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Impacts of natural and anthropogenic factors on soil erosion

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Abstract: *Soil erosion is a serious issue that is caused by both natural and anthropogenic factors. Natural processes, including water and wind erosion, as well as higher temperatures, have been identified as leading causes of soil erosion. Additionally, anthropogenic factors, such as urbanization, road construction, agriculture, industry, mining, and others significantly contribute to this problem. These factors have resulted in the loss of biological productivity of the land and have inflicted damage on the entire ecosystem. Since 2000, soil erosion and desertification have become even more severe, exacerbating the problem. The soil of Mongolia, characterized by an arid and semi-arid climate with low precipitation and high temperature fluctuations, is highly susceptible to erosion with approximately 55% of it being classified as high or very easy to erode. This review provides a comprehensive overview of the natural processes and anthropogenic factors that contribute to soil erosion, as well as the current status of soil in various regions of Mongolia.*

Keywords: *soil erosion, Mongolian soil, natural and anthropogenic factors, ecosystem damage;*

INTRODUCTION

Soil erosion has emerged as a pressing concern due to a combination of natural processes and anthropogenic factors [1]. It refers to the detachment and transport of soil particles, which are eventually deposited in valleys, oceans, rivers, streams and distant areas [2]. This phenomenon results in the loss of topsoil, reducing the productivity of agricultural, forest and grassland ecosystems, and negatively impacts the biodiversity of plants, animals, and soil microorganisms [3]. Additionally, vehicular movement over soil disrupts its natural structural elements, causing displacement of particles [4]. Factors such as rainfall, surface roughness, crop condition and vegetation cover play a crucial role in determining the severity of soil erosion, which is classified as slight, moderate, or severe [5].

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Therefore, it is criticially important to implement effective soil conservation measures to minimize the detrimental effects of erosion on soil health and productivity [6].

Soil erosion is a global problem that affects numerous countries, including Brazil, Mexico, China and Malaysia, as highlighted earlier. Mongolia is also grappling with significant soil erosion concerns, with ongoing erosion observed from the southeast to the northwest in certain regions (Figure 1). The geographical and climatic characteristics of Mongolia play a significant role in triggering natural factors that compound soil erosion. Intense wind patterns and sporadic rainfall in some areas contribute to soil vulnerability, resulting in an increased degree of erosion. These natural factors, combined with anthropogenic influences, further intensify the severity of the problem. Anthropogenic factors, particularly overgrazing of pasturelands, improper land management practices, and deforestation disrupt the delicate balance of ecosystem.

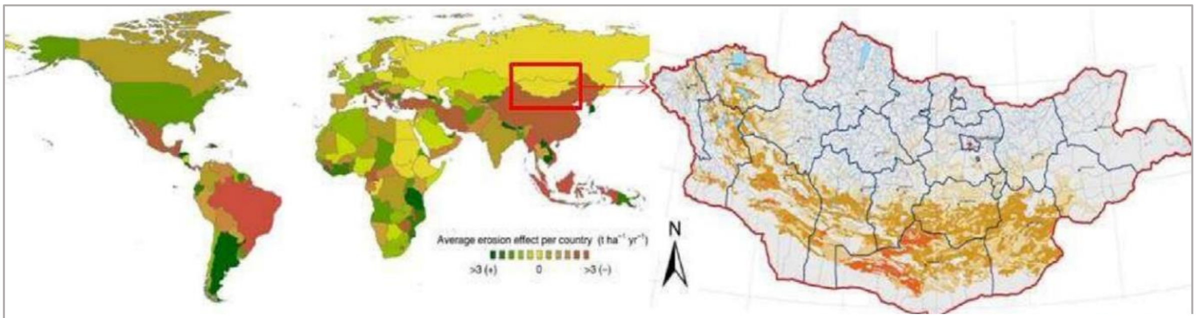

Figure 1. Soil erosion status of world and Mongolia, 2020
Source: Desertification atlas, Ministry of Environment and Tourism, Mongolia 2020
https://www.researchgate.net/figure/A-global-map-of-countries-soil-erosionperformance-The-map-is-based-on-soil-erosion_fig3_337698100

