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Unveiling the Air Quality Impacts of Municipal Solid Waste Disposal: An Integrative Study of On-Site Measurements and Community Perceptions

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Abstract: This study examines air quality conditions in and around a classroom located in the Sarıçam/Adana region of Türkiye, near the campus of Adana Alparslan Türkeş Science and Technology University and the Sofulu municipal solid waste (MSW) facility. This academic setting was strategically chosen due to its proximity to the waste facility. The study aims to provide a comprehensive view of the environmental and social impacts of solid waste management through a methodological approach that combines quantitative on-site measurements and qualitative survey studies. Findings from measurements and surveys underline the significant and measurable impacts of MSW facilities on the ambient air quality of university residents. The analysis revealed a marked increase in concentrations of key pollutants, including carbon monoxide (CO), hydrogen sulfide (H_2S), dust, and methane (CH_4). At sampling point N1, H_2S levels rose from 0 ppm in July to 13 ppm in November. Methane increased from 0.2% to 2.5% of the Lower Explosive Limit (LEL) at the same point, although it remained within safety limits. Additionally, CO levels showed a 40% increase, and dust concentration levels rose from 0.21 mg/m^3 to 2.36 mg/m^3 from summer to winter, indicating a seasonal variation likely influenced by the landfill's operational dynamics, as well as changes in temperature and relative humidity. In particular, the results indicate high concentrations of CO, H_2S and dust, which are directly related to air quality degradation. The study also sheds light on the impacts of these waste disposal facilities on the general well-being and health of the university community, particularly on students and staff. In addition to these findings, the study highlights a general lack of awareness in the university community about the impacts of MSW facilities on air quality. This highlights the need for increased education and information dissemination. The results support the development of comprehensive and effective strategies, including technical solutions and public awareness initiatives, to mitigate the impacts of these facilities on residential areas. In conclusion, the impacts of MSW facilities on air quality should be seen as a multidimensional issue that requires a holistic approach addressing environmental, health, social, and educational dimensions.

Keywords: air pollution; municipal solid waste (MSW); air quality assessment; environmental impact; public health; indoor air quality; waste management strategies

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1. Introduction

Natural ventilation is one of the most common and effective methods of improving indoor air quality in various built environments, including residential, commercial, and industrial spaces [1]. It involves the exchange of indoor air with clean outdoor air using natural forces such as wind and buoyancy. With natural ventilation, fresh air with fewer pollutants from the outside reduces the concentration of pollutants indoors, resulting in a healthier indoor environment. However, the level of pollutants in the outdoor air source is also important for indoor air quality [2]. The World Health Organization has identified six major air pollutants that significantly affect human health: particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead [3]. The main criteria for assessing air quality are the air quality index [4], greenhouse gas emissions of hydrogen sulfide (H_2S) and methane (CH_4) [5], particulate matter and specific air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), and volatile organic compounds (VOCs) [6]. These criteria determine air quality as well as indoor air quality. Monitoring common indoor pollutants will help us reduce the risk of indoor health concerns [7,8].

The regional assessment of air quality in different regions of Türkiye, determination of air quality indices, and evaluation of major air pollutants and their interactions have been the focus of many studies and have provided comprehensive information on the spatial and temporal variations of air pollutants in Türkiye [9–11]. Studies examining air pollution in Türkiye, such as those conducted by Tayanç et al. (2022) [12] and Akan A. (2022) [13], have evaluated the air quality of cities such as Konya and Zonguldak. These studies have highlighted the environmental challenges in these regions and the industrial activities contributing to air pollution.

Studies in Türkiye have investigated the impact of industrial growth, urbanization, and climate change on air pollutants. These studies have focused on determining the causes of air pollution and analyzing long-term changes in atmospheric pollutants, particularly in large cities such as Istanbul [14,15]. As a result, it is known that industrial activities can significantly degrade the air quality of cities.

Reviewing air pollution studies in Adana, Sahrir et al. (2022) [16] focused on risk perception and behavior analysis to improve air quality in Adana. Sezer et al. (2020) [17] employed a new ANN model to estimate NO_x emissions in Adana, contributing to understanding the region's air pollutant emissions and their potential impact on air quality.

Akiner (2020) [18] addressed environmental pollution in the Mediterranean Sea along the Turkish coast, including Adana. Pekdogan et al. (2023) [19] investigated particulate matter measurements in Adana, concluding that PM levels were high during the months of measurement. Consequently, air pollutants such as PM_{10}, O_3, CO, NO_x, NO, NO, NO_2, H_2S, and SO_2 originating from high population density and industrial activities were identified in this region.

In recent years, waste management has become increasingly important within sustainability principles. The National Waste Management and Action Plan outlines policies and strategies for waste reduction at the source, classification, collection, transportation, temporary storage, recycling, disposal, reuse, processing, conversion to energy, and final storage. However, the growing quantity of waste necessitates new municipal solid waste (MSW) facilities, making the selection of alternative landfills critical.

