RESEARCH PAPER

CONCENTRATION OF PHTHALATES IN THE ATMOSPHERIC SURFACE LAYER IN A MONSOON CLIMATE CONDITIONS (THE CASE OF VLADIVOSTOK CITY)

Tatiana I. Vitkina, Dmitry N. Cherenkov, Elena V. Kondratieva
Vladivostok Branch of the Federal State Budgetary Scientific Institution Far Eastern Scientific Center of Physiology and Pathology of Respiration – Research Institute of Medical Climatology and Rehabilitative Treatmen. 73g Russkaya Street, Vladivostok 690105, Russia
*Corresponding author: tash30@mail.ru
Received: July 1st 2025 / Accepted: March 15th 2026 / Published: June 30th 2026
https://doi.org/10.24057/2071-9388-2026-4114

ABSTRACT. The study is aimed at assessing the concentration of phthalic acid esters (dibutyl phthalate — DBP, diisobutyl phthalate — DIBP, diethylhexyl phthalate — DEHP) in suspended particles of the atmospheric surface layer in monsoon climate conditions of Vladivostok city. The relevance of the work is due to the paucity of data on airborne phthalate pollution in the territory of the Russian Federation and the unique climatic conditions of the region influencing their distribution.

Samples were taken during the period of 2014–2022 in two zones, specifically, the urban area (Vtoraya Rechka) and the background area (Russky Island). The gas chromatography with mass spectrometry was used for the sample analysis. It has been found that the DBP and DEHP concentrations in the urban area are significantly higher than those in the background area (6.22 and 10.39 ng/m^3 versus 3.34 and 8.61 ng/m^3, respectively), which is associated with the presence of anthropogenic sources. Almost no differences between the investigated zones were revealed for DIBP concentration (7.17 and 6.08 ng/m^3). This homogeneity likely results from a combination of widespread source distribution and the physicochemical properties governing its environmental transport. The analysis showed significant negative correlations of phthalate concentrations with key meteorological parameters (temperature, humidity, wind speed; r = 0.60–0.84) and a strong positive correlation with vehicle traffic intensity (r = 0.72–0.77), confirming the influence of anthropogenic and natural factors on the distribution of phthalates. Concentrations of phthalates in Vladivostok turned out to be lower than in Asian industrial cities but higher than in European cities. The research outcomes can be used when developing measures to reduce phthalate emissions and predicting their concentrations in a monsoon climate conditions.

KEYWORDS: phthalates, atmospheric surface layer, solid suspended particles, monsoon climate

CITATION: Vitkina T. I., Cherenkov D. N., Kondratieva E. V. (2026). Concentration of phthalates in the atmospheric surface layer in a monsoon climate conditions (the case of Vladivostok city). Geography, Environment, Sustainability, 2 (19), 151-158
https://doi.org/10.24057/2071-9388-2026-4114

ACKNOWLEDGEMENTS: Financing. Ministry of Science and Education of the Russian Federation, state assignment “Pathogenetic mechanisms of diseases of the respiratory system and comorbid conditions” (state registration number 124040100032-3).

Conflict of interests: The authors reported no potential conflict of interests.

INTRODUCTION

Phthalates, which are esters of 1,2-benzenedicarboxylic acid, are being widely used in industry for almost a century, primarily as plasticizers. Their widespread use began back in the 1930s and continues to the present, despite growing concerns about their potential toxicity. High molecular weight phthalates, such as diethylhexyl phthalate (DEHP), are mainly used in the production of polyvinyl chloride (PVC) materials (Afshari et al., 2004; Eichler et al., 2019). These compounds are part of a wide range of products including building materials, medical products, and children’s products (Hahladakis et al., 2018; Tickner et al., 2001). Their main function is to ensure the plasticity and flexibility of polymer compositions (Rahman and Brazel, 2004). At the same time, low molecular weight phthalates are more often used in household and industrial chemicals. They are included in formulations of solvents, adhesives, cosmetics, pharmaceuticals, and insecticides (Heudorf et al., 2007).

Modern industry uses more than 60 different types of phthalates that confirms their wide functionality and chemical diversity (Monti et al., 2022). These compounds are widely used in the production of lubricants, paint and varnish products, printing inks, and many other technical and consumer goods. However, the specificity of their molecular integration with the polymer matrix is physical, rather than chemical binding. This circumstance causes a high susceptibility of these substances to migration into the environment (Songue Same et al., 2023). Under the impact of external factors, such as temperature fluctuations, ultraviolet radiation level, changes in the acidbase balance, and mechanical action, phthalates desorb, evaporate, or leach out (Afshari et al., 2004). When released from materials, phthalates are adsorbed on solid particles and can move in the atmosphere, penetrate soil and aquatic ecosystems through landfill filtrates, wastewater, as well as agricultural and stormwater runoff (Net et al., 2015).