Soil erosion is closely interconnected with desertification, which involves the transformation of vegetated land into barren areas [7-8]. It is evident that both natural and anthropogenic factors contribute to desertification, just as they do to soil erosion. Natural factors include wind, water, and climate change, such as temperature fluctuations, dust storms, and precipitation [9]. Anthropogenic factors include the construction of multi-branch highways, illegal mineral extraction, urbanization, road construction, agriculture, industry, mining, and the use of saxaul (a genus of shrubs or small trees belonging to the plant family Amaranthaceaa) as fuel, among others [10].

In Mongolia, the average annual temperature has increased by 2.1°C, while annual precipitation has decreased by 7% over the past 75 years [11]. The primary driver of vegetation degradation in Mongolia is the decrease in precipitation and the rise in temperature [12]. Indirect factors such as livestock grazing, land cultivation, and wildfires amplify the impact of climatic factors, increasing desertification in arid and semi-arid regions. In certain areas, fires destroy vegetation coverage which further increases desertification [13-14]. Presently, 76.9% of Mongolian land is degraded and has been desertified, with 56% attributed to natural phenomena and 44% to anthropogenic factors (Figure 2).

The measurement of desertification indicators involves the analysis of such factors as overgrazing, deforestation, farming practices, urbanization, other types of land development, climate change, vegetation cover, water and wind erosion, resource depletion, and others. Desertification is categorized into five degrees: no desertification, weak, moderate, strong, and very strong.

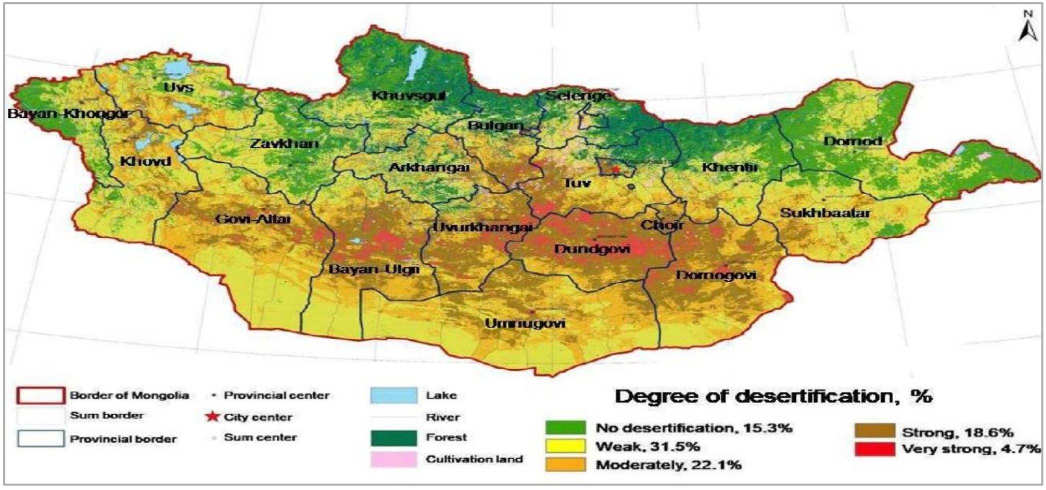

Figure 2. Desertification of Mongolia, 2020
Source: Desertification atlas, Ministry of Environment and Tourism, Mongolia, 2020

In greater detail, certain provinces in Mongolia (Dundgovi, Uvurkhangai, Govisumber, Dornogovi, Bayankhongor, Tuv, Gobi-Altai, and Umnugovi) exhibit higher levels of desertification, as shown in Figure 2. As of 2020, approximately 76.9% of land area in Mongolia had been affected by desertification to varying degrees, with 31.5%, 22.1%, 18.6%, and 4.7%, and classified as weak, moderate, strong and very strong respectively.

