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RESEARCH ARTICLE

Characteristics and health effects of potentially pathogenic bacterial aerosols from a municipal solid waste landfill site in Hamadan, Iran

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Abstract

The aim of this study was to evaluate the potential pathogenic bacterial aerosols produced from the municipal solid waste landfill site and its health risk assessment in the Hamadan city at west of Iran. In this study, air samples were collected every month during spring and summer at six locations including the active zone, leachate collection pond, infectious waste landfill, upwind, closure landfill, and downwind using the Andersen impactor. Spatial and seasonal variations of the potential pathogenic bacterial aerosols were detected. Also, Health risk associated were estimated based on the average daily dose rates (ADD) of exposure by inhalation. The mean concentration of potentially pathogenic bacterial aerosols were 468.7 ± 140 CFU m^{-3} 1108.5 ± 136.9 CFU m^{-3} detected in the active zone in spring and summer, respectively. Also, there was a significant relationship between meteorological parameters and bacterial concentration ($p < 0.05$). The predominant potential pathogenic bacterial identified in the spring were *Proteus mirabilis*, *Streptococcus* sp., and *Pseudomonas* sp., while in summer were *Pseudomonas* sp., *Staphylococcus aureus*, and *Escherichia coli*. The hazard quotient (HQ) in both seasons were less of 1. Bacteria were spread throughout the landfill space, but their maximum density was observed around the active zone and leachate collection pond. This study highlights the importance of exposure to potential pathogenic bacterial aerosols in the summer and its adverse effects, especially in the MSW landfill site active zone. Finally, controlled exposure can reduce the health hazard caused by the potential pathogenic bacterial aerosols.

Keywords Municipal solid waste · Landfill · Bacterial aerosol · Health effects · Hamadan

Introduction

Due to the rapid increase in population, the production of solid waste and its diversity has also increased [1, 2]. More than 1999 million tons of municipal solid waste (MSW) is produced annually in the world, which in many countries, landfilling is the predominant method of MSW disposal [3]. The main features of MSW are the presence of large amounts of organic matter and moisture content, which increases the growth and multiplication of pathogenic microorganisms [4]. MSW operation and its transportation are considered as potential sources of bioaerosols emission that are associated with adverse health effects, in the landfill sites [5]. Besides the

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landfill sites release chemical pollutants or aerosols in the ambient air [6–10].

Pathogenic or non-pathogenic microorganisms including viruses, bacteria, and fungi, as well as toxins, endotoxins, and peptidoglycans, may be contain in bioaerosols [11]. The small size of these particles causes them to become suspended during the operating of MSW landfill sites and eventually enter the human body through ingestion, respiration, and skin adsorption, finally create health problems in individuals [12]. High concentration of potentially pathogenic bacterial aerosols, such as *Streptococcus*, *Staphylococcus*, *Acinetobacter*, and *Kocuria*, in MSW, is the one of the main health concerns in these sites [13]. Exposure to pathogenic bacteria and bacterial compounds in the ambient air can cause infectious diseases, sick building syndrome, allergies, asthma, bronchitis [14]. The most common reports of respiratory problems such as rhinitis, asthma, bronchitis, and sinusitis are through atopic and non-atopic allergic mechanisms as well as non-allergic pathways [15].

Also, investigation of type and concentration of bioaerosols is a helpful indicator for harmful effects due to exposure to solid waste emissions [16]. The concentration and exposure level may be different depending on the route of exposure such as dermal, ingestion and inhalation, weather conditions, personal protective equipment (PPE), and capacity of the MSW operating facilities [17–19].

Worker involved in MSW's collection and landfill are classified as high-risk groups because they are exposed to high concentrations of bioaerosols and other pollutants [5]. It is also essential to consider the health aspects of the employees and people who live near these sites [20]. Therefore, various studies have been conducted on the short-term and long-term effects of waste exposure contaminants on public health in residents near landfill sites [21]. For example, a study conducted in an open dump in Malaysia and reported that unsanitary MSW disposal was dangerous to the health of residents within 1 km of the landfill, thus efforts are needed to minimize the risks [22].

The novelty of this study is the contribution to understanding the characteristics and impacts of potentially pathogenic bacterial aerosols released from the landfill site. Furthermore, many studies have focused on total bacteria released from landfill sites, while few studies have assessed potential pathogenic bacterial aerosols and limited information is available regarding waste workers' risk of exposure to potential pathogenic bacterial aerosols in this areas.

This study was conducted in Hamadan, Iran to; (1) investigate the concentration of potentially pathogenic bacterial aerosols in different location of a MSW landfill site during spring and summer, (2) identify bacterial species and their relative abundances, (3) determine the effect of meteorological conditions during spring and summer on the amount of potentially pathogenic bacterial aerosols (4) health risk assessment of exposure to potential pathogenic bacterial aerosols in landfill sites, and (5) risk spatial distribution of the exposure to potential pathogenic bacterial aerosols in this sites.