Several key phthalates are commonly detected in the air. These are dimethyl phthalate, diethyl phthalate, dibutyl phthalate (DBP) and its isoform diisobutyl phthalate (DIBP), benzylbutyl phthalate, diethylhexyl phthalate, and dioctyl phthalate. Due to the potential toxicity and widespread occurrence of these compounds, various restrictions have been imposed on their use in a number of countries, including the USA, the European Union, China, Japan, and India (Monti et al., 2022).

The human body is exposed to phthalates in various ways: transdermal penetration, intake through the respiratory system, as well as by ingestion with food and drinking water (Benjamin et al., 2017). The most dangerous are urbanized areas, where high concentrations of phthalates in the surface air create conditions for constant and uncontrolled exposure of these substances with the people. Children, pregnant women, and people with weakened immune systems are particularly vulnerable to the chronic impacts of these xenobiotics (Huang et al., 2016; Jurewicz and Hanke, 2011; van't Erve et al., 2019).

Toxicological studies of the recent decade have convincingly confirmed that phthalates can have complex adverse effects on various human physiological systems, and significantly – on the respiratory and immune systems (Yu and Wang, 2024; Zhang et al., 2022). It has been established that exposure to these compounds can cause inflammatory responses, promote the development of allergic diseases, and disrupt the barrier function of the respiratory epithelium (Baek et al., 2021; Bølling et al., 2020; Rafael-Vázquez et al., 2018). One of the studied molecular mechanisms is the ability of individual phthalates, such as DBP, to suppress the activity of the erythroid 2-related nuclear factor (Nrf2), a key regulator of the antioxidant protection of cells (Zeng et al., 2022). This leads to increased production of reactive oxygen species, including from neutrophil granulocytes, and, as a result, to the induction of oxidative stress.

In modern studies of the spread and transformation of phthalates, climatic and meteorological conditions are considered to be key factors determining their behavior in the atmospheric environment (Huo et al., 2023; Munyaneza et al., 2023). In particular, zonal features of temperature, humidity, and precipitation affect the rate of adsorption and desorption of phthalate compounds with suspended solids, their phase distribution between the gas and solid phases, as well as the intensity of photochemical and hydrolytic processes. The Vladivostok city is located on the coast of the Sea of Japan in a zone of strong seasonal temperature fluctuations and high relative humidity. Moreover, significant automotive traffic and heavy maritime traffic create background levels of organic plasticizer emissions, whose degree of migration and degradation can vary significantly depending on prevailing climatic and weather conditions. Monitoring in Vladivostok can allow not only obtaining unique data on seasonal changes in phthalate concentrations, but also developing adaptive models of their distribution with regard to coastal regions.

It should be emphasized that this study is of particular value due to the lack of systematic data on phthalates in atmospheric air in the Russian Federation in general, and especially in the Far Eastern region. In this regard, the main task of the present research is to assess the level of air pollution with complex phthalic acid esters in Vladivostok city.

MATERIALS AND METHODS

The suspended particulate matter (SPM) was sampled at two sites: a background site on Russky Island and an urban site in the Vtoraya Rechka district (Fig. 1). Air samples were collected on a seasonal basis from 2014 to 2022. In total, 693 samples were obtained: 426 from the urban area (Vtoraya Rechka district) and 267 from the background site (Ekipazny settlement on Russky Island). The seasonal distribution for the urban site was 81 (autumn), 60 (winter), 94 (spring), and 191 (summer), and for the background site it was 120 (autumn), 40 (winter), 53 (spring), and 54 (summer). Given the ubiquity of phthalates, stringent measures were implemented to minimize contamination. Specifically, field blanks were collected for each air sampling session, and all filter handling was performed using phthalate-free gloves and glass laboratory equipment.

Sampling was conducted employing a PU-4E aspirator by means of a high-speed Richter absorber. A single-episode air sampling was carried out at a height of 1.5 meters above ground level. The air intake rate was 35 liters per minute, and the particles were collected using an AFA-VP-20 filter. Meteorological indicators (air temperature, humidity, pressure, wind speed and direction) as well as automotive traffic data were recorded during each cycle. Automotive traffic intensity was quantified through manual counts. For each sampling session, the number of vehicles passing the sampling site was recorded per minute at several time points, and the resulting values were averaged to obtain a mean traffic intensity value for the sampling period. Meteorological data were taken from Primorsky Department of Hydrometeorology and Environmental Monitoring (Primhydromet).

The qualitative and quantitative analysis of phthalates associated with suspended particulate matter was performed by gas chromatography method coupled with mass spectrometry (GC–MS) employing a Shimadzu GCMS-QP 2020 gas chromatograph. Chromatographic separation was performed using a SH-Rtx-5MS capillary column (30 m × 0.25 mm, phase thickness of 0.25 microns) in a linear temperature change mode. Initial temperature was 160 °C (2 min), heating rate to 260 °C was 2 °C/min, final isothermal stage was conducted for 10 min. The temperature of the injector was maintained at 250 °C. Helium at a flow rate of 0.6 ml/min was used as the carrier gas. The mass spectra were acquired at an ion source temperature of 200 °C. The chromatographic and spectral data were processed using GCMS Postrun Analysis software package. The quantitative assessment of phthalate concentrations (expressed in ng/m^3) was performed using calibration curve technique based on the analysis of standard solutions of the target compounds. The dibutyl phthalate, diisobutyl phthalate, and diethylhexyl phthalate standards were acquired from Dr. Ehrenstorfer GmbH (Augsburg, Germany).

