European Science Review

2026, No 5–6

PREMIER Publishing

Vienna
2026

European Science Review

Scientific journal

2026, No 5–6

ISSN 2310-5577

Proofreading Kristin Theissen

Cover design Andreas Vogel

Additional design Stephan Friedman

Editorial office Premier Publishing Praha 8
Karlín, Lyčkovo nám. 508/7, PSČ 18600

Email: pub@ppublishing.org

Homepage: ppublishing.org

European Science Review an international, English language, peer-reviewed journal. The journal is published in electronic form.

The decisive criterion for accepting a manuscript for publication is scientific quality. All research articles published in this journal have undergone a rigorous peer review. Based on initial screening by the editors, each paper is anonymized and reviewed by at least two anonymous referees. Recommending the articles for publishing, the reviewers confirm that in their opinion the submitted article contains important or new scientific results.

Premier Publishing s.r.o. is not responsible for the stylistic content of the article. The responsibility for the stylistic content lies on an author of an article.

Instructions for authors

Full instructions for manuscript preparation and submission can be found through the Premier Publishing s.r.o. home page at: http://ppublishing.org

Material disclaimer

The opinions expressed in the conference proceedings do not necessarily reflect those of the Premier Publishing s.r.o., the editor, the editorial board, or the organization to which the authors are affiliated. Premier Publishing s.r.o. is not responsible for the stylistic content of the article. The responsibility for the stylistic content lies on an author of an article.

Included to the open access repositories:

The jurnal has Index Copernicus Value (ICV) 92.08 for 2022.

SJIF 2024 = 6.735 (Scientific Journal Impact Factor Value for 2024).

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 1. Agriculture

DOI:10.29013/ESR-26-5.6-3-10

THE IMPACT OF MICROPLASTICS ON SOIL DEGRADATION: MECHANISMS, INTERACTIONS, AND IMPLICATIONS FOR ECOSYSTEM HEALTH

Caleb Ojomichegbe, Agbanwu [1]

[1] Undergraduate Student, Federal University of Technology, Minna, Nigeria

Cite: *Caleb Ojomichegbe, Agbanwu. (2026). The Impact of Microplastics on Soil Degradation: Mechanisms, Interactions, and Implications for Ecosystem Health. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-3-10

Abstract

Microplastics (MPs) have emerged as pervasive pollutants in terrestrial ecosystems, with growing evidence indicating their potential to alter soil structure, nutrient cycling, and microbial activity. This paper synthesizes findings from recent studies to explore the multifaceted effects of microplastics on soil degradation. Key mechanisms include physical disruption of soil aggregates, chemical leaching of additives, and alterations in microbial community composition. Interactions with environmental stressors such as drought further modulate these effects. The review highlights polymer-specific and dose-dependent responses, underscoring the need for integrated risk assessments and mitigation strategies to preserve soil health and ecosystem functionality.

Keywords: *Microplastics; soil degradation; nutrient cycling; microbial activity; soil aggregation; drought; polymer type; ecosystem multifunctionality*

1. Introduction

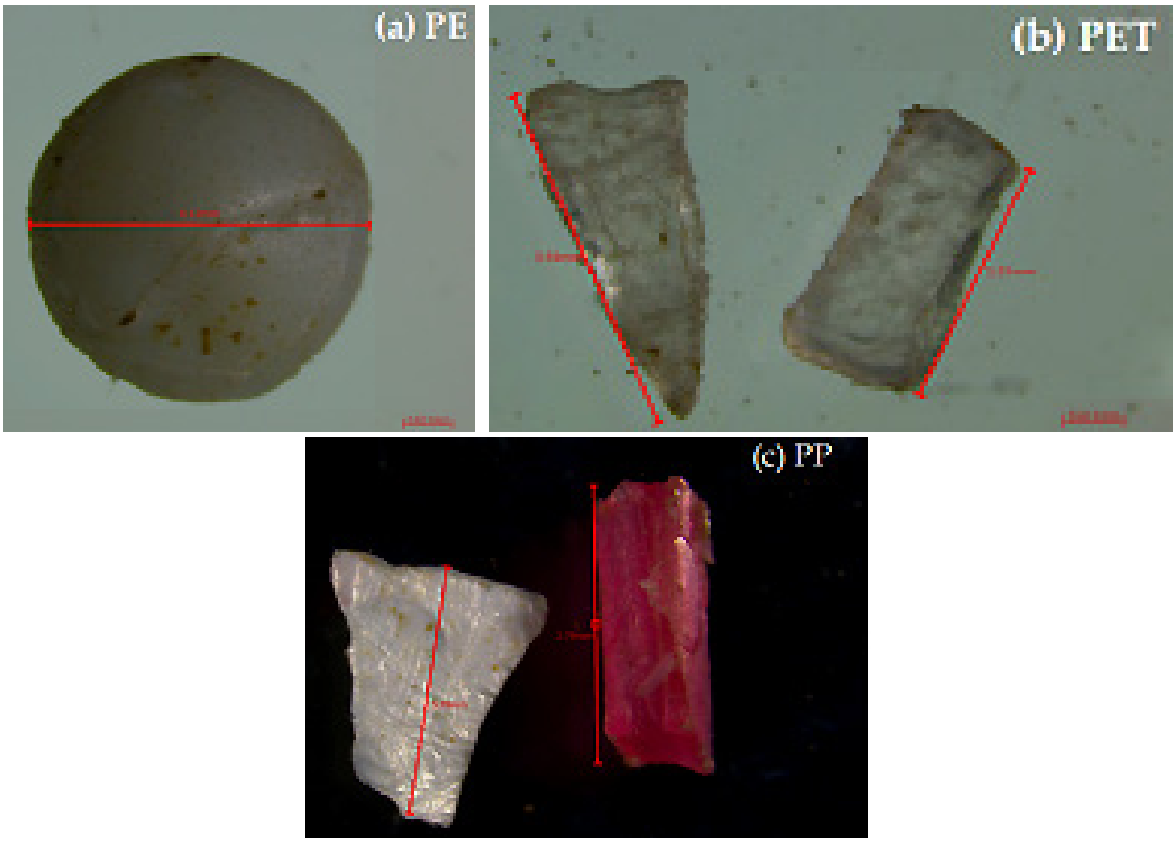
Microplastics – plastic particles less than 5 mm in size – are increasingly recognized as a significant pollutant in terrestrial environments. Introduced through agricultural practices, sewage sludge application, irrigation, and atmospheric deposition, MPs accumulate in soils and interact with biogeochemical processes (Rillig, M.C., 2012). While extensive research has focused on marine systems, the impact of MPs on soil degradation remains less understood (Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., & Svendsen, C., 2017). Soil degradation encompasses declines in physical structure, chemical fertility, and biological activity, all of which can be exacerbated by MP contamination (de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M.C., 2018). This paper reviews current knowledge on how MPs influence soil degradation, drawing on experimental and observational studies to elucidate underlying mechanisms and ecological consequences.

2. Mechanisms of Microplastic-Induced Soil Degradation

2.1 Physical Alteration of Soil Structure

MPs can disrupt soil aggregation – a key indicator of soil health. Fibrous MPs, such as polyester fibers, may entangle soil particles, potentially increasing aggregate stability under certain conditions (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021). However, non-fibrous MPs (e.g., fragments, beads) can reduce aggregate stability by interfering with binding agents like microbial mucilages and organic matter (Lehmann, A., Fitschen, K., & Rillig, M. C., 2019). Changes in soil porosity and water-holding capacity further affect aeration, root penetration, and water infiltration, leading to physical degradation over time (Zhang, G. S., & Liu, Y. F., 2018). The shape and size of MPs play crucial roles in these physical interactions (Figure 1), with fibers generally having more pronounced effects on soil structure than spherical particles (Rillig, M. C., Lehmann, A., Ryo, M., & Bergmann, J., 2019).

Figure 1. *Size, color, and shape characteristics of microplastics used in experimental studies: (a) polyethylene (PE), (b) polyethylene terephthalate (PET), and (c) polypropylene (PP) (Dindar, E., 2025)*



2.2 Chemical Effects on Soil Chemistry

MPs can alter soil pH, nutrient availability, and organic matter dynamics. For instance, polyethylene (PE) and polypropylene (PP) tend to increase soil pH, while polyethylene terephthalate (PET) may release acidic degradation products (Dindar, E., 2025). Additives and adsorbed contaminants leached from MPs (e.g., plasticizers, heavy metals) can introduce toxins into the soil matrix, affecting nutrient cycling and enzyme activities (Hüffer, T., Hofmann, T., & Praetorius, A., 2020). Studies show that MPs can either increase or decrease phosphorus (P) availability depending on polymer type, concentration, and exposure duration (Dindar, E., 2025). The chemical composition of MPs, including the presence of additives such as phthalates and bisphenol A, can have significant implications for soil chemistry and plant health (Wang, J., Liu, X., Li, Y., Powell, T., Wang, X., Wang, G., & Zhang, P., 2019).

2.3 Biological Impacts on Soil Microbiota

Soil microbial communities are highly sensitive to MP contamination. MPs can serve as substrates for microbial colonization, altering community composition and function (Zhu, D., Chen, Q. L., An, X. L., Yang, X. R., Christie, P., Ke, X., ... & Zhu, Y. G., 2018). For example, phosphate-solubilizing bacteria (PSB) may be enriched in MP-contaminated soils, temporarily enhancing P mineralization (Seeley, M. E., Song, B., Passie, R., & Hale, R. C., 2020). However, high MP concentrations often suppress microbial diversity and enzyme activities – particularly phosphatases and dehydrogenases – critical for nutrient transformation (Fei, Y., Huang, S., Zhang, H., Tong, Y., Wen, D., Xia, X., ... & Barcelo, D., 2020, 1). The «phosphorus trap» phenomenon, where P accumulates in unavailable forms due to MP adsorption, further disrupts biogeochemical cycles (Boots, B., Russell, C. W., & Green, D. S., 2019). MPs can also affect soil fauna, including earthworms and nematodes, which play crucial roles in soil structure formation and nutrient cycling (Ju, H., Zhu, D., & Qiao, M., 2019).

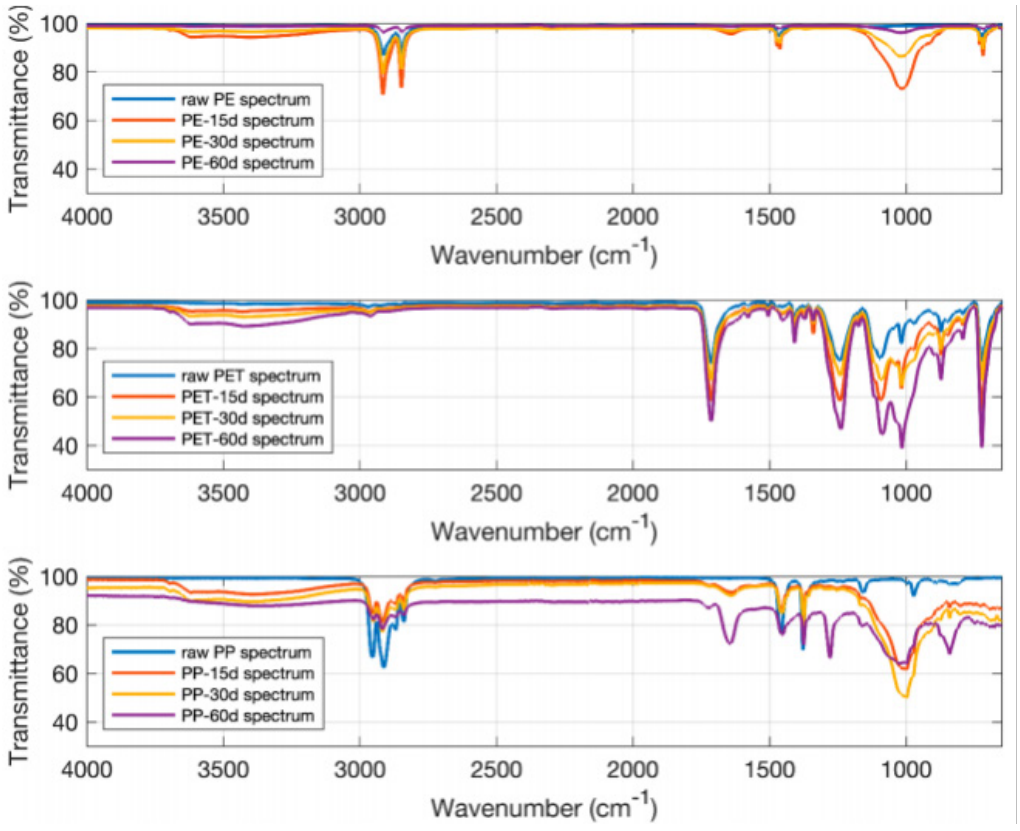
3. Polymer-Specific and Dose-Dependent Responses

Different polymers exhibit distinct degradation behaviors and ecological impacts (Figure 2):

– **PET**: Highly susceptible to hydrolysis and photooxidation, releasing carboxyl and hydroxyl groups that can complex with nutrients. Low doses (0.5% w/w) may stimulate enzyme activity and P availability, while high doses (5% w/w) often inhibit microbial functions (Dindar, E., 2025);

– **PE and PP**: More resistant to degradation due to their saturated hydrocarbon backbones (Figure 3). PE tends to reduce enzyme activity and nutrient availability at high concentrations, while PP shows variable effects on P dynamics (Dindar, E., 2025);

Figure 2. *FTIR spectra showing chemical degradation patterns of PE, PET, and PP microplastics after 60 days of soil incubation (Dindar, E., 2025)*

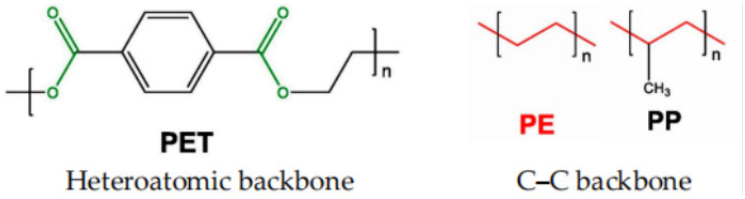


– **Fibers vs. Fragments**: Shape matters – fibers often enhance aggregation but may reduce microbial habitat connectivity, whereas fragments can physically hinder root growth and water movement (Lozano,

Y. M., Lehnert, T., Linck, L. T., Lehmann, A., & Rillig, M. C., 2021);

– **Polystyrene (PS) and Polyvinyl Chloride (PVC)**: These polymers often show more pronounced negative effects on soil biota due to their chemical composition and potential for additive leaching (Qi, R., Jones, D. L., Li, Z., Liu, Q., & Yan, C., 2020).