Materials and methods

Study Area

The descriptive cross-sectional study was performed at the MSW landfill site of Hamadan city in the spring and summer of 2019. Hamadan city located in the west of Iran and the Hamadan municipality waste management organization estimated that the amount of waste generated in the Hamadan city could be 400–450 tons/day. The dominant method of waste disposal in this area is landfilling. The site has been operated for 20 years, and it is estimated complete for the next 30 years [23]. The Hamadan landfill site was located between 33° 59′ and 35° 44′ north latitude and 47° 47′ and 28° 49′ east longitude by a 230-hectare area. The geographical location of the studied landfill site is shown in Fig. 1.

Six points of the landfill site including the active zone, leachate collection pond, infectious waste landfill, upwind, closure landfill, and downwind were selected as air sampling points. Sampling was performed from March to August 2019, between 10 and 12 AM. Air samples were collected every month and all samples were repeated twice. Finally, the number of samples was equal to 72.

Bioaerosols measurement in ambient air

Air sampling

Due to the meteorological and topographical conditions of the studied area and heavy precipitation during autumn and winter, sampling was performed from that locations in spring and summer. Sampling was performed in six points of landfill site at a height of 1.5 m above the ground (human respiratory level) via active air sampler (Quick Take® 30, SKC, Inc., USA) at a flow rate of 28.30 L min^{-1} with a sampling time of 10 min [24, 25].

In this study, all used laboratory equipment were washed by disinfectant solution (alcohol = 70 %). Then they placed in an autoclave for 30 min at standard temperature and pressure. After that, all the equipment inside the sterile packages were transferred to the sampling points. Also, meteorological parameters such as temperature and humidity (KIMO KH-50, USA), wind velocity (KIMO VT-210, USA) were measured. Atmospheric pressure and precipitation data were obtained from the Hamadan meteorological synoptic station.

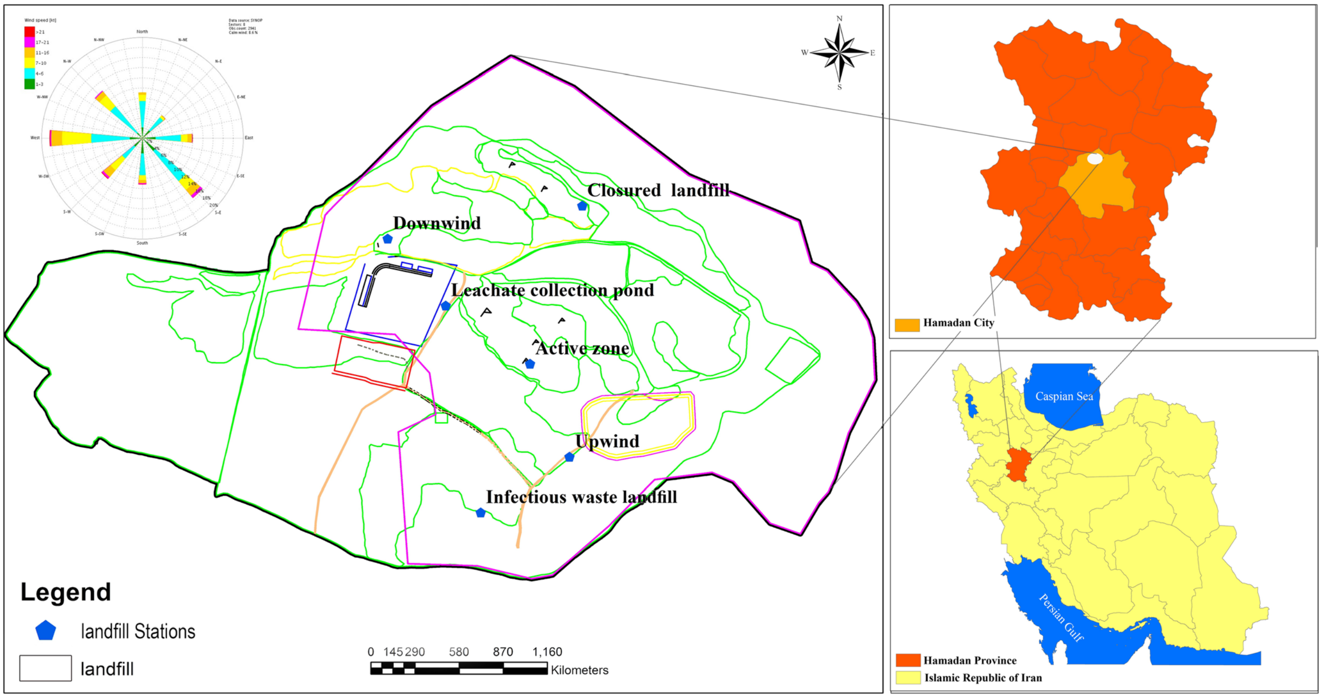


Fig. 1 The geographical location of the studied area

Quantification and characterization of bioaerosols

Nutrient agar (NA) culture media (Merck Co, Germany) with cycloheximide was used to identify and specify bacterial aerosols. The concentration of bacterial aerosols in air samples were counted with the colony counter (Olympus model, Made in Japan) reported as CFU/plate/hr. Bergey's manual and biochemical tests were applied for the identification of bacteria species [24].