Over the past two decades spanning from 2000 to 2020, the process of desertification has continued to spread across Mongolia, extending from the northeast to the southwest of the country. During this period, geographical and climatic factors, along with anthropogenic factors, have collectively like conditions.

Natural factors

Two primary natural factors contribute significantly to soil erosion: water and wind intensity, as mentioned in reference [15]. Both wind and water play a crucial role in influencing the density of soil particles, leading to a decrease in soil productivity through the reduction of topsoil thickness, rooting depth, organic matters, microbial activity, and the presence of higher subsoil clay content. Protecting plant cover is critical in preventing soil erosion [16-17]. The productivity of plants, growth status and development of vegetation cover are largely dependent on climatic conditions, such as temperature, precipitation, and evaporation [18].

Wind erosion

Wind erosion occurs when loose, dry and bare soils are transported by strong winds. Sparse vegetation increases the vulnerability of soil to drying and erosion [19-20]. Adequate plant cover on land can mitigate wind erosion by reducing the direct impact of wind on the soil surface, thereby slowing down wind speed and force [21]. Conversely, direct sunlight reduces soil moisture, resulting in dry and loose soil conditions. Climate, topography and soil characteristics are the three main categories that influence wind erosion [22-23].

Climate factors: Increasing wind speeds cause small soil particles on the surface to be blown and carried away by the wind.

Sparse vegetation cover is a significant factor that accelerates soil erosion [17, 24]. *Topography:* Landscape position and shape act as barriers to reduce the wind force [25]. Therefore, forests and pastures are less susceptible to wind erosion, while agricultural areas are at a higher risk.

Soil characteristics: Sandy soils and medium-to-fine sandy soils with specific mechanical compositions are particularly vulnerable to wind erosion. The stability of soil particles plays a key role in reducing the risk of erosion [26-27]. Soil particles smaller than 0.1 mm are blown into the air, medium-sized particles ranging from 0.1 to 0.5 mm are deflected and drummed, and large particles between 0.5 and 2 mm are carried by rolling on the surface [28]. Large particles close to the soil surface and low moisture content also increase the susceptibility to wind erosion. Soil type and moisture, with higher humus content stabilizing the mineral part of the soil [29-30].

Water erosion

Water erosion is a significant contributor to soil erosion resulting from the accumulation of rainwater intensity and the force of running water [31]. Heavy rainfall causes the movement of fertile soil particles and exacerbates soil and water erosion [32]. The impact of raindrops on soil surface disrupts soil aggregates and dislodges small particles that are carried away, creating depressions in the soil [33]. When water infiltrates the soil pores and creates pressure, it breaks apart soil aggregates, which leads to the dispersion of small soil particles on the surface [34]. The compaction of these small soil aggregates hinders the penetration of rainwater, resulting in surface water accumulation that carries away small soil particles along the slope.

Precipitation intensity, topography and soil texture all play a role in water erosion [35-36]. The rate of soil erosion tends to increase with higher rainfall intensity and steeper slopes [37]. Sloping surfaces have a significantly impact on soil movement, with areas having slopes greater than 2° being susceptible to damage, while areas with a slope of greater than 8-10° are highly vulnerable to water-induced erosion [38]. The water absorption capacity of soil depends on the particle size and humus content, with smaller soil particles increasing the risk of soil erosion. Rocky and sparsely vegetated soils are less affected by water erosion due to their low clay content and good water permeability. Conversely, soils with high clay content are more prone to waterlogging and rapid transport of small soil particles [39-41].

Wind erosion is a significant issue in the area of the Great Lake Depression and southern Mongolia, with annual soil erosion rate exceeding 100 t/ha. Southwestern region experiences severe wind erosion particularly in areas with sparse vegetation and strong winds (Figure 3a,c).

Additionally, wind erosion in Mongolia has increased from 2000 to 2020. In contrast, water erosion is most prevalent in specific areas such as the Great Lake Depression, the Mongolian Altai Mountains, and the Gurvansaikhan mountain, with erosion rates of 0.09 t/ha per year or higher. In most other regions of Mongolia, erosion rates range from 0 to 1 t/ha per year (Figure 3b,d). Figure 3e and 3f provide a visualization of the amount of soil eroded by wind and water between 2000 and 2020, with wind erosion occurring predominantly from southeast to southwest, while water erosion is observed from south to northwest. The southern region of Mongolia, characterized by sparse vegetation, is particularly vulnerable to rapid soil erosion.

