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REVIEW ARTICLE

The Effects of Atmospheric Pollutants on Freshwater Resources and the Protective Role of Meadow and Pasture Ecosystems

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ABSTRACT

Globally, freshwater resources are severely constrained in both quantity and quality, and are increasingly threatened by atmospheric pollutants resulting from anthropogenic activities such as industrialization, urbanization, and intensive agriculture. Atmospheric emissions of heavy metals (Cd, Pb, Hg, etc.), nitrogenous compounds (e.g., NO_x, NH₃), gaseous pollutants (SO₂, NO₂, O₃, CO) and particulate matter (PM_{2.5}, PM₁₀, UFP_{0.1}) are deposited into aquatic systems via dry and wet deposition pathways, thereby altering the physicochemical composition of freshwater bodies and compromising the continuity of essential ecosystem services. Notably, processes such as acid deposition, heavy metal accumulation, and eutrophication contribute to biodiversity loss in surface waters, the extinction of sensitive species, and a decline in overall water quality. These effects not only disrupt ecological integrity but also pose substantial risks to public health and economic sustainability. This study comprehensively examines the incorporation of atmospheric pollutants into hydrological systems through deposition mechanisms and reviews their impacts on the structural and functional integrity of freshwater ecosystems. Furthermore, the ecological functions of natural vegetation—particularly meadow and pasture ecosystems—as biological buffers and filters are critically evaluated. These systems mitigate pollutant transport and soil erosion through dense root networks, high vegetative cover, and biochemical interactions. Natural attenuation processes such as phytoremediation enable the uptake, transformation, or sequestration of atmospheric contaminants, highlighting the strategic hydrological and ecological value of such ecosystems. The findings underscore the necessity of integrating nature-based solutions into land and water management frameworks to ensure long-term environmental sustainability. In conclusion, meadow and pasture ecosystems serve not only agricultural functions but also play a pivotal role in the conservation of freshwater resources and environmental resilience. Protecting and managing these natural filtration systems is imperative for mitigating the adverse impacts of atmospheric pollution and for advancing sustainable resource governance.

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1. Introduction

The Earth has a total surface area of 510 million km², approximately 71% of which is covered by water bodies. The total amount of water on Earth is 1.4 billion km³. Of these water resources, 97.5% consists of salt water found in oceans and seas, while 2.5% consists of fresh water found in rivers and

lakes. However, the vast majority of this freshwater is stored in polar ice caps (68.7%) and groundwater (30.1%), with only 1.2% found in surface water and the atmosphere. These figures clearly demonstrate how limited and valuable a resource usable water is on a global scale (Shiklomanov, 1993; MGM, 2017). A large portion of the usable freshwater available on Earth is essential for the sustainability and protection of ecosystems.

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Oceans and seas, which constitute the majority of saltwater resources, are not suitable for directly meeting human life-sustaining needs. Only 10% of terrestrial water resources are usable freshwater. This amount represents approximately 0.3% of the total water potential and is calculated to be approximately 5,500 km³. Considering that the total discharge of rivers on a global scale is approximately 37,000 km³, this value represents a significant proportion of 15%. This situation indicates that meeting the water demand, which is expected to increase in the future, will pose serious challenges (Denhez, 2007; Dündar 2007; Küçükklavuz, 2009).

The amount of water on Earth is largely constant and cannot escape the Earth or atmosphere under natural conditions. However, this water is in a state of constant motion due to the effects of solar energy and gravity. The continuous circulation of water between the lithosphere (Earth's crust), hydrosphere (water bodies), and atmosphere (air sphere) is called the water cycle or hydrological cycle. This cycle plays a fundamental role in the continuity of ecosystems by enabling the transport of water on Earth to different environments through physical state changes (Kocataş, 1999; Schlesinger, 1997; Wisler & Brater, 1959). Each year, an average of 500,000 km³ of water evaporates into the atmosphere. Continents receive 110,000 km³ of water annually through precipitation, of which 70,000 km³ returns to the atmosphere through evaporation. In this process, 40,000 km³ reaches rivers, seas, and lakes in closed basins through surface runoff. On the other hand, only 9,000 km³ of this precipitation can be used technically and economically (Dündar, 2007; Koluman, 2002). According to the 2024 UN World Water Development Report, approximately 70% of freshwater use worldwide is in agriculture, followed by slightly less than 20% in industry and around 12% in domestic or municipal use (UNESCO, 2024).

When evaluated from Turkey's perspective, the average annual rainfall is 544 mm, and the total amount of water obtained from this rainfall is 450 billion m³. The economically and technically usable portion of this water potential is stated as 91.9 billion m³ for surface water and 18.6 billion m³ for groundwater. Accordingly, Turkey's total technically and economically usable water potential is 110.5 billion m³ annually on average. (DSİ, 2023). According to data from the Turkish Statistical Institute (TÜİK), Turkey's population reached 85,664,944 as of December 31, 2024. For a country to be considered water-rich in terms of water potential, the annual water amount per capita must exceed 1,700 m³. Considering the amount of usable water in Turkey, the per capita amount is 1,289.91 m³/year. This situation clearly demonstrates that Türkiye is a water-stressed country and underscores the critical importance of its water resources.

Water is vital for all components of the biosphere and is an indispensable resource for human health, environmental balance, and the sustainability of freshwater ecosystems. Clean

and high-quality water resources not only meet basic physiological needs but also play a vital role in agricultural production, industry, energy production, and ecosystem services. (Falkenmark & Rockström, 2004). Freshwater ecosystems, with their biological diversity, not only contribute to the preservation of ecological balance but also provide many direct and indirect benefits for human well-being. (Dudgeon et al., 2006). However, atmospheric pollutants, which are increasing due to industrialization, agricultural activities, and urbanization, threaten the chemical and biological quality of these valuable water resources. In particular, heavy metals, nitrogen compounds, and pesticide residues accumulated in the atmosphere are transported to water resources through precipitation, posing serious risks to human health and weakening the functionality of freshwater ecosystems (Smith & Schindler, 2009; Vörösmarty et al., 2010). This situation threatens the right to access clean water while also causing irreversible damage to the ecological balance.

In this context, the effects of global warming and climate change on water resources, along with the contamination of existing water resources through atmospheric pollutants due to various environmental and anthropogenic factors, pose serious threats to both human health and ecosystem balance. Eliminating these threats, or at least mitigating their effects, has become an inevitable necessity in terms of sustainable environmental and water management policies.