Statistical data processing was performed using the StatSoft Statistica 10.0 software package. The data were presented as a median and quartiles (25-th and 75-th percentiles). The Kruskal–Wallis test was used to assess the statistical significance of the differences between the groups. The influence of climatic factors was assessed using Spearman correlation analysis. The multiple regression equation was obtained using the Multiple Regression module in the Statistica 10.0 package. When testing statistical hypotheses, the critical significance level (p) was considered significant at $p < 0.05$.

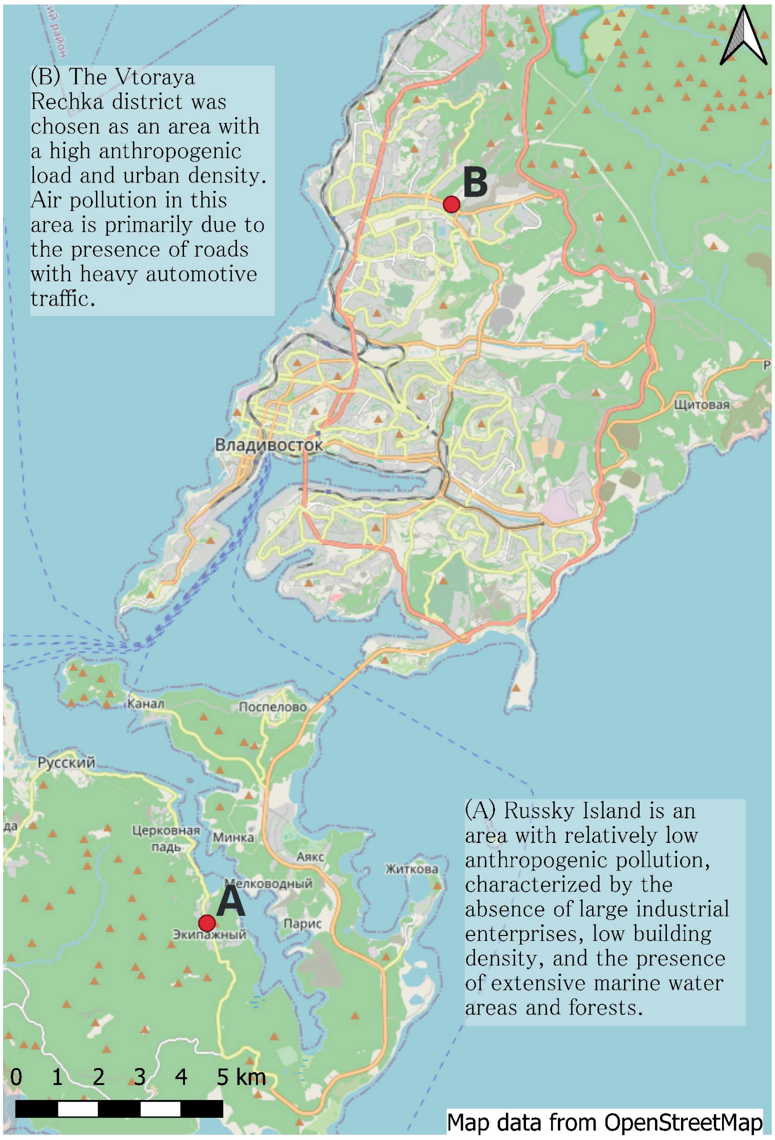

Fig. 1. Map with sample collection points and their characteristics

RESULTS AND DISCUSSION

The data analysis for the period of 2014–2022 has shown the content of three types of phthalates in the air volume of both zones: dibutyl phthalate (DBP), diisobutyl phthalate (DIBP), and diethylhexyl phthalate (DEHP). The results obtained indicate significant differences in the content of DBP and DEHP between the urban and the background areas (Table 1). In the urban area, the median concentrations of DBP and DEHP were 6.22 and 10.39 ng/m^3, respectively, which is 1.9 ($p < 0.001$) and 1.2 ($p < 0.01$) times higher than those detected in the background area (3.34 and 8.61 ng/m^3, respectively). This is due to the high anthropogenic load in the area of the Vtoraya Rechka, where the main source of pollution is automotive transport (releasing both plastic components and exhaust gases).

No significant differences between the two areas were detected for DIBP (7.17 ng/m^3 in the city and 6.08 ng/m^3 on the island). Whereas DEHP, due to its higher molecular weight, expectedly exhibited lower mobility and a more pronounced local distribution, the observed spatial differences for DBP, contrasted with the absence of such variability for DiBP, are likely driven by a combination of differences in source types, emission patterns, and gas–particle partitioning. DBP is commonly associated with personal care products and other localized, intermittent emitters, whereas DiBP may originate from more broadly distributed materials and numerous small, diffuse sources, resulting in a more uniform spatial distribution. Verification of this hypothesis requires dedicated measurements of its distribution across the gas and particle phases.

