



DIFFUSE POLLUTANT LOAD AND ENVIRONMENTAL IMPACTS OF ANIMAL WASTE IN TÜRKİYE

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Abstract: The rapidly increasing population and the resulting demand for animal products have accelerated the growth of the animal husbandry sector in Türkiye, but this has also brought environmental problems. When wastes originating from animal husbandry enterprises are not managed with appropriate methods, they cause severe deterioration in the quality of surface and groundwater resources by creating a diffuse pollutant load. This study aims to quantitatively evaluate Türkiye's diffuse pollutant load (total nitrogen and total phosphorus) and environmental impacts of animal wastes originating from cattle, sheep, and poultry. Considering the data on animal population in Türkiye as of 2024, the annual dry manure amounts and total nitrogen and phosphorus loads originating from these animals were calculated. The results show that the nitrogen and phosphorus load caused by animal wastes threatens biodiversity by causing eutrophication on underground and surface water resources and seriously negatively affects aquatic ecosystems. Therefore, animal waste management should be considered a national priority, not only to mitigate nutrient-driven water pollution and eutrophication, but also to protect diminishing freshwater resources and reduce the long-term risks of water scarcity under changing climatic conditions.

Keywords: Animal waste management, Diffuse pollution, Nutrient load, Nitrogen and phosphorus, Water quality degradation, Eutrophication

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Received: April 30, 2025

Accepted: May 24, 2025

Published: June 15, 2025

Cite as: Tirink, S. (2025). Diffuse pollutant load and environmental impacts of animal waste in Türkiye. *Black Sea Journal of Environmental Sciences*, 1(1), 8–13.

1. Introduction

The rapid increase in population and urbanization globally has led to a significant rise in food demand, particularly for animal products such as meat, milk, and eggs. This demand has catalyzed the development of the agriculture and animal husbandry sectors, which are vital protein sources for human nutrition. In Türkiye, the animal husbandry sector plays a crucial economic and social role. However, it also generates substantial amounts of waste, which, if not appropriately managed, can lead to severe environmental pollution and ecological degradation. The improper handling of animal waste is a pressing issue, as it contributes to diffuse pollution, primarily due to its high organic matter and nutrient content, particularly total nitrogen (TN) and total phosphorus (TP) (Tirink, 2021).

Animal waste significantly contributes to water pollution, as releasing TN and TP into water bodies can lead to eutrophication. This process results in excessive algae growth, which depletes water oxygen and threatens aquatic biodiversity (Sampat, et al., 2018; Kumas, and Akyüz, 2020; Tirink, 2021). The accumulation of nutrients from animal waste can also seep into

groundwater, further contaminating water resources and posing risks to human health and the environment (Sampat et al. 2018; Kumas, and Akyüz, 2020). Moreover, the incorrect application of fertilizers, often exacerbated by the accumulation of animal waste, can lead to nutrient imbalances in the soil, which diminishes agricultural productivity and disrupts soil structure over time (Sampat et al. 2018; Kumas, and Akyüz, 2020). In addition to water and soil pollution, animal waste management is linked to broader environmental issues, including air pollution and climate change. The decomposition of animal waste releases potent greenhouse gases such as methane (CH₄) and nitrous oxide (N₂O), which contribute to global warming (Sampat et al. 2018; Kumas, and Akyüz, 2020; Tirink, 2022). Particularly, practices such as improper storage of manure and its accumulation in open areas exacerbate the release of these gases into the atmosphere (Sampat et al. 2018; Kumas, and Akyüz, 2020). The challenge of managing animal waste effectively is further complicated by regional differences and the varying structures of livestock operations in Türkiye. Small-scale family farms often lack adequate manure management systems, leading to haphazard waste accumulation and increased



environmental risks (Kumas, and Akyüz, 2020). The economic implications of nutrient pollution from livestock waste are substantial. Nutrient runoff contributes to the degradation of water quality, leading to increased costs for water treatment and loss of aquatic biodiversity, which can have cascading effects on local economies reliant on fishing and tourism (Sampat et al. 2018). Therefore, addressing the environmental challenges posed by animal waste is not only a matter of ecological sustainability but also of economic viability for communities dependent on healthy ecosystems. This study quantitatively evaluates the diffuse pollutant loads (TN and TP) and environmental impacts of animal wastes originating from cattle, sheep, and poultry in different regions in Türkiye. The study covers the Mediterranean, Southeastern Anatolia, Eastern Anatolia, Aegean, Marmara, Central Anatolia, and Black Sea regions of Türkiye. Using 2024 data on animal populations, annual dry manure amounts and TN and TP loads originating from animal production were calculated, and the potential effects of these pollutants on water and soil ecosystems were investigated. The results obtained provide important scientific data to better understand the effects of animal waste management on water quality, ecosystem sustainability, and climate change in Türkiye and develop environmental management strategies.