Microbial analyses

Collected samples were transferred to the laboratory and incubated at 35-37°C. After 24–48 h, the type and number of colonies formed were determined using an optical microscope (Memmert model, Made in Germany) [13].

Isolation was performed based on the shape, type, and size of colonies in the blood agar culture medium. After incubation, Gram-staining was performed using the Gram Staining kit (HiMedia, India). To determine the type of bacterial contamination at each station to gram-negative and gram-positive bacteria, the EMB agar culture, and the mannitol salt agar culture medium were used. Biochemical tests were performed on the bacillus and gram-negative coccobacilli after separating and purifying the samples, including oxidase, catalase, indole methyl red, Voges-Proskauer, citrate, urease, TSI agar, glucose fermentation, lactose fermentation, H_2S production, motility. Also, positive bacilli and positive and negative cocci were identified using different tests including catalase, coagulase, oxidase, DNase, bile-esculin, novobiocin, and bacitracin disc resistance, mannitol salt agar, sugar consumption, and others [26].

Quality control and quality assurance

Quality assurance and quality control were checked through the analysis of field and laboratory blank samples and replicated the samples to ensure reproducibility. After each sampling, Samples were transferred to the laboratory with cooling box. Also, field and laboratory blank samples were analyzed in the similar manner and necessary corrections were included.

Risk assessment of exposure to bioaerosols

To exposure risk assessment, exposure levels, frequency, duration, and routes of exposure to bacterial aerosols were evaluated. Exposure risk assessment was calculated as the average daily dose (AAD), according to Eq. 1.

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

Where ADD is the average daily dose of the bacterial aerosols emissions from landfill (CFU/kg.d), C is the concentration of bacteria (CFU m^{-3}), and EF is the exposure frequency or the number of work days in the landfill per year (312 days in the year in this site). Also, ED is the exposure duration (year) with bacterial aerosols due to working in the landfill in a lifetime (30 years), BW is the average body weight (75.1 kg), AT is the average lifetime or life expectancy (days), which for non-carcinogenic effects calculated by multiplying the ED by the number of days of exposure with bacterial aerosols per year (30 × 312) [27–29].

Risk characterization

In the risk characterization step, the adverse health effects due to chronic exposure by bacterial aerosols are estimated based on the amount of exposure to the bacteria bioaerosol in the spring and summer seasons in all sampling stations. It can be made a scientific interpretation based on those estimates previous steps of quantitative risk assessment (QRA) [30].

Non- carcinogenic QRA

The hazard quotient (HQ) was used to assess the non-carcinogenic effects of bacteria bioaerosols in the landfill. Also, HQ and HI were calculated based on ADD and reference dose (RfD), according to Eqs. 2 and 3.

$$HQ = \frac{ADD}{RfD} \tag{2}$$

$$RfD = (RfD \times InhalationRate/BodyWeigh) \tag{3}$$

Where Reference concentrations (RFC) at CFU m^{-3}; inhalable rate (IR) = 20 $m^3.d^{-1}$; average body weight (BW) = 75.1 kg. In the cases where the RfC for the bacterial aerosols was not available, a concentration of 500 CFU m^{-3} was considered as the acceptable guideline by the American conference of governmental industrial hygienists (ACGIH) [31, 32]. According to Yang et al. (2019), Xu et al. (2020), and Yan et al. (2019), Liang et al. (2020), Lu et al. (2020), and Yang et al. (2019) a threshold value of 500 CFU m^{-3} was utilized for health risk assessment of airborne bacteria [33–38].

If the average daily dose is equal to or lower than the reference dose, it is acceptable (HQ < 1). Otherwise, there are potentially be non-carcinogenic effects caused due to bacteria bioaerosol in landfill plan (HQ > 1) [39].

Spatial distributions

To conduct spatial analysis, ArcGIS 10.4.1 software, was used. The inverse distance weighting (IDW) interpolation technique was used to develop an independent raster layer for the seasonal mean concentration of bacterial aerosols. The raster calculator function was then used to overlay each layer and produce seasonal average maps of it. Many researchers have used the IDW method for mapping air pollutants [40]. IDW is, in fact, a non-statistical method, which is usually applied in environmental studies to predict the concentration of pollutants at unmeasured locations through the optimal spatial prediction technique. IDW model assumes that the predictions are in a linear function of available data. The IDW model is as Eq. (4) [41]:

$$\lambda i = \frac{Di - \alpha}{\sum_{i=1}^{n} Di - \alpha} \tag{4}$$

Where λi is the weight of the station i, Di is the distance between the station i and unknown point, α is the weighting power, and n is the total number of known points used in the interpolation.

