# Investigation of $NH_3$ Concentrations around Livestock Farms in Balıkesir and Bursa

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**Abstract**

Ammonia ($NH_3$) is both an air pollutant and a contributor to particulate matter, which has significant effects on human health. The main source of $NH_3$ is agriculture, especially livestock farming. This study evaluated $NH_3$ levels in Balıkesir and Bursa for 2019–2023 via IASI retrievals, EMEP emission inventory, livestock production statistics, and meteorological data. Results showed that $NH_3$ concentrations were lowest in 2019 and highest in 2023. A clear seasonal profile was observed, with maximum levels in summer and minimum in winter, except for autumn 2023, which unusually became the second highest season. Concentrations in Balıkesir were more consistent with the emission inventory with higher correlations (r= 0.82) compared to Bursa (r= 0.48). Districts with both high $NH_3$ levels and intensive livestock activities, such as Altıeylül, Karacabey, and Mustafakemalpaşa, were examined at the farm scale. According to result, some farms appeared to be potential $NH_3$ sources, while for others additional local factors may also have contributed. Wind rose analyses suggested that northerly and northeasterly winds often influenced the transport of $NH_3$ pollution. The study indicated that $NH_3$ levels in Balıkesir and Bursa are closely associated with livestock activity, but also strongly depend on meteorological factors. The study showed the value of combining satellite data, emission inventories, and livestock statistics to better understand $NH_3$ pollution in agricultural regions, while highlighting the importance of farm-scale assessments for evaluating the role of agricultural point sources in local air quality.

## 1. Introduction

Although atmospheric $NH_3$ is not included in air pollution studies as much as the criteria pollutants, it has become increasingly important. In addition to its important role in the nitrogen cycle, it contributes to environmental processes such as acidification. Furthermore, through its reactions in the atmosphere, it is a precursor gas in the formation of secondary inorganic particulate matter (SIA), which has a detrimental effect on both the environment and human health. $NH_3$ is a primary pollutant and can enter the atmosphere from many different sources, including agricultural activities, traffic, industry, wildfires, and shipping. Among various anthropogenic and natural sources, $NH_3$ largely originates from agriculture, and livestock have an important place in agriculture. In the farming operations, processes such as manure management, animal housing and grazing affect $NH_3$ emissions.

Previous studies have identified animal farms as major $NH_3$ emission hotspots in countries including the United States and China, as well as in Basmakcı, Afyonkarahisar, Türkiye (Clarisse et al., 2020). In the study focusing Lombardy, Italy it was seen that $NH_3$, unlike other pollutants, did not decrease during Covid-19 restrictions, and the cause was livestock activities (Lovarelli et al., 2020). High $NH_3$ concentrations were detected in intensive livestock areas of the Hebei, China and emissions have been compared with satellite retrievals (Liu et al., 2022). Studies conducted in Colorado showed that ammonia emissions from concentrated animal feeding operations can be transported over long distances (Li et al., 2017). More recent regional studies in Türkiye reported the largest hotspots near animal farms, particularly in the eastern parts of İzmir (Tokgoz et al., 2025) and in Konya, where intensive livestock production areas were identified as the main source of $NH_3$ emissions (Alban et al., 2025).

This study aims to investigate the impact of livestock farms on $NH_3$ levels for Balıkesir and Bursa via remote sensing. Using the Infrared Atmospheric Sounding Interferometer (IASI) Level 2 $NH_3$ retrievals, the temporal variation of $NH_3$ levels around intensive livestock farms was investigated. $NH_3$ levels were evaluated together with animal production statistics and meteorological parameters for the study period of 2019-2023. This study aims to contribute to the evaluation of the impact of $NH_3$ over single point sources of animal husbandry as hotspots.

## 2. Methodology

Balıkesir and Bursa provinces, located in the southern Marmara Region, contain multiple livestock and poultry farms as point sources of $NH_3$, in addition to biogas plants. These two provinces, where livestock and poultry farming are particularly intense, have high $NH_3$ levels according to recent year evaluations, were selected as the study area. The study area is shown along with different possible point $NH_3$ sources (livestock, poultry, biogas), CORINE land cover (CORINE, 2025), and selected meteorological stations (MS) for further assessment (Figure 1).

$NH_3$ retrievals obtained from IASI, onboard MetOp satellites operated under the European Space Agency (ESA). IASI has spatial nadir resolution of 12 km (circular footprint) and providing data twice a day (9:30, 21:30). In this study, Level 2 morning (AM) overpass data was used, and filtered according to quality criteria (AERIS, 2025). Quality assured data spatially processed to be mapped to grids with a search radius of 6 km with a 1×1 $km^2$ gridded study area.