2. Materials and Methods

In this study, in order to determine the amount of waste originating from animal farms in Türkiye, the number of animal data from the Turkish Statistical Institute for the period 01.01.2024-31.12.2024 were used.

It examines the environmental impacts of animal waste originating from animal husbandry activities in the provinces located in seven geographical regions of Türkiye. Türkiye is geographically divided into seven regions: Mediterranean, Southeastern Anatolia, Eastern Anatolia, Aegean, Marmara, Central Anatolia, and Black Sea. The study area was determined to cover the regional distribution and environmental impacts of waste originating from cattle, sheep, and poultry farming activities in these regions.



Figure 1. Regions of Türkiye.

2.1. Methodology

To estimate the total pollutant load and manure quantity from livestock activities in Türkiye, pollutant coefficients and animal waste production parameters were adapted BSJ Env Sci / Sevtap TIRINK

from various literature sources. The assumptions were selected to ensure consistency with similar regional studies and to reflect realistic values based on animal species, live weight, and local management conditions. The estimated unit loads originating from diffuse pollution sources were adopted based on values recommended in the literature (Tırınk, 2021).

2.2. Estimation of Diffuse Pollutant Load

The total pollutant load due to nitrogen (TN) and phosphorus (TP) load from livestock was calculated using the following general formula given in Equation 1:

$$Q_T = Q_{YK} * A_{CH} * Y_U * 365/1000 \quad (1)$$

where:

Q_T = Annual pollutant load per animal (kg/year),

Q_{YK} = Daily pollutant load coefficient (kg/ton animal/day),

A_{CH} = Average live weight of the animal (kg),

Y_U = Percentage of pollutant that reaches the receiving environment.

For this study, live weights were assumed as 500 kg for cattle (BBH), 45 kg for sheep/goats (KBH), and 2 kg for poultry (KH), following standard values in literature (Yontar, 2009; ÇŞB, 2016). It was assumed that 15% of nitrogen and 5% of phosphorus reach water bodies through leaching and runoff processes.

Based on Q_T , the total annual nitrogen and phosphorus loads were calculated as given in Equation 2 and 3:

$$Q_{TN} = Q_T * N_{CH}/1000 \quad (2)$$

$$Q_{TP} = Q_T * N_{CH}/1000 \quad (3)$$

where:

Q_{TN} , Q_{TP} = Annual total nitrogen and phosphorus loads (tons/year),

N_{CH} = Number of animals (headcount).

2.3. Estimation of Dry Manure Generation

The daily manure production was computed using live weight and an estimated manure generation factor (Equation 4):

$$T_{YGM} = A_{CH} * Y_{CHA} \quad (4)$$

where:

T_{YGM} = Daily manure production (kg/day),

Y_{CHA} = Manure output as a percentage of live weight (%),

A_{CH} = Live weight (kg).

The estimation of dry manure quantities was carried out using values suggested in the literature (Tırınk, 2021). Assumed daily manure production was 27 kg/day for BBH, 2.48 kg/day for KBH, and 0.26 kg/day for KH, based on regional livestock management data. The usable portion of the dry manure was calculated considering both collectability and dry matter content (Equation 5):

$$T_{GM} = T_{YGM} * Y_{KG} * Y_{KM} \quad (5)$$

where:

T_{GM} = Usable dry manure (tons/day),

Y_{KG} = Usability coefficient (%),

Y_{KM} = Dry matter content of manure (%).

Finally, annual usable dry manure per animal was calculated as given in Equation 6:

$$T_{YGP} = T_{KYGM} * N_{CH} * 365/1000 \quad (6)$$

3. Results and Discussion

Within the scope of the study, firstly, the number of live Ruminant, Small Ruminant and poultry in Türkiye for the year 2024 was determined according to TÜİK data. As seen in Figure 2, the region with the highest Ruminant presence in Türkiye is the Central Anatolia Region with 3,988,911 cases and 23%. The region with the lowest Ruminant presence is the Mediterranean Region with 1,291,399 cases and 8%. The region with the highest Small Ruminant presence in this province is the Eastern Anatolia Region with 13,535,297 cases and 25%. The region with the lowest Small Ruminant presence is the Black Sea Region with 2,453,051 cases and 4%. In addition, the region with the highest poultry presence in this province is the Marmara Region with 106,908,059 cases and 28%. The region with the lowest poultry presence is the Southeastern Anatolia Region with 12,635,030 cases and 3%. When the animal numbers in Türkiye are examined, it is seen that poultry breeding has a higher rate.