In addition to sustainable strategic steps, landfills can be a source of various air pollutants, such as chemicals, odor, and volatile organic compounds, which can negatively affect public health [20]. Improper management of MSW can lead to ecological impacts such as water and air pollution [21]. It has come to the forefront to consider MSW as an energy source, and it has been emphasized that MSW should be disposed of in an environmentally sound manner and used as an energy source [22]. In addition, studies have highlighted the need for effective waste management practices to reduce air pollution by underlining urban air pollution caused by the open burning of waste in landfills [23].

The primary source of bioaerosols in landfills is accumulated organic waste. MSW may include elements that may contain enteric pathogenic bacteria. In addition, landfilled wastes from residential areas may contain decayed food waste, packaging materials, etc., that contain large amounts of bacteria [24]. These wastes can become bacterial and fungal bioaerosols during collection, transportation, and disposal [20]. These bioaerosols can cause chronic lung diseases as they can be in respirable sizes [25]. A study by Ithnin et al. (2013) [26] examined the impacts on air quality and students' respiratory health at a school near a former landfill site and found high lead concentrations and respiratory symptoms among students near the former site. In Adana, rapid population growth and urbanization have increased waste production, leading to urban waste collection and disposal problems. The location of the existing MSW facility in the city negatively affects health and social life [27].

However, sanitation landfills can be a source of various air pollutants such as chemicals, foul odors, and volatile organic compounds, which can negatively impact public health [28]. Therefore, it has been emphasized that landfills and disposal sites can cause emotional and physical disturbances resulting from the topographical profile of the area, the management of neighboring lands, and the population in nearby residential areas [29]. Şener et al. (2011) [30], in MSW site selection with GIS and AHP methodology: A case study in Senirkent-Uluborlu (Isparta/Türkiye), emphasized that Türkiye does not have a systematic solid waste management strategy and 67% of the MSW generated is dumped in open dumps. Therefore, the environmental impacts of industrial facilities such as MSW plants should be closely scrutinized, especially their impact on air quality. Table 1 contains a literature review of the geographical focal points, main research areas, and key findings of the impact of MSW on air quality.

Table 1. Overview of the air quality aspect in the field of MSW.

Reference (Year)	Geographic Location	Study Focus	Environmental Impacts	Main Research Areas	Key Findings
Ibor et al. (2020) [31]	Nigeria, Calabar	Environmental and public health impacts of municipal solid waste at Lemna Dumpsite	Public health and environment	MSW, public health impact	Impact of municipal waste on public health and environment
Sakanyi and Kooma (2022) [32]	Zambia, Chililabombwe District	Municipal solid waste management issues	Environmental degradation, public health threats	Waste management, recycling, disposal	Environmental and health threats due to poor waste management
Daffi et al. (2020) [33]	Nigeria, Jos Metropolis	Environmental impact of open burning of municipal solid wastes	Air pollution, open burning impacts	MSW, air quality	Effects of open burning on air quality and pollution levels
Zakir Hossain et al. (2014) [34]	Bangladesh, Dhaka	Air quality impact and health risks of solid waste disposal at Matuail landfill	Air quality, health risks	Solid waste disposal, landfill impact	Air quality impact of solid waste disposal on the environment
Omang et al. (2021) [35]	Nigeria, Bekwarra Local Government	Public health implications of solid waste generated by households	Health hazards, infectious diseases	Household solid waste, public health	Health hazards associated with solid waste
Yang and Li (2021) [36]	Vietnam	Air pollution from household solid waste open-burning	Air pollution, public health implications	Household solid waste, open burning	Amount of air pollution from open burning of household waste
Ozbay et al. (2021) [37]	General	Effective landfill design and operation	Environmental and health effects	Landfill management, design	Importance of well-managed landfills for environmental and health protection

Table 1. *Cont.*

Reference (Year)	Geographic Location	Study Focus	Environmental Impacts	Main Research Areas	Key Findings
Citton et al. (2020) [38]	Lebanon	Impacts of solid waste disposal practices near a regional landfill	Water, air, and health impacts	Landfill impact, waste disposal practices	Environmental and health effects associated with landfill sites
Heaney et al. (2011) [39]	USA	Relation between malodor, hydrogen sulfide, and health near a landfill	Health effects, hydrogen sulfide exposure	Landfill emissions, public health	Health effects of exposure to landfill emissions
Mattiello et al. (2013) [40]	General	Health effects of solid waste disposal in landfills and incinerators	Health impacts, environmental exposure	Landfill and incinerator disposal, health review	Potential health Impacts on populations near landfill sites
Khoiron et al. (2020) [41]	General	Environmental impact and public health caused by MSW landfill	Environmental and health effects	MSW landfill, environmental health	Environmental and health impacts of MSW landfills
Matsuto et al. (2015) [42]	Sendai, Japan	Passive aeration and airflow mechanism in a semi-aerobic landfill	Airflow, aeration impacts	Landfill aeration, airflow	Effects of landfill aeration on air quality
Feuyit et al. (2019) [43]	Cameroon, Yaoundé	Air quality and health risk assessment near Nkolfoulou Landfill	Air quality, human health risk	Landfill, air quality, health risk	Impact of landfill operations on air quality and human health
Ololade et al. (2019) [44]	South Africa, Bloemfontein	Impact of leachate from a landfill site on water and soil quality	Water and soil quality	Landfill leachate, environmental pollution	Effects of landfill on water and soil quality
Teta and Hikwa (2017) [45]	Zimbabwe, Bulawayo	Heavy metal contamination of groundwater from an unlined landfill	Groundwater contamination	Landfill, groundwater, heavy metals	Impact of landfill operations on groundwater quality
Mor et al. (2006) [46]	Gazipur, Bangladesh	Groundwater pollution assessment near a municipal solid waste landfill site	Groundwater contamination	Landfill, groundwater, leachate	Impact of landfill leachate on groundwater quality
Njoku et al. (2019) [47]	South Africa	Health and environmental risks for residents near a landfill site	Air quality, odor pollution	Landfill, public health, environmental pollution	Air quality contamination linked to landfill site