Figure 3. *Chemical backbone structures of selected plastic polymers. C–C backbone: polyethylene (PE), polypropylene (PP). Heteroatomic backbone: polyethylene terephthalate (PET) (Dindar, E., 2025)*

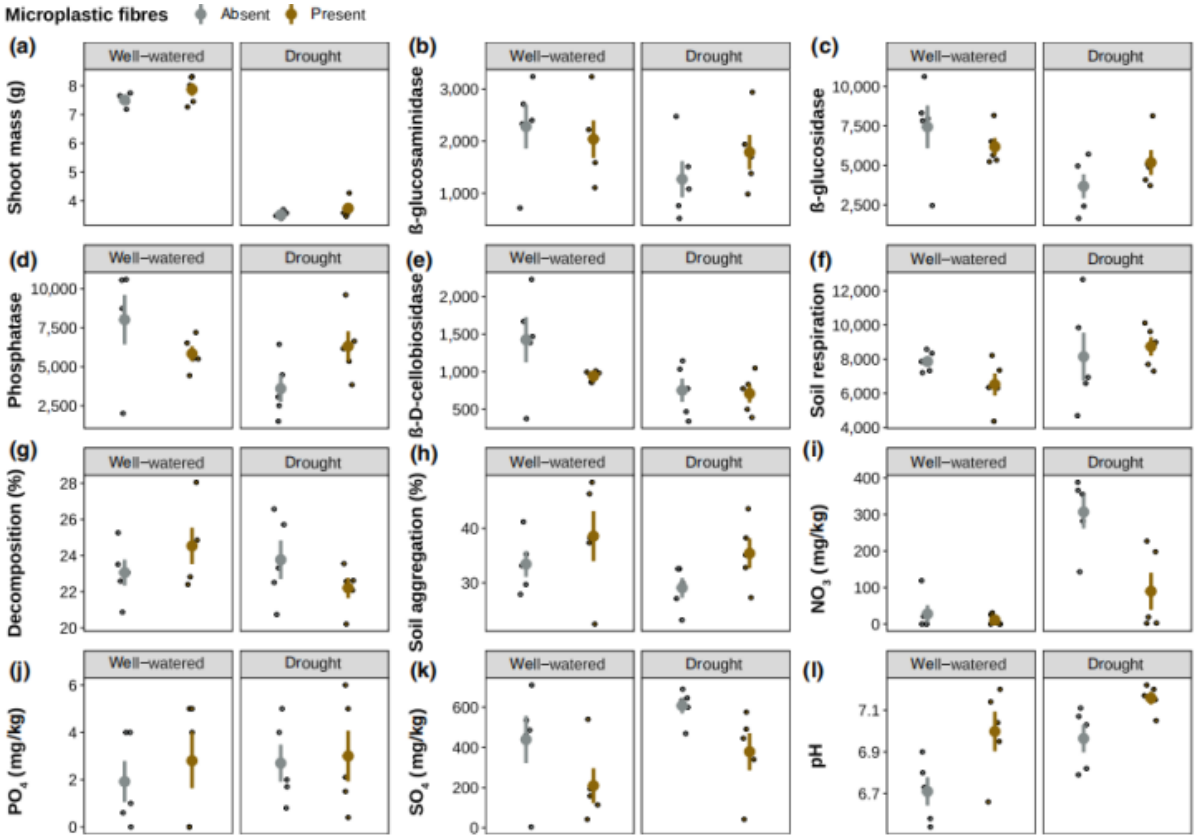


Dose-dependent effects are evident across studies. Low MP concentrations (≤0.5% w/w) may transiently stimulate microbial activity, whereas higher concentrations (≥1% w/w) typically induce toxicity, reducing enzyme activities, nutrient cycling, and plant growth (Wan, L., Cheng, H., Liu, Y., Shen, Y., Liu, G., Su, X., 2023). The threshold concentrations at which MPs transition from stimulatory to inhibitory effects vary depending on soil type, polymer characteristics, and environmental conditions (Zhou, J., Wen, Y., Marshall, M. R., Zhao, J., Gui, H., Yang, Y., ... & Jones, D. L., 2021).

4. Interactions with Abiotic Stressors: The Case of Drought

Microplastics can interact with drought to amplify or mitigate soil degradation.

Figure 4. *Microplastic fibers and drought effects on 12 ecosystem functions: (a) shoot mass, (b) β-glucosaminidase, (c) β-glucosidase, (d) phosphatase, (e) β-D-cellobiosidase, (f) soil respiration, (g) litter decomposition, (h) soil aggregation, (i) NO3, (j) PO4, (k) SO4, (l) soil pH (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021)*

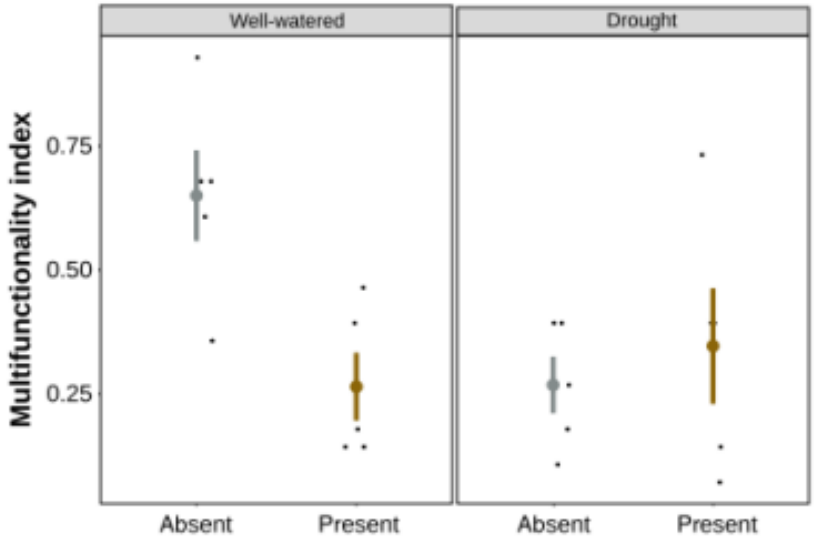


Lozano et al. (Lozano, Y.M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M.C., 2021) found that under well-watered conditions, MPs reduced enzyme activities and soil respiration, but under drought, MPs sometimes alleviated stress by improving water retention and aggregation (Figure 4). However, MP fibers combined with drought reduced litter decomposition – a key process in carbon cycling (Liu, H., Yang, X., Liu, G., Liang, C., Xue, S., Chen, H., ... & Geissen, V., 2017). These interactions highlight the context-dependent nature of MP impacts and the need to consider co-occurring global change factors. The combined effects of MPs and drought on soil microbial communities can be particularly complex, with outcomes depending on the specific microbial taxa involved and their tolerance to both stressors (Sanaullah, M., Blagodatskaya, E., Chabbi, A., Rumpel, C., & Kuzyakov, Y., 2011).

5. Implications for Ecosystem Multifunctionality

Soil multifunctionality – the simultaneous provision of multiple ecosystem services – is increasingly used to assess MP impacts. Studies indicate that MPs can reduce multifunctionality to an extent comparable to drought, particularly under well-watered conditions (Figure 5) (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M.C., 2021). Functions most affected include nutrient cycling (e.g., phosphatase activity), carbon decomposition, and soil respiration (Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F.T., Mace, G., ... & Fischer, M., 2018). The decline in multifunctionality underscores the broad ecological risks posed by MP pollution. Different ecosystem functions respond differently to MP contamination, with some showing greater sensitivity than others (Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C.,... & Fischer, M., 2016). This differential sensitivity has implications for the stability and resilience of soil ecosystems in the face of MP pollution.

Figure 5. *Microplastic fibers and drought effects on ecosystem multifunctionality (Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C., 2021)*



6. Transport and Fate of Microplastics in Soil Systems

Understanding the movement and persistence of MPs in soil systems is crucial for assessing their long-term impacts. MPs can be transported vertically through soil profiles via leaching and bioturbation, and horizontally through erosion and runoff (O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W. M., & Hou, D., 2019). The persistence of different polymer types varies significantly, with some MPs remaining in soils for decades or

longer (Chae, Y., & An, Y. J., 2018). The fragmentation of larger plastic items into secondary MPs represents an ongoing source of contamination in agricultural and natural soils (Bläsing, M., & Amelung, W., 2018). The interaction between MPs and soil organic matter affects both the mobility of MPs and the cycling of organic carbon in soil systems (Rillig, M. C., Lehmann, A., de Souza Machado, A. A., & Yang, G., 2019).

7. Effects on Plant Health and Agricultural Productivity

MP contamination has direct and indirect effects on plant health and agricultural productivity. MPs can affect seed germination, root development, and nutrient uptake in various crop species (de Souza Machado, A. A., Lau, C. W., Kloas, W., Bergmann, J., Bachelier, J. B., Faltin, E., ... & Rillig, M. C., 2019). The physical presence of MPs in the rhizosphere can alter root architecture and function, potentially affecting water and nutrient acquisition (Li, L., Luo, Y., Li, R., Zhou, Q., Peijnenburg, W. J., Yin, N., ... & Zhang, S., 2020). Some studies have reported reduced crop yields in MP-contaminated soils, particularly at higher contamination levels (Jiang, X., Chen, H., Liao, Y., Ye, Z., Li, M., & Klobučar, G., 2019). However, responses vary significantly among plant species and cultivars, suggesting that genetic factors may influence plant tolerance to MP stress (Pignattelli, S., Broccoli, A., & Renzi, M., 2020).

8. Knowledge Gaps and Future Research Directions

– **Long-Term Studies**: Most experiments are short-term (<60 days); long-term field studies are needed to assess chronic exposure effects (Rillig, M. C., & Bonkowski, M., 2018);

– **Mechanistic Insights**: The molecular mechanisms linking MP degradation to microbial gene expression and metabolic pathways remain unclear (Zhu, F., Zhu, C., Wang, C., & Gu, C., 2019).

– **Real-World Concentrations**: More data on environmentally relevant MP concentrations in different soil types and land-use systems are essential for risk assessment (Xu, B., Liu, F., Cryder, Z., Huang, D., Lu, Z., He, Y., ... & Xu, J., 2020);

– **Interactive Effects**: Research on MP interactions with other pollutants (e.g., pesticides, heavy metals) and climate variables (e.g., temperature, precipitation) is limited (Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., ... & He, D., 2018);

– **Standardized Methods**: Development of standardized methods for MP extraction, identification, and quantification in soil matrices is needed to enable comparisons across studies (Hurley, R. R., & Nizzetto, L., 2018);

– **Remediation Strategies**: Research on effective remediation techniques for MP-contaminated soils, including biological, chemical, and physical approaches, is still in its infancy (Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., ... & Wong, M. H., 2020).

9. Conclusion

Microplastics represent a novel and persistent threat to soil health, contributing to physical, chemical, and biological degradation. Their impacts are mediated by polymer type, concentration, shape, and environmental context. While low doses may occasionally stimulate microbial processes, higher concentrations generally impair ecosystem functions. The interaction of MPs with drought and other stressors further complicates risk prediction. Addressing MP pollution requires integrated strategies – including improved waste management, biodegradable alternatives, and remediation technologies – to safeguard soil ecosystems and the services they provide. Future research should prioritize field-based studies, mechanistic investigations, and the development of standardized assessment protocols to better understand and mitigate the impacts of MPs on soil systems.

References

Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maass, S., Zhao, T., & Rillig, M. C. (2021). Effects of microplastics and drought on soil ecosystem functions and multifunctionality. *Journal of Applied Ecology*, – 58(5). – P. 988–996.

Lehmann, A., Fitschen, K., & Rillig, M. C. (2019). Abiotic and biotic factors influencing the effect of microplastics on soil aggregation. *Soil Systems*, 3(1). – 21 p.
Dindar, E. (2025). Impact of Microplastic Contamination on Phosphorus Availability, Alkaline Phosphatase Activity, and Polymer Degradation in Soil. *Polymers*, 17(10). – 1586 p.
Fei, Y., Huang, S., Zhang, H., Tong, Y., Wen, D., Xia, X., ... & Barcelo, D. (2020). Response of soil enzyme activities and bacterial communities to the accumulation of microplastics in an acid cropped soil. *Science of The Total Environment*, – 707. – 135634 p.
Wan, L., Cheng, H., Liu, Y., Shen, Y., Liu, G., Su, X. (2023). Global meta-analysis reveals differential effects of microplastics on soil ecosystem. *Science of The Total Environment*, – 867. – 161403 p.
Rillig, M. C. (2012). Microplastic in terrestrial ecosystems and the soil? *Environmental Science & Technology*, – 46(12). – P. 6453–6454.
Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, – 586. – P. 127–141.
de Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology*, – 24(4). – P. 1405–1416.
Zhang, G. S., & Liu, Y. F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of The Total Environment*, – 642. – 12–20.
Rillig, M. C., Lehmann, A., Ryo, M., & Bergmann, J. (2019). Shaping up: Toward considering the shape and form of pollutants. *Environmental Science & Technology*, – 53(14). – P. 7925–7926.
Hüffer, T., Hofmann, T., & Praetorius, A. (2020). Microplastic in terrestrial ecosystems. *Science*, – 368(6498). – P. 1430–1431.
Wang, J., Liu, X., Li, Y., Powell, T., Wang, X., Wang, G., & Zhang, P. (2019). Microplastics as contaminants in the soil environment: A mini-review. *Science of The Total Environment*, – 691. – P. 848–857.
Zhu, D., Chen, Q. L., An, X. L., Yang, X. R., Christie, P., Ke, X., ... & Zhu, Y. G. (2018). Exposure of soil collembolans to microplastics perturbs their gut microbiota and alters their isotopic composition. *Soil Biology and Biochemistr*y, – 116. – P. 302–310.
Seeley, M. E., Song, B., Passie, R., & Hale, R. C. (2020). Microplastics affect sedimentary microbial communities and nitrogen cycling. *Nature Communication*s, – 11(1). – P. 1–10.
Boots, B., Russell, C. W., & Green, D. S. (2019). Effects of microplastics in soil ecosystems: Above and below ground. *Environmental Science & Technology*, – 53(19). – P. 11496–11506.
Ju, H., Zhu, D., & Qiao, M. (2019). Effects of polyethylene microplastics on the gut microbial community, reproduction and avoidance behaviors of the soil springtail, Folsomia candida. *Environmental Pollution*, – 247. – P. 890–897.
Lozano, Y. M., Lehnert, T., Linck, L. T., Lehmann, A., & Rillig, M. C. (2021). Microplastic shape, polymer type, and concentration affect soil properties and plant biomass. *Frontiers in Plant Scienc*e, – 12. – 616645 p.
Qi, R., Jones, D. L., Li, Z., Liu, Q., & Yan, C. (2020). Behavior of microplastics and plastic film residues in the soil environment: A critical review. *Science of The Total Environment*, – 703. – 134722 p.
Zhou, J., Wen, Y., Marshall, M. R., Zhao, J., Gui, H., Yang, Y., ... & Jones, D. L. (2021). Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. *Journal of Hazardous Materials*, – 388. – 121814 p.
Liu, H., Yang, X., Liu, G., Liang, C., Xue, S., Chen, H., ... & Geissen, V. (2017). Response of soil dissolved organic matter to microplastic addition in Chinese loess soil. *Chemosphere*, – 185. – P. 907–917.

Sanaullah, M., Blagodatskaya, E., Chabbi, A., Rumpel, C., & Kuzyakov, Y. (2011). Drought effects on microbial biomass and enzyme activities in the rhizosphere of grasses depend on plant community composition. *Applied Soil Ecology*, – 48(1). – P. 38–44.

Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., ... & Fischer, M. (2018). Redefining ecosystem multifunctionality. *Nature Ecology & Evolution*, – 2(3). – P. 427–436.

Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., ... & Fischer, M. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. *Nature Communications*, – 7(1). – 11109 p.

O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W. M., & Hou, D. (2019). Microplastics undergo accelerated vertical migration in sand soil due to small size and wet-dry cycles. *Environmental Pollution*, – 249. – P. 527–534.