2. Transport and Accumulation of Atmospheric Pollutants

The atmosphere facilitates the transport of suspended particles in solid, liquid, and gaseous form emitted from various natural and anthropogenic sources. In this process, heavy metals (Pb, Cd, Ni, As, Zn, Mn, Cu, Cr, Hg), particulate matter (PM_{2.5}, PM₁₀, UFP_{0.1}), and gaseous pollutants (SO₂, NO₂, O₃, CO) are among the main harmful components carried (WHO, 2021). These particles differ in size, shape, chemical composition, and solubility and are generally classified according to aerodynamic diameter as PM₁₀ (coarse) (diameter less than 10 µm), PM_{2.5} (fine) (diameter less than 2.5 µm), and UFP (ultrafine) (diameter less than 0.1 µm). (Pope & Dockery, 2006) While natural sources include soil, sea salt, and volcanic activity, industrial activities, agricultural practices, urbanization, traffic emissions, and fossil fuel combustion are the most significant anthropogenic sources (Dalman, 2012; Ghose & Majee, 2000; Kumari et al., 2024). PM_{2.5} and UFP particles, in particular, pose a serious threat to human and environmental health because they can remain in the atmosphere for long periods and reach organisms through respiration. (Pope & Dockery, 2006). Atmospheric accumulation processes play a critical role in the transport of atmospheric pollutants and metals to terrestrial and aquatic ecosystems. This deposition is defined by two main

mechanisms: dry deposition, which occurs without snow or rain, and wet deposition, which occurs with precipitation (Kara et al., 2014; Mijić et al., 2010; Yun et al., 2002). In dry deposition, fine particles can travel longer distances, while coarse particles settle more quickly. Industrial areas and areas with heavy traffic are the main sources of trace metals in the atmosphere through dry deposition. In addition, wind direction, speed, seasonal changes, and topography are the main meteorological factors affecting dry deposition rates. (Negral et al., 2020) In wet deposition, atmospheric particles combine with precipitation droplets and are transported to the ground. This process depends on factors such as particle solubility, rainwater pH, the form of atmospheric deposition, particle size, and source. (Budiwati et al., 2016; Wuana & Okieimen, 2011; Yang et al., 2023) Studies have shown that metals such as Cd, Zn, Pb, and Cu are largely anthropogenic in origin and exhibit high solubility rates. (Azimi et al., 2005; Duruibe et al., 2007; Jiang et al., 2014; Khayan et al., 2019; Thiagarajan et al., 2024). Although control measures implemented to reduce pollution from industrial and traffic sources have led to significant reductions in the load of trace metals in the atmosphere, the transport and accumulation of atmospheric pollutants are critical processes that must be monitored for global environmental quality and ecosystem health.

3. The Effects of Air Pollutants on Human Health

There is a constant exchange of matter and energy between the air, soil, and water ecosystems found in nature. Due to this dynamic structure, pollution occurring in one environment can spread to other ecosystems, causing a chain reaction of negative effects (Göçmez, 2006; Kocaer & Başkaya, 2003). Atmospheric pollutants, in particular, pose serious threats to human health through both direct and indirect means, beyond merely disrupting environmental balances. Air pollutants can enter the human body directly through respiration, as well as indirectly through the food chain, thereby affecting human health.

These pollutants, which have multifaceted effects on human health, cause damage to various organs, primarily the respiratory, cardiovascular, nervous, urinary, and digestive systems. Respiratory diseases such as bronchoconstriction, asthma, lung inflammation, and loss of function occur particularly in those exposed to sulfur dioxide (SO₂), nitrogen oxides (NO_x), and heavy metals (Balmes, 1987; Ghio & Huang, 2004; Kagawa, 1985; Uysal & Schapira, 2003). Carbon monoxide (CO) affects heart and brain functions by reducing hemoglobin's oxygen-carrying capacity (Badman & Jaffe, 1996). Particulate matter increases the risk of blood clotting in the blood vessels (Vermylen et al., 2005), while heavy metals such as mercury, lead, and arsenic cause cognitive impairment in the nervous system and damage to the glutamate and

dopamine systems (Ewan & Pamphlett, 1996; Lasley & Gilbert, 2000). In addition, dioxins have been found to adversely affect mental development in children (Thömke, 1999). Impaired kidney function, stone formation, and cancer risk are among the effects of heavy metals on the urinary system (Järup, 2003), while dioxins can cause cell damage in the digestive system and liver cancer (Mandal, 2005).

4. The Effect of Atmospheric Pollutants on Water Resources

Atmospheric pollutants exert significant and multifaceted impacts on freshwater resources through both wet and dry deposition processes. When transported onto terrestrial surfaces or directly into aquatic bodies, these pollutants alter the physicochemical properties of water systems, thereby disrupting ecological balance and threatening both ecosystem health and the efficient and sustainable use of water resources (Gruber & Galloway, 2008; Jickells et al., 2017; Rockström et al., 2009). Nitrogen oxides (NO_x) and sulfur dioxide (SO₂), released into the atmosphere primarily from fossil fuel combustion and industrial activities, transform into nitric and sulfuric acids and are subsequently deposited via precipitation, accelerating severe acidification processes. The resulting decline in pH reduces biological diversity, negatively affects fish reproduction, and increases the solubility and mobility of toxic metals in sediments (Dereli et al., 2017; Feyzioğlu & Ögüt, 2005). Similarly, atmospheric nitrogen deposition contributes substantially to eutrophication. Excess nitrogen derived from NO_x and ammonia (NH₃) emissions elevates nutrient loads in lakes, reservoirs, and coastal waters. This process promotes algal blooms, depletes dissolved oxygen, and leads to fish deaths, the disappearance of sensitive species, shifts in species composition, and the degradation of aquatic habitats (Bui et al., 2020; Gross & Hagy, 2017; Hudnell et al., 2008; Lapointe et al., 2018; Lapointe et al., 2020; Li et al., 2020; M. H. Yu et al., 2011; Zhou et al., 2019).

Another major threat is the accumulation of heavy metals such as mercury (Hg), lead (Pb), and cadmium (Cd) in aquatic ecosystems through atmospheric transport. These metals are capable of traveling long distances in the atmosphere before settling into freshwater systems. Mercury, in particular, undergoes microbial methylation in sediments, transforming into highly toxic methylmercury, which biomagnifies through the food web (Bravo et al., 2017; Schartup et al., 2013; Tang et al., 2020; W. Zhao et al., 2024). In addition, atmospheric pollutants alter key chemical characteristics of water—such as conductivity, alkalinity, ionic composition, and buffering capacity—thereby disrupting biogeochemical cycles and reducing ecosystem resilience to other environmental stressors. The long-range transport of atmospheric pollutants indicates that water bodies far from emission sources may still be subjected to significant contamination. This underscores the

transboundary nature of atmospheric pollution and highlights the necessity of integrated regional and global management strategies (Desboeufs et al., 2022; He et al., 2023; Keresztesi et al., 2020; Ruiz-Fernández et al., 2014). Consequently, acidification driven by NO_x and SO₂, nitrogen-induced eutrophication, and heavy metal fluxes collectively contribute to declines in species richness and increase the risk of extinction for particularly sensitive taxa within aquatic ecosystems (Bennama, 2006; Eren, 2006; M. H. Yu et al., 2011).