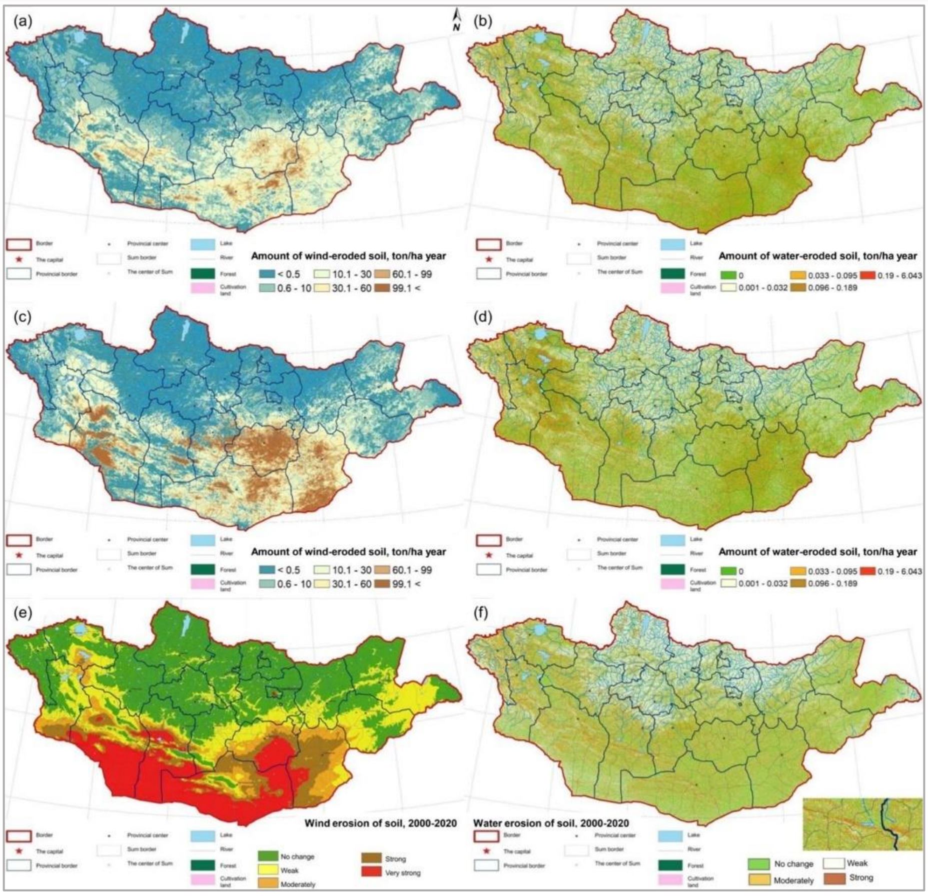

Figure 3. (a,b) Wind and water erosion, 2000, (c,d) wind and water erosion, 2020, and (e,f) changes in wind and water erosion between 2000 and 2020 in Mongolia. Source: Desertification Atlas, Ministry of Environment and Tourism, Mongolia 2020

Anthropogenic factors

As mentioned earlier, there are several anthropogenic factors that contribute to soil erosion. In this review, we focus on key concepts related to anthropogenic factors, including urbanization, road construction, pasturelands, agriculture, industry and mining.

Urbanization

Urbanization refers to the process of population concentration in urban areas, often characterized by the development of residential and industrial infrastructure. This process involves the replacement of natural vegetation and landscapes with impervious surfaces such as buildings, roads, parking lots, and sidewalks [42-43]. These surfaces increase surface runoff during rainfall, leading to soil erosion and other negative environmental impacts [44]. Urbanization also contributes to soil compaction through the use of heavy construction equipment, vehicles and foot traffic, which reduce the soil's ability to absorb water and increase its susceptibility to erosion. The removal of vegetation during urbanization further exacerbates soil erosion. Trees, shrubs and other plants play a crucial role in stabilizing the soil and absorbing rainfall, thereby reducing runoff and erosion [45-47]. However, the removal of vegetation during urban development increases the vulnerability of soil to erosion.