The higher weighting powers are assigned to the values nearer to the interpolated points. A decrease in weight will be observed with increasing distance.

Statistical analysis

Obtained data were analyzed using independent t-test, Kruskal-Wallis, Mann-Whitney statistical tests, depending on the distribution of data. Spearman Rank Correlation was used to determine data correlation. Statistical analyzes were performed at a 95 % confidence level using Stata version 16 software.

Results and discussion

Concentration of pathogenic and non-pathogenic bacterial aerosols

The MSW landfill sites provide the suitable conditions for the growth of microorganisms, that if pathogenic microorganisms are entered through inhalation and penetration into the depths of the lungs, can cause disorders and adverse health effects in workers [5]. Hence, pathogenic and non-pathogenic bacterial aerosols concentration at different types was also measured, as shown in Fig. 2.

As shown in Fig. 2a the predominant concentration of pathogenic bacterial aerosols related to *Proteus mirabilis* (183.85 ± 68.05 CFU m^{-3}), *Streptococcus* sp. (153.28 ± 61.47 CFU m^{-3}), and *Pseudomonas* sp. (140.13 ± 95.58 CFU m^{-3}) in the spring, and *Pseudomonas* sp. (635.25 ± 77.24 CFU m^{-3}), *Staphylococcus aureus* (460.91 ± 49.42 CFU m^{-3}), and *Escherichia coli* (449.20 ± 9.61 CFU m^{-3}) in the summer. In a similar study, the concentration of total bacteria has been reported (3658 CFU m^3) in spring including *Pseudomonas fluorescens* (11.5 CFU m^3), *Staphylococcus* sp. (257.9 CFU m^3), and *Escherichia coli* (28.9 CFU m^3) and in summer including *Pseudomonas fluorescens* (51.1 CFU m^3), *Staphylococcus* sp. (369.5 CFU m^3), and *Escherichia coli* (51.9 CFU m^3) [24].

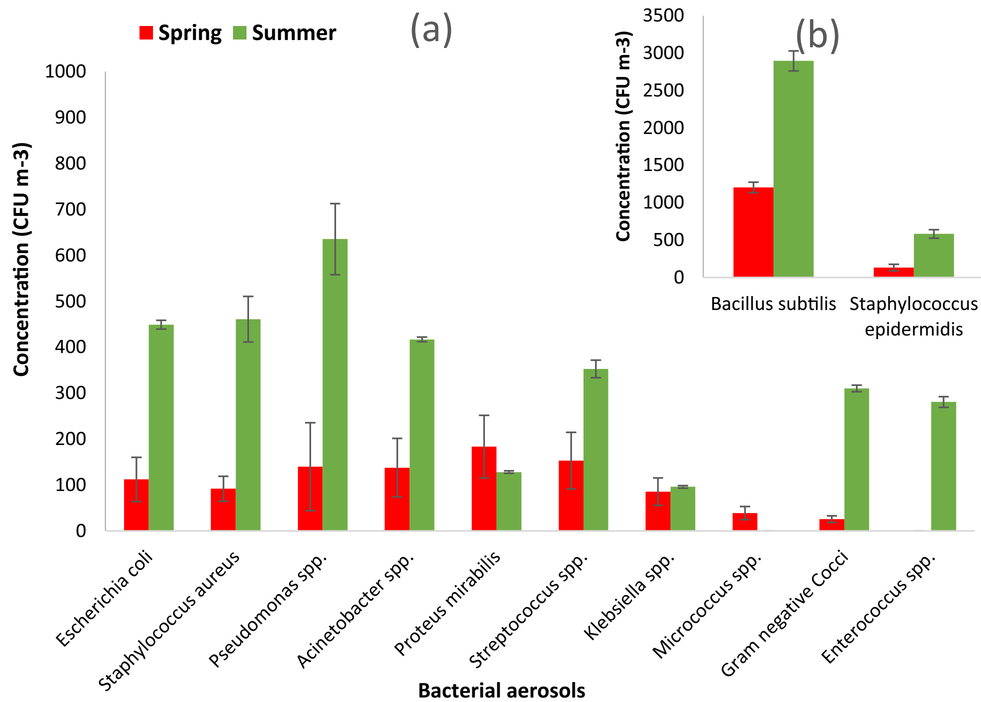


Fig. 2 Bacterial aerosols concentration at both season in the studied area (A: pathogenic and B: non-pathogenic)

As shown in Fig. 2b the highest concentration of the non-pathogenic bacterial aerosols in the spring and summer was *Bacillus subtilis* (1204.28 ± 69.32 CFU m^{3}) and (2896.22 ± 133.38 CFU m^{-3}), respectively. Also, the lowest concentration related to *Staphylococcus epidermidis*. *Bacillus subtilis* produces endospores that protect it from heat and dry weather conditions [42]. Therefore, it has a higher concentration of pathogenic and non-pathogenic bacterial aerosols, especially in summer. *Staphylococcus epidermidis* commonly regarded as a beneficial skin microbe and rarely causes infection, except for immuno-compromised persons [43].