The distribution of TN load originating from livestock in Türkiye by region is shown in Figure 3 and the distribution by animal species is shown in Figure 4. In addition, the distribution of TP load calculated by region is shown in Figure 5 and the distribution by animal species is shown in Figure 6.

The Central Anatolia Region stands out as the region with the highest diffuse pollutant load in Türkiye with 48,130.26 tons/year TN and 4,605.48 tons/year TP load. This situation can be explained by the region having wide pastures, intensive livestock farming and high cattle population. TN and TP load originating from cattle constitute approximately 68% of the total load. Similarly, the Eastern Anatolia Region has a high diffuse pollutant load with 41,010.11 tons/year TN and 3,697.80 tons/year TP load. Especially in this region where small cattle farming is widespread, the contribution of small cattle to TN and TP load is higher than in the Central Anatolia Region. The TN load originating from small cattle is 14,005.99 tons/year, which is the highest level compared to other regions.

The Aegean Region ranks third with 34,634.22 tons/year TN and 3,694.01 tons/year TP loads. TN and TP loads originating from poultry are significant in this region. The TP load originating from poultry farming is 824.21 tons/year, which is the second highest value after the Marmara Region. This result reflects the prevalence of commercial poultry farming in the region.

The Marmara Region has a moderate diffuse pollutant load with 26,211.17 tons/year TN and 2,808.11 tons/year TP loads. However, the TN and TP loads originating from poultry are significantly high in this region (TN: 6,087.35 tons/year, TP: 858.47 tons/year). The prevalence of industrial livestock enterprises in the Marmara Region causes these loads to be high.

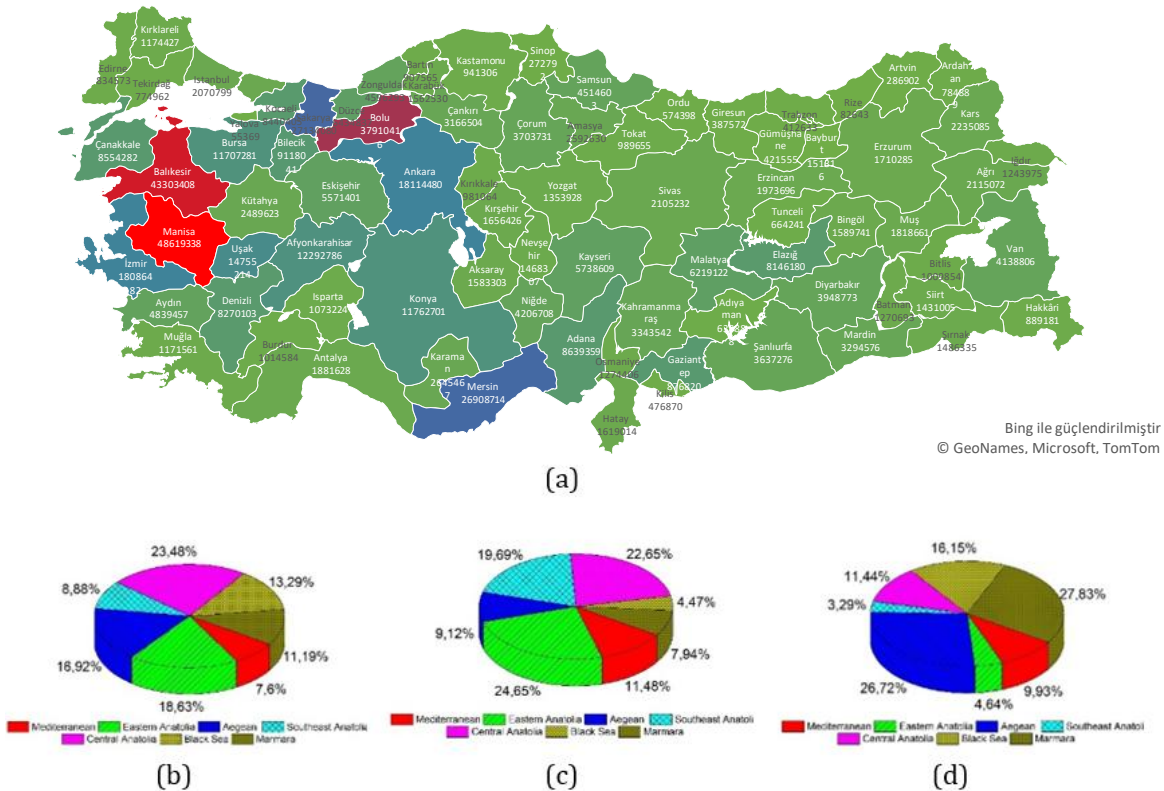


Figure 2. Distribution of total animal numbers in Türkiye (a) Total animal numbers by province, (b) Ruminant numbers by region, (c) Small ruminant numbers by region, (d) poultry numbers by region.