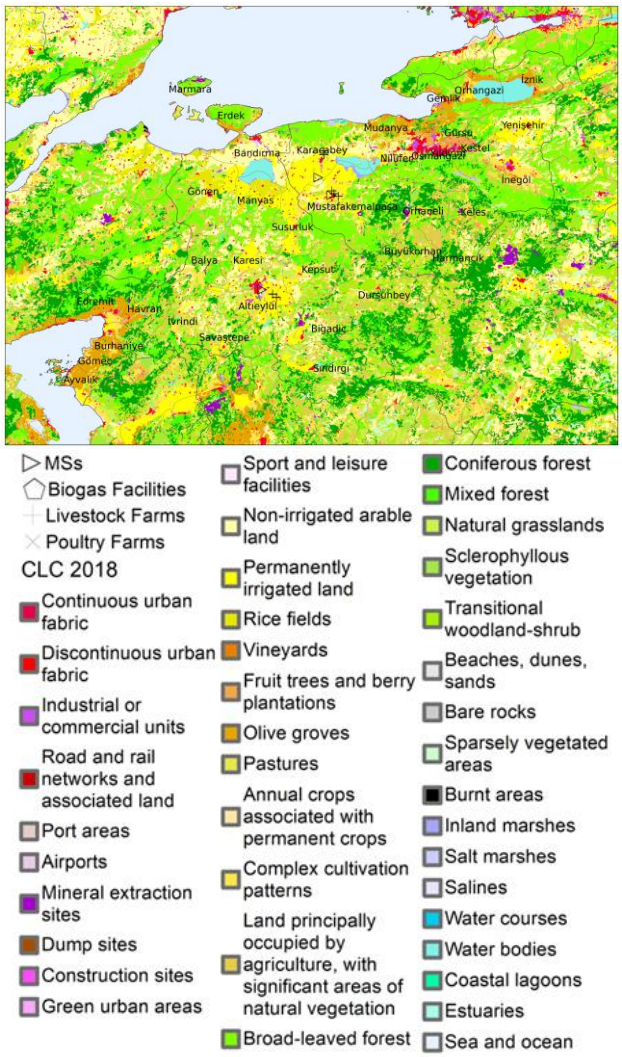


Figure 1. The study area covering Balıkesir and Bursa

The temporal changes of $NH_3$ levels around livestock farms were examined for the years 2019-2023. European Monitoring and Evaluation Programme (EMEP) compiles national emission reports and provides annual emission inventories comes from different sectors. In this study, the total $NH_3$ emissions obtained from EMEP (EMEP CEIP, 2025) were also compared with IASI $NH_3$ concentrations to evaluate similarities and differences for 2019. For this, province and district-based correlations were done using the same resolution (0.1˚× 0.1˚) gridded values for the two data sets.

The locations of livestock and poultry farms within the study area were determined using Google Earth. District-based annual livestock and poultry production statistics were obtained from the Turkish Statistical Institute (TURKSTAT, 2025), and the years between 2019 and 2023 were examined.

Meteorological data were obtained from the Ministry of Environment, Urbanization and Climate Change, General Directorate of Meteorology (MoEUCC, 2025a) to investigate the effect of meteorological parameters on $NH_3$ levels and possible pollution transport. In this study, evaluations were made using hourly temperature (T), relative humidity (RH), wind speed (WS) and wind direction (WD) measurements.

## 3. Results

Based on 2019-2023 annual $NH_3$ distributions, 2023 had the highest concentrations and selected as the representative year. Its annual and seasonal levels were presented together with livestock/poultry farms and biogas facilities (Figure 2).

In Balıkesir, annual distributions showed that between 2019 and 2023, Balıkesir recorded the lowest levels in 2019. The year 2023 showed the highest levels, with a 56% increase compared to 2019 concentrations. When the district level changes were investigated, 2019 was the lowest year across all districts, while 2023 was the highest year, and 2020 was recorded as the second highest year. The highest average $NH_3$ concentrations were consistently observed in Altıeylül district in all years. The second districts with highest $NH_3$ levels were Bandırma in 2019 and 2022, Susurluk in 2020 and 2023 and Manyas in 2021.