Considering the abovementioned literature, air quality around MSW facilities and its effects on human health is a critical issue in environmental research. This study examines the comfort and indoor air quality conditions in Adana Alparslan Türkeş Science and Technology University (ATU) campus and the designated classroom near the Sofulu MSW facility. According to the literature search conducted for this purpose, there are no published reports characterizing the impact of SWM on air quality in ATU. Accordingly, this is the first study to provide qualitative and quantitative data on the impact of the Sofulu landfill site in Adana province on a university classroom air quality.

2. Methodology

This study was conducted in Sarıçam/Adana, where the ATU and Sofulu MSW facilities are located on a total of 1,431,673.82 m^2 in Adana/Türkiye which houses approximately 10% of the total population with rapid development transformation and urbanization, see Figure 1. The architectural design studio located approximately 1.5 km from the Sofulu MSW facility was chosen as the study area. Furthermore, this study investigates the environmental impacts of the Sofulu MSW Facility using two different methodologies: on-site measurements and survey studies.

The first method involves measurements to determine the concentrations of various atmospheric pollutants. The second method is based on structured surveys to assess the facility's impact on the surrounding university population. Integrating these two approaches provides a comprehensive overview of solid waste management's environmental and social dimensions.

2.1. On-Site Measurements

The points determined for outdoor measurements are shown in Figure 1. Measurements and samples were taken from 3 different points, and outdoor measurements were made at the architecture studio's indoor air quality, located 1.5 km from the facility, at the university entrance gate 500 m away, and on Çatalan Street 100 m from the facility.

The identified points represent locations N1 (opposite MSW), N2 (University gate), and N3 (Classroom), as shown in Figure 1. These are strategic locations exposed to various environmental impacts and where potential impacts of the MSW can be observed. While N1 is located directly in the MSW impact area, N2 and N3 are located within the university campus and represent the air quality many users are exposed to. Here, data from July and November on environmental and occupational hygiene measurements have been obtained for key atmospheric pollutants such as CO, H_2S, CH_4, formaldehyde, oxygen (O_2) level, and dust concentrations, as well as to assess compliance with occupational hygiene standards and safety limits. Safety limits established by organizations such as NIOSH, IEC, and MDHS specify the maximum concentrations of pollutants individuals can encounter without exposure to health risks. The safety limit determined for CO is 50 ppm per hour on average according to the NIOSH-NMAM 6604 standard [48]; for H_2S, it is 10 ppm according to OSHA [49]; and for dust concentrations, it is TWA (average weight) 5 mg/m^3 according to the MDHS 14/3 standard [50]. The short-term exposure limit (STEL) for formaldehyde concentration is set to 2.46 mg/m^3 or 2 ppm according to the NIOSH-NMAM 3500 standard [51].

