9. doi: [10.6133/apjcn.2015.24.2.09](https://doi.org/10.6133/apjcn.2015.24.2.09).
 30. Primavera A, Fustinoni S, Biroccio A, Ballerini S, Urbani A, Bernardini S, et al. Glutathione transferases and glutathionylated hemoglobin in workers exposed to low doses of 1,3-butadiene. *Cancer Epidemiol Biomarkers Prev*. 2008;17(11):3004-12. doi: [10.1158/1055-9965.Epi-08-0443](https://doi.org/10.1158/1055-9965.Epi-08-0443).
 31. Holinstat M. Normal platelet function. *Cancer Metastasis Rev*. 2017;36(2):195-8. doi: [10.1007/s10555-017-9677-x](https://doi.org/10.1007/s10555-017-9677-x).
 32. Bayil S, Cicek H, Cimenci IG, Hazar M. How volatile organic compounds affect free radical and antioxidant enzyme activity in textile workers. *Arh Hig Rada Toksikol*. 2008;59(4):283-7. doi: [10.2478/10004-1254-59-2008-1918](https://doi.org/10.2478/10004-1254-59-2008-1918).
 33. Sinha BK. Roles of free radicals in the toxicity of environmental pollutants and toxicants. *J Clin Toxicol*. 2013;S13:e001. doi: [10.4172/2161-0495.S13-e001](https://doi.org/10.4172/2161-0495.S13-e001).
 34. Varma M, Makwane H, Kare P, Jha R, Parmar A. Study of serum ferritin, serum uric acid and plasma malondialdehyde (MDA) levels in non-alcoholic fatty liver disease. *Int J Biomed Adv Res*. 2016;7(4):169-74. doi: [10.7439/ijbar.v7i4.3183](https://doi.org/10.7439/ijbar.v7i4.3183).
 35. St George A, Bauman A, Johnston A, Farrell G, Chey T, George J. Effect of a lifestyle intervention in patients with abnormal liver enzymes and metabolic risk factors. *J Gastroenterol Hepatol*. 2009;24(3):399-407. doi: [10.1111/j.1440-1746.2008.05694.x](https://doi.org/10.1111/j.1440-1746.2008.05694.x).
 36. Kalas MA, Chavez L, Leon M, Taweeseedt PT, Surani S. Abnormal liver enzymes: a review for clinicians. *World J Hepatol*. 2021;13(11):1688-98. doi: [10.4254/wjh.v13.i11.1688](https://doi.org/10.4254/wjh.v13.i11.1688).