Chae, Y., & An, Y. J. (2018). Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. *Environmental Pollution*, – 240. – P. 387–395.

Bläsing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of The Total Environmen*t, – 612. – P. 422–435.

Rillig, M. C., Lehmann, A., de Souza Machado, A. A., & Yang, G. (2019). Microplastic effects on plants. *New Phytologist*, – 223(3). – P. 1066–1070.

de Souza Machado, A. A., Lau, C. W., Kloas, W., Bergmann, J., Bachelier, J. B., Faltin, E., ... & Rillig, M. C. (2019). Microplastics can change soil properties and affect plant performance. *Environmental Science & Technology*, – 53(10). – P. 6044–6052.

Li, L., Luo, Y., Li, R., Zhou, Q., Peijnenburg, W. J., Yin, N., ... & Zhang, S. (2020). Effective uptake of submicrometre plastics by crop plants via a crack-entry mode. *Nature Sustainability*, – 3(11). – P. 929–937.

Jiang, X., Chen, H., Liao, Y., Ye, Z., Li, M., & Klobučar, G. (2019). Ecotoxicity and genotoxicity of polystyrene microplastics on higher plant Vicia faba. *Environmental Pollution*, – 250. – P. 831–838.

Pignattelli, S., Broccoli, A., & Renzi, M. (2020). Physiological responses of garden cress (L. sativum) to different types of microplastics. *Science of The Total Environment*, – 727. – 138609 p.

Rillig, M. C., & Bonkowski, M. (2018). Microplastic and soil protists: A call for research. Environmental Pollution, – 241. – P. 1128–1131.

Zhu, F., Zhu, C., Wang, C., & Gu, C. (2019). Occurrence and ecological impacts of microplastics in soil systems: A review. *Bulletin of Environmental Contamination and Toxicology*, – 102(6). – P. 741–749.

Xu, B., Liu, F., Cryder, Z., Huang, D., Lu, Z., He, Y., ... & Xu, J. (2020). Microplastics in the soil environment: Occurrence, risks, interactions and fate–A review. *Critical Reviews in Environmental Science and Technology*, – 50(21). – P. 2175–2222.

Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., ... & He, D. (2018). Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. *Environmental Pollution*, – 242. – P. 855–862.

Hurley, R. R., & Nizzetto, L. (2018). Fate and occurrence of micro(nano)plastics in soils: Knowledge gaps and possible risks. *Current Opinion in Environmental Science & Health*, – 1. – P. 6–11.

Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., ... & Wong, M. H. (2020). Source, migration and toxicology of microplastics in soil. *Environment International*, – 137. – 105263 p.

submitted 04.04.2026;
accepted for publication 18.04.2026;
published 30.06.2026

Contact: agbanwucaleb4@gmail.com

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 2. Economics and management

DOI:10.29013/ESR-26-5.6-11-16

SUDAN GRASS IN ARID CONDITIONS: PRODUCTIVITY, DROUGHT TOLERANCE, AND FORAGE POTENTIAL

Juzbayev Dalel [1]

[1] Director of Asso LLP, Kazakhstan, Astana

Cite: *Juzbayev D. (2026). Sudan Grass in Arid Conditions: Productivity, Drought Tolerance, and Forage Potential. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-11-16

Abstract

The article discusses Sudanese grass as a potential fodder crop for arid areas, where obtaining a consistent supply of feed is challenging due to a lack of water, high temperatures, and the instability of environmental and climatic conditions. It explores the theoretical foundations for studying the productivity and drought tolerance of this crop, analyzes the characteristics of the arid environment in which it grows, and summarizes data on how moisture availability, agricultural practices, and biological traits of the plant influence crop yield. Special attention is given to assessing Sudanese grass's productivity based on its yield of dry matter and hay, number of harvests, and ability to maintain value in difficult years. Sudanese grass is highlighted as a significant component of forage production in arid regions because of its drought resistance, versatility, rapid regrowth after harvest, and multiple uses. The conclusion is made regarding the high practical significance of the culture in strengthening the forage base of arid areas and enhancing the sustainability of forage production.

Keywords: *Sudanese grass, arid zone, productivity, drought resistance, forage production, green mass, yield, fodder base, multi-crop area, arid territories*

Relevance of the study

The relevance of the research topic stems from the fact that, for arid and semi-arid regions, one of the main challenges remains securing a stable supply of feed in the face of moisture deficiencies and high temperatures. Sudanese grass has been identified as a promising crop precisely because of its drought and heat tolerance, as well as its ability to produce significant biomass under adverse growing conditions.

Scientific and reference materials indicate that crops in the sorghum family, including Sudanese grass and Sudanese-sorghum hybrids, are better suited to warm regions and exhibit greater resistance to drought than corn, which is particularly significant for farms in arid zones.

The practical significance of Sudanese grass increases due to its use as green fodder, hay, and haylage. It also has the advantage of rapid regrowth after being cut, which allows for its multi-faceted use in the feed production system. In arid conditions, according to agronomic and scientific literature, Sudanese grass can provide 2–3 cuts per season. Its economic value is not only related to its yield but also to the flexibility it provides in forming the fodder base during the summer months.

The relevance of the topic increases due to the need to choose varieties and technologies that are ideally suited to the specific climatic conditions of the region. Scientific research explicitly states that for each region, it is necessary to select varieties that can maximize the use of local natural resources. In the conditions of arid steppes, the productivity of sorghum forage crops strongly depends on the water regime and agrotechnical techniques. Therefore, the assessment of the productivity and drought resistance of Sudanese grass in the arid zone has not only theoretical but also practical significance for increasing the sustainability of forage production.

The purpose of the study

The aim of this research is to assess the productivity and drought resistance of Sudanese grass in arid regions and to analyze its potential contribution to sustainable forage production in these areas.

Materials and research methods

The study used open scientific publications, agronomic and reference data, as well as the results of field observations and production indicators related to the cultivation of Sudanese grass in arid conditions.

Various methods were used in the work: analysis of scientific literature, generalization of published information, comparative analysis of productivity indicators, descriptive method, as well as presentation of data in the form of tables and diagrams.

The results of the study

Sudanese grass is an annual cereal forage crop related to sorghum. It is widely used as green fodder, hay, haylage, and for grazing livestock. Sudanese grass is valued in feed production due to its ability to adapt to hot and arid conditions. According to scientists and experts, forage sorghum, including Sudanese grass, is highly resistant to drought. They can grow successfully in places where growing corn is difficult due to high temperatures and lack of moisture. This makes Sudanese grass especially attractive for regions with unstable moisture.

The productivity of Sudanese grass is usually assessed by the yield of green mass, dry matter, and hay, as well as by the plant's ability to grow quickly after mowing. Scientific publications note that this crop forms a significant amount of feed mass and is characterized by high yield, which allows it to be used in a multi-axis system. Studies have shown that in conditions of drought, the productivity of Sudanese grass significantly depends on the availability of moisture and the level of mineral nutrition. This suggests that its yield is influenced not only by the biological characteristics of the crop but also by the specific growing conditions (Khalgaeva K. E., Balinova T. A., Eviev V. A. [et al.] 2021, p. 49).

The drought resistance of Sudanese grass is due to its unique morphological and physiological characteristics. Scientific literature notes that this plant has a powerful root system capable of extracting moisture from deep soil layers. This feature allows Sudanese grass to easily tolerate prolonged periods of drought and continue to grow at high air temperatures. The combination of a well-developed root system, heat resistance, and the ability to quickly restore vegetative mass after mowing makes it an indispensable fodder crop for arid regions.

The key feature of Sudanese grass is that its productivity should not be considered in isolation but in the context of external conditions. Even with the high natural stability of this crop, the actual yield level depends on many factors: moisture regime, agrotechnical techniques, soil conditions, and the period of use of the herbage. In scientific research, the evaluation of Sudanese grass is usually based on comparing its potential productivity with actual yields in specific soil and climatic conditions.

Sudanese grass is a crop that has adapted to growing in environments with high temperatures and low moisture levels. For a better understanding of the natural and climatic conditions in the arid region, it is helpful to see the main indicators in Table 1.

Table 1. *The main natural and climatic indicators of the arid zone, significant for assessing the growing conditions of Sudanese grass*

Indicator	Meaning	Scientific significance for research
Average annual precipitation	250–350 mm	Confirms the lack of moisture in the area
Hydrothermal coefficient	About 0.5	Characterizes the pronounced aridity of the climate
The state of humidification	Evaporation exceeds precipitation	It is the main feature of the arid zone
Dynamics of summer precipitation in arid zones of the Volga region	Reduction by 23–30%	Increases the risk of water shortage during the active growing season
The risk of severe atmospheric droughts in the semi-desert zone	Height from 55% to 82%	It shows an increase in climatic restrictions for feed production
Characteristic soils	light brown	Determine the features of soil moisture accumulation and consumption

A source: (Gubarev D. I., Levitskaya N. G., Derevyagin S. S., 2022; Tashninova A. A., 2020; Shumova N. A., 2021)

These data suggest that moisture availability is the main limiting factor for crop growth in the arid region. Therefore, it is important to assess the productivity of Sudanese grass under these conditions, taking into account not only its total yield but also its ability to maintain growth and development in the face of limited moisture and high temperatures. This highlights the practical significance of studying Sudanese grass, which is one of the most promising forage crops for arid regions.

The productivity of Sudanese grass in the arid zone is primarily estimated by the yield of dry matter, hay yield, number of mowings, and stability of fodder mass production over the years. Field data from Kalmykia show that even in arid conditions, this crop retains practical value for forage production. However, the yield level varies significantly depending on the moisture regime and weather conditions. In particular, at the Bashanti State Variety Site, the average dry matter productivity of Sudanese grass for 2018––2020 ranged from 52.7 c/ha (Kamyshinskaya 51) to 64.7 c/ha (Grazia). There was also a sharp variability across years, with the Grazia variety yielding 68.0, 87.2, and 38.0 c/ha, respectively, in 2018, 2019, and 2020. This highlights the direct dependence of crop yield on moisture availability during the growing season.

In the same materials, it was noted that in the central zone of Kalmykia, during years with a dry period in the second half of summer, the productivity of late crops sharply decreases, and in Sudanese grass, the yield can decrease by 2–3 times. At the same time, production data show that even with these restrictions, the crop provides an economically significant feed yield. In 2020, farms in Kalmykia produced over 6 tons per hectare of hay in the Wormwood SEC, over 7 tons per hectare in the Gagarin SEC, and over 8 tons per hectare in the Pervomaisky SEC. This confirms that Sudanese grass is valuable in the arid zone not only as a potentially productive crop but also as a relatively reliable fodder crop.

The level of agricultural technology has a significant impact on productivity. Open research has shown that Sudanese grass responds well to improved mineral nutrition, particularly nitrogen fertilizers. This is because it removes a significant amount of nutrients from the soil during the formation of a large vegetative mass. Published works emphasize that high yields of this crop can only be achieved when the biological characteristics of the plant are combined with a correct cultivation system (Magomedov K. G., Magomedov M. K., 2005).

The resistance of Sudanese grass to arid conditions is determined not by one indicator, but by a whole complex of biological and economically valuable traits. Scientific and reference literature notes that this crop is adapted to growing in conditions of insufficient moisture, is able to tolerate high temperatures, and has relatively high resistance to drought compared to a number of other forage plants. In addition, the herbage quickly recovers after mowing. However, field studies show that even in drought-resistant crops, the level of productivity largely depends on the severity of water scarcity. To clearly demonstrate the main signs of drought resistance of Sudanese grass, they can be summarized (Table 2).

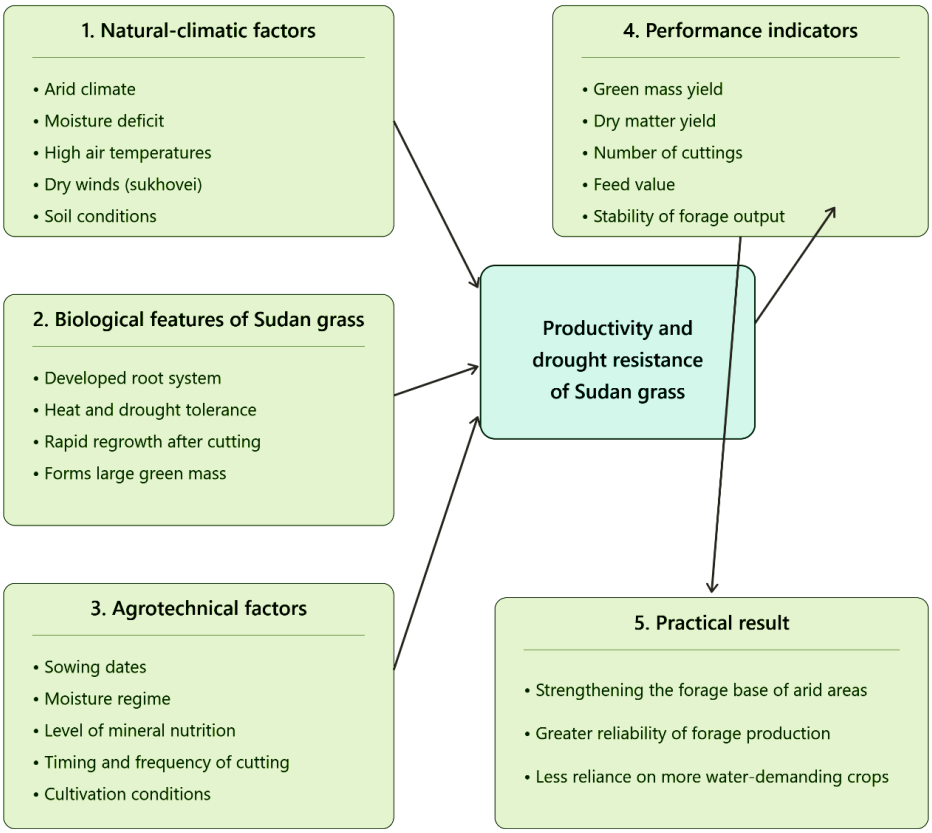
Table 2. *The main signs of drought resistance of Sudanese grass*

Sign	Confirmed information
General characteristics of drought resistance	Sudanese grass is a drought-resistant forage crop
Comparative stability	Sorghum crops, including Sudanese grass, are more drought-tolerant than corn
Adaptation to the conditions of semi-arid and arid territories	The crop is well-suited for cultivation in stressful and arid regions
Ability to recover after mowing	After mowing or bleaching, Sudanese grass regrows quickly
Reaction to increased drought	In dry years, productivity can decrease by 2–3 times

A source: author's development based on open data

To better understand what factors affect the yield and resistance of Sudanese grass to drought in the arid zone, they can be presented in the form of a diagram (Figure).

Figure 1. *Factors affecting the productivity and drought resistance of Sudanese grass in the arid zone [author's development]*



Sudanese grass plays an important role in forage production in arid regions, as it offers economic versatility, high productivity, and adaptability to growing in conditions with insufficient moisture. In these areas, the ability to use this crop for various purposes is particularly significant: for green feed, hay, silage, and pasture management. This versatility allows farmers to more flexibly build their feed base based on weather conditions, land use, and animal husbandry needs.