Correlation analysis has revealed a significant relationship between phthalate concentrations and climatic and anthropogenic factors (Fig. 2). Negative correlations with temperature ($r = -0.71$ for DBP), humidity ($r = -0.84$ for DEHP), and wind speed ($r = -0.68$ for DBP) are explained by increased desorption and particle dispersion in adverse weather conditions. For example, high temperatures in summer activates the evaporation of phthalates from polymers, but at the same time increase their degradation, reducing the final concentration in the air.

The positive correlation with automotive traffic ($r = 0.72–0.77$) confirms the key role of vehicles as a source of phthalate pollution. This is especially noticeable in the urban area, where heavy automotive traffic contributes to the constant flow of plasticizers from tires, interior upholstery, and exhaust systems.

The variations in phthalate concentrations were analyzed in different year seasons (Tables 3–5).

The highest concentrations of all three phthalates were detected in autumn and spring due to a combination of moderate temperatures, high humidity, and stable wind conditions that contribute to the accumulation of particles. The median DBP values in the urban area reached

Table 1. Distribution of phthalates in different districts of Vladivostok.

Phthalates	Area	Median (Q25–Q75) ng/м³	p-level
DBP	Urban area	6,22 (5.47–7.1)	p<0.00
DBP	Background area	3,34 (2.78–4.27)	
DIBP	Urban area	7,17 (6.62–8.04)	p<0.01
DIBP	Background area	6,08 (5.31–6.94)	
DEHP	Urban area	10,39 (9.66–11.12)	
DEHP	Background area	8,61 (7.87–9.22)	

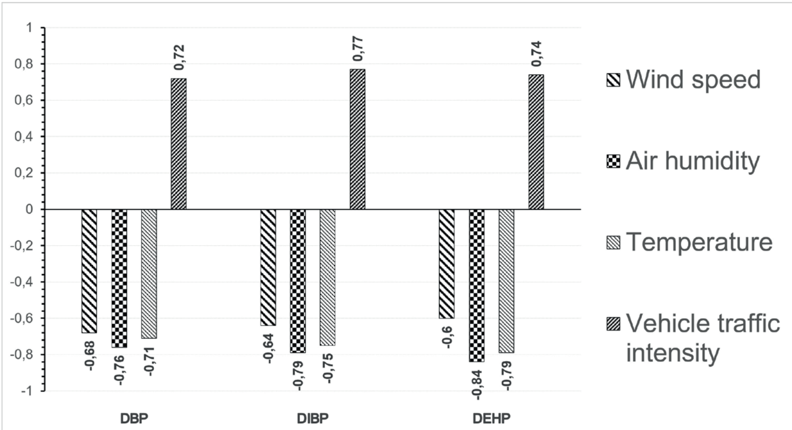

Fig. 2. Correlation coefficients of phthalate concentration with climatic and weather factors, and intensity of vehicle traffic

Table 2. Correlation coefficients of phthalate concentration with climatic and weather factors, and intensity of vehicle traffic

Year season	Area	Median (Q25–Q75) ng/m³	p
Autumn	Urban area	6.82 (5.67–7.84)	1–2 (p<0.05) 1–3 (p<0.01)
Winter	Urban area	4.10 (3.56–5.11)	1–4 (p<0.05)
Spring	Urban area	7.15 (6.04–7.92)	
Summer	Urban area	5.61 (4.45–6.27)	
Autumn	Background area	4.95 (3.83–5.79)	
Winter	Background area	2.62 (1.98–3.24)	1–2 (p<0.05) 1–3 (p<0.05)
Spring	Background area	2.68 (1.87–3.46)	
Summer	Background area	3.10 (2.74–4.08)	

Table 3. Seasonal variations in DIBP concentration

Year season	Area	Median (Q25–Q75) ng/m^3	p
Autumn	Urban area	19.12 (18.09–19.89)	1–2 (p<0.00) 1–3 (p<0.01) 1–4 (p<0.00)
Winter	Urban area	6.11 (5.44–7.12)	2–3 (p<0.05) 2-4 (p<0.05)
Spring	Urban area	8.23 (7.33–8.94)	
Summer	Urban area	3.41 (2.18–4.57)	
Autumn	Background area	12.80 (11.45–13.67)	1–2 (p<0.00) 1–3 (p<0.00) 1–4 (p<0.01)
Winter	Background area	5.23 (4.42–6.57)	
Spring	Background area	3.42 (2.51–4.32)	
Summer	Background area	4.44 (3.69–5.18)	

Table 4. Seasonal variations in DEHP concentration

Year season	Area	Median (Q25–Q75) ng/m^3	p
Autumn	Urban area	12.92 (11.87–13.76)	1–2 (p<0.01) 1–4 (p<0.01)
Winter	Urban area	7.87 (6.52–8.44)	2–3 (p<0.00)
Spring	Urban area	13.88 (12.91–14.66)	3–4 (p<0.00)
Summer	Urban area	7.82 (6.46–8.22)	
Autumn	Background area	10.00 (9.41–11.06)	1–2 (p<0.05) 1–3 (p<0.01)
Winter	Background area	8.27 (7.61–9.08)	
Spring	Background area	6.83 (5.48–7.66)	3–4 (p<0.01)
Summer	Background area	9.41 (8.87–10.24)	

6.82 ng/m^3 in autumn and 7.15 ng/m^3 in spring, while in winter and summer they decreased to 4.10 and 5.61 ng/m^3, respectively (p<0.05).