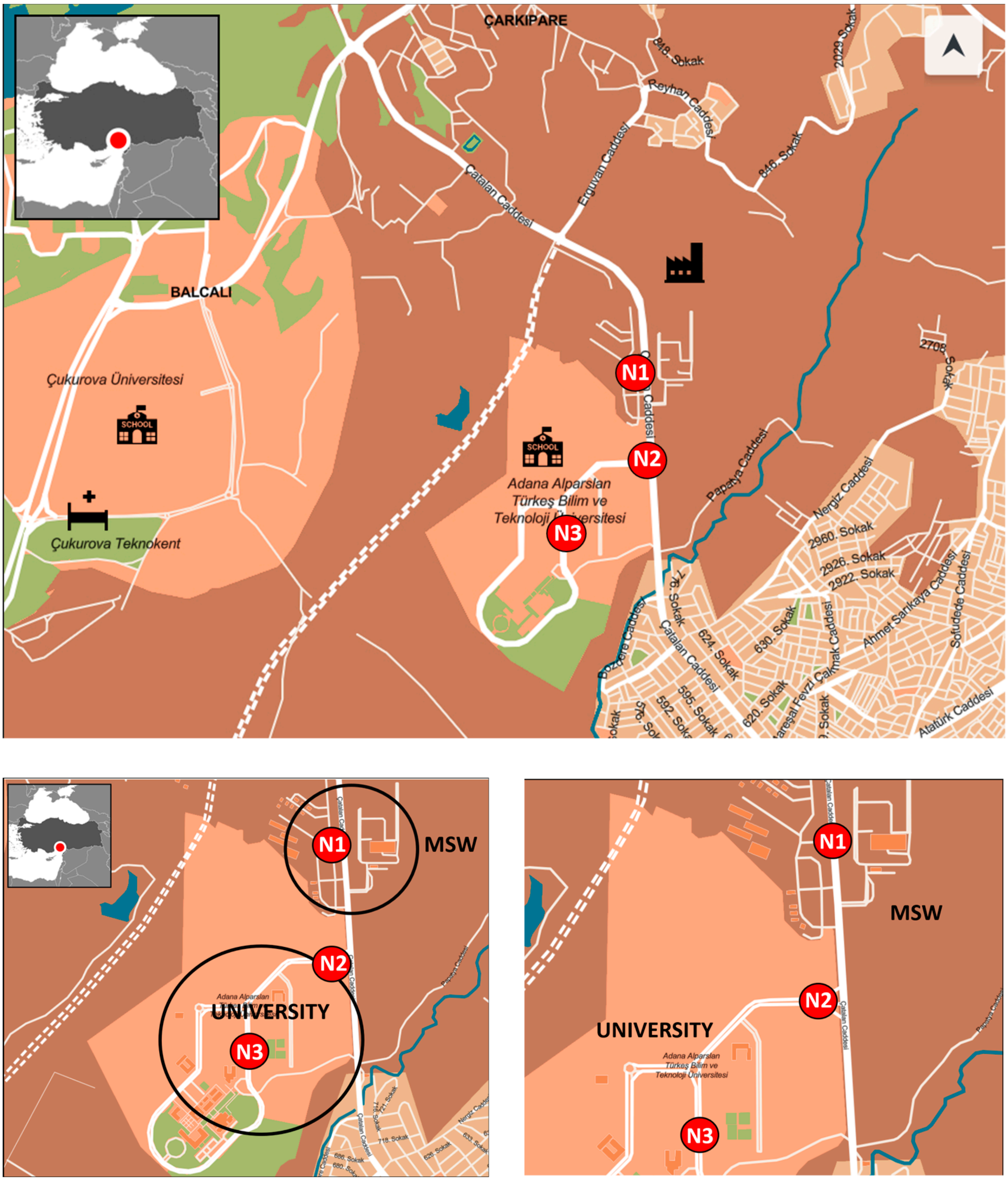

Figure 1. Measurement points in Adana province and Sarıçam district [52].

2.1.1. Sampling

Air samples were taken during summer and winter evenings for each location. July is the hottest month in Adana and is important for air pollution and odor dispersion. November is the wettest month, creating an ideal environment to observe the effects of precipitation on air quality. This seasonal choice allows the study to assess the impact of MSW in different environmental conditions. The choice of summer and winter seasons to evaluate the impacts of Sofulu landfills on air quality in Adana province is justified by significant seasonal changes in microbial activity related to reduced sulfur compounds

(RSCs) and methane oxidation, as highlighted in the studies of Susaya et al. (2011) [53] and Lee et al. (2018) [54].

Susaya et al. (2011) [53] show that the high temperatures common in summer increase the volatility of odor-causing compounds, thus affecting their detectability and perceived intensity. This phenomenon is crucial to understanding the potential worsening of odor problems during the warmer months. It underscores the need for effective odor management strategies considering seasonal temperature fluctuations. Lee et al. (2018) [54] confirm the seasonal focus of this study by describing how summer conditions leading to higher temperatures significantly increase microbial activity in landfill covers and promote methane oxidation rates of 85–96%. In contrast, a noticeable decrease in microbial productivity and methane removal efficiency (35–43%) is observed during the winter season, directly affecting the effectiveness of odor control measures. This biological aspect is crucial to evaluating the odor reduction potential and challenges associated with MSW disposal sites in different seasons. In this area, terms are chosen based on preliminary observations and survey results.

The tally sheet, organized in Table 2, was used to record the intensity of the odor for 24 h every day for 3 weeks by an observation team of three different people. Each observer marked each hour that they felt the odor to determine the change in the odor throughout the day. Quality control was ensured by employing multiple observers and cross validating their observations to mitigate individual sensitivity bias. This study used resident recordings to document odor observations [55,56]. This practice draws on the opinions of individuals regularly exposed to the odor source without specialized training in odor assessment. Recognizing the different sensitivity and potential biases between individual observers, a strategy of aggregating the collected odor recordings was adopted. This approach enabled data to be analyzed in aggregate, focusing on identifying recurring patterns across observations, thereby reducing reliance on the subjective sensitivity of individual participants. By aggregating and analyzing these recordings, the aim was to discern consistent odor trends and intensities, providing a more objective basis for assessing the impact of the odor source on the community.

As a result of this detailed observation process, during the summer season, the peak time of the odor was usually between 3:00–4:00 a.m., and in winter, this time was usually between 8:00–9:00 p.m. These results are color-highlighted in Table 2.