Despite the material benefits that urbanization brings to human society, it also has significant negative environmental impacts, including soil erosion. The effects of soil erosion resulting from urbanization have direct impact on the economy, environment, and public health [48]. Dust particles containing pollutants have the potential to degrade air quality, and among these particles, fine particles known as PM2.5 pose particular human health concern. These tiny particles are small enough to be suspended in the air and can be easily inhaled into the respiratory system, leading to various health issues [49].

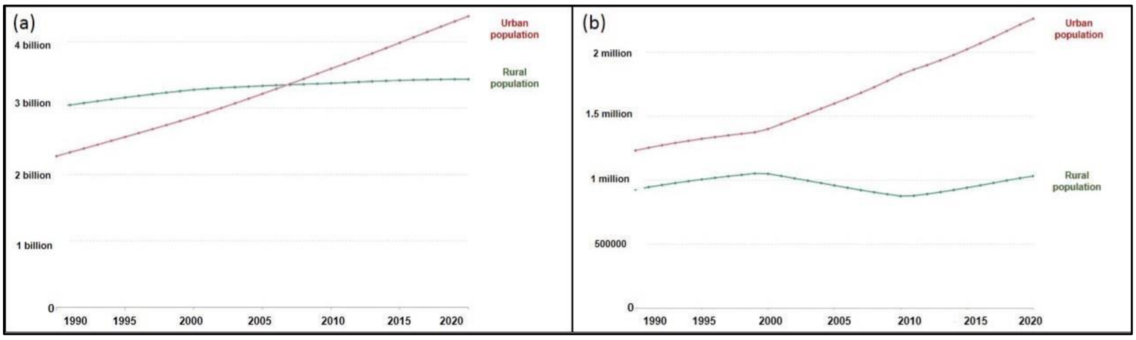

Figure 4. Urban and rural population rate (a) worldwide and (b) in Mongolia, 1990-2020

Source: https://ourworldindata.org/grapher/urban-and-rural-population

According to data from 1990, global population was 5.28 billion, with 3.01 billion individuals residing in urban areas and 2.27 billion in rural areas. As of 2020, the world population had grown to 7.76 billion, with 4.36 billion living in urban areas and 3.40 billion in rural areas Indicating a doubling of the global urban population (Figure 4a). In Mongolia, the population increased to 3.28 million in 2020, with 2.25 million living in urban areas, also doubling compared to 1990 (Figure 4b). Over the past three decades, there has been a significant growth in urban population globally and in Mongolia as well, while the number of individuals in rural areas has remained relatively constant.

Road construction

Road construction has seen significant growth worldwide in recent decades, aiming to improve human mobility, goods transportation, and urban development. However, roads are known to concentrate runoff, leading to increased soil loss and sediment yield on hill slopes, ultimately degrading the water quality of nearby water bodies [50]. Studies have shown that road-stream crossings serve as significant sediment sources, primarily due to erosion occurring on the road verges and fill slopes. This erosion reduces the capacity of pastureland and gives rise to gullies, leading to severe soil erosion [51]. The bare and steep gradients of roadcuts and fill embankments generate runoff and sediment yield, while the absence of vegetation cover intensifies soil detachment and susceptibility to erosion by reducing soil cohesion and shear strength. Steep gradients also contribute to slope erosion by reducing water infiltration and increasing runoff accumulation [52-53].

Inadequate implementation of erosion control measures during road construction results in negative impacts, such as increased sedimentation in nearby waterways, reduced soil fertility and an elevated risk of landslides and other slope failures, particularly in areas with steep terrain or unstable soils [54]. Soil roads play a significant role in soil erosion as the movement of vehicles and the passage of air dislodge lead to the loss of topsoil and nutrients, cause damage to aquatic ecosystems, reduced water quality and an increased risk of flooding [55].