The observed spring peak of DEHP within the urban area (13.88 ng/m^3) may be related to increased construction activity in the Snegovaya Pad area adjacent to the sampling point, which typically intensifies in spring. Municipal records for Vladivostok (public registry; available since 2018) confirm that several construction projects in the Snegovaya Pad area were authorized during the overlapping sampling interval (2018–2022). Thus, although the permit data support the likelihood that construction underlies the spring DEHP anomaly, this explanation remains provisional for the earlier portion of the sampling period (2014–2017). In the background area, maximum concentrations of DEHP were recorded in summer (9.41 ng/m^3), which may be explained by sea breezes bringing pollutants from the mainland.

At the next stage of the study, the following multiple regression models were constructed to detail the effects of various factors and predict the accumulation of phthalic acid esters:

$$DBP = 8.6 - 0.71 \times H - 0.69 \times T - 0.64 \times WS + 0.62 \times AT$$
$$(R = 0.68;\ Durbin - Watson\ test = 1.9;\ p < 0.008;\ F = 16.8) \quad (1)$$

$$DIBP = 12.42 + 0.74 \times AT - 0.72 \times T - 0.71 \times H - 0.61 \times WS$$
$$(R = 0.76;\ Durbin - Watson\ test = 1.8;\ p < 0.0017;\ F = 23.3) \quad (2)$$

$$DEHP = 6.28 - 0.79 \times T - 0.77 \times H + 0.68 \times AT - 0.53 \times WS$$
$$(R = 0.79;\ Durbin - Watson\ test = 1.84;\ p < 0.001;\ F = 28.21) \quad (3)$$

where *H* is the humidity (%), *T* is the temperature (°C), *WS* is the wind speed (m/s), *AT* is the vehicle traffic (vehicles/min).

The models take into account climatic and anthropogenic factors that had the greatest impact on the content of the studied phthalates in the monsoon climate conditions. The regression models were developed using the pooled dataset from the two sampling locations, which included all 693 samples collected across all four seasons (autumn, winter, spring, and summer).

Among the constructed models, the model for DEHP (R = 0.79) has demonstrated the greatest predictive power, where temperature, humidity, and automotive traffic were the key predictors. The Durbin–Watson test values for all models are within the acceptable range, which indicates the absence of autocorrelation of residuals. An important characteristic in all three models is that p-value is less than 0.05, and the level of Fisher coefficients are adequate, which indicates the statistical significance of the developed models and the possibility of their application.

Modern studies indicate the widespread presence of phthalates in the atmospheric air, including in remote regions and the regions with minimal anthropogenic impact, such as the seas and the Arctic region (Mi et al., 2023; Xie et al., 2007). At the same time, their concentration levels in different geographical zones vary depending on the intensity of the anthropogenic load, climatic and weather conditions, and the local ground features.

Among all phthalates, DEHP occupies a leading position in terms of detection frequency in studies of atmospheric air pollution. This is primarily due to its widespread use in industry, especially in the production of plastics, building materials, and packaging. Despite the legal restrictions, mass production of DEHP is not discontinued, but only transformed towards reducing its areas of use. Other phthalates, such as DBP and DIBP are used in a similar way. However, in recent years there has been a tendency to increase the share of industrial use of DIBP, which, in turn, is reflected by its increased concentrations in the environment.

A comparative analysis of the data obtained in the present study with the data published by other authors allows concluding that the level of atmospheric air pollution with phthalates within the urban territory of Vladivostok is intermediate compared to other regions. In particular, it was revealed that the average annual concentrations of phthalates in Vladivostok city are lower than in a number of industrially developed areas, such as for example the Okhla industrial zone in India, where the DEHP concentration reaches 25.446 ng/m^3, while in Vladivostok it is about 10.39 ng/m^3. At the same time, the content of DIBP in the air of Vladivostok is significantly higher than in the area in Okhla (7.17 and 6.08 ng/m^3 in the city and on the island, respectively, versus 1.172 ng/m^3 in Okhla) (Das et al., 2014). Hangzhou city in China has also recorded measurable levels of phthalates in the outdoor air, with concentrations in the particulate phase reaching 126 ng/m^3 (Lu et al., 2023). In other Asian countries, phthalate concentrations range from 0.8 μg/m^3 in Vietnam (Tran et al., 2017) to 6.2 μg/m^3 in Japan (Takeuchi et al., 2014). At the same time, compared with megacities that do not have a pronounced industrial component, such as Paris, for example, where phthalate concentrations are significantly lower (0.211–0.33 ng/m^3 for DIBP and 3.8–8.9 ng/m^3 for DEHP in summer season), Vladivostok demonstrates a higher level of pollution (Teil et al., 2016). This fact suggests that in the context of phthalate air pollution, Vladivostok occupies an intermediate position between large industrial regions and urbanized areas with relatively low anthropogenic activity. Such status is due to both the scale of the urban industry and the natural and climatic conditions of the region.