Based on the results of this preliminary qualitative survey, it was decided to conduct sampling at set times. Sampling was conducted at 03:00 at night in summer and 8:00 p.m. in winter, when the environmental impact of MSW is felt most intensely. Samples were taken at a height of approximately 1.5 m above ground level. This height was preferred as it is close to the level of human respiration and allows for more representative samples. The sampling process was carried out using standardized and repeatable methods. At each sampling point, air samples were collected over a period and properly preserved for subsequent analysis. The sampling process posed several challenges, especially during the variability of weather conditions and sample collection. Sample collection was conducted flexibly to overcome these difficulties, and the conditions at each sampling point were as favorable as possible.

Table 2. Evaluation tally of the odor exposure in summer and winter.

	Evaluation Tally of the Odor Exposure (Summer)							Evaluation Tally of the Odor Exposure (Winter)						
Time Slot	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
07:00–08:00	X													
08:00–09:00	XX							XX		XX	XX			
09:00–10:00					XX		X					X		X
10:00–11:00					XX		XX					X		
11:00–12:00	X													
12:00–13:00	X													
13:00–14:00					X		XX					X		
14:00–15:00						X	X						X	X
15:00–16:00	X							X						
16:00–17:00	XX							XX						
17:00–18:00							X							X
18:00–19:00							X							X
19:00–20:00				X							X			
20:00–21:00			X	X		XX		**X**	**XX**		**X**		**XXX**	
21:00–22:00								XX					XXX	
22:00–23:00	XX													
23:00–24:00					X		X					X		X
24:00–01:00							X							X
01:00–02:00	X							X						
02:00–03:00	XXX							X						
03:00–04:00		**X**			**X**		**XXX**		X					XX
04:00–05:00							XXX							XXX
05:00–06:00				X							X			
06:00–07:00			X	X		XX							XX	

2.1.2. Measurement Methods

Four main measurement methods were used in this study as part of the environmental monitoring and air quality assessment process: Instantaneous gas concentration measurements, thermal comfort measurements, particulate matter measurements, and volatile organic compound measurements. Each method is designed to assess specific parameters and environmental factors.

Instantaneous Gas Concentration Measurements

Instantaneous gas concentration measurements are critical to determine the levels of harmful gases in the air. The concentrations of carbon monoxide (CO), formaldehyde (HCHO), hydrogen sulfide (H_2S), and methane gas (CH_4) gases in the air were determined using the ASTM D 4490 Color Comparison Method. The measurements include the stain length, performance characteristics of the detector tubes, and associated pumps (detector tube measurement system) under defined laboratory conditions and experimental methods. These measurements were performed with a Henan Hanwei measuring instrument. The instrument has multiple detector tubes that can measure several different gases simultaneously. The gas meters manufactured by Henan Hanwei are reliable and precise instruments widely used in industry to determine the concentrations of various gases. The instrument's calibration, precision, and accuracy are determined and periodically tested following laboratory conditions. This way, reliable results are obtained in air quality monitoring studies and environmental health assessments [57].

Thermal Comfort Measurements

According to ISO 7730 [58] and ISO 7243 [59] standards, thermal comfort measurements determine important factors affecting the efficiency of heating and cooling systems of working environments, employee comfort, and productivity. These measurements are made to understand how the thermal characteristics of an environment affect people's thermal comfort levels. These standards include measurements such as Wet Bulb Globe Temperature (WBGT), Predicted Mean Vote (PMV), and Percentage of Personal Dissatisfaction (PPD). The measurements were performed using a relative humidity and air temperature probe, and the temperature was recorded between −40 °C and +80 °C and the relative humidity between 0% and 100%. Thermal comfort measurements were performed with a TESTO 480 Easy Climate instrument [60–62]. Thermal comfort measurements made with a TESTO 480 Easy Climate device and according to ISO 7730 and ISO 7243 standards are critical for ensuring a healthy and efficient indoor environment. These measurements help evaluate the effectiveness of climate control systems, increase users' comfort and satisfaction levels, and reduce potential health risks. For this reason, precise and real-time measurements were taken using this measuring instrument and the classroom environment was also evaluated.

Particulate Matter Measurements

Total dust and respirable dust concentrations were determined for ambient and personal exposure using the MDHS 14/3 method and a Zefon DG5 m. These measurements were made using Gillian, buck gas/dust sampler, precision balance, glass Petri dishes, 37 mm diameter filter, and 25 mm diameter respirable dust filters with PVC and glass fiber filter holders [62]. The dust value was calculated by determining the dust with the air passed through the filter. MDHS 14/3 (Methods for the Determination of Hazardous Substances) is a method used to measure airborne concentrations of respirable and inhalable dust applied within the scope of OHS measurements. This method is designed to monitor dust levels to which workers are exposed. The basic features of all systems consist of a collection substrate, such as a filter, and a pump to draw air through it. The weight of the collected dust is determined by weighing the substrates before and after sampling. The particulate matter measurements applied in this study were carried out at 3 designated points, and the results were evaluated under European and international standards.