In summary, road construction and dirt roads have a substantial impact on soil erosion. (Figure 5). Figure 5 shows the dirt roads in Khentii and Tuv provinces of Mongolia. In these rural areas, vegetation cover remains sparse due to irresponsible vehicle use, which poses risks such as dust pollution and river dry-ups. The lack of vegetation cover exacerbates soil erosion and increases the vulnerability of the surrounding environment to negative impacts.

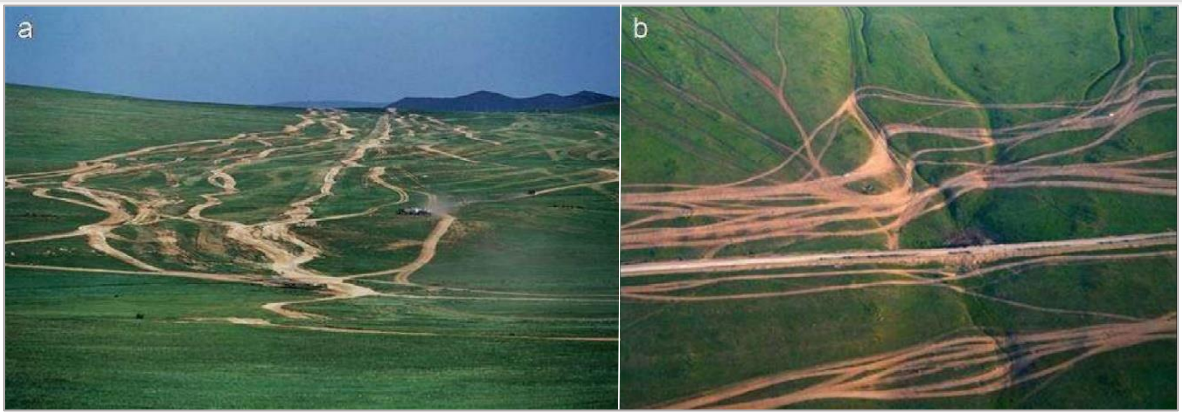

Figure 5. (a) Jargaltkhaan soum of Khentii province 2001, and (b) Lun soum of Tuv province 2008, Mongolia. Source:http://www.baabar.mn/article/2183

Pasturelands

Livestock grazing has a significant impact on soil erosion, primarily influenced by factors such as vegetation cover, soil composition and topography [56-57]. *Vegetation cover:* The removal of vegetation through grazing exposes the soil, particularly when grazing intensity and frequency are high.

Soil compaction: Livestock trampling and grazing also compact the soil, reducing its permeability and increasing surface runoff, which contributes to erosion.

Topography: The effects of grazing on soil erosion vary depending on the topography of the land, with grazing on steep slopes causing more soil disturbance and runoff compared to flatter terrain [57-59].