Climate and weather conditions play a significant role in the variability of phthalate content in the outdoor air, especially in regions with pronounced seasonality. Vladivostok, located in the monsoon climate zone at the junction of the continent and the ocean, is characterized by significant seasonal fluctuations due to the complex orographic structure of the territory. This affects both the total phthalate content in the air and their distribution between the gas and solid phases. In most climatic regions of the world, researchers traditionally consider winter and summer seasons as most representative for identifying seasonal pollution dynamics. In moderate climate conditions, where winter and summer differ significantly in temperature and the nature of anthropogenic load, clear seasonal trends are identified in general: in summer, phthalate concentrations reach peak values, while in winter they decrease significantly (Ouyang et al., 2019; Teil et al., 2016; Zhu et al., 2016). On the one hand, such pattern is due to increased levels of solar radiation and automotive traffic intensity during the warmer months, and, on the other hand, to increased emissions from heating systems in winter season.

However, Vladivostok is characterized by a different climatic dynamics. Summer months are characterized by a combination of high temperature and humidity (Veremchuk et al., 2018), which leads, on the one hand, to more intensive migration of phthalates from polymer materials, and, on the other hand, to increased degradation of these compounds due to both biotic and abiotic processes. Moreover, high humidity reduces the effectiveness of phthalate adsorption on the solid phase of the particles, which reduces their total content in the air. The sea winds prevailing in summer contribute to the transfer of pollutants from the city area towards the mainland. On the contrary, temperatures and humidity in winter are low, and air masses move from land to sea, which also prevents the accumulation of phthalates in the atmosphere. As a result, unlike in a number of other regions, no significant seasonal differences in phthalate concentrations were revealed in Vladivostok with the monsoon climate.

The highest levels of these substances were recorded in the autumn season, which is associated with climatic conditions that contribute to their accumulation in the solid phase of the air. It is at this time that is characterized by the relatively stable meteorological conditions, contributing to a decrease in the degradation rate of phthalates and an increase in their adsorption on aerosol particles.

In the context of phthalate pollution, special attention should be paid to the geographical location of Vladivostok. Its proximity to the sea facilitates constant exchange processes between seawater and the atmosphere, which is confirmed by current studies (Mi et al., 2023; Xie et al., 2007). In this case, the marine environment acts as a phthalate absorber, and the interphase transport rate and direction depend on weather conditions and the direction of prevailing winds.

Thus, based on the data obtained, it can be concluded that the concentrations of the most common phthalates, specifically DBP, DIBP, and DEHP in the atmospheric air of Vladivostok are lower than the concentrations typical for large industrial cities in Asia, but exceed the values typical for urbanized non-industrial areas in Europe. The space-time distribution of phthalate content is determined by a variety of factors, including climate features, terrain, air mass directions, and local anthropogenic load. The conducted statistical analysis made it possible to establish correlations between phthalate concentrations and climatic and weather parameters, as well as to identify their seasonal distribution features. Based on the collected data, multifactorial regression models were developed that allow predicting the levels of atmospheric air pollution with phthalates in the monsoon climate of Vladivostok, taking into account seasonal and weather fluctuations. The research outcomes are intended not only to fill the existing information gap, but also to provide scientifically sound ideas about the impact of specific climatic conditions of the coastal zone on the nature of chemical pollution of the atmospheric environment.

CONCLUSIONS

1. The content of three phthalates, specifically, dibutyl phthalate, diisobutyl phthalate, and diethylhexyl phthalate was revealed in the two studied zones. In both zones, DEHP accounts for about 50% of the total mass of phthalates, DIBP is in second place in terms of mass, while DBP is represented in the least amount.

2. Differences in concentrations were revealed between the two studied zones: the concentration of DIBP in the urban area is 18% higher than in the background area; the concentration of DBP in the city is almost twice as high as on the island; and the concentration of DEHP in the city is 21% higher than on the island. Concentrations

of DBP and DEHP in the urban area are higher than those in the background area, which is associated with a greater anthropogenic load in this area. However, no statistically significant differences in DIBP content were found between these two areas, which may be due to the same sources of this phthalate in both areas.

3. Correlations have been established between the concentration of detected phthalates and weather factors, namely a negative correlation with temperature, humidity, and wind speed, and a positive correlation with the intensity of automotive traffic.

4. The variability of phthalate concentrations in the atmospheric environment with a moderate monsoon climate of Vladivostok has been revealed depending on seasons of the year.