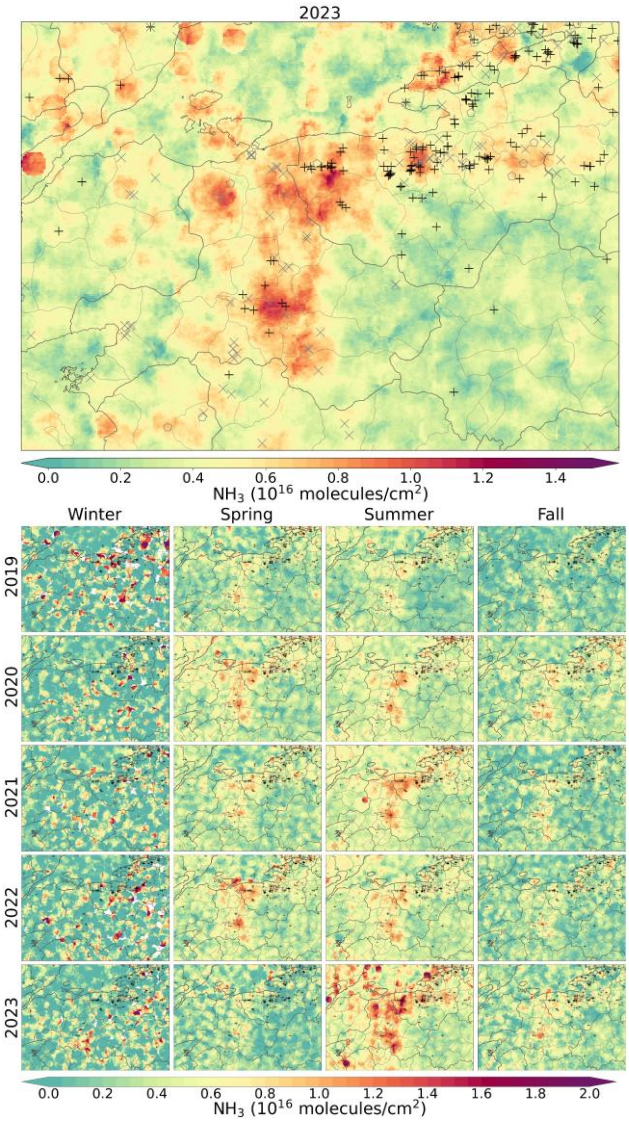


Figure 2. 2023 annual (top) and 2019-2023 seasonal (bottom) average IASI $NH_3$ (molecules/cm$^2$) levels over the study area (+: livestock farms, ×: poultry farms, ⬠: biogas plants).

Based on Corine land cover/use classification, when considering only *agricultural areas* 2019 was again identified as the lowest year, while 2023 showed the highest $NH_3$ concentrations overall. Among the districts, Altıeylül recorded the highest levels, but

unlike other areas, the influence of agricultural land was also evident in Bigadiç district this time. In seasonal variations, summer had the maximum and winter had the minimum levels. In Balıkesir, the highest $NH_3$ concentration was recorded in the summer of 2023, while the second highest season was mostly spring. However, in 2023, autumn was the second highest season, which differed from other years.

District-based assessments also showed that, in almost all districts, the highest year and season were the summer of 2023. In general, although there were exceptions (for example, in Erdek, the maximum occurred in the winter of 2019), summer was usually the highest, spring the second highest, and winter the lowest season. In some districts, spring or autumn were exceptionally the highest in certain years, but this pattern did not repeat every year. Nevertheless, for each district, autumn 2023 was the second highest season. It is thought that meteorology rather than the source may be effective in the seasonal extreme values. In fact, in the National Climate Report, it was seen that the 2023 fall season was the 2nd warmest fall in the last 53 years (MoEUCC, 2025b).

In Bursa, the lowest $NH_3$ concentrations were recorded in 2019, while the highest levels were observed in 2020. Compared to 2019, the year 2020 showed an increase of almost 60%. District-based $NH_3$ levels indicated that, although the highest concentrations varied considerably, 2020 was the peak year in about half of the districts. Among the districts, Karacabey consistently recorded the highest average concentrations each year and the districts with the second highest levels were Yenişehir in 2019 and 2020, Nilüfer in 2021 and 2023, and Yıldırım in 2022. When considering $NH_3$ levels in *agricultural areas* only, 2019 was again the lowest year, while 2020 was the highest in most districts. In addition, Mustafakemalpaşa was also a district where high and average $NH_3$ levels were observed. Seasonal variations in Bursa showed that the highest season was the summer of 2023. In general, the highest $NH_3$ levels were observed in summer and the lowest in winter; however, in 2023, the lowest season was spring and the second highest was autumn, which marked a difference from other years. District-based assessments showed quite different results. In some districts, the summer of 2023 continued to be the highest, while in others, the highest levels were recorded in winter. When the districts were evaluated individually over the years, different results were obtained but, in most districts, the second highest season in 2023 was autumn. When $NH_3$ levels across the districts were compared, Karacabey had the highest concentrations in most years and seasons.

Altıeylül and Bigadiç have the highest average $NH_3$ levels in Balıkesir in every year. The analysis of daily average $NH_3$ concentrations shows a clear seasonal pattern. $NH_3$ levels are lowest in winter, increase in spring, and reach the highest values in summer. This seasonal trend has become stronger in recent years. Among the districts, Altıeylül and Bigadiç clearly stand out with the highest $NH_3$ levels throughout the year. Although the seasonal profile in Altıeylül is less pronounced compared to Balıkesir, seasonal profile is clear and this district has extreme $NH_3$ values. Although $NH_3$ changes in Bigadiç do not have a clear profile, extreme values were observed here as well. Monthly changes are important for assessing $NH_3$ pollution. For this purpose, monthly distributions are shown for all areas (dark color) and for agricultural areas only (light color) in Balıkesir and Bursa provinces as a whole (black box), and for selected districts within these provinces (colored) (Figure 3).

In Balıkesir, and in the Altıeylül and Bigadiç districts, $NH_3$ levels are low in winter and reach their highest in summer. Levels are consistently higher in agricultural areas, with the difference becoming more noticeable in summer. In Altıeylül, $NH_3$ averages are higher than in Balıkesir throughout the year, and these differences increases during spring and summer (Figure 3).