5. The Natural Filtering Role of Plants Against Atmospheric Pollutants

Plants play a significant regulatory role in the environmental transport processes of pollutants found in the atmosphere. In particular, the retention and transformation effects of plants in the transport of pollutants to river systems through wet and dry deposition play an important role in the protection and sustainability of water resources. In this context, the physical surface properties and biochemical activities of plants function as key mechanisms that reduce the transport of atmospheric pollutants to the soil and, consequently, to aquatic ecosystems (Brooker 2006; Hui et al., 2023; S. H. Lee et al., 2023; Shah et al., 2024; Su et al., 2022).

Plants play an effective protective role in reducing atmospheric pollutants through both physical and biochemical mechanisms. The physical barrier process allows pollutant-laden water to accumulate on the soil surface through wet deposition, and plant cover also increases soil infiltration by reducing surface runoff. In addition, plants act as windbreaks, preventing the spread of pollutants through dry deposition and contributing to the prevention of soil and sand erosion (Guan et al., 2000). Another way of physical trapping occurs through the retention of pollutants, particularly in the stomata and epidermis of leaves. In this process, gaseous pollutants and particulate matter are mechanically adsorbed onto the leaf surface or removed from the atmosphere by sticking to it (Kulshreshtha et al., 2009). Furthermore, morphological characteristics such as the hairy surface structure of leaves, the wax layer, and the large leaf area increase the retention capacity of pollutants, thereby supporting the effectiveness of this physical barrier mechanism.

The biochemical mechanism involves plants contributing to environmental cleanup by taking up, transforming, or accumulating pollutants through their metabolic and enzymatic activities. Phytoremediation is an important example of this mechanism, encompassing the processes of separation, degradation, stabilization, or removal of pollutants within plants (Dhir et al., 2009; Gatidou et al., 2017; Gatliff et al., 2016; J. H. Lee, 2013; J. Pandey et al., 2019; N. Pandey et al., 2021; Reichenauer & Germida, 2008). The absorption of pollutants mainly occurs in the above-ground parts of plants, mostly in leaf stomata. The degradation of pollutants occurs

through their breakdown by plant metabolites, such as enzymatic activities. Therefore, plants contribute to the removal of pollutants such as hazardous compounds, heavy metals, organic compounds, carbon dioxide (CO₂), and methane (CH₄) from the atmosphere during their growth processes (Fischer et al., 2009; López et al., 2013; Wei & Wang, 2020). Furthermore, when sulfur dioxide (SO₂) is absorbed through plant stomata, it is reduced to substances beneficial for plant growth and development, while nitrogen oxides (NO_x) are converted into compounds necessary for plant growth (Arena et al., 2014; Wang et al., 2019; Weyens et al., 2015).

6. The Protective Function of Meadow and Pasture Ecosystems for Water Resources

In today's environmental conditions, we face multifaceted environmental pollution problems that have profound effects on the integrity of ecosystems, human health, and economic development. These challenges are particularly exacerbated by anthropogenic factors such as rapid industrialization and urbanization, which increase the spread of atmospheric pollutants and make the pressures on water and soil ecosystems more complex. Methods used to combat pollution, such as mechanical cleaning and chemical treatment, generate additional environmental and economic burdens in the form of secondary pollution, high energy consumption, and high costs. Therefore, there is a growing need for new strategies that are environmentally compatible, economically feasible, and prioritize sustainability (Han et al., 2022; S. H. Lee et al., 2023; Su et al., 2022).

Meadow and pasture plants are widely found, especially in rural areas, semi-natural ecosystems, mountain foothills and valley floors, forest clearings and forest edges, plateaus, and water catchment areas. They are plant communities that contribute in various ways to the protection of water resources, providing significant support for both ecological balance and sustainable land use. These plants act as natural filters, reducing the transport of atmospheric pollutants into soil and water ecosystems thanks to their dense root systems at different depths, short but dense structures, and biochemical properties (Altın et al., 2011; Brooker, 2006; B. Liu et al., 2015; Ratté-Fortin et al., 2019; C. Yu et al., 2019; Yuan et al., 2009).

The protective function of meadow and pasture ecosystems on water resources is a holistic mechanism that emerges through the interrelated processes of the biotic and abiotic elements that make up the ecosystem. These ecosystems have multifaceted ecological functions, such as trapping atmospheric pollutants, regulating soil–water interactions, and transforming pollutants through natural processes. Both living organisms and physical-chemical environmental factors play a critical role in maintaining the physical, chemical, and biological quality of water resources. Therefore, fully understanding the water

conservation capacity of pastures requires an integrated assessment of the roles of biotic and abiotic ecosystem components, which are not independent but complementary. Furthermore, in the face of increasing environmental pressures, ecologically based approaches such as phytoremediation, which utilize natural processes, are becoming increasingly important in sustainable water management. In this context, the use of plants in environmental management offers a significant advantage (Rychnovská, 2007; K. Liu & Shao, 2024).

Abiotic factors are key determinants in preserving the physical and chemical integrity of water resources in meadow and pasture ecosystems. Soil structure and high organic matter content limit the transfer of heavy metals and other atmospheric pollutants to groundwater and surface water by facilitating their adsorption. Porous soil texture increases infiltration, reduces surface runoff, and prevents pollutants carried by precipitation from being transported into waterways. Sunlight and temperature accelerate the photodegradation of organic pollutants, reducing their toxicity, while wind prevents pollutants from concentrating in one area in open rural areas, reducing atmospheric accumulation. Moisture level and soil pH are decisive factors in the solubility and mobility of pollutants, contributing to the retention of toxic substances in the soil before they reach the water. When all these abiotic processes are considered together, it is evident that meadow and pasture areas act as a natural physicochemical filter, protecting water quality (Fageria, 2012; Jankowska-Huflejt, 2006; Kwiatkowska-Malina, 2015; McDowell & Wilcock, 2008; Nortjé & Laker 2021; Novák et al., 2020; Yang et al., 2020; J. Zhao et al., 2005).

Biotic factors play a complementary role in the protection of water resources by forming the living components of ecological processes. Plants, as producers, trap atmospheric particles on their leaves and stems, preventing pollutants from being carried into water by rainfall. In addition, their dense and deep root systems increase soil stability, reducing erosion and surface runoff. Consumer organisms ensure the renewal of plant cover, thereby preserving the continuity of the ecosystem and contributing to the uninterrupted continuation of the filtration function. Decomposing soil invertebrates, fungi, and bacteria accelerate the biochemical breakdown of organic pollutants, converting toxic compounds into less harmful forms. The continuity of vegetation cover, the activity of soil organisms, and the mutual interaction of living communities increase soil stability in pasture areas, reduce pollutant transport, and preserve the physical, chemical, and biological quality of water. In this respect, biotic factors are the fundamental ecological components that transform pastures into indispensable natural buffer zones for water catchment areas (Altın et al., 2021; Bano et al., 2021; Bano et al., 2022; Dong et al., 2023; Gheorghe & Ion, 2011; Gökkuş, 2024; Serin & Tan 2001; Sjöqvist et al., 2020; Sun et al., 2022; Wróblewska & Jeong 2021; Zehnle et al., 2023; Zhang et al., 2023).