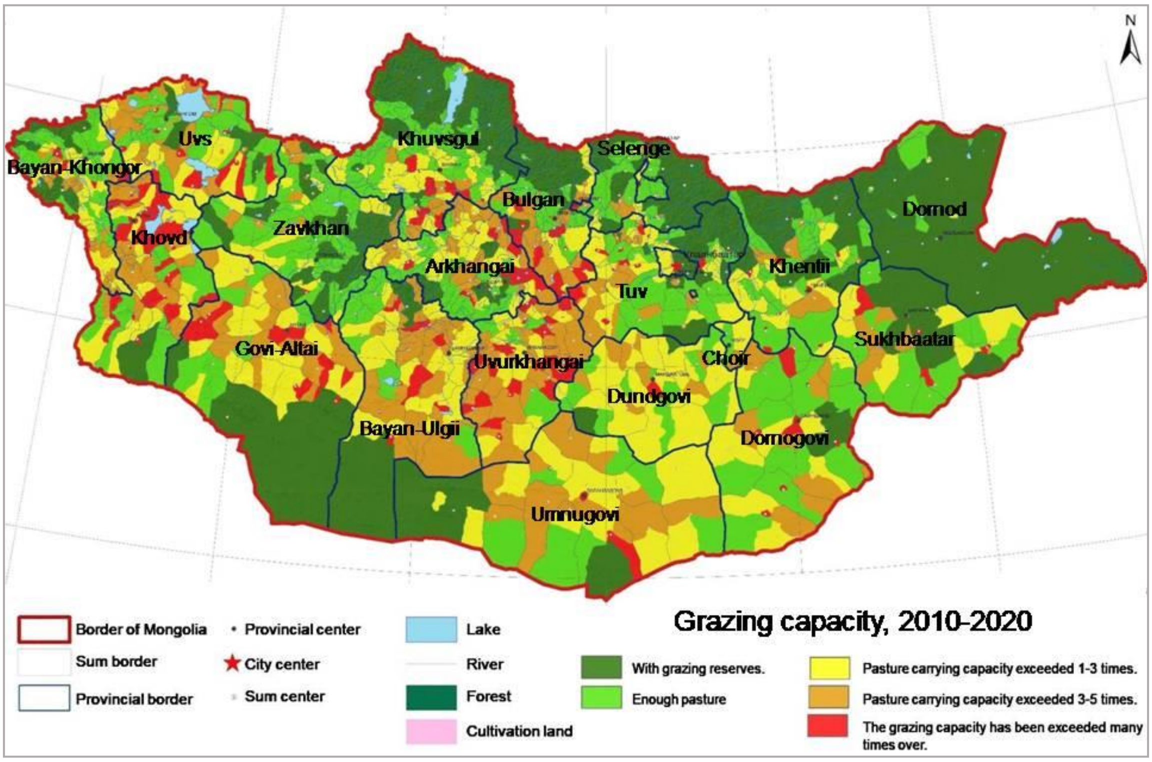

Figure 6. Grazing capacity, 2010-2020. Source: Desertification Atlas, Ministry of Environment and Tourism, Mongolia 2020

In Mongolia, a vast majority of agricultural land consists of pastures, accounting for 97% of the total land area. The grazing area has decreased over the years, while the number of livestock has increased significantly. This trend has led to intensified erosion rates due to overgrazing. Figure 6 illustrates the degradation of pasture capacity in all Mongolian provinces except Dornod. In 2020, approximately 67.1 million animals utilized pasturelands, indicating the direct impact of pasture degradation on livestock sector's capacity. This degradation has severe consequences, including increased vulnerability to drought and other risks.

Agriculture

Agriculture has been an integral part of human civilization for over 10,000 years. However, agriculture has indeed faced significant challenges in pest management, with pests causing substantial crop losses, particularly in fruits, vegetables and cereals. Losses of up to 78% in fruits, 54% in vegetables, and 32% in cereals have been reported. [60]. To address this issue and to maintain agricultural productivity, pesticides are widely used in many countries. The application of pesticides has proven effective in reducing crop losses caused by pests by almost 35 to 42%. [61-62]. To address this issue and maintain agricultural productivity, pesticides are widely used in many countries. The application of pesticides has proven effective in reducing crop losses caused by pests by almost 35 to 42%. [63]. They are categorized into different types, such as herbicides, insecticides, nematicides, molluscicides and fungicides. Among these, herbicides are the most commonly used, accounting for approximately 80% of all pesticide used worldwide. [60].

While pesticides are important in pest management, their excessive and inappropriate use poses significant threats to soil health and biodiversity. Uncontrolled and excessive pesticide use can lead to a decline in soil fertility, regeneration and overall soil health. [64-65]. This, in turn, can contribute to soil pollution and erosion, as well as negatively impact the diversity and abundance of beneficial organisms in the soil.

It is important to emphasize the need for responsible and judicious pesticide use in agricultural practices to minimize adverse impacts on soil and ecosystem health. Integrated pest management strategies, which combine various pest control methods and prioritize ecological balance, can help reduce reliance on pesticides and promote sustainable agriculture, while at the same time minimizing soil erosion and pollution.