The result of study showed, 42.05 % of the total identified bacterial aerosols in the spring and 47.38 % in summer were pathogenic, that similar to results of Z_o_łwineWypaleniska landfill site (Poland), that reported more than 68 % of airborne bacteria have microflora (non-pathogenic) and only 15 % of all bacteria were gram-negative bacteria formed [44].

The concentration of pathogenic (P = 0.015) and non-pathogenic bacteria (P = 0.039) were significantly higher in summer than spring. Because temperature is one of the main factors that can affect the growth, reproduction, and its transfer in the environment. Therefore, the bioaerosols concentration and variation trend can be altered in various climatic conditions and the concentration was increased in the summer [5, 45].

Effect of the different locations in the landfill site

Based on the type of activity in different locations of the landfill, the bacterial aerosols concentration varies [46] and accordingly, bacterial aerosols concentration is of particular

Table 1 Potential pathogenic bacterial aerosols concentration at different sampling stations (CFU m^{-3})

	Spring				Summer				
	Min	Max	Mean	SD	Min	Max	Mean	SD	p-value
Sampling sites									0.021
Active zone	353.4	624.5	468.7	140	964.3	1236.7	1108.5	136.9	
Leachate collection pond	21.6	182.7	76.6	92.6	219.1	706.7	516.8	261.1	
Infectious waste landfill	0.0	99.4	59.4	36.8	106.1	152.5	126.3	23.8	
Closed landfill	16.5	75.5	37.7	32.8	90.0	336.0	218.6	123.4	
Upwind	0.0	53.4	28.8	21.8	106.4	200.1	155.5	47.0	
Downwind	11.8	54.2	42.0	11.8	158.9	447.1	307.2	144.3	

Table 2 Meteorological parameters during the sampling operation in the studied area

Season/ Month	Temperatures (°C)	Humidity (%)	Wind velocity (m/s)	Atmospheric pressure (mbar)	Precipitation (mm)
Spring					
March	7.95	65.38	2.91	823.06	6.43
April	13.21	51.61	2.67	825.83	0.20
May	20.94	34.56	2.66	825.90	0.03
Summer					
June	25.95	24.18	2.86	821.26	0.00
July	26.45	24.40	3.12	821.74	0.03
August	21.67	26.74	2.55	825.39	0.00

importance to determine the health effect in different locations. Potential pathogenic bacterial aerosols concentration, according to different locations, are shown in Table 1.

The results showed that the sampling location has a significant effects on the potential pathogenic bacterial aerosols concentration ($p = 0.021$). The maximum concentration of potentially pathogenic bacterial aerosols in the spring and summer were 468.7 ± 140 and 1108.5 ± 136.9 CFU m^{-3}, respectively in the active zone that consistent with the results of similar research [40] The reasons for the higher potential pathogenic bacterial aerosols concentration in this sampling station could be due to mechanical agitator by front-end loaders and other related activities [5].

The minimum concentration was detected in upwind (28.8 ± 21.8 CFU m^{-3}) in the spring and infectious waste landfill (126.3 ± 23.8 CFU m^{-3}) in the summer. The reasons for the lower potential pathogenic bacterial aerosols concentration in the infectious waste landfill and upwind could be due to the type and amount of the buried waste and wind direction. The amount of organic material in MSW is higher than in infectious waste. On the other hand, the amount of infectious waste was very low compared to other component of MSW in this site (7 tons/day versus 550 tons/day). Also, wind direction can influence the diffusion of bioaerosols. The prevailing wind direction in the Hamadan landfill site is from southeast to northwest (Fig. 1).

Another study conducted in the municipal landfill environment in Poland showed that the most polluted was the active sector and the total viable bacteria and Gram-negative bacteria were 3.94×10^3 and 6.58×10^2 CFU m¯3, respectively and the lowest concentration was found outside the landfill site [47]. Therefore, the source of contamination (received waste) and type of solid waste affect the production and release of bioaerosols [5, 45].

Effect of meteorological conditions

Changes in meteorological parameters were also measured and shown in Table 2.

According to Table 2, the minimum and maximum average daily temperatures were recorded in March (7.95 °C) and July (26.45 °C). The minimum and maximum relative humidity were in June (24.18 %) and March (65.38 %), respectively. The highest and lowest wind velocity was in August (2.55 m s^{-1}) and July (3.12 m s^{-1}). Also, the minimum and maximum atmospheric pressures were in June (821.26 mbar) and May (825.90 mbar).