Phytoremediation utilizes the capacity of plants to accumulate, absorb, transform, or render pollutants inert through their physiological and metabolic mechanisms. Beyond direct pollution reduction, the phytoremediation method also provides numerous benefits, such as restoring natural habitats, conserving biodiversity, improving landscape integrity, and enhancing ecosystem services. This approach, which utilizes plants as one of the most important components of the natural cycle, stands out as a low-cost, sustainable, and environmentally compatible solution (Bortoloti & Baron 2022; Shah et al., 2024).

Within phytoremediation, different mechanisms such as phytoextraction, rhizofiltration, phytovolatilization, and phytostabilization can intervene against many pollution factors. For example, phytoextraction allows plants to accumulate pollutants in their above-ground parts and remove them from the system, while rhizofiltration ensures that pollutants in water are retained by roots. Phytovolatilization allows plants to release harmful compounds into the atmosphere by converting them into less toxic forms, while phytostabilization reduces the mobility of pollutants, thereby decreasing their bioavailability. All of these processes utilize plants' natural adaptations for defense against environmental stress conditions (Alvarenga et al., 2009; Hallett & Bengough, 2013). This general framework of phytoremediation highlights how critical roles natural and semi-natural vegetation cover, spread over large areas, can play in controlling environmental pollutants.

In conclusion, meadow and pasture ecosystems have a multi-layered ecological structure where physical, chemical, and biological processes operate simultaneously, and this structure plays a unique role in the protection of water resources. Thanks to both abiotic filtration processes and biotic decomposition, retention, and transformation mechanisms, these ecosystems form a sustainable and effective protective barrier against both natural and anthropogenic pollutants. Therefore, meadows and pastures, due to their structural and functional characteristics, hold a strategic position as indispensable natural infrastructure components for water quality management, protection, and the sustainability of ecosystem health.

7. Conclusion

Meadow and pasture ecosystems are of multifaceted and strategic importance not only for agricultural production and livestock farming, but also for the protection of water resources, ecological balance, the continuity of biological diversity, and human health. These ecosystems act as a natural filter that prevents atmospheric pollutants from reaching water resources, forming an important gateway for the protection of water quality. Preventing or reducing atmospheric pollutants not only improves water quality but also contributes to the revitalization of habitats, the conservation of species diversity, and the

sustainability of ecosystem services. Clean water sources also generate economic benefits in areas such as drinking water supply, fishing, tourism, and recreation. This highlights the importance of meadow and pasture areas for ecosystem conservation at both the environmental and socio-economic levels. Furthermore, meadow and pasture areas, which are home to numerous plant species with different morphological characteristics, are directly exposed to rainfall. The plants covering the soil in these areas increase infiltration through the galleries they form with their dense root structures reaching different depths in the soil profile, allowing surface water to seep into the soil and contributing to the replenishment of freshwater sources.

In this context, the protection and sustainable management of meadow and pasture areas is an absolute necessity in terms of reducing pressure on water resources and combating atmospheric pollution. It also contributes to the indirect protection of human health. Assessing ecosystem services with a holistic approach and considering these areas not only for their economic but also their ecological value will be an important step in preventing future water crises and reducing environmental risks. Therefore, the protection of meadow and pasture areas should be addressed not only as an environmental issue but also as a matter of public health, food security, and national water policy.

Compliance with Ethical Standards

This study does not require ethical committee approval.

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Conflict of Interest

The authors declare no conflict of interest.

References

- Altın, M., Gökkuş, A., & Koç, A. (2011). *Çayır ve mera yönetimi*. Tarım ve Köy İşleri Bakanlığı, Tarımsal Üretim ve Geliştirme Genel Müdürlüğü Yayınları. (In Turkish)
- Altın, M., Gökkuş, A., Koç, A. (2021). *Çayır mera ıslahı*. Palme Yayınevi. (In Turkish)
- Alvarenga, P., Gonçalves, A. P., Fernandes, R. M., de Varennes, A., Vallini, G., Duarte, E., & Cunha-Queda, A. C. (2009). Organic residues as immobilizing agents in aided phytostabilization:(I) Effects on soil chemical characteristics. *Chemosphere*, 74(10), 1292-1300. <https://doi.org/10.1016/j.chemosphere.2008.11.063>
- Arena, C., De Maio, A., De Nicola, F., Santorufo, L., Vitale, L., & Maisto, G. (2014). Assessment of eco-physiological performance of *Quercus ilex* L. leaves in urban area by an integrated approach. *Water, Air, & Soil Pollution*, 225, 1824. <https://doi.org/10.1007/s11270-013-1824-6>
- Azimi, S., Rocher, V., Garnaud, S., Varrault, G., & Thevenot, D. R. (2005). Decrease of atmospheric deposition of heavy metals in an urban area from 1994 to 2002 (Paris, France). *Chemosphere*, 61(5), 645-651. <https://doi.org/10.1016/j.chemosphere.2005.03.022>
- Badman, D. G., & Jaffé, E. R. (1996). Blood and air pollution; state of knowledge and research needs. *Otolaryngology-Head and Neck Surgery*, 114(2), 205-208. <https://doi.org/10.1016/S0194-59989670166-3>
- Balmes, J. R., Fine, J. M., & Sheppard, D. (1987). Symptomatic bronchoconstriction after short-term inhalation of sulfur dioxide. *American Review of Respiratory Disease*, 136(5), 3674-3675. <https://doi.org/10.1164/ajrccm/136.5.1117>
- Bano, H., Rather, R. A., Bhat, J. I., Bhat, T. A., Azad, H., Bhat, S. A., & Bhat, M. A. (2021). Effect of pre-sowing treatments using phytohormones and other dormancy breaking chemicals on seed germination of *Dioscorea deltoidea* Wall. Ex Griseb.: An endangered medicinal plant species of north western Himalaya. *Ecology Environment and Conservation*, 27, 253-260.
- Bano, H., Malik, S., Rather, R. A., Bhat, J. I., Islam, S., Bhat, T. A., & Bhat, M. A. (2022). Impact of anthropogenic activities on physico-chemical properties of sediment of Hokersar wetland: A protected wildlife reserve (Ramsar Site No. 1570) of Kashmir Himalaya. *Bangladesh Journal of Botany*, 51(1), 83-92. <https://doi.org/10.3329/bjb.v51i1.58824>
- Bennama, M. M. (2006). *Libya toprak örneklerinin bazı özelliklerinin saptanması* (Master's thesis, Hacettepe University). (In Turkish)
- Bortoloti, G. A., & Baron, D. (2022). Phytoremediation of toxic heavy metals by *Brassica* plants: A biochemical and physiological approach. *Environmental Advances*, 8, 100204. <https://doi.org/10.1016/j.envadv.2022.100204>
- Bravo, A. G., Bouchet, S., Tolu, J., Björn, E., Mateos-Rivera, A., & Bertilsson, S. (2017). Molecular composition of organic matter controls methylmercury formation in boreal lakes. *Nature Communications*, 8, 14255. <https://doi.org/10.1038/ncomms14255>
- Brooker, R. W. (2006). Plant-plant interactions and environmental change. *New Phytologist*, 171(2), 271-284. <https://doi.org/10.1111/j.1469-8137.2006.01752.x>
- Budiwati, T., Setyawati, W., & Aries Tanti, D. (2016). Chemical characteristics of rainwater in Sumatera, Indonesia, during 2001–2010. *International Journal of Atmospheric Sciences*, 2016(1), 1876046. <https://doi.org/10.1155/2016/1876046>