In the arid zone of Sudan, grass has practical value as an agricultural crop that can provide nutrition during periods when other plants are experiencing difficulties due to high temperatures and lack of moisture. Its inclusion in the feeding system helps to maintain the stability of green feed intake, as it germinates quickly after mowing and can be harvested several times. Thanks to this, Sudanese grass helps to prolong the production period of green fodder during the season, which is especially valuable for regions with unpredictable climates.

The forage value of Sudanese grass is significant. It forms a nutritious green mass, but its quality depends on the plant's stage of development and timing of harvest. As the plants age, their nutrient content decreases. Therefore, it is important to cut the grass at the right time to ensure proper nutrient content.

Sudanese grass has the ability to produce multiple cuttings per season, which is especially useful in arid areas. This increases the reliability of forage production and allows for more feed even in conditions of limited water. The multiple cuttings also contribute to more efficient use of land and make Sudanese grass a valuable component of the field forage system.

It is equally important to consider Sudanese grass as a crop that is more adapted to water scarcity than a number of traditional forage plants. This makes it more significant in regions where moisture availability is the main limiting factor for crop yield. In these conditions, Sudanese grass plays not only an industrial but also an adaptive role, allowing farmers to maintain the stability of their feed base during adverse weather conditions.

To better understand the role of Sudanese grass in forage production in arid areas, it is helpful to present its major economic benefits in Table 3.

Table 3. *The role of Sudanese grass in the forage production of arid territories*

Indicator	Characteristic	Importance for feed production
Directions of use	Green fodder, hay, haylage, silage, pasture	Provides multi-purpose use of culture
Adaptability to arid conditions	It is capable of growing and yielding crops in conditions of moisture deficiency	Increases the stability of the food supply in the arid zone
Participation in the green pipeline	It can be used at any time of the year	Increases the period of receipt of fresh herbs
The ability to regrow	It recovers quickly after mowing	Makes it possible to get multiple mows
Feed value	Forms a nutritious green mass	It is an important component of the animal diet
Importance in case of water shortage	It is less dependent on a high level of moisture compared to crops that require more water	Reduces the risk of feed shortages in dry years

A source: author's development based on open data

Conclusions

The results of the analysis allow us to conclude that Sudanic grass is one of the most promising fodder crops for arid areas. Its value is due to a combination of characteristics such as drought resistance, the ability to form

a significant amount of green mass, rapid recovery after mowing, and versatility in use.

It was found that the productivity of this crop largely depends on the availability of moisture, weather conditions during the year, and the level of agricultural technology. However, even in arid regions, Sudanese grass retains its high economic value. Its cultivation helps to strengthen the feed base, prolong the period of green mass intake, and reduce the dependence of farms on more moisture-consuming crops.

Thus, the cultivation of Sudanese grass in the arid zone is of both theoretical and practical importance for increasing the sustainability of feed production.

References

Goldvarg B. A., Tsagan-Mandzhiev N. L. (2024). Forage base – the basis for the development of beef cattle breeding in the Republic of Kalmykia // International Research Journal. 2024. – No. 1(139). URL: https://research-journal.org/archive/1-139-2024-january/10.23670/IRJ.2024.139.17. – DOI: 10.23670/IRJ.2024.139.17.

Gubarev D. I., Levitskaya N. G., Derevyagin S. S. (2022). The impact of climate change on soil degradation in arid zones of the Volga region // Arid ecosystems. 2022. – Vol. 28. – No. 1(90). – P. 20–27. – DOI 10.24412/1993–3916–2022–1–20–27.

Magomedov K. G., Magomedov M. K. (2005). Mineral nutrition and productivity of Sudan grass // Modern problems of science and education. 2005. – No. 1. URL: https://science-education.ru/ru/article/view?id=21.

Tashninova A. A. (2020). Cenopopulations of medicinal plants and their habitat as a fragment of biological diversity in the ravine ecosystems of Ergeni // Bulletin of the Institute. 2020. – P. 52–58.

Khalgaeva K. E., Balinova T. A., Eviev V. A. [et al.] (2021). The influence of pre-irrigation moisture and mineral nutrition levels on the productivity of Sudan grass in arid conditions of Kalmykia // Bulletin of the Michurinsk State Agrarian University. 2021. – No. 2 (65). – P. 47–51.

Shumova N. A. (2021). Quantitative climate indicators in application to the assessment of hydrothermal conditions in the Republic of Kalmykia // Arid ecosystems. 2021. – Vol. 27. – No. 4 (89). – P. 13–24.

submitted 09.06.2026;
accepted for publication 23.06.2026;
published 30.06.2026

Contact: Dalelkaz@gmail.com

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

DOI:10.29013/ESR-26-5.6-17-20

ESG STANDARDS IN THE GEORGIAN FINANCIAL SECTOR: AN ANALYSIS OF THE CURRENT SITUATION

Tea Khorguashvili [1], Neli Sesadze [2], Medea Zurabishvili [3]

[1] Doctor of Economic Sciences, Professor of Gori State University, Gori, Georgia

[2] Doctor of Economic Sciences, Professor of Georgian Technical University (GTU)

[3] Assistant Professor of the School of Economics, Caucasus University, Tbilisi, Georgia

Cite: *Khorguashvili T., Sesadze N., Zurabishvili M. (2026). ESG Standards in the Georgian Financial Sector: An Analysis of the Current Situation. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-17-20

Abstract

This article analyzes the role of Environmental, Social, and Governance (ESG) standards within Georgia's financial system. The primary objective of the research is to assess the current state of the financial sector and the readiness of Georgian financial institutions to integrate sustainable development principles.

The paper examines the measures implemented by the National Bank of Georgia and their alignment with international best practices. The analysis reveals that, despite notable progress, the sector faces significant challenges, such as data quality management and the refinement of ESG risk assessment methodologies.

The concluding section offers strategic recommendations aimed at enhancing transparency and attracting sustainable investments into the country's economy.

Keywords: *ESG Standards, Sustainable Finance, Green Taxonomy, National Bank of Georgia, Pillar 3, Greenwashing*

Methodology

The present study is based on qualitative research methods, specifically a comprehensive analysis of secondary data. The paper employs descriptive and comparative analysis techniques to examine the dynamics of ESG (Environmental, Social, and Governance) standard implementation within the Georgian financial sector.

The information base of the research consists of: The legal framework of the National Bank of Georgia, The "Sustainable Finance Roadmap" and the "Green Taxonomy,"Public disclosures and reports published by commercial banks.

To establish the international context, the study analyzes EU directives and recommendations from international financial institutions. The theoretical framework is built upon scientific literature and sectoral studies from the last decade, ensuring a multifaceted understanding of the subject through existing data without the need for primary empirical research.

Introduction

In today's global economy, Environmental, Social, and Governance (ESG) standards are no longer viewed merely as an expression of corporate goodwill; they have become critical factors determining financial stability and long-term sustainability.

Climate change and the urgent demand for sustainable development have compelled international financial institutions to rethink traditional risk management models and integrate sustainability criteria into them. Currently, on a global scale, it is of paramount importance to implement ESG standards, support environmental initiatives, and introduce innovative financial instruments for sustainable funding.Today, green finance is an integral part of sustainable development and the formation of a green economy both at the global level and at the level of individual countries. (Mzevinar Nozadze, 2025).

For Georgia, as an emerging market and an EU candidate country, the ESG agenda is of paramount importance. The financial sector – the most vital segment of the country's economy – has been at the forefront of this transformation.

In recent years, with the assistance of international organizations, the National Bank of Georgia has taken significant steps to develop the "Sustainable Finance Roadmap," which aims to harmonize the local market with international standarts.

Results and Discussion

The integration of Environmental, Social, and Governance (ESG) standards into the global financial landscape has fundamentally reshaped international development priorities. By prioritizing social equity and environmental stewardship, this framework strengthens institutional resilience against systemic shocks and drives sustainable economic growth. While the three pillars of ESG are intrinsically linked, each possesses distinct operational characteristics.

ESG factors cover a broad range of topics and issues. Many of them, such as climate change, can affect specific firms, sectors or countries but can also impair the stability of an economy (IFC ESG Guidebook, 2021).

This decision has established the legal foundation for the development of "green finance," as member states have committed to aligning financial flows with the principles of a green economy and low-emission development. Traditional financial models, which were focused solely on the classical relationship between profit and risk, are today being transformed into the context of sustainable financing, where ESG (Environmental, Social, and Governance) factors play a crucial role (Zurabishvili, 2026). ESG standards help banks measure the sustainability of a particular business. Green finance, on the other hand, represents the actual capital (loans, bonds) provided exclusively for projects that meet the environmental (E) component of ESG.

Therefore, ESG standards and green finance represent two inseparable parts of a unified sustainable ecosystem. Green bonds enable companies to raise capital on more favorable terms – a phenomenon known as the „Greenium" – as institutional investors increasingly prioritize assets dedicated to financing environmental projects (Badri Giorgidze, 2026). If ESG is the assessment methodology that determines a company's level of responsibility, then in the Georgian context, integrating ESG standards into banking risk management systems directly increases the accessibility of green finance. Green finance and sustainable business create a synergy, where businesses integrate environmental, social, and governance (ESG) principles into their long-term perspective (Mzevinar Nozadze L. V., 2025).

Banks that utilize ESG scoring are more effective at identifying green assets, which ultimately reduces the risks of "greenwashing" and increases investor confidence in the local market. It is the practical mechanism through which capital realization occurs. The implementation of ESG practices within the banking sector, particularly in emerging economies, is fraught with significant challenges. Without well-defined benchmarks and metrics, banks face significant challenges in providing consistent and proactive evidence of their ESG performance.

Based on the analysis conducted, it is evident that the Georgian financial sector is in an active phase of ESG transformation. The reforms initiated by the National Bank of Georgia since 2019 are fully aligned with in-

ternational best practices. Specifically, within the framework of the "Sustainable Finance Roadmap," commercial banks have begun integrating climate-related risks into their credit policies. Integrating climate and ESG considerations into the operations, internal policies, and activities of central banks and financial sectorregulators is crucial (Sustainable Finance Roadmap For Georgia, 2025).

In Georgia, ESG criteria aim to foster the development of green and sustainable finance, ensuring that banks not only generate profits but also contribute to environmental protection and social development.

In the modern global context, the establishment of ESG standards and support for environmental projects are closely linked to the existence of a unified sustainable finance framework. A fundamental role in this process is played by the Green Taxonomy, which serves as a transparent classification system for economic activities. It is noteworthy that Georgia's Green Taxonomy is largely based on the EU Taxonomy best practices, ensuring the harmonization of the local financial system with international standards. Furthermore, the definition of sustainable finance used within the taxonomy encompasses social finance alongside green finance (including climate-related finance) (Sustainable Finance Taxonomy for Georgia 2022, 2022).

It is a well-established fact that Georgia's two leading commercial banks -TBC Bank and the Bank of Georgia -trade their issued securities on the London Stock Exchange.

The Bank of Georgia executed a strategic transition to the Premium Listing segment in 2012, enabling its shares to be traded directly on the Main Market of the London Stock Exchange.

Bank of Georgia has a strong, formal commitment to Environmental, Social, and Governance (ESG) criteria. The Bank of Georgia's ESG framework includes: – Environmental (E) – The Bank integrates environmental measures into its credit risk management and has supported the Caucasus Nature Fund (CNF) since 2009, which focuses on preserving the region's ecosystem. – Social (S) – Corporate responsibility is driven by initiatives such as the "Tree of Life" Foundation, which supports social issues such as education and inclusion. – Governance (G) – the Bank is listed on the London Stock Exchange and adheres to the UK Corporate Governance Code. As od 2024, Lion Financial Group PLG recieved on MSCI ESC Rating of AA. (Sustainability Report 2024).

In 2016, following the precedent set by the Bank of Georgia, **TBC Bank** achieved a Premium Listing and was subsequently admitted to the FTSE 250 Index. TBC Bank serves as a prime example of the rapid growth in sustainable finance portfolios. The bank actively utilizes dedicated 'green lines' secured from International Financial Institutions (IFIs), such as the EBRD, EIB, and IFC, to fund environmentally sustainable projects. TBC Bank Group PLC (the "Company" and, together with its subsidiaries, the "Group") is committed to the highest standards of corporate governance which are in accordance with UK and international best practice (TBC Releases Its Sustainability Report 2024, 2025). Moreover, under Georgian banking legislation, TBC Bank and Bank of Georgia are required to publish a Pillar 3 Report alongside their annual reports, which includes dedicated tables for ESG risks.

It is important to note that between 2023 and 2025, the National Bank of Georgia (NBG) implemented the "ESG Reporting and Disclosure Principles." This means that not only the major systemic banks but also medium-sized banks and other financial-credit institutions are now obligated to disclose their sustainability indicators.These financial institutions include, for instance, microfinance organisations, institutional investors and credit unions, andenterprises whose securities are admitted to trading on the stock exchange (ESG Reporting and Disclosure Principles, 2020).

An analysis of ESG reporting in the Georgian banking sector reveals that genuine transparency is primarily observed only in relation to environmental standards. Other components (Social and Governance) are not yet adequately reflected in public data. Measuring social impact and long-term benefits is an additional challenge as they involve subjective assessments and difficulties in quantifying social and governance aspects (Andreea-Larisa Olteanu, 2023).

ESG standards for Georgian banks are dictated not only by shareholders but also by

creditors (such as the EBRD, IFC, and ADB). Attracting low-interest resources from these institutions is directly linked to how effectively a bank complies with ESG criteria.

The implementation of ESG is not merely an expense but an opportunity – it enables the country to attract more "cheap" and long-term foreign investment.

Conclusion

Despite the positive dynamics, the implementation of ESG standards is associated with numerous challenges, encompassing both regulatory complexities and the readiness of the private sector. The examples of TBC Bank and the Bank of Georgia confirm that international transparency and adherence to sustainable development criteria are directly linked to attracting low-cost financial resources and maintaining competitiveness in the global market.

The "Green Taxonomy" and ESG reporting rules introduced by the National Bank of Georgia provide a solid foundation for preventing "greenwashing" and ensuring data objectivity. The future challenge will be the deeper integration of these standards not only into large systemic banks but also into small and medium-sized financial institutions, which will ultimately determine the long-term sustainability of the country's economy.