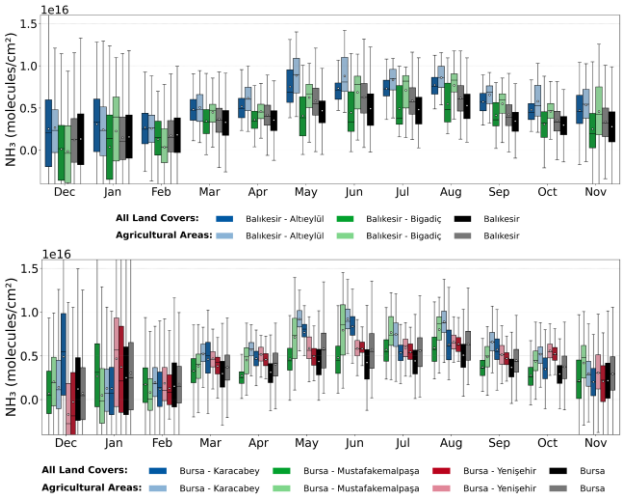


Figure 3. Monthly distribution of IASI $NH_3$ concentrations (molecules/cm$^2$) for Balıkesir (top) and Bursa (bottom)

Based on daily average $NH_3$ levels, the seasonal profile in Bursa is not as clear as in Balıkesir, but peak levels in summer are evident, and extreme values were observed. In the districts of Karacabey, Mustafakemalpaşa, and Yenişehir, there is also no distinct seasonal pattern, but notably high values were recorded during the summer months. In Bursa, monthly averages showed a seasonal pattern, which was clearer in agricultural areas. In Karacabey, $NH_3$ levels were high in May and June, and in July and August, agricultural areas had much higher averages than other areas. In Mustafakemalpaşa, $NH_3$ levels increased from May, and agricultural areas had higher levels than other areas even in winter. In Yenişehir, there was also a seasonal change, but the differences between land types were smaller than in the other districts.

$NH_3$ emissions are strongly influenced by livestock activities, and livestock-related data are important for interpreting $NH_3$ emissions. For emission and concentration assessments, livestock and poultry production changes in Balıkesir and Bursa over the last five years have been presented.

In both provinces, sheep account for the largest share (~60%) of the total livestock production, followed by bovine (cattle) and then goat. Horse, asses, pig, and camel categories contribute negligible shares. In Balıkesir, broilers hold the largest share, with laying hens second; turkey, goose, and duck are minor. In Bursa, lying hen had highest production, followed by broilers; turkey, goose, and duck had small production (Figure *4*).

According to annual livestock production statistics, the districts with the highest production are Altıeylül, Karesi, and İvrindi. Although overall livestock production in Balıkesir increased by 1.94% during the last five years, this rate was 10.9% in Altıeylül, 8.4% in Karesi, and -9.1% in İvrindi. Compared to 2022, however, production amounts decreased in most of the districts Altıeylül had increase. In Bursa, the number of livestock in 2023 decreased by 0.8% compared to 2019 and by 3.2% compared to 2020.

The districts with the highest livestock production in Bursa are Karacabey, Mustafakemalpaşa, and Yenişehir. Despite the overall decline in production across the province, Karacabey increased its production by 33% compared to 2019, while the other two districts recorded decreases (Figure 5).

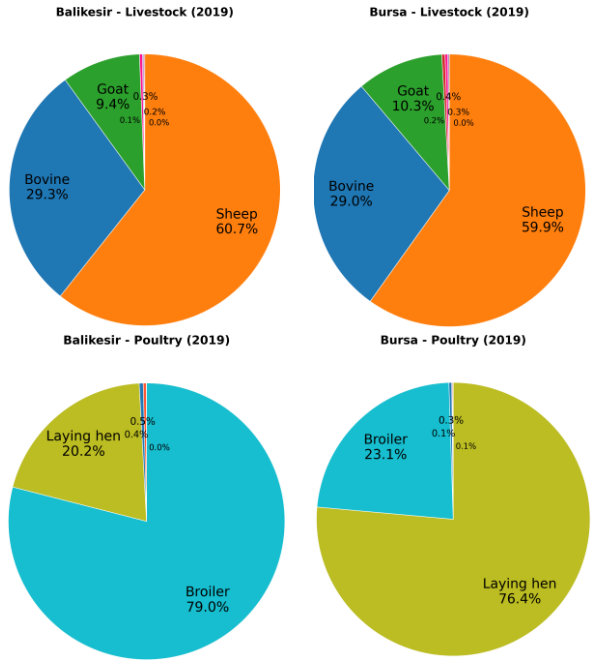


Figure 4. Livestock (top) and poultry (bottom) production distributions for Balıkesir and Bursa for 2019