The relationship between meteorological parameters with bacterial aerosols is shown in Table 3.

The results indicated that the concentration of the potential pathogenic bacterial aerosols decreased with increasing wind

Table 3 Relationship between meteorological parameters with the concentration of bacterial aerosols

Variables	Concentration	Temperature	Precipitation	Wind velocity	Atmospheric pressure	Humidity
Concentration	1.000					
Temperature	0.397	1.000				
Precipitation	-0.455	-0.685	1.000			
Wind velocity	-0.264	0.127	0.463	1.000		
Atmospheric pressure	0.024	-0.574	0.330	-0.637	1.000	
Humidity	-0.397	-0.939	0.849	-0.010	0.635	1.000

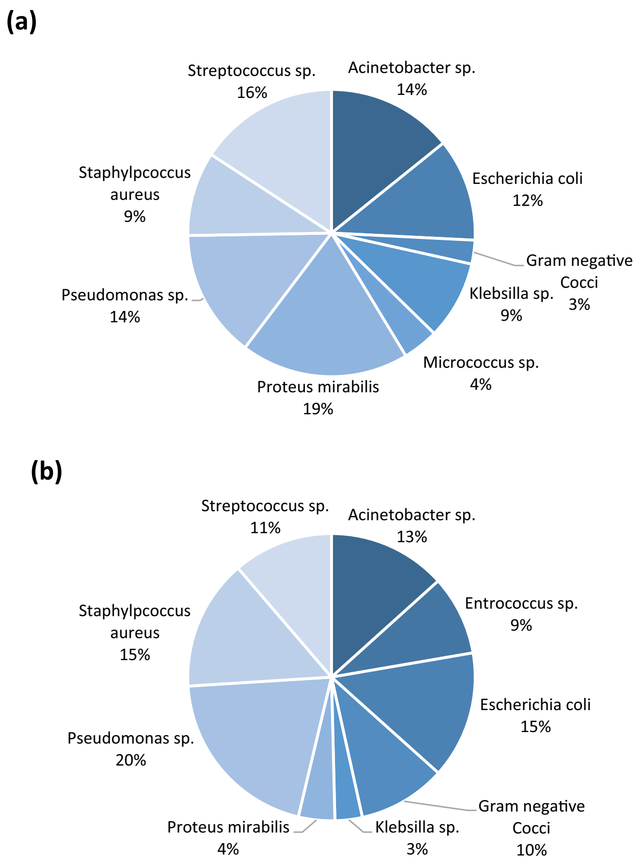


Fig. 3 Contribution of the different type of potentially pathogenic bacterial aerosols in the ambient air of the studied area (a: spring and b: summer)

velocity and humidity. Also, with increasing temperature, the levels of potentially pathogenic bacterial aerosols concentration have increased (Table 3). According to the results, there was a relationship between temperature, humidity, wind velocity and precipitation variations, and concentration of potentially pathogenic bacterial aerosols.

There are also reports of similarly significant correlations between the concentration of bioaerosols and meteorological parameters such as relative humidity and temperature in a landfill site in India [19] in a compost facility in Iran [17] and a municipal landfill site in Poland [18].

Also, some other studies found no significant relationship between meteorological parameters with the concentration of bacterial aerosols distribution [5, 47].

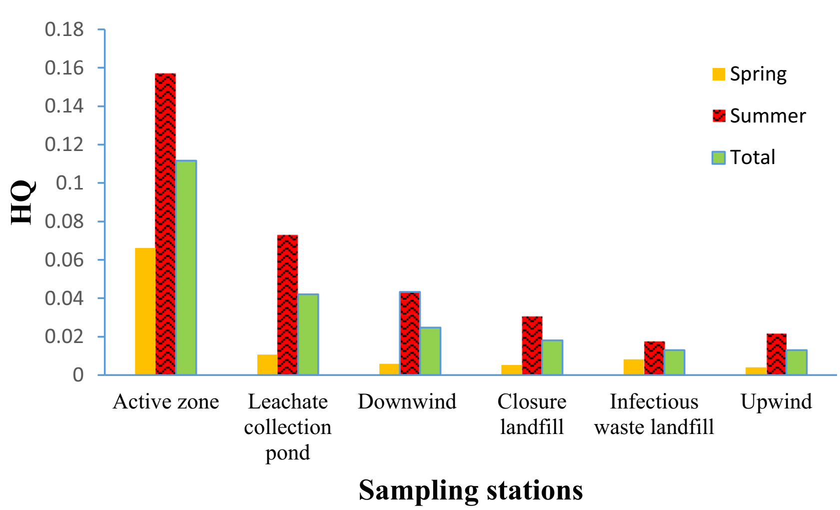
Frequency of the potential pathogenic bacterial aerosols

The frequency of the different types of potentially pathogenic bacterial aerosols in spring and summer are shown in Fig. 3.