Although the Black Sea Region has relatively low pollutant loads, with 24,609.59 tons/year TN and 2,678.90 tons/year TP loads, the TN and TP loads originating from cattle are at significant levels. Due to the region's sloping terrain and high rainfall regime, the risk of these pollutants being carried to surface waters is higher compared to other regions.

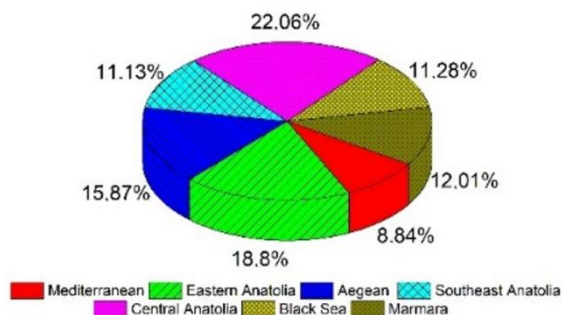


Figure 3. Regional distribution of TN loads from livestock farming across Türkiye in 2024.

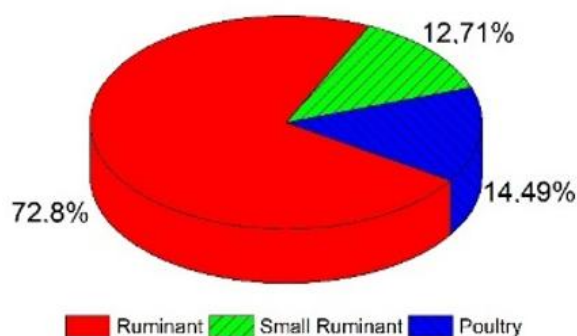


Figure 4. Distribution of TN loads by livestock category (cattle, small ruminants, and poultry) in Türkiye.

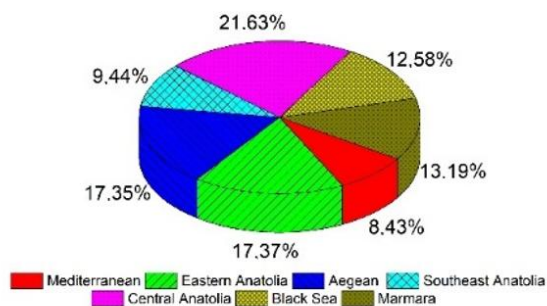


Figure 5. Regional distribution of TP loads originating from livestock activities across Türkiye in 2024.

The Southeastern Anatolia Region has a moderate pollutant load with 24,291.43 tons/year TN and 2,010.40 tons/year TP loads. However, in this region where small livestock farming is widespread, the TN load originating from small cattle is quite high (11,185.20 tons/year). The Mediterranean Region has the lowest diffuse pollutant load in Türkiye with 19,298.09 tons/year TN and 1,795.30 tons/year TP loads. However, there is a risk of pollution of water resources in this region, especially in coastal areas where tourism activities are intense, due

to improper animal waste management. Necessary precautions should be taken to prevent pollutants with such high pollution loads from polluting underground and surface water resources.

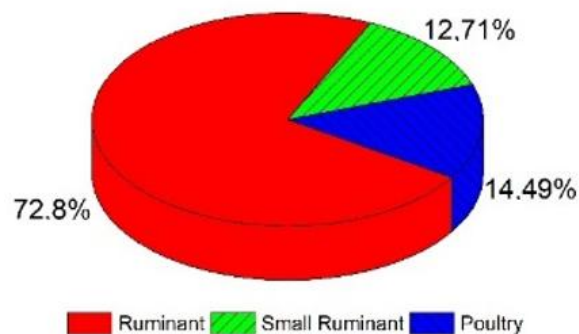


Figure 6. Distribution of TP loads by livestock type (cattle, small ruminants, and poultry) across Türkiye.

A summary of total nitrogen and phosphorus loads by region and the primary livestock contributors is presented in Table 1 to facilitate comparison across Türkiye's regions.