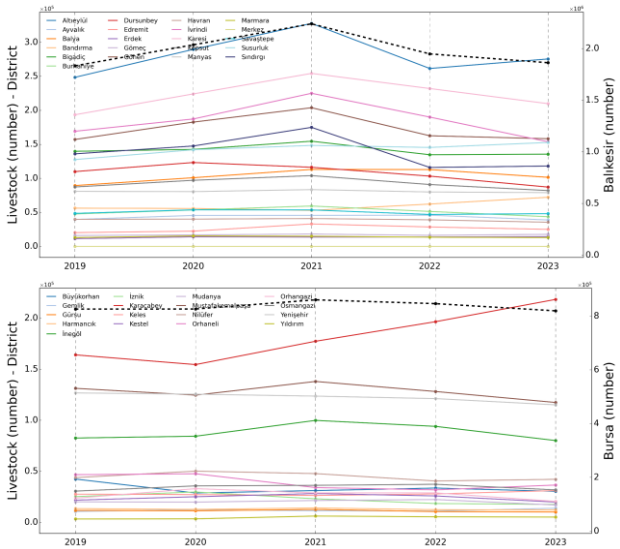


Figure 5. TURKSTAT animal statistics for Balıkesir (top) and Bursa (bottom)

When $NH_3$ emissions are evaluated in all emission sectors, 95.2% of total emissions of Türkiye in 2019 originated from the agricultural sector, and 70% came from the livestock sub-sector of agriculture. Since the livestock sector contributes significantly to total $NH_3$ emissions, emissions were also evaluated with IASI $NH_3$ concentrations, and scatter plots with correlation coefficients (r) were used to examine the relationships at the district levels. In Balıkesir, the overall correlation was high (r = 0.82). At the district level, both $NH_3$ concentrations and EMEP emissions were high in districts of Altıeylül and Bandırma, while both values were low in districts like Edremit, Gömeç, and Havran. However, discrepancies were observed in some districts. Dursunbey showed moderate emissions compared to the general trend, but relatively low $NH_3$ concentrations, while Marmara district recorded average concentrations and zero emissions (Figure 6).

The overall correlation in Bursa (r = 0.48) was lower compared to Balıkesir. Districts such as Karacabey and Mustafakemalpaşa showed both high concentration and emissions, while Harmancık, Keles, Orhaneli, and Büyükorhan districts indicated low values in both. In some districts, such as Gemlik, Kestel and Gürsu, there are discrepancies such as high concentration values but very low emissions (Figure 6).

High $NH_3$ concentrations may be due to transport from nearby districts, and detailed examination of emissions in general is necessary

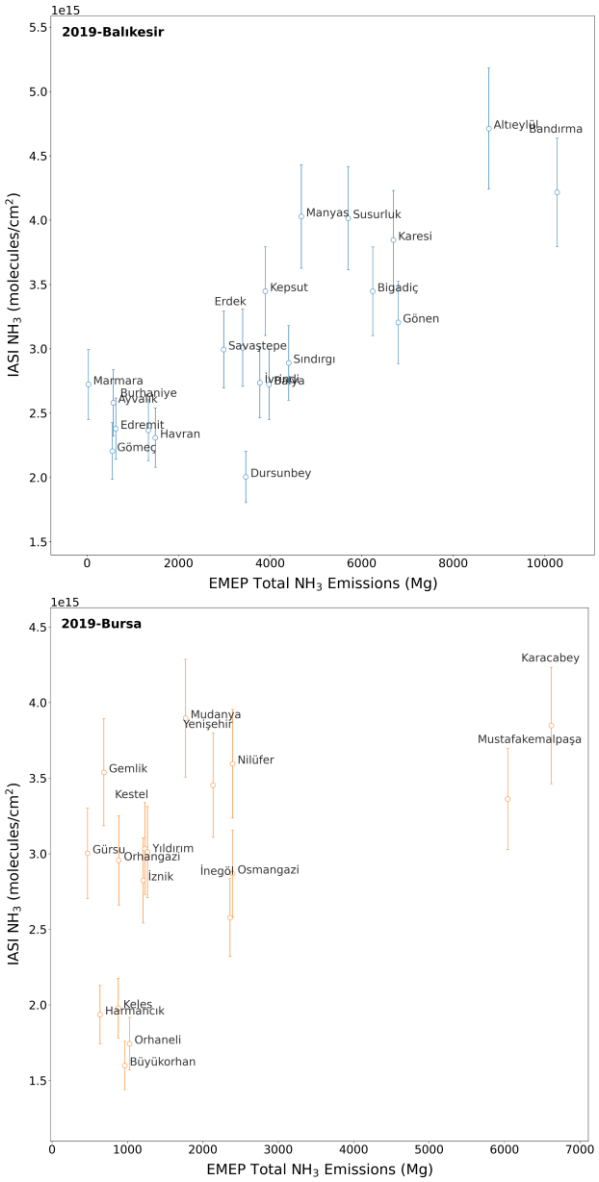


Figure 6. 2019 IASI $NH_3$ concentrations (molecules/cm$^2$) versus EMEP $NH_3$ emissions (mg) for Balıkesir (top) and Bursa (bottom)

$NH_3$ changes in Balıkesir and Bursa provinces, where the highest $NH_3$ levels were recorded between 2019 and 2023 and where there are intensive animal farms, are important. Between 2019 and 2023, a total of eight livestock farms were selected from areas with both high $NH_3$ levels, and high TURKSTAT animal statistics in Balıkesir and Bursa (three in Mustafakemalpaşa, three in Karacabey, and two in Altıeylül) (Figure 7).