- Bui, X. T., Vo, T. D. H., Ngo, H. H., Guo, W., Nguyen, T. V., & Nguyen, P. D. (2020). Multicriteria assessment of advanced treatment technologies for micropollutants removal at large-scale applications. *Science of The Total Environment*, 563-564, 1050-1067. <https://doi.org/10.1016/j.scitotenv.2016.04.191>
- Dalman, O., & Arslan, A. E. (2012). Trabzon'da yağmur sularının analizi. *Ekoloji*, 21(85), 107-113. <https://doi.org/10.5053/ekoloji.2012.8512> (In Turkish)
- Denhez, F. (2007). *Küresel ısınma atlası*. NTV Yayınları. (In Turkish)
- Dereli, E. M., Ertürk, A., & Çakmakçı, M. (2017). Yüzeysel sularda ağır metallerin etkileri ve ötrofikasyon ile ilişkisi. *Turkish Journal of Aquatic Sciences*, 32(4), 214-230. <https://doi.org/10.18864/TJAS201720> (In Turkish)
- Desboeufs, K., Fu, F., Bressac, M., Tovar-Sánchez, A., Triquet, S., Doussin, J. F., ... & Guieu, C. (2022). Wet deposition in the remote western and central Mediterranean as a source of trace metals to surface seawater. *Atmospheric Chemistry and Physics*, 22(4), 2309-2332. <https://doi.org/10.5194/acp-22-2309-2022>
- Dhir, B., Sharmila, P., & Saradhi, P. P. (2009). Potential of aquatic macrophytes for removing contaminants from the environment. *Critical Reviews in Environmental Science and Technology*, 39(9), 754-781. <https://doi.org/10.1080/10643380801977776>
- Dong, J., Kang, Y., Kuang, S., Ma, H., Li, M., Xiao, J., & Wu, H. (2023). Combined biological effects of polystyrene microplastics and phenanthrene on *Tubifex tubifex* and microorganisms in wetland sediment. *Chemical Engineering Journal*, 462, 142260. <https://doi.org/10.1016/j.cej.2023.142260>
- DSİ. (2023). 2023 yılı faaliyet raporu. https://cdn.ys.tarimorman.gov.tr/api/File/GetFile/425/Sayfa/759/1107/DosyaGaleri/dsi_2023_yili_faaliyet_raporu.pdf (In Turkish)
- Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews*, 81(2), 163-182. <https://doi.org/10.1017/S1464793105006950>
- Dündar, M. (2007). *Su kaynaklarının uluslararası sorun oluşturmaları* (Master's thesis, Karadeniz Technical university). (In Turkish)
- Duruibe, J. O., Ogwuegbu, M. O. C., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences*, 2(5), 112-118.
- Eren, S. (2006). *Sahra tozunun biyolojik arıtım prosesine olan etkilerinin araştırılması* (Master's thesis, Hacettepe University). (In Turkish)
- Ewan, K. B., & Pamphlett, R. (1996). Increased inorganic mercury in spinal motor neurons following chelating agents. *Neurotoxicology*, 17(2), 343-349.
- Fageria, N. K. (2012). Role of soil organic matter in maintaining sustainability of cropping systems. *Communications in Soil Science and Plant Analysis*, 43(16), 2063-2113. <https://doi.org/10.1080/00103624.2012.697234>
- Falkenmark, M., & Rockström, J. (2004). *Balancing water for humans and nature: The new approach in ecohydrology*. Routledge.
- Feyzioğlu, A. M., & Ögüt, H. (2005). Sahra tozları: Güneydoğu Karadeniz'de temmuz 2001 yılındaki *Gymnodinium sanguineum* bloomundan sorumlu olabilir mi? Ulusal Su Günleri, Trabzon. (In Turkish)
- Fischer, M. L. (2009). *Observation of CH4 and other Non-CO2 Green House Gas Emissions from California*. Lawrence Berkeley National Laboratory, Pier Final Project Report.
- Gatidou, G., Oursouzidou, M., Stefanatou, A., & Stasinakis, A. S. (2017). Removal mechanisms of benzotriazoles in duckweed *Lemna minor* wastewater treatment systems. *Science of the Total Environment*, 596-597, 12-17. <https://doi.org/10.1016/j.scitotenv.2017.04.051>
- Gatliff, E., Linton, P. J., Riddle, D. J., & Thomas, P. R. (2016). Phytoremediation of soil and groundwater: economic benefits over traditional methodologies. In M. N. V Prasad (Ed.), *Bioremediation and bioeconomy* (pp. 589-608). Elsevier. <https://doi.org/10.1016/B978-0-12-802830-8.00023-X>
- Gheorghe, I. F., & Ion, B. (2011). The effects of air pollutants on vegetation and the role of vegetation in reducing atmospheric pollution. In M. K. Khallaf (Ed.), *The impact of air pollution on health, economy, environment and agricultural sources* (pp. 241-280). IntechOpen. <https://doi.org/10.5772/17660>
- Ghio, A. J., & Huang, Y. C. T. (2004). Exposure to concentrated ambient particles (CAPs): A review. *Inhalation Toxicology*, 16(1), 53-59. <https://doi.org/10.1080/08958370490258390>
- Ghose, M. K., & Majee, S. R. (2000). Assessment of dust generation due to opencast coal mining—an Indian case study. *Environmental Monitoring and Assessment*, 61, 257-265. <https://doi.org/10.1023/A:1006127407401>
- Göçmez, S. (2006). *Menemen ovası topraklarında iz su kentsel arıtma çamuru uygulamalarının mikrobiyal aktivite ve biyomas ile bazı fiziksel ve kimyasal toprak özellikleri üzerine etkisi* (Doctoral thesis, Ege University). (In Turkish)
- Gökkuş, A. (2024). Tarım kaynaklı sorunlar ve sürdürülebilir bir tarım için çok yıllık yem bitkilerinin önemi: I. Sorunlar. *Journal Of Science-Technology-Innovation Ecosystem*, 5(1), 67-80.