Predominate type among determined potential pathogenic bacteria in the spring included *Proteus mirabilis* (19 %), *Streptococcus* sp. (16 %), *Pseudomonas* sp., and *Acinetobacter* sp. (14 %). Whereas in smaller amounts were determined Gram-negative Cocci (3 %) and *Micrococcus* sp. (4 %) (Fig. 3a). The study specified that the *Pseudomonas florescens* > *E. coli* > *Streptococcus* sp. were the predominant type in the spring [24].

On the other hand, predominate type among determined potential pathogenic bacteria in summer included *Pseudomonas* sp. (20 %), *Staphylococcus aureus*, and *Escherichia coli* (15 %). Whereas in smaller amounts were determined *Klebsiella* sp. (3 %) and *Proteus mirabilis* (4 %) (Fig. 3b). Also, the study specified that *Pseudomonas florescens* > *Streptococcus* sp. > *E. coli* were the predominant type in the summer [24]. In another study, gram-negative bacilli of the Enterobacteriaceae (e.g. Escherichia sp., Proteus sp.) and the genus *Pseudomonas* were of particular concern in MSW landfill, similar to results of this study [48, 49]. *Staphylococcus* genus is consider as air pollution indicator

Fig. 4 HQ of potentially pathogenic bacterial aerosols by inhalation exposure in the landfill site workers



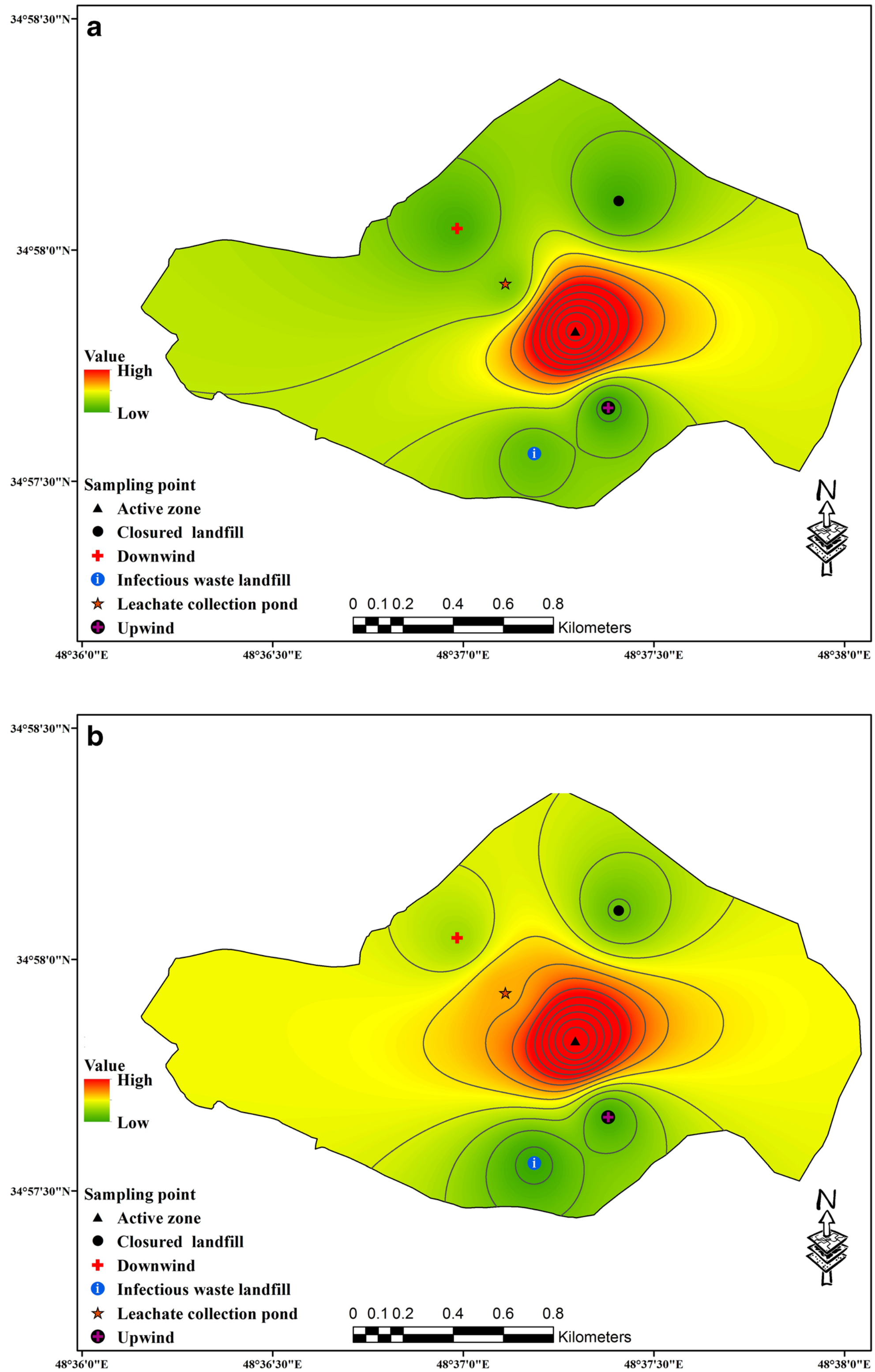


Fig. 5 Spatial distribution of potentially pathogenic bacterial aerosols in the study area (a: spring and b: summer)