For DBP, the highest concentrations were observed in autumn, and the minimum concentrations (1.5–2 times lower) in both zones were observed in winter and summer seasons. Concentrations of DIBP in the urban area were high in spring and autumn seasons, while in the island area – only in autumn. The minimum concentrations (3–5 times lower) were observed in summer season. Maximum concentrations in DEHP were detected in spring and autumn seasons, while minimum concentrations (1.5 times lower) were observed in winter and summer in the urban area. The DEHP concentrations in the background area were maximum in summer and autumn, while minimum in spring season.

REFERENCES

Afshari A., Gunnarsen L., Clausen P.A., and Hansen V. (2004). Emission of phthalates from PVC and other materials. Indoor Air, 14, 120. DOI: 10.1046/j.1600-0668.2003.00220.x

Baek H.S., Won H.Y., Kim J.H., Ha E.K., Jee H.M., Shin Y.H., Kim M.A., and Han M.Y. (2021). Association of phthalate exposure and airway dysfunction with mediation by serum periostin. Pediatric Allergy and Immunology, 32, 1681–1690. DOI: 10.1111/PAI.13602

Benjamin S., Masai E., Kamimura N., Takahashi K., Anderson R.C., and Faisal P.A. (2017). Phthalates impact human health: Epidemiological evidences and plausible mechanism of action. Journal of Hazardous Materials, 340, 360–383. DOI: 10.1016/J.JHAZMAT.2017.06.036

Bølling A.K., Sripada K., Becher R., and Bekö G. (2020). Phthalate exposure and allergic diseases: Review of epidemiological and experimental evidence. Environment International, 139, 105706. DOI: 10.1016/J.ENVINT.2020.105706

Das M.T., Ghosh P., and Thakur I.S. (2014). Intake estimates of phthalate esters for South Delhi population based on exposure media assessment. Environmental Pollution, 189, 118–125. DOI: 10.1016/J.ENVPOL.2014.02.021

Eichler C.M.A., Cohen Hubal E.A., and Little J.C. (2019). Assessing Human Exposure to Chemicals in Materials, Products and Articles: The International Risk Management Landscape for Phthalates. Environmental Science & Technology, 53, 13583–13597. DOI: 10.1021/ACS.EST.9B03794

Hahladakis J.N., Velis C.A., Weber R., Iacovidou E., and Purnell P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials, 344, 179–199. DOI: 10.1016/J.JHAZMAT.2017.10.014

Heudorf U., Mersch-Sundermann V., and Angerer J. (2007). Phthalates: Toxicology and exposure. International Journal of Hygiene and Environmental Health, 210, 623–634. DOI: 10.1016/J.IJHEH.2007.07.011

Huang P.C., Tsai C.H., Liang W.Y., Li S.S., Huang H.B., and Kuo P.L. (2016). Early phthalates exposure in pregnant women is associated with alteration of thyroid hormones. PLoS One, 11, e0159398. DOI: 10.1371/JOURNAL.PONE.0159398

Huo C.Y., Li W.L., Liu L.Y., Sun Y., Guo J.Q., Wang L., Hung H., and Li Y.F. (2023). Seasonal variations of airborne phthalates and novel non-phthalate plasticizers in a test residence in cold regions: Effects of temperature, humidity, total suspended particulate matter, and sources. Science of The Total Environment, 863, 160852. DOI: 10.1016/J.SCITOTENV.2022.160852

Jurewicz J., and Hanke W. (2011). Exposure to phthalates: Reproductive outcome and children health. A review of epidemiological studies. International Journal of Occupational Medicine and Environmental Health, 24, 115–141. DOI: 10.2478/S13382-011-0022-2

Lu H., Chen D., Zhu Z., Yang L., Huang L., Xu C., and Lu Y. (2023). Atmospheric phthalate esters in a multi-function area of Hangzhou: temporal variation, gas/particle phase distribution, and population exposure risk. Science of The Total Environment, 894, 163987. DOI:/10.1016/j.scitotenv.2023.163987

Mi L., Xie Z., Xu W., Waniek J.J., Pohlmann T., and Mi W. (2023). Air-Sea Exchange and Atmospheric Deposition of Phthalate Esters in the South China Sea. Environmental Science & Technology, 57, 11195–11205. DOI: 10.1021/ACS.EST.2C09426

Monti M., Fasano M., Palandri L., and Righi E. (2022). A review of European and international phthalates regulation: Focus on daily use products. European Journal of Public Health, 32. DOI: 10.1093/EURPUB/CKAC131.226

Munyaneza J., Hossain M.F., Jia Q., Duan Y., and Xiu G. (2023). Space-time characteristics of 16 PM2.5-bound phthalates (PAEs) in ambient air from Shanghai: Profiles, sources, meteorological effects, and exposure risks. Aerosol and Air Quality Research, 23, 220465. DOI: 10.4209/AAQR.220465