- Gross, C., & Hagy III, J. D. (2017). Attributes of successful actions to restore lakes and estuaries degraded by nutrient pollution. *Journal of Environmental Management*, 187, 122-136. <https://doi.org/10.1016/j.jenvman.2016.11.018>
- Gruber, N., & Galloway, J. N. (2008). An Earth-system perspective of the global nitrogen cycle. *Nature*, 451, 293-296. <https://doi.org/10.1038/nature06592>
- Guan, D. S., Ding, J., & Wang, L. (2000). The impact of tourism and environmental pollution on plants and soil of forests in urban parks of Guangzhou. *China Environmental Science*, 20(3), 277-280.
- Hallett, P. D., & Bengough, A. G. (2013). Managing the soil physical environment for plants. In P. J. Gregory & S. Nortcliff (Eds.), *Soil conditions and plant growth* (pp. 238-268). Blackwell Publishing Ltd. <https://doi.org/10.1002/9781118337295.ch8>
- Han, Y., Lee, J., Haiping, G., Kim, K. H., Wanxi, P., Bhardwaj, N., & Brown, R. J. (2022). Plant-based remediation of air pollution: A review. *Journal of Environmental Management*, 301, 113860. <https://doi.org/10.1016/j.jenvman.2021.113860>
- He, L., Wang, S., Liu, M., Chen, Z., Xu, J., & Dong, Y. (2023). Transport and transformation of atmospheric metals in ecosystems: A review. *Journal of Hazardous Materials Advances*, 9, 100218. <https://doi.org/10.1016/j.hazadv.2022.100218>
- Hudnell, H. K., Dortch, Q., & Zenick, H. (2008). An overview of the interagency, international symposium on cyanobacterial harmful algal blooms (ISOC-HAB): Advancing the scientific understanding of freshwater harmful algal blooms. In H. K. Hudnell (Ed.), *Cyanobacterial harmful algal blooms: state of the science and research needs* (pp. 1-16). Springer New York. https://doi.org/10.1007/978-0-387-75865-7_1
- Hui, C. X., Dan, G., Alamri, S., & Toghraie, D. (2023). Greening smart cities: An investigation of the integration of urban natural resources and smart city technologies for promoting environmental sustainability. *Sustainable Cities and Society*, 99, 104985. <https://doi.org/10.1016/j.scs.2023.104985>
- Jankowska-Huflejt, H. (2006). The function of permanent grasslands in water resources protection. *Journal of Water and Land Development*, (10), 55-65. <https://doi.org/10.2478/v10025-007-0005-7>
- Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68(1), 167-182. <https://doi.org/10.1093/bmb/ldg032>
- Jiang, S. Y., Yang, F., Chan, K. L., & Ning, Z. (2014). Water solubility of metals in coarse PM and PM_{2.5} in typical urban environment in Hong Kong. *Atmospheric Pollution Research*, 5(2), 236-244. <https://doi.org/10.5094/APR.2014.029>
- Jickells, T. D., Buitenhuis, E., Altieri, K., Baker, A. R., Capone, D., Duce, R. A., & Zamora, L. M. (2017). A reevaluation of the magnitude and impacts of anthropogenic atmospheric nitrogen inputs on the ocean. *Global Biogeochemical Cycles*, 31(2), 289-305. <https://doi.org/10.1002/2016GB005586>
- Kagawa, J. (1985). Evaluation of biological significance of nitrogen oxides exposure. *The Tokai Journal of Experimental and Clinical Medicine*, 10(4), 348-353.
- Kara, M., Dumanoglu, Y., Altiok, H., Elbir, T., Odabasi, M., & Bayram, A. (2014). Seasonal and spatial variations of atmospheric trace elemental deposition in the Aliaga industrial region, Turkey. *Atmospheric Research*, 149, 204-216. <https://doi.org/10.1016/j.atmosres.2014.06.009>
- Keresztesi, Á., Nita, I. A., Birsan, M. V., Bodor, Z., Pernyeszi, T., Micheu, M. M., & Szép, R. (2020). Assessing the variations in the chemical composition of rainwater and air masses using the zonal and meridional index. *Atmospheric Research*, 237, 104846. <https://doi.org/10.1016/j.atmosres.2020.104846>
- Khayan, K., Heru Husodo, A., Astuti, I., Sudarmadji, S., & Sugandawaty Djohan, T. (2019). Rainwater as a source of drinking water: Health impacts and rainwater treatment. *Journal of Environmental and Public Health*, 2019(1), 1760950. <https://doi.org/10.1155/2019/1760950>
- Kocaer, F. O., & Başkaya, S. H. (2003). Metallerle kirlenmiş toprakların temizlenmesinde uygulanan teknolojiler. *Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 8(1), 121-131. (In Turkish)
- Kocataş, A. (1999). *Ekoloji, çevre biyolojisi*. Ege Üniversitesi Su Ürünleri Fakültesi Yayınları. (In Turkish)
- Koluman, A. (2002). *Dünyada su sorunları ve stratejileri*. ASAM Yayınları. (In Turkish)
- Küçükklavuz, E. (2009). *Küresel ısınmanın su kaynakları üzerine etkileri: Türkiye örneği* (Master's thesis, Harran University). (In Turkish)
- Kulshreshtha, K., Rai, A., Mohanty, C. S., Roy, R. K., & Sharma, S. C. (2009). Particulate pollution mitigating ability of some plant species. *International Journal of Environmental Research*, 3(1), 137-142.
- Kumari, D., Thakur, A., Tiwari, A. K., & Singh, R. (2024). Types and sources of agricultural pollution: Identifying the different pollutants generated by farming practices and their origins. In A. Kumar, J. Singh, D. Kumar & R. Kumar (Eds.), *A comprehensive exploration of soil, water, and air pollution in agriculture* (pp. 71-85). BFC Publications.
- Kwiatkowska-Malina, J. (2015). The comparison of the structure of humic acids from soil amended with different sources of organic matter. *Polish Journal of*