Volatile Organic Compound Measurements

The ISO 16200-1 [63] standard measures volatile organic compounds (VOCs) in air samples [64]. This standard is designed to determine VOC concentrations in workplaces and industrial facilities. Toluene, 1.2-dibromoethane, Tetrachloroethylene, Ethylbenzene, p.m-xylene, o-xylene, 1.3.5-trimethylbenzene, and 1.2-dibromo-3-chloropropane VOC compounds were measured following the ISO 16200-1 standard. The collected air samples are usually analyzed using analytical techniques such as gas chromatography (GC). This technique allows us to precisely determine the concentrations of different VOCs in air samples. The results are compared with occupational exposure limits, usually specified in local or national health and safety regulations. VOC measurements are pollutants that must be carefully monitored due to their impact on human health and the environment.

Many common furniture and building materials can emit VOCs, especially in classrooms. This leads to poor air quality and health problems [65].

Measurement Equipment Information

The equipment used in this study was a Testo 480 Easy Climate, BUCK Libra Plus™ Air Sampling Pump, Henan Hanwei Gas Detector, and Zefon DigiCal™ Primary Flow Calibrator. The measuring range for the Testo 480 is −100 °C to +400 °C using a Pt100 sensor with a resolution of 0.01 °C. This instrument was used for humidity measurements from 0 to 100% with a resolution of 0.1%. Airflow velocity measurements were performed in the 0.6 to 50 m/s range with a resolution of 0.01 m/s. BUCK Libra Plus™ series air sampling pumps were used to collect air contaminants and were operated with ±5% accuracy at flow rates ranging from 0.6 LPM to 15 LPM. The Zefon DigiCal™ Primary Flow Calibrator was used to calibrate these air sampling pumps and provide instant flow measurements with 0.5% accuracy. The Hanwei Gas Detector was used to measure the concentrations of the identified gases. The instrument was operated in the measurement ranges 0–30,000 ppm CH_4 and 10,000 ppm H_2S with an accuracy of better than 50 ppm and a response time of T90 < 5 s. In addition, the Testo 480 and BUCK Libra Plus™ pumps were calibrated at −100 °C, 0 °C, 100 °C and 400 °C and flow rates of 0.6 LPM, 5 LPM, and 12 LPM, respectively, at the factory. The Hanwei Gas Detector was calibrated for CH_4 concentrations of 5000 ppm, 10,000 ppm, and 15,000 ppm. These calibrations improved the accuracy of the recorded data and reduced measurement uncertainties.

2.2. Survey Studies

Surveys designed to assess the impact of the MSW Facility on air quality were conducted among university personnel and students. First, the questionnaire survey mentioned in this study is based on an earlier study by Pekdogan (2023) [52]. The study used statistical techniques to examine the relationships between respondents' answers and landfill regulation. Among 100 participants, ethics committee approval was obtained to analyze the survey results, and participants were informed about the subject. It was emphasized that the participants participated voluntarily and had the right to withdraw from the study at any time. Participants included 50 university students and 50 academic and administrative personnel. Within the scope of the research, a questionnaire was designed to collect data on the thermal comfort of office/classroom environments, indoor air quality, and the impact of MSW. The survey data were coded and analyzed using SPSS statistical software. The questionnaire consisted of ten questions on indoor air quality, thermal comfort, the impact of MSW, and indoor air pollutants (Table 3) and Appendix A. The differences between these two groups were statistically observed by cross-classification analysis [52].

Table 3. Survey questions [52].

1	Perception of Clean Air Rate
2	Perception of Air Quality
3	Satisfaction with Indoor Temperature
4	Perception of Indoor Temperature
5	Solid Waste Disposal Facility Information
6	Impact of the Facility on the Campus
7	Effect Duration of Facility Odor
8	Impact of the Facility on Classroom/Office Air Quality
9	Impact of the Facility on Health
10	Indoor Air Pollution Parameters

The data analysis process is an important component of the qualitative part of this study and has an important role in understanding the impact of MSW on air quality. Descriptive statistics were first applied to the data set. This provided an overall data summary, including the general distribution of participants' responses and key trends. Basic statistical measurements such as mean, median, mode, and standard deviation were performed at this stage. Cross-classification analysis was used to identify differences between the student and personnel groups. This analysis revealed the relationships and differences between the respondents' responses in the different groups to the various questions of the questionnaire. The cross-classification analysis between the two groups revealed significant differences in response patterns, indicating a varied perception of odor intensity. This variation may be attributed to differing sensitivities and prior exposure to similar odors. The research also included correlation analyses to understand the relationships between the perceived impacts of the MSW facility and various air quality parameters. This analysis was conducted to determine the statistical relationships between different variables and the strength of these relationships. A *t*-test was also conducted to determine whether the perceived impacts of the MSW facility were statistically significantly different between students and personnel.

This methodology and data analysis process were designed to understand the environmental impacts of the MSW facility and how these impacts are perceived by various segments of the university community, as well as being a critical element to increase the reliability of the research and the validity of the results. The findings are intended to understand better the impacts of MSW facilities on air quality and contribute to developing policies and practices to manage these impacts. The study design, participant selection, data collection, and analysis methods were carefully planned to support the reliability and validity of the study.