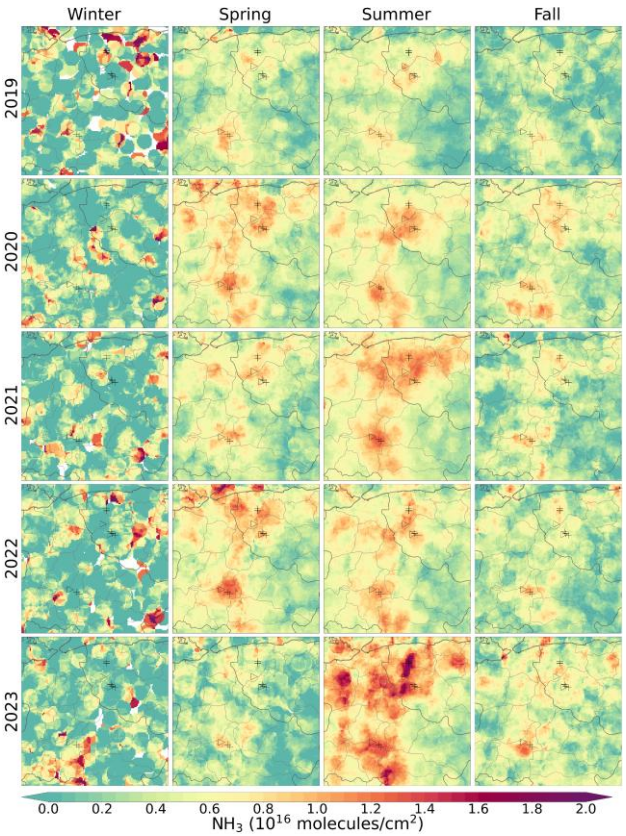


Figure 7. Seasonal average IASI $NH_3$ (molecules/cm$^2$) levels zoomed to the selected farms in the study area (+: livestock farms, ▷: meteorology stations).

Three of these farms are presented here in detail. Using IASI satellite retrievals within a 12 km radius of the selected farms, daily $NH_3$ time series were obtained. In addition, monthly $NH_3$ distributions were calculated based on satellite data within 6 km, 9 km, and 12 km radius investigating the change in pollution levels according to distance. Furthermore, seasonal wind roses were generated for the MS located closest to these livestock farms to evaluate possible $NH_3$ pollution transport between 2019 and 2023 (Figure 8, Figure 9, Figure 10).

The daily changes observed at the livestock farm in Altıeylül showed that $NH_3$ levels were very irregular and did not show clear seasonal trend. This was also clear in the monthly distributions. In the area closest to the farm (0–6 km), $NH_3$ levels were highly variable, while at greater distances (0–9 km and 0–12 km) the values became more stable. In other words, as the distance from the farm increased, the average levels were more consistent and extreme values had less effect. During 2019–2023, no strong seasonal pattern was observed. According to wind roses in MS 17150, the winds mostly came from the north and northeast in all years and seasons. Moreover, the pollution was generally carried by medium to strong winds (8-10 m/s), which explains the high $NH_3$ levels observed in Altıeylül (Figure 8).