- Soil Science*, 48(1), 57-64. <https://doi.org/10.17951/pjss.2015.48.1.57>
- Lapointe, B. E., Burkholder, J. M., & Van Alstyne, K. L. (2018). Harmful macroalgal blooms in a changing world: Causes, impacts, and management. In S. E. Shumway, J. M. Burkholder & S. L. Morton (Eds.), *Harmful algal blooms: A compendium desk reference* (pp. 515-560). John Wiley & Sons. <https://doi.org/10.1002/9781118994672.ch15>
- Lapointe, B. E., Herren, L. W., Brewton, R. A., & Alderman, P. K. (2020). Nutrient over-enrichment and light limitation of seagrass communities in the Indian River Lagoon, an urbanized subtropical estuary. *Science of the Total Environment*, 699, 134068. <https://doi.org/10.1016/j.scitotenv.2019.134068>
- Lasley, S. M., & Gilbert, M. E. (2000). Glutamatergic components underlying lead-induced impairments in hippocampal synaptic plasticity. *Neurotoxicology*, 21(6), 1057-1068.
- Lee, J. H. (2013). An overview of phytoremediation as a potentially promising technology for environmental pollution control. *Biotechnology and Bioprocess Engineering*, 18(3), 431-439. <https://doi.org/10.1007/s12257-013-0193-8>
- Lee, S. H., Park, H., & Kim, J. G. (2023). Current status of and challenges for phytoremediation as a sustainable environmental management plan for abandoned mine areas in Korea. *Sustainability*, 15(3), 2761. <https://doi.org/10.3390/su15032761>
- Li, X., Zhang, X., Zhang, X., Han, L., & Liu, Y. (2020). Impact of industrial wastewater discharge on water quality and aquatic ecosystem in receiving rivers. *Journal of Cleaner Production*, 267, 122173.
- Liu, B., Xie, G., Zhang, X., Zhao, Y., Yin, X., Cheng, C. (2015). *Vegetation root system, soil erosion and ecohydrology system: A review*. International Forum on Energy, Environment Science and Materials (IFEESM 2015). Shenzhen. <https://doi.org/10.2991/ifeesm-15.2015.52>
- Liu, K., & Shao, X. (2024). Grassland ecological management and utilization for sustainability. *Agronomy*, 14(1), 149. <https://doi.org/10.3390/agronomy14010149>
- López, J. C., Quijano, G., Souza, T. S., Estrada, J. M., Lebrero, R., & Muñoz, R. (2013). Biotechnologies for greenhouse gases (CH₄, N₂O, and CO₂) abatement: State of the art and challenges. *Applied Microbiology and Biotechnology*, 97, 2277-2303. <https://doi.org/10.1007/s00253-013-4734-z>
- Mandal, P. K. (2005). Dioxin: A review of its environmental effects and its aryl hydrocarbon receptor biology. *Journal of Comparative Physiology B*, 175, 221-230. <https://doi.org/10.1007/s00360-005-0483-3>
- McDowell, R., & Wilcock, R. (2008). Water quality and the effects of different pastoral animals. *New Zealand Veterinary Journal*, 56(6), 289-296. <https://doi.org/10.1080/00480169.2008.36849>
- MGM. (2017). *Hidrometeoroloji*. <https://www.mgm.gov.tr/genel/hidrometeoroloji.aspx?s=1> (In Turkish)
- Mijić, Z., Stojić, A., Perišić, M., Rajšić, S., Tasić, M., Radenković, M., & Joksić, J. (2010). Seasonal variability and source apportionment of metals in the atmospheric deposition in Belgrade. *Atmospheric Environment*, 44(30), 3630-3637. <https://doi.org/10.1016/j.atmosenv.2010.06.045>
- Negrál, L., Suárez-Peña, B., Zapico, E., Fernández-Nava, Y., Megido, L., Moreno, J., Marañón, E., & Castrillón, L. (2020). Anthropogenic and meteorological influences on PM₁₀ metal/semi-metal concentrations: Implications for human health. *Chemosphere*, 243, 125347. <https://doi.org/10.1016/j.chemosphere.2019.125347>
- Nortjé, G. P., & Laker, M. C. (2021). Factors that determine the sorption of mineral elements in soils and their impact on soil and water pollution. *Minerals*, 11(8), 821. <https://doi.org/10.3390/min11080821>
- Novák, J., Jankowski, K., Sosnowski, J., Malinowska, E., & Wiśniewska-Kadżajan, B. (2020). Influence of plant species and grasslands quality on sequestration of soil organic carbon. *Ekologia*, 39(3), 289-300. <https://doi.org/10.2478/eko-2020-0023>
- Pandey, J., Verma, R. K., & Singh, S. (2019). Suitability of aromatic plants for phytoremediation of heavy metal contaminated areas: A review. *International Journal of Phytoremediation*, 21(5), 405-418. <https://doi.org/10.1080/15226514.2018.1540546>
- Pandey, N., Chandra, J., Xalxo, R., & Sahu, K. (2021). Concept and types of phytoremediation. In M. Hasanuzzaman (Ed.), *Approaches to the remediation of inorganic pollutants* (pp. 281-302). Springer Singapore. https://doi.org/10.1007/978-981-15-6221-1_14
- Pattanayak, S. K., Jeuland, M., Lewis, J. J., Usmani, F., Brooks, N., Bhojvaid, V., & Ramanathan, V. (2019). Experimental evidence on promotion of electric and improved biomass cookstoves. *Proceedings of the National Academy of Sciences*, 116(27), 13282-13287. <https://doi.org/10.1073/pnas.1808827116>
- Pope, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: Lines that connect. *Journal of the Air & Waste Management Association*, 56(6), 709-742. <https://doi.org/10.1080/10473289.2006.10464485>
- Ratté-Fortin, C., Rousseau, A. N., Thériault, G., & Van Bochove, E. (2019). Evaluating the effects of BMPs on agricultural contaminants using a novel method accounting for uncertainty in water flow and contaminant loads. *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques*,