3. Results and Discussion

Data on environmental and occupational hygiene measurements at ATU for July and November are summarized in a table that includes concentrations of important atmospheric pollutants and exposure limits for these pollutants. Table 4 presents information on indoor and outdoor air pollutants such as CO, H_2S, CH_4, formaldehyde, oxygen (O_2) level, and dust concentrations. N1, N2, and N3 represent sampling points identified throughout the study area; N1 is closest to the MSW plant, N2 at the university entrance, and N3 within a classroom, providing a gradient in exposure levels to atmospheric pollutants. In the July measurement period, we observed a temperature of 26 °C, wind speed of 2 km/h, and humidity at 94%. Conversely, during the November measurement session, the climatic conditions included a temperature of 15 °C, heavy rain with thunderstorms, 88% humidity, and a 35 km/h wind speed [66].

For carbon monoxide (CO), 2 ppm was measured opposite the garbage facility, 1 ppm at the entrance of the university and 0 ppm in the classroom in July, while 7 ppm was measured opposite the garbage facility and 1 ppm at other locations in November. Oxygen (O_2) levels remained constant at 20.9% in both months and at all locations, which is above the exposure limit of 19.5% and is considered safe. For hydrogen sulfide (H_2S), 0 ppm was measured at all three locations in July, while 13 ppm was detected opposite the waste facility in November, exceeding the exposure limit of 10 ppm. Methane (CH_4) measurements were 0.2% LEL in July opposite the waste facility and increased to 2.5% LEL in November but remained below the 5% exposure limit in both cases. According to all results, meteorological factors are important in the local community's acceptance of odor nuisance. Rain can affect the intensity and duration of odors, especially from landfills. Therefore, the reason for such a high H_2S difference and other pollutants, especially between July and November, may be due to meteorological factors and the operational conditions of the landfill. According to studies in the literature [67–69], weather conditions significantly affect odor intensity and frequency. Factors such as wind direction and speed, temperature and humidity, and operational conditions can significantly affect the odor concentration transported from the landfill.

Table 4. Concentrations of measured atmospheric pollutants in July and November measurements. The table also lists the Clo, Met, PPD, and PMV values for site N3.

	Standards and Recommendations	**Exposure Limit Value**	**Measuring Device**	**N1**	**N2**	**N3**	**N1**	**N2**	**N3**
					July			**November**	
CO (ppm)	NIOSH NMAM 6604 [48]	50	Henan Hanwei	2	1	0	7	1	0
H_2S (ppm)	OSHA [49]	10		0	0	0	13	0	0
CH_4 (LEL%)	IEC 60079-10-1:2020 [70]	5		0.2	0	0	2.5	0	0
Formaldehyde Concentration STEL (mg/m^3)	NIOSH-NMAM 3500 [51]	2.46	Zefon DG5 and Buck Libra Plus 5	0.21	0	0	0.17	0	0
Dust Concentration TWA (mg/m^3)	MDHS 14/3 [50]	5	Zefon DG 5	0.21	0.04	0.07	2.36	0.51	0.1
VOC	TS ISO 16200-1 [63]	-		-	-	-	-	-	-
Clo	TS EN ISO 7730 [58] and ISO 7243 [59]	-	TESTO 480 Easy Climate	-	-	1.2	-	-	1.2
Met		-		-	-	1.2	-	-	1.5
PPD (%)		-		-	-	11.2	-	-	10.9
PMV		-		-	-	0.54	-	-	0.45

In addition to the experimental analysis, an important aspect to consider is the perception of students and personnel of the university. Therefore, an analysis based on surveys and interviews provides valuable information on the perception of the impacts of MSW on air quality [52]. It helps to identify potential health risks and is a crucial tool to inform decision-making on waste management practices.

The questionnaire consists of ten questions about indoor air quality, thermal comfort, the impact of MSW facilities, and indoor air pollutants. The survey questions are designed using a Likert-type scale and ask respondents to indicate their level of agreement with certain statements. The questions and responses were coded into numerical values and evaluated with the SPSS statistical program in the survey data analysis. Statistical analysis of the survey data showed significant differences in perceptions of air quality and thermal comfort between students and personnel. Table 5 shows the descriptive statistics results of these surveys.

Table 5. Statistical Analysis of Survey Data: Mean, Median, and Standard Deviation Measurements.

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
Mean	2.4444	2.4568	3.0741	3.3333	1.6049	3.963	1.3827	3.8272	1.0988
Median	3	3	3	3	2	5	1	4	1
Std. Deviation	1.01242	1.00062	1.3302	1.0247	0.49191	1.2985	0.48908	1.30183	0.30021
	Q10-1	**Q10-2**	**Q10-3**	**Q10-4**	**Q10-5**	**Q10-6**			
Mean	1.716	2.875	4.2982	4.32	5.0625	6			
Median	2	3	5	4	5	6			
Std. Deviation	0.82514	1.0473	1.10138	0.55678	0.25	0			

The questions and methods in the questionnaire are designed to assess the impact of the MSW facility on air quality (Appendix A). The questions in the survey measure respondents' perceptions and knowledge about air quality, thermal comfort, and the impacts of the MSW facility in the classroom or office environments.