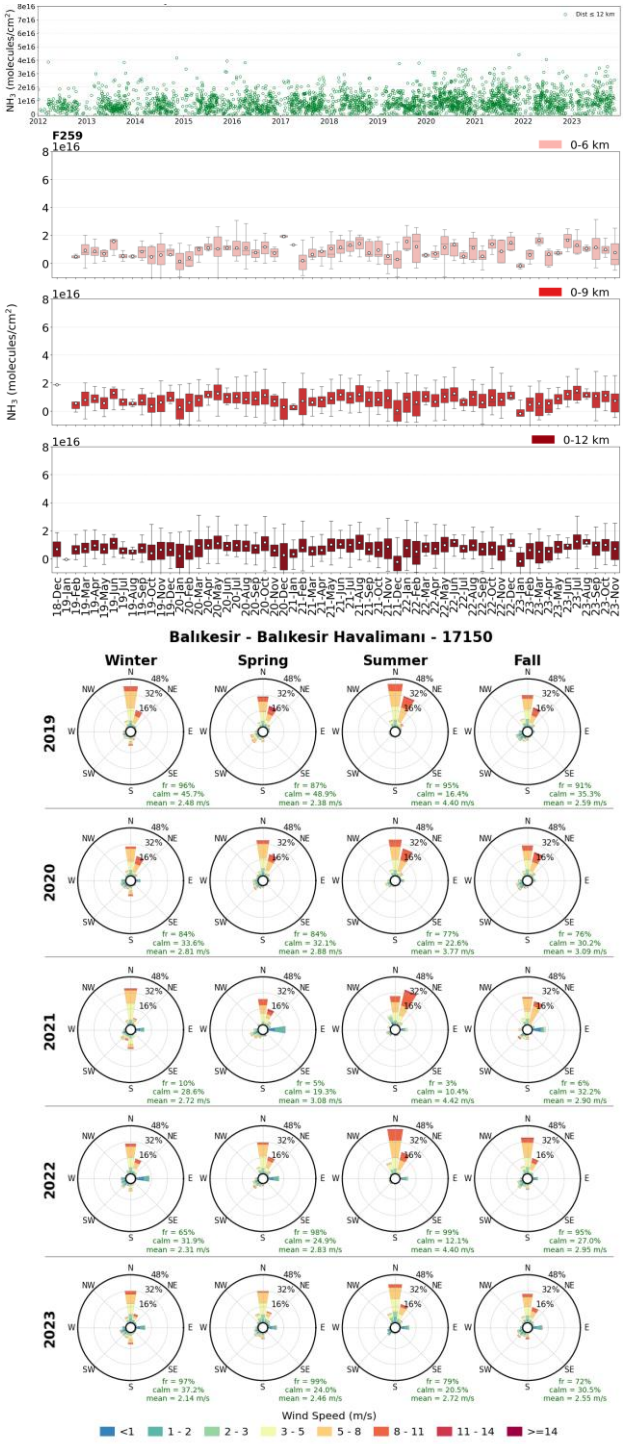


Figure 8. Long term daily time series (top) and 2019-23 monthly distribution (center) of $NH_3$ concentrations in the selected livestock farm in Altıeylül/Balıkesir with seasonal wind roses for MS 17150 (bottom).

The daily variation of the farm in Karacabey, Bursa, showed that $NH_3$ concentrations did not show a clear patternd and had extreme values. When looking at the monthly distributions, no consistent seasonal pattern was observed. At the closest distance to the farm (0–6 km), $NH_3$ levels were highly irregular and at 0–9 km, and 0-12 km the $NH_3$ variations became more stable but still showed variability. According to the seasonal wind roses at the nearest MS 17673 between 2019 and 2023, the prevailing wind direction was from the northeast. Pollution was generally transported by moderate and high wind speeds (Figure 9).

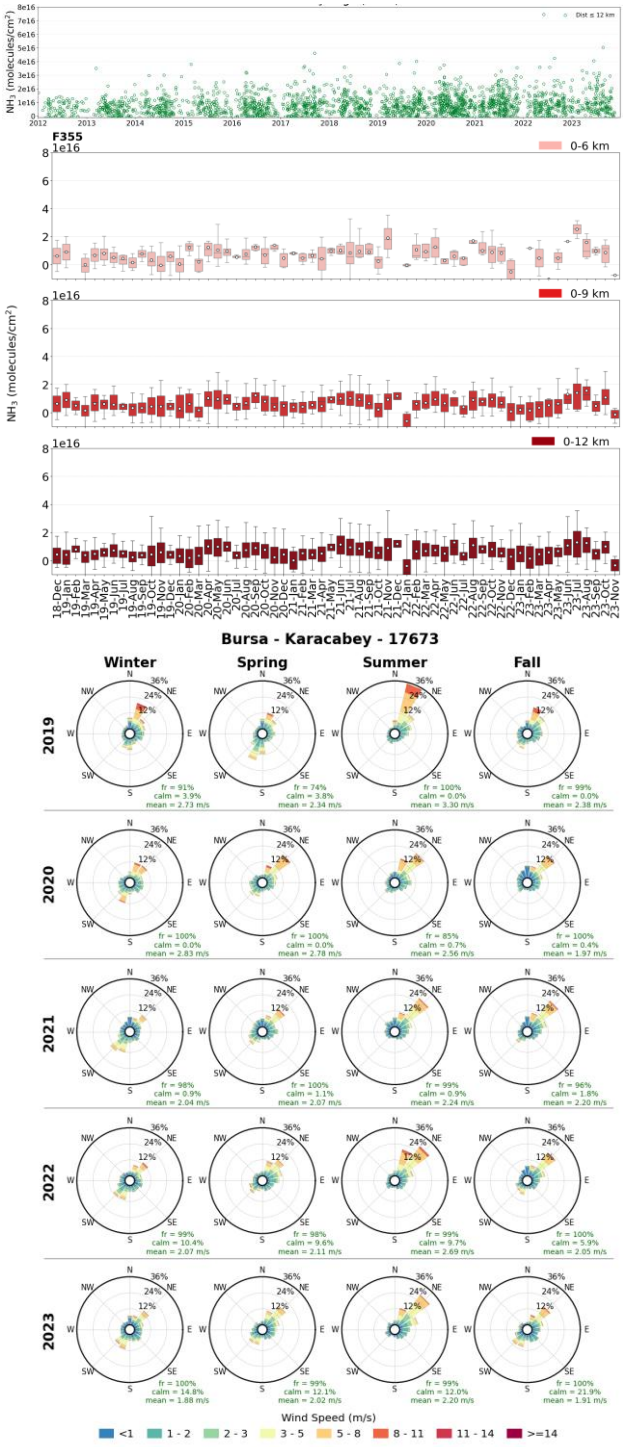


Figure 9. Long term daily time series (top) and 2019-23 monthly distribution (center) of $NH_3$ concentrations in the selected livestock farm in Karacabey/Bursa with seasonal wind roses for MS 17673 (bottom).