- 44(3), 263-279. <https://doi.org/10.1080/07011784.2019.1581093>
- Reichenauer, T. G., & Germida, J. J. (2008). Phytoremediation of organic contaminants in soil and groundwater. *ChemSusChem: Chemistry-Sustainability-Energy-Materials*, 1(8 - 9), 708-717. <https://doi.org/10.1002/cssc.200800125>
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., & Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461, 472-475. <https://doi.org/10.1038/461472a>
- Ruiz-Fernández, A. C., Ontiveros-Cuadras, J. F., Sericano, J. L., Sanchez-Cabeza, J. A., Kwong, L. L. W., Dunbar, R. B., Mucciarone, D. A., Pérez-Bernal, L. H., & Páez-Osuna, F. (2014). Long-range atmospheric transport of persistent organic pollutants to remote lacustrine environments. *Science of the Total Environment*, 493, 505-520. <https://doi.org/10.1016/j.scitotenv.2014.05.002>
- Rychnovská, M. (2007). Fungování travinných ekosystémů je klíčem k porozumění jejich funkce v krajině. In V. Krajčovič (Ed.), *Ekológia trávneho porastu VII* (pp. 16-19). Banská Bystrica. (In Czech)
- Schartup, A. T., Mason, R. P., Balcom, P. H., Hollweg, T. A., & Chen, C. Y. (2013). Methylmercury production in estuarine sediments: Role of organic matter. *Environmental Science & Technology*, 47(2), 695-700. <https://doi.org/10.1021/es302566w>
- Schlesinger, W. H. (1997). *Biogeochemistry: An analysis of global change*. Academic Press. <https://doi.org/10.1016/C2012-0-01654-7>
- Serin, Y., & Tan, M. (2001). *Yem bitkileri kültürüne giriş*. Atatürk Üniversitesi Ziraat Fakültesi Ders Yayınları. (In Turkish)
- Shah, N., Irshad, M., Murad, W., Hamayun, M., Qadir, M., Hussain, A., & Ali, S. (2024). IAA is more effective than EDTA in enhancing phytoremediation potential for cadmium and copper contaminated soils. *BMC Plant Biology*, 24, 815. <https://doi.org/10.1186/s12870-024-05329-5>
- Shiklomanov, I. A. (1993). World freshwater resources. In P. H. Gleick (Ed.), *Water in crisis: A guide to the world's water resources* (pp. 13-24). Oxford University Press.
- Sjöqvist, H., Längkvist, M., & Javed, F. (2020). An analysis of fast learning methods for classifying forest cover types. *Applied Artificial Intelligence*, 34(10), 691-709. <https://doi.org/10.1080/08839514.2020.1771523>
- Smith, V. H., & Schindler, D. W. (2009). Eutrophication science: Where do we go from here? *Trends in Ecology & Evolution*, 24(4), 201-207. <https://doi.org/10.1016/j.tree.2008.11.009>
- Su, R., Wang, Y., Huang, S., Chen, R., & Wang, J. (2022). Application for ecological restoration of contaminated soil: Phytoremediation. *International Journal of Environmental Research and Public Health*, 19(20), 13124. <https://doi.org/10.3390/ijerph192013124>
- Sun, X., Ye, Y., Liao, J., Soromotin, A. V., Smirnov, P. V., & Kuzyakov, Y. (2022). Organic mulching increases microbial activity in urban Forest soil. *Forests*, 13(9), 1352. <https://doi.org/10.3390/f13091352>
- Tang, W. L., Liu, Y. R., Guan, W. Y., Zhong, H., Qu, X. M., & Zhang, T. (2020). Understanding mercury methylation in the changing environment: Recent advances in assessing microbial methylators and mercury bioavailability. *Science of the Total Environment*, 714, 136827. <https://doi.org/10.1016/j.scitotenv.2020.136827>
- Thiagarajan, V., Nah, T., & Xin, X. (2024). Impacts of atmospheric particulate matter deposition on phytoplankton: A review. *Science of The Total Environment*, 950, 175280. <https://doi.org/10.1016/j.scitotenv.2024.175280>
- Thömke, F., Jung, D., Besser, R., Röder, R., Konietzko, J., & Hopf, H. C. (1999). Increased risk of sensory neuropathy in workers with chloracne after exposure to 2, 3, 7, 8-polychlorinated dioxins and furans. *Acta Neurologica Scandinavica*, 100(1), 1-5. <https://doi.org/10.1111/j.1600-0404.1999.tb00716.x>
- UNESCO. (2024). *The United Nations World Water development report 2024: Water for prosperity and peace*. <https://unesdoc.unesco.org/ark:/48223/pf0000388948>
- Uysal, N., & Schapira, R. M. (2003). Effects of ozone on lung function and lung diseases. *Current Opinion in Pulmonary Medicine*, 9(2), 144-150. <https://doi.org/10.1097/00063198-200303000-00009>
- Vermeylen, J., Nemmar, A., Nemery, B., & Hoylaerts, M. F. (2005). Ambient air pollution and acute myocardial infarction. *Journal of Thrombosis and Haemostasis*, 3(9), 1955-1961. <https://doi.org/10.1111/j.1538-7836.2005.01471.x>
- Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., & Davies, P. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555-561. <https://doi.org/10.1038/nature09440>
- Wang, Y., Jin, W., Che, Y., Huang, D., Wang, J., Zhao, M., & Sun, G. (2019). Atmospheric nitrogen dioxide improves photosynthesis in mulberry leaves via effective utilization of excess absorbed light energy. *Forests*, 10(4), 312. <https://doi.org/10.3390/f10040312>
- Wei, C., & Wang, M. (2020). Spatial distribution of greenhouse gases (CO₂ and CH₄) on expressways in the megacity Shanghai, China. *Environmental Science and Pollution*

- Research, 27, 31143-31152. <https://doi.org/10.1007/s11356-020-09372-1>
- Weyens, N., Thijs, S., Popek, R., Witters, N., Przybysz, A., Espenshade, J., & Gawronski, S. W. (2015). The role of plant-microbe interactions and their exploitation for phytoremediation of air pollutants. *International Journal of Molecular Sciences*, 16(10), 25576-25604. <https://doi.org/10.3390/ijms161025576>
- Wisler, C. O., & Brater, E. F. (1959). *Hydrology*. John Wiley & Sons Inc.
- Wróblewska, K., & Jeong, B. R. (2021). Effectiveness of plants and green infrastructure utilization in ambient particulate matter removal. *Environmental Sciences Europe*, 33, 110. <https://doi.org/10.1186/s12302-021-00547-2>
- Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*, 2011(1), 402647. <https://doi.org/10.5402/2011/402647>
- Yang, J., Shi, B., Shi, Y., Marvin, S., Zheng, Y., & Xia, G. (2020). Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form. *Sustainable Cities and Society*, 54, 101941. <https://doi.org/10.1016/j.scs.2019.101941>
- Yang, J., Ma, L., He, X., Au, W., Miao, Y., Wang, W., & Nah, T. (2023). Measurement report: Abundance and fractional solubilities of aerosol metals in urban Hong Kong—Insights into factors that control aerosol metal dissolution in an urban site in South China. *Atmospheric Chemistry and Physics*, 23(2), 1403-1419. <https://doi.org/10.5194/acp-23-1403-2023>
- Yu, C., Duan, P., Yu, Z., & Gao, B. (2019). Experimental and model investigations of vegetative filter strips for contaminant removal: A review. *Ecological Engineering*, 126, 25-36. <https://doi.org/10.1016/j.ecoleng.2018.10.020>
- Yu, M. H., Tsunoda, H., & Tsunoda, M. (2011). *Environmental toxicology: Biological and health effects of pollutants*. CRC Press. <https://doi.org/10.1201/b11677>
- Yuan, Y., Bingner, R. L., & Locke, M. A. (2009). A review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. *Ecohydrology*, 2(3), 321-336. <https://doi.org/10.1002/eco.82>
- Yun, H. J., Yi, S. M., & Kim, Y. P. (2002). Dry deposition fluxes of ambient particulate heavy metals in a small city, Korea. *Atmospheric Environment*, 36(35), 5449-5458. [https://doi.org/10.1016/S1352-2310\(02\)00660-X](https://doi.org/10.1016/S1352-2310(02)00660-X)
- Zehnle, H., Otersen, C., Benito Merino, D., & Wegener, G. (2023). Potential for the anaerobic oxidation of benzene and naphthalene in thermophilic microorganisms from the Guaymas Basin. *Frontiers in Microbiology*, 14, 1279865. <https://doi.org/10.3389/fmicb.2023.1279865>
- Zhang, Z., Sun, J., Gong, X., Wang, C., & Wang, H. (2023). Anaerobic biodegradation of pyrene and benzo [a] pyrene by a new sulfate-reducing *Desulforamulus aquiferis* strain DSA. *Journal of Hazardous Materials*, 459, 132053. <https://doi.org/10.1016/j.jhazmat.2023.132053>
- Zhao, J., Chen, C., & Ma, W. (2005). Photocatalytic degradation of organic pollutants under visible light irradiation. *Topics in Catalysis*, 35, 269-278. <https://doi.org/10.1007/s11244-005-3834-0>
- Zhao, W., Gan, R., Xian, B., Wu, T., Wu, G., Huang, S., & Zhang, Y. (2024). Overview of methylation and demethylation mechanisms and influencing factors of mercury in water. *Toxics*, 12(10), 715. <https://doi.org/10.3390/toxics12100715>
- Zhou, Y., Shao, Y., Gao, N., & Zhu, S. (2019). Adsorption of organic pollutants from industrial wastewater onto porous materials prepared from sewage sludge. *Chemical Engineering Journal*, 359, 1445-1455.