References

Andreea-Larisa Olteanu, A. E. (2023). ESG Reporting Standards in The Banking Sector: A Global Analysis. *Economic Sciences Series, XXIII*(1), – P. 1032–1039. doi: DOI: 10.61801/OUAESS.2023.1.132

Badri Giorgidze, M. N. (2026). Green Bonds and Esg Ratings as Tools For Corporate Investment Attractiveness. *International Journal of Innovative Technologies in Economy,* – 1(53). – P. 1–6. Doi: https://doi.org/10.31435/ijite.1(53).2026.5730

Esg Reporting and Disclosure Principles. (2020). Tbilisi: OECD / National Bank of Georgia. Retrieved from https://nbg.gov.ge/fm

IFC ESG Guidebook. (2021). Retrieved from https://www.ifc.org/content/dam/ifc/doc/mgrt/ifc-esg-guidebook.pdf

Mzevinar Nozadze, G. B. (2025). Business Social Responsibility and "Green Innovations" – Cause-and-Effect Relationship. *International Journal of Innovative Technologies in Social Science,* – 1(45). – P. 1–5. Doi: https://doi.org/10.31435/ijitss.1(45).2025.3261

Mzevinar Nozadze, L. V. (2025). The Impact of Green Finance on Business Sustainability. *European Science Review,* – 11–12. – P. 1–4. Doi:10.29013/ESR-25–11.12–33–36. P. 4. ppublishing.org

(n.d.). *Sustainability Report 2024*. Tbilisi: Bank of Georgia. Retrieved from https://ramad.bog.ge/s3/BogGroup/Sustainability-Report-2024.pdf

Sustainable Finance Roadmap For Georgia. (2025). – Tbilisi: National Bank of Georgia. Retrieved from https://nbg.gov.ge/fm

Sustainable Finance Taxonomy for Georgia 2022. (2022). – Tbilisi: National Bank of Georgia. Retrieved from https://nbg.gov.ge/fm.pdf

TBC Releases Its Sustainability Report 2024. (2025). – Tbilisi: TBC Bank. Retrieved from https://tbcbankgroup.com/news-media/press-releases/82c8177b-5d87-4a31-8079-7acb970c0a42

Zurabishvili, M. (2026). Modern Financial Markets and Sustainable Finance Instruments. *The European Journal of Humanities and Social Sciences,* – 1. – P. 1–5. doi: DOI:10.29013/EJHSS-26-1-9-13

submitted 02.05.2026;
accepted for publication 16.05.2026;
published 30.06.2026

Contact: teakhorguashvili@gu.edu.ge; n.sesadze@gtu.ge; mzurabishvili@cu.edu.ge

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

DOI:10.29013/ESR-26-5.6-21-27

FISCAL JUSTICE AND TAX GOVERNANCE IN ALBANIA: EVALUATING THE NEW FISCAL PACKAGE FOR FREE PROFESSIONS AND SMALL BUSINESSES

Dr. Mikel Alla [1]

[1] Owner and Certified Accountant. Accounting & Fiscal Expertise Studio, Elbasan, Albania.Lecturer in Accounting, Auditing and Taxation, University of Elbasan "Aleksandër Xhuvani" (UE), Albania. Lecturer in Accounting, Auditing and Taxation University "Aleksandër Moisiu" Durrës (UAMD), Albania

Cite: *Mikel A. (2026). Fiscal Justice and Tax Governance in Albania: Evaluating the New Fiscal Package for Free Professions and Small Businesses. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-21-27

Abstract

The digital transformation of tax administration has intensified debates regarding the relationship between effective tax enforcement, taxpayer rights and institutional legitimacy. Within this context, Albania has proposed a new fiscal package introducing significant amendments to taxpayer classification, administrative sanctions, cash-holding restrictions and tax control mechanisms.

This study evaluates the proposed reforms through the theoretical perspectives of fiscal justice, tax neutrality, proportionality and risk-based tax administration. Adopting a qualitative research design based on legal analysis, comparative assessment and policy evaluation, the paper examines four key dimensions of the reform: the treatment of professional activities, restrictions on business cash holdings, the proportionality of administrative sanctions and the interaction between fiscalization and traditional enforcement mechanisms.

The findings indicate that while the proposed measures pursue legitimate objectives related to compliance enhancement and fiscal oversight, several provisions may generate tensions between enforcement objectives and established principles of effective tax governance. In particular, the proposed classification of professional activities may affect tax neutrality, while cash-holding restrictions and certain administrative sanctions may increase compliance burdens and raise proportionality concerns. Furthermore, the effectiveness of expanded tax controls depends largely on their integration with fiscalization and risk-based compliance management systems.

The study concludes that sustainable tax administration reform requires a balanced approach that combines effective enforcement with fiscal fairness, legal certainty and taxpayer trust. The Albanian case demonstrates that the long-term success of tax reform depends not only on strengthening compliance and reducing informality but also on preserving neutrality, proportionality and administrative legitimacy within an increasingly digitalized fiscal environment.

Keywords: *Fiscal justice; Tax governance; Tax neutrality; Fiscalization; Risk-based compliance; Free professions; Albania*

1. Introduction

The digital transformation of tax administration has significantly altered the manner in which governments monitor economic activity, manage fiscal risk and promote taxpayer compliance. Advances in electronic reporting systems, fiscalization and data analytics have expanded the informational capacity of tax authorities and encouraged a gradual shift toward risk-based compliance management (OECD, 2020; OECD, 2021).

Within this context, tax administration reforms are increasingly evaluated not only through their capacity to enhance revenue collection but also through their consistency with broader principles of fiscal justice, tax neutrality, proportionality and administrative legitimacy (Musgrave, 1959; Stiglitz & Rosengard, 2015).

Albania has followed this international trend through the implementation of fiscalization and a broader modernization of tax administration. More recently, the government has proposed a new fiscal package introducing significant amendments to taxpayer classification, cash-holding restrictions, administrative sanctions and tax control mechanisms. While these measures aim to strengthen compliance and reduce informality, they have also generated debate regarding their implications for free professions, small businesses and taxpayer rights.

Despite growing scholarly interest in fiscalization and digital tax administration, limited research has examined how taxpayer classification, compliance obligations, administrative sanctions and enforcement mechanisms interact within the context of digitally transforming tax systems, particularly in transition economies.

This study addresses that gap by evaluating Albania's proposed fiscal package through the perspectives of fiscal justice, tax neutrality, proportionality and risk-based tax administration. The central research question guiding the analysis is:

To what extent does Albania's proposed fiscal package align with the principles of fiscal justice, tax neutrality, proportionality and modern risk-based tax administration?

The study contributes to the literature by providing an integrated assessment of a contemporary tax reform within a transition economy and by highlighting the importance of aligning digital tax administration, taxpayer rights and enforcement strategies within a coherent framework of effective tax governance.

2. Literature Review

2.1 Fiscal Justice, Tax Neutrality and Professional Taxation

Fiscal justice represents one of the fundamental principles of public finance and serves as a key benchmark for evaluating tax policy reforms. According to Musgrave (1959), a fair tax system should allocate tax burdens in accordance with taxpayers' economic capacity while maintaining institutional legitimacy. In developing and transition economies, tax policy must simultaneously support revenue mobilization, economic competitiveness and administrative feasibility (Tanzi & Zee, 2000).

Closely related to fiscal justice is the principle of tax neutrality. Tax neutrality requires that taxpayers engaged in economically comparable activities should not be subject to substantially different fiscal treatment unless such differentiation is justified by clear policy objectives (Stiglitz & Rosengard, 2015). This issue is particularly relevant for free professions, whose activities combine human capital investment, entrepreneurial risk and market competition. As noted by Bird and Zolt (2014), tax policies affecting highly skilled professionals may influence labor mobility, entrepreneurial incentives and investment decisions.

The principles of fiscal justice and tax neutrality therefore provide an important framework for assessing reforms that introduce differentiated treatment among taxpayer categories.

2.2 Digital Tax Administration and Risk-Based Compliance

The digital transformation of tax administration has significantly altered the relationship between taxpayers and tax authorities. Electronic reporting systems, fiscalization

and data analytics have improved transparency, strengthened compliance monitoring and expanded the informational capacity of tax administrations (OECD, 2021; OECD, 2022).

A central feature of modern tax administration is the adoption of risk-based compliance management. Under this approach, enforcement resources are concentrated on taxpayers presenting the highest probability of non-compliance, thereby improving administrative efficiency and reducing unnecessary interventions for compliant taxpayers (OECD, 2021).

The OECD Tax Administration 3.0 framework further emphasizes that digital technologies should support real-time reporting, automated compliance processes and evidence-based enforcement strategies (OECD, 2020). Consequently, contemporary tax administration increasingly relies on the integration of fiscalization, digital monitoring and risk assessment mechanisms.

Recent OECD research further emphasizes that digital technologies should not only strengthen enforcement capabilities but also reduce compliance burdens, improve taxpayer experience and support more cooperative relationships between taxpayers and tax administrations (OECD, 2024). Consequently, the effectiveness of modern tax administration depends not only on the availability of digital information but also on the capacity of tax authorities to transform such information into risk-based, evidence-driven and taxpayer-oriented compliance strategies.

2.3 Research Gap and Analytical Framework

Although extensive literature exists on fiscal justice, tax neutrality and digital tax administration, these dimensions are frequently examined as separate areas of inquiry. Comparatively limited attention has been devoted to understanding how taxpayer classification, compliance obligations, administrative sanctions and enforcement mechanisms interact within the broader framework of tax governance, particularly in digitally transforming tax systems.

This gap is especially relevant in transition economies such as Albania, where governments simultaneously pursue fiscal modernization, compliance enhancement and institutional reform. The interaction between fiscal justice, taxpayer rights and enforcement strategies remains an important but insufficiently explored aspect of contemporary tax policy and tax administration reform.

Accordingly, this study evaluates the proposed fiscal package through four analytical dimensions: (i) professional activities and tax neutrality; (ii) cash-holding restrictions and compliance costs; (iii) administrative sanctions and proportionality; and (iv) fiscalization and risk-based tax administration. These dimensions establish the analytical framework through which the proposed reform is assessed and provide the basis for examining its consistency with the principles of fiscal justice, tax neutrality, proportionality and modern risk-based tax administration.

3. Methodology

3.1 Research Design

This study adopts a qualitative research design based on legal analysis, comparative assessment and policy evaluation. The approach is appropriate because the proposed fiscal package consists of legislative measures whose economic and administrative effects have not yet been empirically observed. Consequently, the analysis focuses on assessing the consistency of the proposed reforms with established principles of fiscal justice, tax neutrality, proportionality and risk-based tax administration.

3.2 Research Question and Hypotheses

The study is guided by the following research question:

To what extent does Albania's proposed fiscal package align with the principles of fiscal justice, tax neutrality, proportionality and modern risk-based tax administration?

Based on the theoretical framework developed in the literature review, four hypotheses are formulated:

H1: The distinction between professional and non-professional activities may affect tax neutrality.

H2: Restrictions on business cash holdings increase compliance costs for small businesses and self-employed taxpayers.

H3: Increased administrative sanctions raise proportionality concerns.

H4: The expansion of field-based tax controls is not fully aligned with risk-based tax administration principles.

3.3 Data Sources and Analytical Framework

The study relies on primary and secondary sources. Primary sources include Albanian legislation governing taxation, tax procedures and fiscalization. Secondary sources consist of academic literature and OECD publications addressing fiscal justice, professional taxation and digital tax administration.

The proposed fiscal package is evaluated through four analytical dimensions: (i) professional activities and tax neutrality; (ii) cash-holding restrictions and compliance costs; (iii) administrative sanctions and proportionality; and (iv) fiscalization and risk-based tax administration. These dimensions provide the analytical framework for assessing the consistency of the reform with contemporary principles of effective tax governance.

4. Results and Discussion

4.1 Professional Activities and Tax Neutrality

One of the most debated elements of the proposed fiscal package concerns the distinction between professional and non-professional activities. From the perspective of tax neutrality, taxpayers operating under comparable economic conditions should not be subject to substantially different fiscal treatment unless such differentiation is justified by objective and transparent policy considerations.

Independent professionals assume entrepreneurial risk, invest in human capital and compete within market environments similarly to other business operators. Consequently, broadly defined classification criteria may create uncertainty regarding the distinction between genuine self-employment and dependent economic activity. Such uncertainty may result in differentiated treatment among taxpayers performing economically comparable functions and may influence organizational and professional choices.

Beyond fiscal considerations, the classification of professional activities may also influence broader economic behavior. Independent professionals frequently organize their activities through flexible contractual arrangements that reflect market demand, specialization and project-based work. Consequently, classification criteria that are perceived as uncertain may affect business planning, professional autonomy and long-term investment decisions. From a tax governance perspective, legal certainty is essential because taxpayers are more likely to comply voluntarily when regulatory obligations are predictable and transparent.

The analysis provides support for H1, suggesting that the proposed classification framework may affect tax neutrality. To minimize uncertainty and preserve equal treatment, the implementation of the reform should be supported by clear, transparent and objectively verifiable classification criteria.

4.2 Cash-Holding Restrictions and Compliance Costs

The proposed restrictions on business cash holdings seek to improve transparency and reduce opportunities for undeclared transactions. While these objectives are consistent with international efforts to strengthen fiscal governance and combat informality, their practical implications may vary across taxpayer categories.

For small businesses and self-employed taxpayers, mandatory cash-deposit requirements may generate additional compliance costs associated with banking services, liquidity management and administrative procedures. Although such obligations may be relatively manageable for larger enterprises, they are likely to impose proportionally greater burdens on smaller taxpayers with more limited financial and administrative resources.

The economic impact of compliance obligations should also be considered from an administrative efficiency perspective. Compliance costs represent an indirect regulatory burden that may affect business performance even when no additional tax liability arises. International experience suggests that tax reforms are generally more effective when compliance obligations remain proportionate to taxpayer size and operational capacity. Excessive procedural requirements may divert financial and managerial resources away from productive activities and reduce the overall effectiveness of the intended policy objectives.

The analysis supports H2 and indicates that the proposed measures may increase compliance burdens, particularly for small

businesses and self-employed professionals. Consequently, policymakers should carefully balance transparency objectives with the need to maintain proportionate compliance obligations and administrative efficiency.

4.3 Administrative Sanctions and Proportionality

The reform also proposes stronger administrative sanctions for tax-related violations. Although effective enforcement requires credible deterrence mechanisms, sanctions should remain proportionate to both the severity of violations and the economic capacity of taxpayers.

Fixed monetary penalties may produce unequal effects across taxpayers of different sizes. While large businesses may absorb such penalties with relatively limited consequences, smaller taxpayers may face substantially greater financial impacts. As a result, identical sanctions may generate different practical outcomes depending on the economic circumstances of the taxpayer.

The relationship between deterrence and proportionality remains a central challenge in contemporary tax administration. While stronger sanctions may improve compliance in certain circumstances, their effectiveness depends largely on taxpayer perceptions of fairness and legitimacy. Excessively punitive measures may increase disputes and weaken cooperative relationships between taxpayers and tax authorities. Consequently, modern enforcement strategies increasingly seek to balance deterrence with procedural fairness, thereby strengthening both compliance outcomes and institutional trust.

The analysis provides support for H3 and suggests that a more differentiated sanctioning framework may better align enforcement objectives with principles of proportionality, fairness and legal certainty. Such an approach may contribute to both the effectiveness and legitimacy of tax administration.

4.4 Fiscalization and Risk-Based Tax Administration

The final issue concerns the relationship between fiscalization and traditional tax controls. Fiscalization has significantly expanded the informational capacity of tax administration through real-time reporting and digital monitoring systems.

Modern tax administrations increasingly allocate enforcement resources according to risk indicators and data-driven compliance strategies. Within this framework, field-based controls remain important but are expected to complement, rather than substitute for, digital risk assessment mechanisms.

The increasing availability of digital information creates new opportunities for evidence-based compliance management. Real-time reporting systems allow tax authorities to identify anomalies, prioritize high-risk cases and allocate enforcement resources more efficiently. In this environment, the strategic value of fiscalization extends beyond transaction monitoring and increasingly supports predictive and risk-oriented approaches to tax administration.

Table 1. *Assessment of Research Hypotheses*

Hypothesis	Assessment	Main Finding
H1	Supported	The classification of professional activities may affect tax neutrality.
H2	Supported	Cash-holding restrictions are likely to increase compliance costs for small businesses and self-employed taxpayers.
H3	Supported	Certain administrative sanctions may raise proportionality concerns.
H4	Partially Supported	Traditional controls are most effective when integrated with fiscalization and risk-based administration.