Daily average $NH_3$ levels at farm in Mustafakemalpaşa/Bursa changed a lot and did not show a clear seasonal pattern. In the monthly results, the $NH_3$ values within 0–6 km was very irregular and the averages were quite different from month to month. From 0–9 km, a seasonal trend started to appear: $NH_3$ was generally higher in the summer and lower in the winter. At 0–12 km, this seasonal pattern became clearer and the $NH_3$ values were more stable. The seasonal profile suggested that the pollution source in the district might be another source other than/together with animal farms.

Because considering that animal farms are in continuous operation, a distinct profile between seasons was not expected. According to the wind rose at this station, the prevailing winds were from the north–northeast with low and moderate speed (Figure 10).

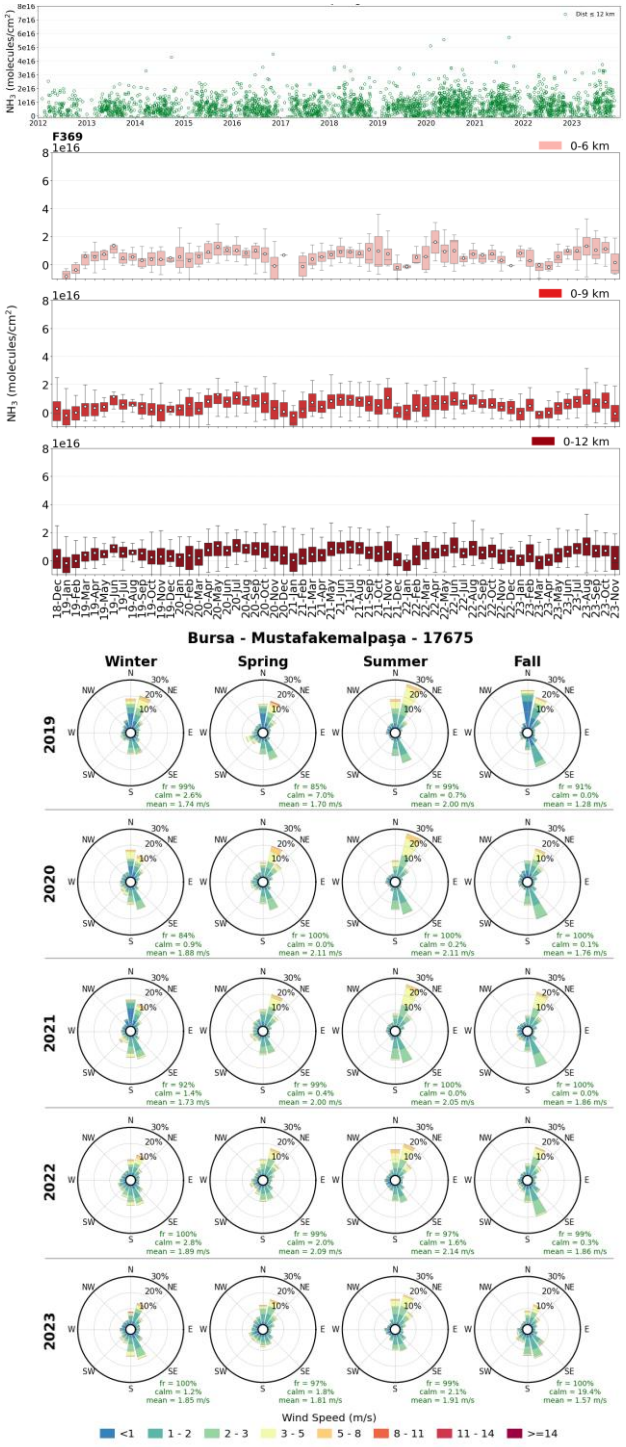


Figure 10. Long term daily time series (top) and 2019-23 monthly distribution (center) of IASI $NH_3$ concentrations in the selected livestock farm in Mustafakemalpaşa/Bursa with seasonal wind roses for MS 17675 (bottom).

## 4. Conclusions

Balıkesir and Bursa, in the Marmara Region, have high $NH_3$ levels and dense livestock farming in the recent years. According to IASI $NH_3$ distributions 2019 was the lowest and 2023 was the highest year. A clear seasonal profile obtained with highest level in summer and lowest level in winter.

According to district-based evaluation, In Balıkesir Altıeylül was highest in many years and seasons while Bandırma, Susurluk, Manyas, also showed significant levels. In Bursa, Karacabey leads, with Mustafakemalpaşa and Yenişehir also high. In both provinces, areas with high $NH_3$ concentrations also showed high emissions and livestock counts.

From districts with high $NH_3$ levels and intense livestock farms, eight livestock farms were selected, and three were examined in detail. Using meteorological data, it was found that some farms may be responsible for potential local $NH_3$ transport to nearby areas.

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