After calculating the diffuse pollutant load originating from animal wastes in Türkiye, the amount of dry fertilizer that can be formed from animal wastes was calculated. The total amount of dry fertilizer generated as animal wastes per year was calculated as 6,1945,552.434 tons. Proper storage and evaluation of commercially valuable animal wastes will contribute to both the local and national economies.

The findings show that TN and TP loads reach significant levels in regions where animal husbandry activities are concentrated and pose environmental risks to water and soil ecosystems.

When similar studies are examined in the literature, in a study conducted specifically for the province of Bursa, it was determined that diffuse pollution loads originating from animal wastes significantly threaten water resources and that the annual TN load is 3,241.94 tons and the total phosphorus load is 341.33 tons (Hacısalihoğlu, 2022). Similarly, in the pollution load calculations made in Muş and Bitlis provinces, it was determined that animal-based wastes increased the pressure on regional water resources (Yetis and Yetis, 2018; Yetis et al., 2018). In the study conducted by Tırnık, (2021) in Iğdır province, the diffuse pollutant loads of cattle, sheep and poultry were determined and the effects of animal wastes on water resources and the environment were revealed. These studies emphasize that animal husbandry activities create significant environmental pressure regarding diffuse pollution and the necessity of sustainable waste management strategies. Different studies in the literature support the environmental effects of diffuse pollutant loads.

Table 1. Summary of TN and TP loads by region and the main contributing livestock category

Region	TN Load (tons/year)	TP Load (tons/year)	Main TN Contributor	Main TP Contributor
Central Anatolia	48,130.26	4,605.48	Cattle	Cattle
Eastern Anatolia	41,010.11	3,697.80	Small Ruminants	Small Ruminants
Aegean	34,634.22	3,694.01	Poultry	Poultry
Marmara	26,211.17	2,808.11	Poultry	Poultry
Black Sea	24,609.59	2,678.90	Cattle	Cattle
Southeastern Anatolia	24,291.43	2,010.40	Small Ruminants	Small Ruminants
Mediterranean	19,298.09	1,795.30	Cattle	Cattle

In a study conducted in the Alaşehir Stream Sub-basin, it was stated that agricultural fertilizer use and animal husbandry activities were determinants of TN and TP loads, and 79% of the total TN and 61% of TP in the basin were from diffuse sources (Gürsoy Haksevenler and Ayaz, 2021). This finding shows that unconsciously releasing animal waste into nature can lead to serious quality losses in water resources. Similarly, a study conducted in Adana province emphasized that a large portion of animal manure is not efficiently utilized and can cause environmental pollution due to unconscious storage (Erkan Can, 2021).

On the other hand, the results of our study support that diffuse pollution is more difficult to manage than point pollution and its effects spread over large areas. It is stated in the literature that the effects of diffuse pollution loads on water resources and soil systems are long-term and cause problems such as eutrophication and reduced biodiversity (Sartaş, 2019). In this context, environmentally friendly waste management strategies such as biogas production, composting and integrated manure management should be encouraged, especially in regions with high TN and TP loads.

As a result, this study emphasizes the need to determine and implement animal waste management strategies by considering regional differences throughout Türkiye. The data obtained provide a scientific basis to guide decision makers in determining animal waste management and environmental policies. In addition, increasing the commercial value of animal waste by storing it appropriately will contribute to both reducing environmental impacts and providing economic benefits.

4. Conclusion

This study presents a comprehensive regional assessment of TN and TP loads originating from livestock activities across Türkiye, based on current national livestock data. The results reveal significant spatial heterogeneity in pollutant loads, with Central and Eastern Anatolia contributing disproportionately due to the prevalence of ruminant farming, while poultry-related phosphorus load are notably elevated in the Marmara and Aegean regions. These findings underscore the critical need for regionally differentiated and species-specific waste management strategies.

From an environmental policy perspective, the management of animal waste must be reframed not only

as an agricultural necessity but also as a key element of national water resource protection and climate mitigation frameworks. The integration of sustainable technologies such as anaerobic digestion, composting, and regionally tailored nutrient management plans should be prioritized. Moreover, the quantification of pollutant loads at the regional scale offers an empirical basis for guiding regulatory action and allocating resources efficiently.

In conclusion, the data and insights generated by this study contribute to the growing body of evidence supporting the transition toward integrated, science-based livestock waste management. It is imperative that future environmental governance frameworks in Türkiye embed these findings into actionable policies, particularly within the context of basin-scale pollution control and sustainable rural development.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	S.T.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declare that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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