The analysis provides partial support for H4. Expanded control activities may contribute to compliance objectives when integrated with fiscalization and risk-based compliance systems. However, excessive reliance on traditional controls may reduce administrative efficiency, increase compliance burdens for low-risk taxpayers and

limit the potential benefits of digital tax administration.

Consequently, the effectiveness of contemporary enforcement strategies depends on the successful integration of fiscalization, risk assessment methodologies and evidence-based compliance management.

5. Conclusions and Policy Implications

This study evaluated Albania's proposed fiscal package through the analytical perspectives of fiscal justice, tax neutrality, proportionality and risk-based tax administration. The objective was to assess whether the proposed reforms are consistent with contemporary principles of effective tax governance and modern tax administration.

The analysis indicates that the proposed measures pursue legitimate objectives related to strengthening compliance, reducing informality and improving fiscal oversight. However, the findings also suggest that several provisions may create tensions between enforcement objectives and broader principles of fiscal fairness, neutrality and proportionality. In particular, the proposed classification of professional activities may affect tax neutrality, while cash-holding restrictions and certain administrative sanctions may increase compliance burdens and raise concerns regarding proportionality. Furthermore, the effectiveness of expanded tax controls appears to depend largely on their integration with fiscalization and risk-based compliance systems.

From a theoretical perspective, the study contributes to the growing literature on tax governance by demonstrating that the effectiveness of tax administration reform depends not only on enforcement capacity but also on the alignment between fiscal justice, tax neutrality, proportionality and administrative legitimacy. The findings suggest that sustainable compliance is more likely to emerge when digital tax administration and enforcement strategies operate within a framework that preserves legal certainty, fairness and taxpayer trust.

The Albanian case reflects a broader challenge faced by many transition economies. As tax administrations become increasingly digitalized, the focus of reform should gradually shift from information collection toward information utilization. Fiscalization, real-time reporting and digital monitoring systems provide substantial amounts of information; however, their effectiveness ultimately depends on the capacity of tax authorities to transform information into objective, risk-based and evidence-driven compliance strategies.

The study generates several policy implications. First, taxpayer classification criteria should be based on clear, transparent and objectively verifiable standards in order to preserve neutrality and reduce legal uncertainty. Second, compliance obligations and administrative sanctions should be calibrated according to taxpayer size and economic capacity to ensure proportionality and fairness. Third, future reforms should prioritize the integration of fiscalization, digital monitoring and risk-based compliance management, thereby reducing reliance on broad field-based controls and improving administrative efficiency.

In conclusion, the long-term success of tax administration reform depends not only on strengthening enforcement mechanisms but also on preserving the institutional principles that support voluntary compliance and taxpayer confidence. Reforms that successfully balance enforcement effectiveness with fiscal justice, neutrality and proportionality are more likely to achieve sustainable compliance, institutional legitimacy and effective tax governance.

References

Bird, R. M., & Zolt, E. M. (2014). *Redistribution via taxation: The limited role of the personal income tax in developing countries. Annals of Economics and Finance,* – 15(2). – P. 625–683.

Musgrave, R. A. (1959). *The theory of public finance: A study in public economy*. McGraw-Hill.

OECD. (2020). *Tax Administration 3.0: The Digital Transformation of Tax Administration*. OECD Publishing.

OECD. (2021). *Tax administration 2021: Comparative information on OECD and other advanced and emerging economies*. OECD Publishing.

OECD. (2022). *Tax administration 2022: Comparative information on OECD and other advanced and emerging economies*. OECD Publishing.
OECD. (2024). *Tax policy reforms 2024: OECD and selected partner economies*. OECD Publishing.
Stiglitz, J. E., & Rosengard, J. K. (2015). *Economics of the public sector* (4th ed.). W. W. Norton & Company.
Tanzi, V., & Zee, H. H. (2000). *Tax policy for emerging markets: Developing countries*. IMF Working Paper WP/00/35. International Monetary Fund.
Republic of Albania. (1998). *Constitution of the Republic of Albania*, as amended.
Republic of Albania. (2008). *Law No. 9901, dated 14 April 2008, On Entrepreneurs and Commercial Companies*, as amended.
Republic of Albania. (2008). *Law No. 9920, dated 19 May 2008, On Tax Procedures in the Republic of Albania*, as amended.
Republic of Albania. (2019). *Law No. 87/2019, On the Invoice and Turnover Monitoring System*.
Republic of Albania. (2023). *Law No. 29/2023, On Income Tax*.

submitted 05.06.2026;
accepted for publication 19.06.2026;
published 30.06.2026

Contact: kontabelfiskale@gmail.com

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 3. Geography

DOI:10.29013/ESR-26-5.6-28-31

GEOGRAPHICAL ANALYSIS OF IRRIGATION EROSION PROCESSES IN THE IRRIGATED AREAS OF THE KASHKADARYA REGION

Poyanov Javlonbek Shodmon ogli [1], ***Yusupov Shokhboz Doniyor ogli*** [1]

[1] Karshi State Technical University, Karshi, Uzbekistan

Cite: *Poyanov J.Sh., Yusupov Sh.D. (2026). Geographical analysis of Irrigation erosion processes in the Irrigated areas of the Kashkadarya Region. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-28-31

Abstract

This article provides a detailed analysis of the extent of irrigation-induced erosion in the irrigated lands of the country, with particular emphasis on the irrigated areas of the Kashkadarya region. The negative impacts of this erosion on irrigated lands are discussed, and a number of recommendations are proposed as potential solutions to mitigate its adverse effects.

Keywords*: irrigation erosion, irrigation-induced erosion, soil erosion, Kashkadarya Basin*

Erosion occurring in irrigated lands under the influence of natural and anthropogenic factors is referred to as irrigation erosion. Irrigation erosion is widespread in foothill areas, sloping plains, and hilly terrains, particularly within the irrigated zones of the gray soil regions.

Irrigation erosion leads to a sharp decline in soil fertility and, eventually, to the complete degradation of the soil. Soils affected by this type of erosion are characterized by a reduced thickness of the soil profile, a lighter texture in the upper layer, lower contents of organic matter and mobile compounds, and higher pH values. In such soils, biological activity decreases, and surface crust formation is commonly observed.

In Uzbekistan, the area of croplands affected by irrigation erosion amounted to 798 thousand hectares (National Action Program to Combat Desertification in the Republic of Uzbekistan, p. 63–66). The largest affected areas were observed in the foothill and hilly zones of the Tashkent, Samarkand, Kashkadarya, Surkhandarya, Andijan, and Namangan regions, primarily on light-colored, typical, and in some cases dark gray soils (Maksudov, H.M., & Gafurova, L.A., 2012, p. 216–217).

As can be seen from the data in Table 1, the regions of Uzbekistan most affected by irrigation erosion are predominantly mountainous areas. This is explained by the fact that the leading factors in the development of water erosion are, undoubtedly, the degree of slope in the relief combined with the intensity of precipitation. In particular, when comparing the regions most affected by erosion of irrigated lands, Syrdarya accounts for

57.1%, Samarkand for 50%, and Tashkent for 24.5%, making them the leading regions in terms of irrigation erosion (Table 1).

Table 1. *Area of agricultural lands affected by irrigation erosion, in thousand hectares (1999) (National Action Program to Combat Desertification in the Republic of Uzbekistan, p. 63–66)*

Administrative divisions	Total agricultural land, thousand ha	Irrigation erosion		
		Not observed	Observed	Share in percentage
Republic of Karakalpakstan	504	396	108	21,4
Andijan	276	255	21	7,6
Bukhara	275	269	6	2,1
Jizzakh	289	240	49	16,95
Kashkadarya	500	402	98	19,6
Navoi	115	114	1	0,86
Namangan	276	215	61	22,1
Samarkand	374	187	187	50
Syrdarya	327	140	187	57,1
Tashkent	389	292	97	24,9
Fergana	349	329	20	5,7
Khorezm	274	274	–	–
Across the Republic	4243	3445	798	18,8

In the Kashkadarya region, nearly one-fifth of irrigated lands – specifically 19.6% or about 98 thousand hectares – were affected by irrigation erosion. At the national level, this indicator stood at 18.8%, meaning that the Kashkadarya region corresponded to the national average. However, in several regions of the country, the figures were significantly lower than the average. For example, in Bukhara it was 2.1%, in Navoi 0.86%, and in Fergana 5.7%, while in Khorezm irrigation erosion was entirely absent, which is noteworthy.

It is evident that the processes of irrigation erosion in the irrigated lands of Uzbekistan have undergone a number of changes. In particular, the total area affected by this erosion across the country amounted to 682 thousand hectares in 2009, which is almost 100 thousand hectares less compared to ten years earlier. However, among the internal regions of the republic, the most significant changes were observed in Kashkadarya (159.7 thousand ha), Tashkent (138.6 thousand ha), and Samarkand (121.7 thousand ha). Together, these three regions account for 61.5% of the total area affected by irrigation erosion in the country (Figure 1).

Erosion occurring in irrigated lands under the influence of natural and anthropogenic factors is referred to as irrigation erosion. In the Kashkadarya region, irrigation erosion is mainly distributed across foothill sloping plains and hilly areas (within the irrigated lands of the gray soil zone). In 2009, soils affected by irrigation erosion in the region covered nearly 159.7 thousand hectares, accounting for about 31% of all irrigated lands. Analysis of the available data indicates that the expansion of irrigated areas is accompanied by an increase in the extent of land affected by irrigation erosion (Figure 1).

Taking into account that examining this type of erosion at the district level within the Kashkadarya region may enhance the practical significance of the study, the state of this negative natural–anthropogenic process was analyzed for the year 2021 (Figure 2).

Figure 1. *Area of lands affected by irrigation erosion, in thousand hectares (2009)*

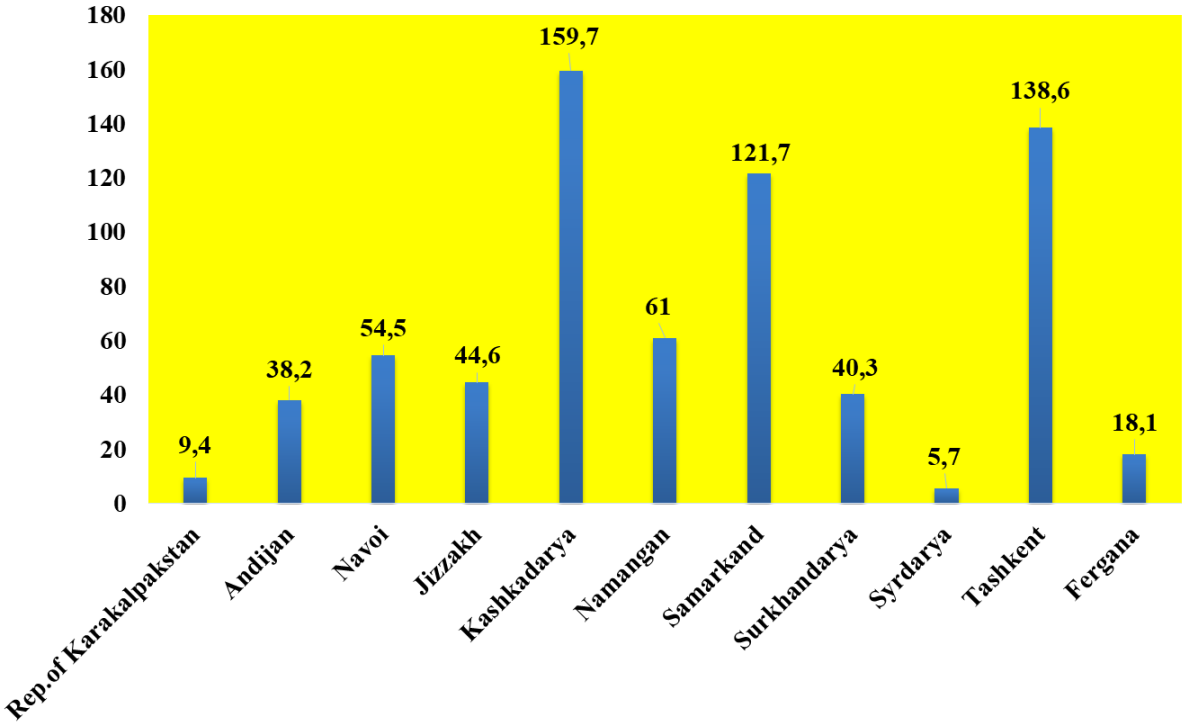
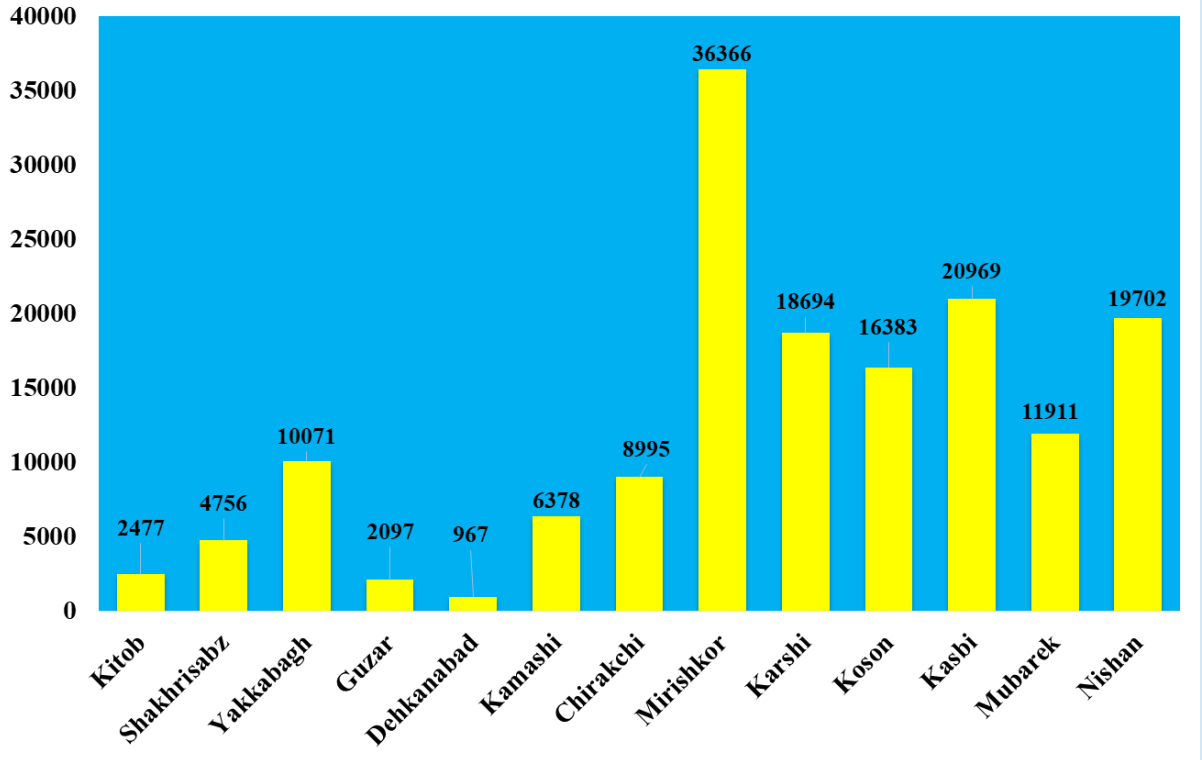


Figure 2. *Areas affected by irrigation erosion in the region, in hectares (2021)*



The data in the table were compiled by the author using information provided by the Regional Cadastral Chamber.