3.1. Perception and Satisfaction Regarding Air Quality and Temperature

Participants' perception of clean air in classrooms and offices generally indicates a low level of satisfaction, with an average degree of perception also indicating concerns about the availability of clean air. This closely aligns with their satisfaction with air quality, reflecting a slight trend of dissatisfaction among survey respondents. These findings highlight a potential area for improving environmental conditions in university facilities. The survey also revealed a disparity in thermal comfort satisfaction; Average satisfaction levels indicate room for improvement. The consistency of median values on questions about air quality and thermal comfort indicates a uniform perception among respondents. However, this points towards the need to better manage indoor environmental conditions. Students expressed particular concern about indoor temperatures, often finding them uncomfortably low. This may suggest that adjusting heating, ventilation, and air conditioning (HVAC) settings, especially in classrooms, may be beneficial.

3.2. Awareness and Impact of MSW Facility

Responses regarding the MSW facility revealed low awareness of the facility's operating principles among both students and staff. This points to a potential area for educational interventions to improve environmental literacy across campus. Participants' opinions regarding the impact of the MSW facility on classroom and office air quality were very high; here, a significant number of participants felt that the facility had a negative impact on their immediate environment. There was no consensus among participants regarding health effects; this indicated uncertainty or lack of awareness of potential health effects. This uncertainty highlights the need for communication and research into the health impacts of waste management facilities, potentially informing future policy and operational decisions. Finally, the survey shed light on the general awareness of indoor air pollution parameters, with respondents recognizing particulate matter, methane, and carbon monoxide. While most students and personnel are aware of particulate matter, methane, and carbon monoxide, there is a significant lack of knowledge about the effects of these pollutants on indoor air quality, especially carbon dioxide and particulate matter.

4. Conclusions

This study comprehensively examines the impacts of MSW facilities on air quality and their perceived impacts on university campus users. The results show that MSW facilities have significant and measurable impacts on air quality due to their proximity to campus. These impacts are manifested as a significant increase in the concentration and variety of pollutants in the atmosphere. For example, increases in carbon monoxide, hydrogen sulfide, and particulate matter have direct negative health impacts and lead to poor air quality. This study also indicates that having MSW facilities on campus significantly affects the health and well-being of campus occupants, students, and personnel. The presence of pollutants during specific seasons can reach levels that endanger health and lead to various health issues.

Furthermore, the survey highlights a lack of awareness regarding how MSW plants impact air quality, emphasizing the necessity for increased information and education on this matter. The survey findings underscore a lack of understanding surrounding the effects of MSW plants on air quality.

These findings emphasize that the impacts of MSW facilities on air quality are not only an environmental issue but also have significant impacts on public health and quality of life. In this context, comprehensive and effective strategies should be developed to mitigate the impacts of these facilities on residential areas. These strategies should include technical and engineering solutions and steps to further inform and educate the public on these issues.

The scope of the study was limited by the fact that measurements were taken only on specific days in summer and winter, which is a limitation in providing a comprehensive understanding of air quality variations throughout the year. Recognizing this limitation, future research studies will cover more extensive and longitudinal measurement periods. This approach will facilitate more detailed and continuous air quality monitoring by providing a richer dataset that accurately reflects seasonal variations and long-term trends.

In conclusion, the impacts of MSW plants on air quality should be considered a multi-dimensional problem. It should be addressed holistically, considering all environmental, health, social, and educational aspects. This approach will not only solve current problems but also contribute to preventing potential future impacts.

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Appendix A. Air Quality Survey

This survey assessed perceptions of air quality within classroom and office environments on the university campus. Participants were asked to rate various aspects of air quality, temperature, and their understanding and opinions on the impact of the solid waste disposal facility on campus.

1. How do you feel about the amount of clean air in your classroom/office? Rate from 1 (Dirty/Smelly) to 5 (Clean/Fresh).
2. How satisfied are you with the air quality in your classroom/office? Rate from 1 (Dissatisfied) to 5 (Pleased).
3. Are you satisfied with the indoor temperature of your classroom/office? Rate from 1 (Dissatisfied) to 5 (Pleased).
4. How do you feel about the indoor temperature of your classroom/office? Rate from 1 (Cold) to 5 (Hot).
5. Do you have information about the working principle of a solid waste disposal facility? (Yes/No).
6. Evaluate the impact of the solid waste disposal facility on the university campus. Rate from 1 (Ineffective) to 5 (Very Efficient).
7. The period when the odor emitted from the solid waste disposal facility to the environment is most effective. (Fall Term/Spring Term).
8. Evaluate the impact of the solid waste disposal facility on classroom/office air quality. Rate from 1 (Ineffective) to 5 (Very Efficient).
9. Do you think the solid waste disposal facility impacts your health? (Yes/No).
10. Please tick the parameters below that cause indoor air pollution (You can mark more than one): Particulate Matter (PM), Carbon Dioxide (CO_2), Methane (CH_4), Hydrogen Sulfide (H_2S), Carbon Monoxide (CO), Formaldehyde (HCHO).

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