for determine a probability of pathogenic microorganism's presence [42]. Endotoxin gram-negative bacteria may cause an inflammatory reaction in the lungs, fever and gas exchange disturbances [24].

Health risk assessment

In the present study, the risk of the exposure to potential pathogenic bacterial aerosols in the landfill site workers and the

HQ caused by them was investigated. HQ of bacterial aerosols by inhalation exposure according to the different sampling stations were shown in Fig. 4.

According to Fig. 4, HQ by inhalation exposure for all sampling stations was not higher than 1 (HQ ≤ 1). The highest HQ rate in the spring was related to the active zone (0.07) and the lowest was upwind (0.01). Also, the calculated highest HQ in the summer was related to the active zone (0.16) and the lowest was related to the infectious waste landfill (0.02).

Therefore, exposure to bacterial aerosols in the summer can have adverse effects on workers and people living around the landfill, Due to their small size, bioaerosols can penetrate deeply into the respiratory system [47]. However, due to the complex structure of the respiratory system, it is improbable that a similar dose will be deadly, but, the additional exposure will increase the risk of developing invasive disorders by the exposed workers, especially the immunocompromised [50, 51]. In the study by Madhwal et al. on the risk of exposure to bacterial bioaerosol through respiration, the highest sediments were observed in the lung tissue of adults [5]. Results of this study has demonstrated that the Hamadan MSW landfill site was a main source of bacterial aerosols spread that can contribute negatively to the respiratory health of the site workers and others that are working or living near this place. The graphic visualization of the HQ in stations enables a better assessment of the hygienic condition of potential pathogenic bacterial aerosols distribution.

Spatial distribution

The map of the distribution of potentially pathogenic bacterial aerosols by using the IDW interpolate method was shown in Fig. 5.

According to spatial distribution GIS maps (Fig. 5a, b), by moving away from active and contaminated sites (active zone and then leachate collection pond), the amount of potentially pathogenic bacterial aerosols has decreased. The reasons for the higher concentration in these units could be due to the wind direction from the active zone to the leachate collection pond and then the downwind area. However, the bacterial aerosols density in the downwind area was significantly higher than the upwind area. The results of a study by Akpeimeh et al. indicated a significant decrease in concentration with the distance from the active zone [52]. In another study, the highest emission of bioaerosol occurred in the area of the waste landfill site and during compost pile processing, which were near to active zones [5, 53]. The other reason is that in the active zone of landfill sites, displacement, transmission, and processing of the waste for sanitary management play an important role in the release of bioaerosols into the air [54].

The findings of this study revealed that in contrast to spring (Fig. 5a) that the concentration of potentially pathogenic bacterial aerosols and consequently health effect is higher in around the active zone and leachate collection pond, in summer (Fig. 5b) were relatively high in throughout the study area. Nevertheless, distinct spatial variations were observed in both seasons. This may be due to the same specification of the sampling areas, which were all located in an MSW landfill. In some studies, the high concentration distribution was observed in summer, which is consistent with the results of the present study [24, 55]. The reason for the higher risk in the summer could be due to the methodological condition. Unlike spring, where the risk is greater around the active zone and leachate.

Conclusions

Meteorological factors, such as temperature and wind direction, had major impacts on the distributions of the potential pathogenic bacterial aerosols. The predominant types of pathogenic bacteria that detected were *Proteus mirabilis*, *Streptococcus* sp., *Pseudomonas* sp. and *Acinetobacter* sp. in spring and *Pseudomonas* sp., *Staphylococcus aureus*, and *Escherichia coli* in summer and indicated that a high risk for the health of the workers if they work for a long period. The HQ of the potential pathogenic bacterial aerosols was less than 1, indicating "an acceptable hazard". Although the numerical values of HQ in different locations of the landfill site were an acceptable level, this study highlights the importance of decreasing the potential pathogenic bacterial aerosols emissions in landfill sites. Furthermore, the total HQ in the summer was above the acceptable level (1.48), indicated that the exposure to bacterial aerosols in the summer have possible adverse effects on workers and people around this site. Finally, controlled exposure by using personal protective equipment (PPE) can reduce health risks and other disorders caused by potential pathogenic bacterial aerosols.

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Declarations

Conflict of interest No conflict of interest has been reported by the authors.

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