In the region, the total area affected by irrigation erosion amounted to 159.7 thousand hectares; however, this indicator varies significantly across districts. The largest areas

subject to irrigation erosion were observed in Mirishkor (36.3 thousand ha), Kasbi (20.9 thousand ha), and Karshi (18.6 thousand ha) districts. Together, these three districts accounted for 47.5% of all lands affected by irrigation erosion in the region.

One of the main reasons for the intensification of irrigation erosion in the irrigated lands of the oasis is the low resistance of gray soils to washout. According to A. Rasulov (1976), the total area of gray soils in the Kashkadarya Basin amounts to 2,068 thousand hectares, or 65.3% of the total territory. Of this, 917 thousand hectares are typical gray soils and 282 thousand hectares are dark gray soils. In addition, 55 thousand hectares of meadow-gray and meadow saline soils are distributed within the basin (Rasulov, A. M., 1974). The widespread occurrence of these soil types in Kashkadarya undoubtedly plays a significant role in the development of irrigation erosion.

The distribution and intensity of irrigation erosion depend not only on the slope gradient, exposure, and morphology of the terrain but are also largely influenced by irrigation techniques. Indeed, one of the primary causes of the development of irrigation erosion is the inherent susceptibility of soils to washout.

In addition, chemical reclamation, the establishment of shelterbelts, the cultivation of protective crops, and the application of crop rotation are proven measures in combating soil erosion.

References

Maksudov, H. M., & Gafurova, L. A. (2012). *Erosion studies*. Tashkent: State Scientific Publishing House “National Encyclopedia of Uzbekistan”. – 390 p. (in Uzbek)

National Action Program to Combat Desertification in the Republic of Uzbekistan. (1999). Tashkent. – 131 p. (in Russian)

Rasulov, A. M. (1974). *Soils of the Karshi Steppe, ways of their development and fertility improvement*. – Tashkent: Fan. – 248 p. (in Russian)

National Atlas of Uzbekistan, Vol. 1. (2020). – Tashkent. – 275 p. [in Uzbek]

submitted 14.06.2026;
accepted for publication 28.06.2026;
published 30.06.2026

Contact: poyonovjavlon309@gmail.com; yusupovshoxboz494@gmail.com

European Science Review 2026,
No 5–6
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 4. Medicine

DOI:10.29013/ESR-26-5.6-32-39

THE ROLE OF THE MAXILLOFACIAL ANATOMICAL COMPLEX IN THE PATHOGENESIS OF DENTAL IMPLANT COMPLICATIONS

Konstantine Mardaleishvili [1]***, Tamar Baramidze*** [2]

[1] Head of Oncology Research Medical Center in Tbilisi. PhD in Medical Sciences, professor

[2] Maxillofacial Surgeon in Oncology Research Medical Center in Tbilisi,
PhD in medical sciences, Professor in the Head and Neck Oncology,
Department in BAU International University Batumi

Cite: *Mardaleishvili K., Baramidze T. (2026). The Role of the Maxillofacial Anatomical Complex in the Pathogenesis of Dental Implant Complications. European Science Review 2026, No 5–6.* https://doi.org/10.29013/ESR-26-5.6-32-39

Abstract

Dental implantology is a surgically precise discipline in which the success of treatment depends not only on implant design and operative technique, but also on the clinician's detailed understanding of the maxillofacial anatomical complex. The maxilla and mandible contain compactly arranged neurovascular, lymphatic, osseous, sinus, and fascial structures. Because these structures communicate through arterial, venous, lymphatic, and neural pathways, even a limited peri-implant inflammatory focus may progress to abscess formation, diffuse phlegmon, venous thrombophlebitis, neurosensory impairment, or life-threatening airway and intracranial complications. This article reviews the anatomical basis of dental implant complications, emphasizing the topographic differences between the maxilla and mandible, the role of vascular and lymphatic pathways in infection dissemination, and the clinical relevance of trigeminal nerve branches. Particular attention is given to sinus membrane perforation, nasopalatine and infraorbital-region injuries, inferior alveolar and mental nerve trauma, lingual cortical perforation, sublingual or submental hematoma, and postoperative infectious spread. The article also highlights the preventive value of cone-beam computed tomography (CBCT), preservation of safety margins, atraumatic surgical technique, irrigation to prevent thermal osteonecrosis, strict asepsis, and timely management of early infectious signs.

Keywords: *dental implantology; maxillofacial anatomy; inferior alveolar nerve; maxillary sinus; peri-implantitis; phlegmon; venous thrombosis; lymphatic drainage; CBCT*

1. Introduction

Dental implant placement is not merely a mechanical or prosthetic procedure. It is an intervention performed within one of the most anatomically dense regions of the human body, where millimeters may determine surgical safety, functional recovery, and patient quality of life. The head and neck region contains the eye, ear, nose, oral cavity, maxilla, mandible, hard and soft palate, salivary glands, major cervical vessels, cranial nerves, lymphatic channels, and deep fascial spaces in close proximity. This compact arrangement explains why procedures in the maxillofacial region require a high level of anatomical precision.

Figure 1. *Risk-oriented anatomical comparison of the maxilla and mandible in implant planning*

Maxilla	***Mandible***
• *Maxillary sinus and Schneiderian membrane*	• *Inferior alveolar canal*
• *Nasopalatine / incisive canal*	• *Mental foramen and anterior loop*
• *Thin buccal cortical plate*	• *Lingual cortical plate and floor-of-mouth vessels*
• *Infraorbital and pterygopalatine region*	• *Dense cortical bone and heat generation*

The anatomical and topographic complexity of the upper and lower jaws forms the background against which local and generalized complications develop. These include infectious complications, vascular events, and neurogenic disorders. Contemporary implant treatment therefore requires a preventive anatomical approach: identification of risk zones before surgery, careful selection of implant dimensions and angulation, preservation of neurovascular safety margins, and early recognition of postoperative complications.

2. Anatomical Basis of Implant-Related Complications

The pathogenesis of complications after dental implant placement is best understood as the interaction of four anatomical systems: bone architecture, fascial spaces, vascular communications, and neural pathways. The maxilla is characterized by relatively porous cancellous bone, a thin cortical plate, proximity to the maxillary sinus, and extensive venous and arterial communications. The mandible contains denser cortical bone and critical neurovascular structures, particularly the inferior alveolar canal, mental foramen, lingual cortical plate, and vascular structures of the floor of the mouth.

Because oral tissues communicate with deep fascial spaces and venous plexuses, infection that begins around an implant may remain localized as an abscess, spread diffusely as phlegmon, or enter the venous system and progress to septic thrombophlebitis. Similarly, traumatic or thermal injury during osteotomy may damage bone, nerve, or vascular structures and create the conditions for postoperative pain, paresthesia, hematoma, or implant failure.

Figure 2. *Principal pathways by which a peri-implant infectious focus may progress to abscess, phlegmon, venous thrombophlebitis, or life-threatening complications*

Major anatomical pathways of infection after dental implant placement

Peri-implant bacterial focus	↗	*Localized abscess (capsulated pus)*	→	*Sinus/orbital involvement*
	→	Deep fascial spread (phlegmon)	→	Ludwig angina / airway risk
	↘	Venous route (thrombophlebitis)	→	Cavernous sinus thrombosis

3. Maxillary Anatomical Risk Zones

The maxilla presents a distinct surgical risk profile because of its cancellous architecture, thin buccal cortical plate, and close relationship to the maxillary sinus, nasal floor, nasopalatine canal, and infraorbital region. These characteristics are clinically important in both anterior and posterior implant sites.

3.1. Maxillary sinus and Schneiderian membrane

In the posterior maxilla, the maxillary sinus may lie close to the alveolar ridge, especially after tooth loss and vertical bone resorption. Implant preparation or insertion may perforate the sinus floor or Schneiderian membrane. Depending on the size of the perforation and the presence of contamination or graft material displacement, consequences may include sinusitis, oro-antral communication, implant migration into the sinus, chronic inflammation, or failure of osseointegration. Prevention requires CBCT-based evaluation of residual bone height, sinus-floor morphology, septa, mucosal thickening, and the need for sinus floor elevation before implant placement.

3.2. Nasopalatine, incisive, and anterior maxillary canals

In the anterior maxilla, implant placement near the central incisors may injure the nasopalatine canal or incisive neurovascular bundle. Trauma in this area may cause pain, altered palatal sensation, localized bleeding, or infection. Radiographic localization of the canal and appropriate implant positioning are necessary to avoid contact with neurovascular structures.

3.3. Thin buccal cortical plate and esthetic-region exposure

The facial cortical plate of the anterior maxilla is often extremely thin and may be less than 1 mm in certain sites. A thin buccal plate increases the risk of dehiscence, fenestration, soft-tissue recession, implant thread exposure, and esthetic failure. Preventive strategies include selecting an implant of appropriate diameter, positioning the implant slightly palatally when indicated, maintaining adequate facial bone thickness, and using guided bone regeneration when the ridge is deficient.

3.4. Infraorbital region

Although uncommon, trauma to the infraorbital neurovascular region may occur during procedures near the canine and premolar region or during extensive surgery in the anterior maxilla. Such injury may produce infraorbital pain, paresthesia, or hematoma. Preoperative imaging and controlled osteotomy depth are essential where anatomic variation reduces the safety zone.

Figure 3. *Maxillary sinus and posterior maxillary neurovascular anatomy relevant to sinus-floor elevation and posterior implant placement*

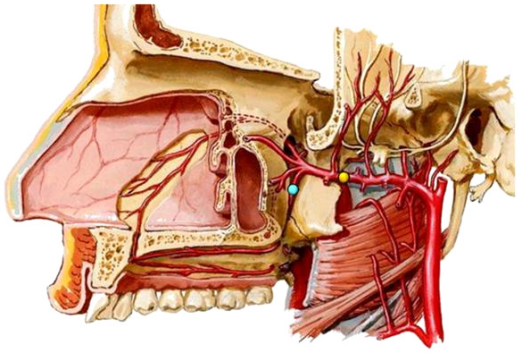
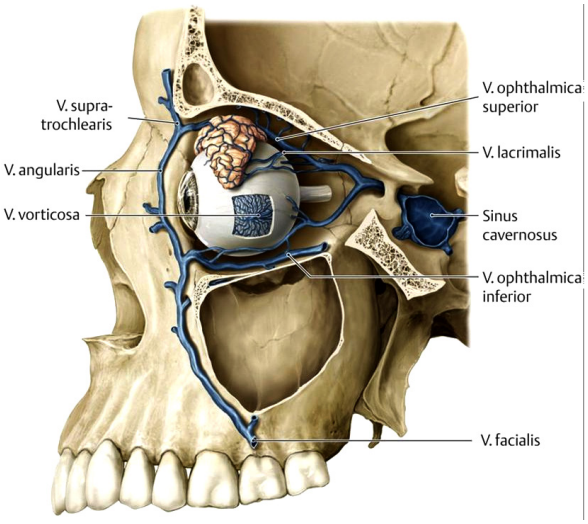


Figure 4. *Venous communication between the facial, angular, ophthalmic, and cavernous sinus systems*



4. Mandibular Anatomical Risk Zones

The mandible differs from the maxilla by its denser cortical structure and by the presence of major neurovascular structures within or immediately adjacent to the implant field. Dense bone may increase heat generation during drilling, and inadequate irrigation can contribute to thermal osteonecrosis. However, the most clinically important mandibular risks are neural and vascular.

4.1. Inferior alveolar nerve injury

The inferior alveolar nerve is one of the most serious structures at risk during implant placement in the premolar and molar regions. Compression, direct penetration, thermal injury, or postoperative inflammatory edema may cause paresthesia, dysesthesia, anesthesia, or chronic neuropathic pain affecting the lower lip, chin, or teeth. Prevention requires CBCT-based mapping of the mandibular canal, appropriate implant length selection, depth control, and maintenance of a safety distance from the canal.

4.2. Mental foramen and anterior loop

The mental nerve emerges through the mental foramen, commonly near the second premolar region, and may present an anterior loop. Implant surgery in this region can cause pain, sensory disturbance, or hematoma if the foramen or loop is not identified. Three-dimensional imaging is particularly valuable because panoramic radiographs may not reliably define the canal trajectory or anterior loop in all patients.

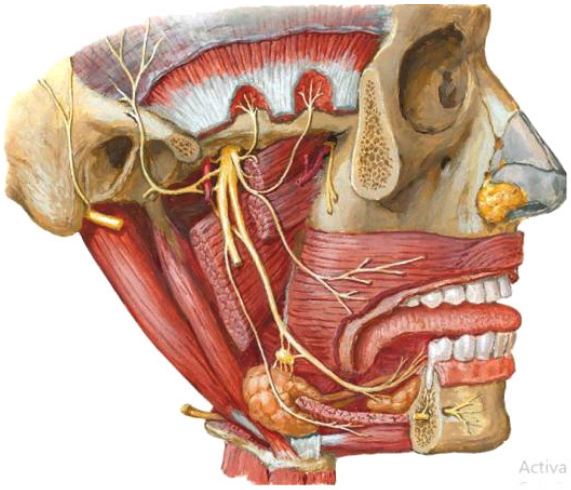
4.3. Lingual cortical perforation and floor-of-mouth hematoma

Perforation of the lingual cortical plate, especially in the anterior mandible or molar region, may injure sublingual, submental, or submandibular vessels. Bleeding into the sublingual and submental spaces can rapidly elevate the floor of the mouth and compromise the airway. This rare but potentially fatal complication requires immediate recognition, airway assessment, hemostasis, and urgent surgical management if expansion occurs.

4.4. Thermal osteonecrosis

Mandibular cortical bone is relatively dense, making it more susceptible to heat accumulation during osteotomy. Excessive drill speed, worn drills, inadequate irrigation, or prolonged drilling can cause thermal injury and osteonecrosis, impairing osseointegration. Prevention includes sharp sequential drills, copious irrigation, intermittent drilling, appropriate speed and torque, and avoidance of excessive pressure.

Figure 5. *Trigeminal nerve branches and mandibular/maxillary neural pathways relevant to implant-related neurosensory complications*



5. Infectious Complications: Abscess, Phlegmon, and Venous Thrombophlebitis

General infectious complications associated with implant surgery include abscess, phlegmon, and venous thrombophlebitis. These entities differ in morphology and severity but share an anatomical basis: oral bacteria may spread through cancellous bone, periosteal planes, fascial spaces, lymphatic channels, and valveless venous communications.

5.1. Abscess formation

An abscess is a localized purulent focus formed when the host response partially confines infection. In implantology, abscess formation may result from peri-implantitis, intraoperative contamination, inadequate debridement, foreign-body reaction, or disruption of anatomical barriers. In the maxilla, infection may spread to the buccal space, infraorbital region, or palatal tissues. In the mandible, abscesses may involve the buccal, sublingual, submental, or submandibular spaces depending on the site of origin and muscle attachments.