Net S., Delmont A., Sempéré R., Paluselli A., and Ouddane B. (2015). Reliable quantification of phthalates in environmental matrices (air, water, sludge, sediment and soil): A review. Science of The Total Environment, 515–516, 162–180. DOI: 10.1016/J.SCITOTENV.2015.02.013

Ouyang X., Xia M., Shen X., and Zhan Y. (2019). Pollution characteristics of 15 gas- and particle-phase phthalates in indoor and outdoor air in Hangzhou. Journal of Environmental Sciences, 86, 107–119. DOI: 10.1016/J.JES.2019.05.008

Rafael-Vázquez L., García-Trejo S., Aztatzi-Aguilar O.G., Bazán-Perkins B., and Quintanilla-Vega B. (2018). Exposure to diethylhexyl phthalate (DEHP) and monoethylhexyl phthalate (MEHP) promotes the loss of alveolar epithelial phenotype of A549 cells. Toxicology Letters, 294, 135–144. DOI: 10.1016/J.TOXLET.2018.05.012

Rahman M., and Brazel C.S. (2004). The plasticizer market: An assessment of traditional plasticizers and research trends to meet new challenges. Progress in Polymer Science, 29, 1223–1248. DOI: 10.1016/J.PROGPOLYMSCI.2004.10.001

Songue Same O., Nobosse P., Ngolong Ngea G.L., Piveteau C., Lemdani M., Kamga R., and Deprez B. (2023). Migration study of phthalates from non-food plastic containers used in food preservation. Heliyon, 9, e20002. DOI: 10.1016/J.HELIYON.2023.E20002

Takeuchi S., Kojima H., Saito I., Jin K., Kobayashi S., Tanaka-Kagawa T., and Jinno H. (2014). Detection of 34 plasticizers and 25 flame retardants in indoor air from houses in Sapporo, Japan. Science of The Total Environment, 491–492, 28–33. DOI: 10.1016/J.SCITOTENV.2014.04.011

Teil M.J., Moreau-Guigon E., Blanchard M., Alliot F., Gasperi J., Cladière M., Mandin C., Moukhtar S., and Chevreuil M. (2016). Endocrine disrupting compounds in gaseous and particulate outdoor air phases according to environmental factors. Chemosphere, 146, 94–104. DOI: 10.1016/J.CHEMOSPHERE.2015.12.015

Tickner J.A., Schettler T., Guidotti T., McCally M., and Rossi M. (2001). Health risks posed by use of di-2-ethylhexyl phthalate (DEHP) in PVC medical devices: A critical review. American Journal of Industrial Medicine, 39, 100–111. DOI: 10.1002/1097-0274(200101)39:1<100::AID-AJIM10>3.0.CO;2-Q

Tran T.M., Le H.T., Minh T.B., and Kannan K. (2017). Occurrence of phthalate diesters in indoor air from several Northern cities in Vietnam, and its implication for human exposure. Science of The Total Environment, 601–602, 1695–1701. DOI: 10.1016/J.SCITOTENV.2017.06.016

van 't Erve T.J., Rosen E.M., Barrett E.S., Nguyen R.H.N., Sathyanarayana S., Milne G.L., Calafat A.M., Swan S.H., and Ferguson K.K. (2019). Phthalates and phthalate alternatives have diverse associations with oxidative stress and inflammation in pregnant women. Environmental Science & Technology, 53, 3258–3267. DOI: 10.1021/ACS.EST.8B05729

Veremchuk, L. V., Mineeva, E.E., Vitkina, T.I., Gvozdenko, T.A. (2018). The influence of climate on the respiratory function of the healthy population of Vladivostok and patients with bronchopulmonary pathology. Gigiena i Sanitariya, 97, 418–423. DOI: 10.18821/0016-9900-2018-97-5-418-423

Xie Z., Ebinghaus R., Temme C., Lohmann R., Caba A., and Ruck W. (2007). Occurrence and air-sea exchange of phthalates in the Arctic. Environmental Science & Technology, 41, 4555–4560. DOI: 10.1021/ES0630240

Yu Y., and Wang J.Q. (2024). Phthalate exposure and lung disease: The epidemiological evidences, plausible mechanism and advocacy of interventions. Reviews in Environmental Health. DOI: 10.1515/REVEH-2022-0077

Zeng G., Zhang Q., Wang X., and Wu K.H. (2022). Urinary levels of phthalate metabolite mixtures and pulmonary function in adolescents. Environmental Pollution, 293, 118595. DOI: 10.1016/J.ENVPOL.2021.118595

Zhang Y., Lyu L., Tao Y., Ju H., and Chen J. (2022). Health risks of phthalates: A review of immunotoxicity. Environmental Pollution, 313, 120173. DOI: 10.1016/J.ENVPOL.2022.120173

Zhu Z., Ji Y., Zhang S., Zhao J., and Zhao J. (2016). Phthalate ester concentrations, sources, and risks in the ambient air of Tianjin, China. Aerosol and Air Quality Research, 16, 2294–2301. DOI: 10.4209/AAQR.2015.07.0473