5.2. Phlegmon and deep fascial-space spread

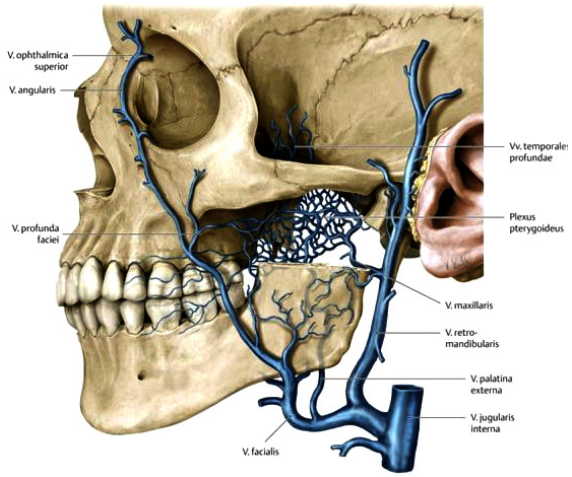
Phlegmon is a diffuse purulent inflammation not limited by a capsule. Once the periosteal and fascial barriers are breached, infection may spread quickly through communicating spaces.

Maxillary infection may extend toward the infraorbital region, buccal space, pterygopalatine fossa, orbit, or cavernous sinus through vascular channels. Mandibular molar infections may spread to the submandibular, sublingual, or parapharyngeal spaces. When bilateral floor-of-mouth spaces become involved, Ludwig angina may occur, with swelling, tongue elevation, dysphagia, and airway compromise.

5.3. Venous thrombophlebitis and cavernous sinus risk

The venous system of the face is clinically important because facial, angular, ophthalmic, pterygoid, and cavernous sinus communications may allow retrograde spread of infection. Septic thrombophlebitis may develop when bacteria and inflammatory thrombi propagate within valveless veins. In severe cases, this route may lead to orbital cellulitis or cavernous sinus thrombosis, which may present with fever, periorbital edema, pain, cranial nerve signs, diplopia, and systemic sepsis.

Figure 6. *Pterygoid venous plexus and facial venous communications, highlighting a potential pathway for odontogenic or peri-implant infection spread*



6. Arterial and Venous Anatomy of the Maxillofacial Region

The blood supply of the head and neck begins from the aortic arch, from which the brachiocephalic trunk, left common carotid artery, and left subclavian artery arise. The asymmetry between the right and left sides is due to the right common carotid and right subclavian arteries arising through the brachiocephalic trunk, whereas the left common carotid and left subclavian arteries arise independently from the aortic arch. At the level of the superior border of the thyroid cartilage, the common carotid artery divides into the internal and external carotid arteries.

Figure 7. *Aortic arch, common carotid, subclavian, and laryngeal neurovascular relationships in the lower neck*

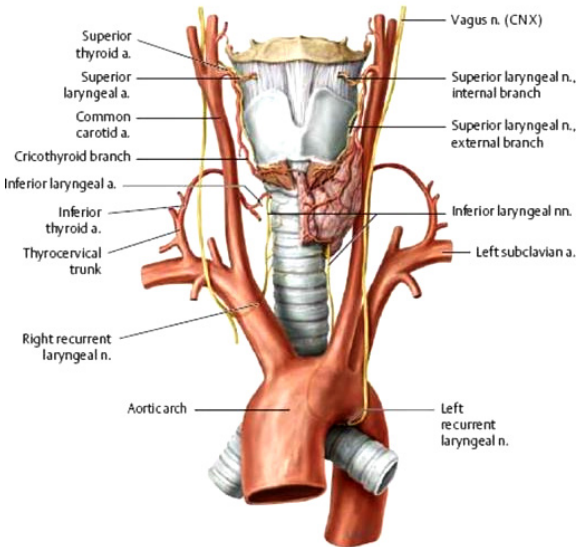
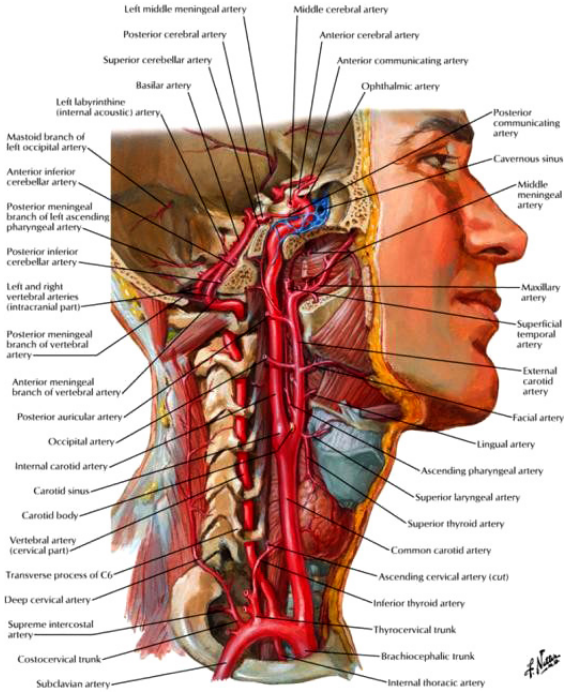


Figure 8. *Arterial supply of the head and neck, including the external carotid system and maxillary artery*



The internal carotid artery ascends toward the skull base and gives rise to the oph-

thalmic artery within the orbit. The terminal dorsal nasal branch of the ophthalmic artery anastomoses with the angular artery, a terminal branch of the facial artery from the external carotid system. This connection is clinically relevant because it links intraorbital, facial, and external carotid circulation.

6.1. Maxillary artery

The maxillary artery is one of the largest and most topographically complex terminal branches of the external carotid artery. It supplies the maxilla, mandible, nasal cavity, palate, pterygopalatine region, deep facial spaces, masticatory muscles, and parts of the temporomandibular region. It is traditionally divided into mandibular, pterygoid, and pterygopalatine segments.

The mandibular segment passes through the infratemporal fossa and gives off branches such as the deep auricular, middle meningeal, and inferior alveolar arteries. The inferior alveolar artery enters the mandibular canal with the inferior alveolar nerve and supplies the mandibular teeth before continuing as the mental artery. Injury to this branch during implant surgery may cause intraosseous bleeding, hematoma, or compressive neuropathy.

The pterygoid segment supplies the masseter, temporalis, buccinator, and pterygoid muscles through branches such as the masseteric, deep temporal, and buccal arteries. Because these branches are close to the pterygoid venous plexus, injury or infection in this region may contribute to hematoma or facilitate deep-space inflammatory spread.

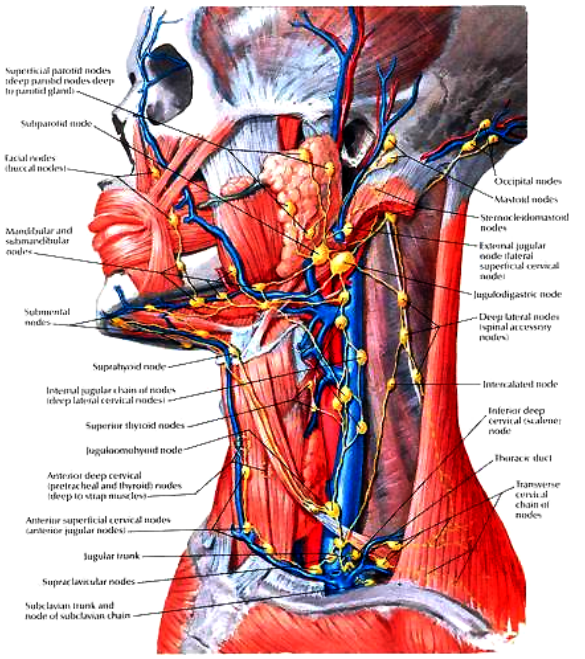
The pterygopalatine segment is especially important in maxillary implantology. Its branches include the infraorbital artery, posterior superior alveolar arteries, descending palatine artery, and sphenopalatine artery. These vessels form an anastomotic network that may connect the maxillary sinus, palate, nasal cavity, orbit, and pharyngeal region. Knowledge of these branches is essential when performing posterior maxillary implants, sinus-floor elevation, or procedures near the pterygopalatine fossa.

7. Lymphatic System as a Defensive and Diagnostic Pathway

The lymphatic system of the maxillofacial region is closely associated with the vascular system and serves as an early biological barrier against infection. Topographically, lymphatic drainage can be grouped into facial lymph nodes, submandibular and submental lymph nodes, and superficial and deep cervical lymph nodes. Lymph from the face ultimately drains toward the jugular lymphatic trunk through deep cervical nodes.

In the upper lip, lower lip, and cheek, superficial and submucosal lymphatic channels converge near the vestibular folds and then follow the branches of the facial vessels. The maxillary lymphatic vessels drain anterior, lateral, and posterior regions through bony channels toward submandibular nodes and, in deeper infections, toward infraorbital and deep cervical pathways. Mandibular lymphatic vessels communicate through the mandibular canal and smaller bony channels toward the floor of the mouth, submental, submandibular, and deep cervical nodes.

Figure 9. *Lymphatic drainage of the face and neck, including submental, submandibular, parotid, and deep cervical nodes*



After implant placement, early lymphatic activation may present as regional lymphadenitis, usually with painful enlargement of submandibular, submental, or cervical nodes. In abscess formation, this reaction may be limited to one or several regional nodes. In phlegmon, lymphatic drainage may become blocked, resulting in multilocular

lymphadenopathy or suppurative lymphadenitis. In septic thrombophlebitis, deep cervical lymph nodes may participate in systemic inflammatory response. Clinically, lymphatic swelling may therefore be an early sign that infection is no longer limited to the peri-implant region.

8. Trigeminal Nerve and Neurogenic Complications

The trigeminal nerve is the principal sensory nerve of the maxillofacial region. Its three major divisions – ophthalmic (V1), maxillary (V2), and mandibular (V3) – form a dense anatomical network that is closely related to vessels, bone, dental roots, sinus structures, and fascial spaces. Implant-related trauma or infection may therefore produce nociceptive, neuropathic, or mixed pain mechanisms.

The maxillary division and its infraorbital, posterior superior alveolar, middle superior alveolar, and anterior superior alveolar branches are relevant to maxillary implant procedures. Injury or inflammatory irritation may produce neuralgic pain, altered sensation, or referred symptoms toward the midface and orbital region. The mandibular division gives rise to the inferior alveolar, mental, lingual, buccal, and auriculotemporal nerves. Inferior alveolar and mental nerve injuries are particularly important because they may cause sensory changes in the lower lip and chin, while lingual nerve irritation may affect tongue sensation and taste-related complaints.

Neurogenic complications may arise from direct drilling trauma, implant contact with the canal, compression by hematoma, inflammatory edema, thermal injury, or postoperative infection.

Management depends on the mechanism and severity but should begin with early diagnosis, radiographic assessment of implant position, neurosensory testing, control of inflammation and infection, and urgent surgical intervention when the implant violates the nerve canal or compresses a neurovascular bundle.

9. Prevention and Clinical Planning

Prevention of complications begins before surgery. CBCT is central to modern implant planning because it allows three-dimensional evaluation of bone height, ridge width, sinus anatomy, mandibular canal position, mental foramen, lingual concavity, cortical thickness, and local anatomical variants. Imaging should be interpreted together with clinical examination, prosthetic requirements, systemic risk assessment, and the anticipated need for augmentation.

A preventive surgical protocol includes: strict asepsis; atraumatic flap elevation; careful osteotomy angulation; preservation of safety margins around canals, foramina, and sinus structures; copious irrigation; use of sharp drills; avoidance of excessive pressure; selection of implant dimensions appropriate to the bone envelope; and early postoperative follow-up. In the presence of pain out of proportion, rapidly expanding swelling, floor-of-mouth elevation, fever, ocular symptoms, diplopia, progressive paresthesia, or signs of systemic toxicity, urgent reassessment is required.

Table 1. *Anatomical mechanisms and prevention of selected dental implant complications*

Anatomical area	Main complication	Pathogenetic mechanism	Preventive focus
Posterior maxilla	Sinus perforation / sinusitis	Implant or drill violates sinus floor or Schneiderian membrane	CBCT; sinus-floor assessment; sinus lift when indicated
Anterior maxilla	Nasopalatine canal trauma	Injury to incisive neurovascular bundle	Identify canal; adjust implant diameter/position
Anterior esthetic zone	Buccal dehiscence / exposure	Thin facial cortical plate and inadequate bone envelope	Palatal positioning; grafting; preserve facial bone
Posterior mandible	Inferior alveolar nerve injury	Canal contact, compression, thermal trauma, edema	CBCT canal mapping; depth control; safety margin

Anatomical area	Main complication	Pathogenetic mechanism	Preventive focus
Premolar mandible	Mental nerve injury	Foramen or anterior loop trauma	3D localization; avoid foraminal zone
Lingual mandible	Sublingual/submental hematoma	Lingual cortical perforation and vascular injury	Assess lingual concavity; controlled osteotomy; airway vigilance

11. Conclusion

The maxillofacial anatomical complex determines both the safety and the biological outcome of dental implant treatment. The maxilla, with its sinus cavity, thin buccal plate, and rich vascular communications, is particularly vulnerable to sinus, orbital, and venous-route complications. The mandible, with its dense cortical bone, inferior alveolar canal, mental foramen, lingual cortex, and floor-of-mouth vessels, is particularly vulnerable to neurovascular injury, thermal osteonecrosis, and airway-threatening hematoma. Infectious complications such as abscess, phlegmon, and venous thrombophlebitis are not random events; they follow predictable anatomical pathways through fascial spaces, lymphatic channels, and valveless venous networks.

A detailed topographic understanding of arteries, veins, lymphatic drainage, trigeminal nerve branches, sinus anatomy, and jawbone architecture is therefore not an auxiliary topic but a core requirement of safe implantology. Modern implant treatment must unite anatomical precision, biological reasoning, three-dimensional imaging, and disciplined surgical technique. This integration is the most reliable strategy for reducing complications and improving postoperative rehabilitation.

References

Scarano, A. (2023). Current status of peri-implant diseases: A clinical review for evidence-based decision making. PMC10142594.

Bali, R. K., Sharma, P., Gaba, S., Kaur, A., & Ghanghas, P. (2015). A review of complications of odontogenic infections. National Journal of Maxillofacial Surgery, – 6(2). – P. 136–143.

Hoerter, J. E., & Malkin, B. D. (2023). Odontogenic Orofacial Space Infections. StatPearls. National Center for Biotechnology Information.

Morgan, N., et al. (2023). CBCT for diagnostics, treatment planning and monitoring of sinus floor elevation procedures. Diagnostics, – 13(10). – 1684 p.

Alghamdi, H. (2024). Management of infected tissues around dental implants. PMC11506315.

Peña-Cardelles, J. F., Markovic, J., Akhondi, S., Pedrinaci, I., Lanis, A., & Gallucci, G. O. (2025). Inferior alveolar nerve damage related to dental implant placement: A systematic review and meta-analysis. Medicina Oral, Patología Oral y Cirugía Bucal, – 30(4). – e578-e589.

Tufekcioglu, S., Delilbasi, C., & Gurler, G. (2017). Is 2 mm a safe distance from the inferior alveolar canal to avoid neurosensory complications in implant surgery? PubMed ID: 28256479.

Alshamrani, A. M., et al. (2023). Maxillary sinus lift procedures: An overview of current evidence and anatomical considerations. PMC10753870.

submitted 14.06.2026;
accepted for publication 28.06.2026;
published 30.06.2026

Contact: tamarbaramidze5@gmail.com

Contents