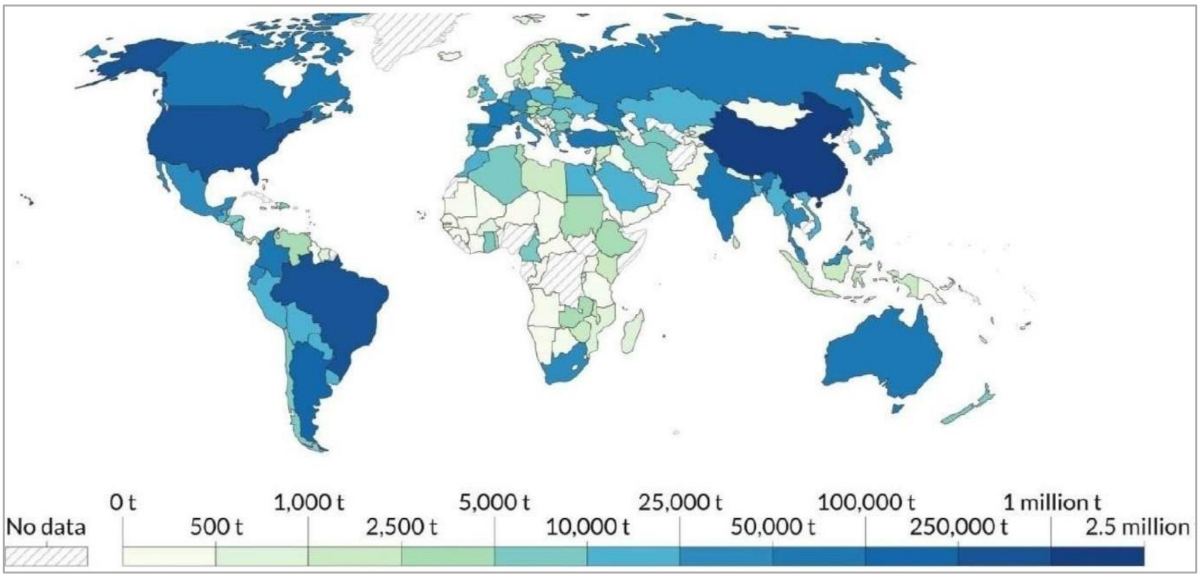

Figure 7. Pesticide usage, 2019. Source: Food and Agriculture Organization of the United Nations

Asia accounts for the highest pesticide usage globally, with China being the largest consumer of pesticides. Other significant consumers in the region include India, Indonesia, and Vietnam. North America and Europe also have high rates of pesticide consumption, with the United States and certain European countries being major users. Although pesticide usage in Africa is relatively low, it has been increasing in recent years due to the industrialization and commercialization of agriculture. Table 1 presents the top 10 pesticide-consuming countries worldwide. China ranks the highest with usage at 55.5%, followed by the United States at 12.8% and Brazil at 11.9% (Figure 7). It is noteworthy that China and the United States have been consistently leading pesticide users since 1990.

Table 1. Pesticide usage in the top 10 countries worldwide

№	Country	Pesticide use, tons	Percent for top 10 countries, %	Amount of pesticide per ha of cropland, kg
1.	China	1,763,000	55.5%	13.1
2.	United States	407,779	12.8%	2.5
3.	Brazil	377,176	11.9%	6.0
4.	Argentina	196,009	6.2%	4.9
5.	Canada	90,839	2.9%	2.4
6.	Ukraine	78,201	2.5%	2.3
7.	France	70,589	2.2%	3.6
8.	Malaysia	67,288	2.1%	8.1
9.	Australia	63,416	2%	2.0
10.	Spain	60,896	1.9%	3.6
	Total	3,175,193	100%	48.5

Industry and mining

Industry and mining activities contribute significantly to soil contamination through the direct discharge of industrial and mining wastewater, which releases heavy metals into the environment. These heavy metals, including chromium, zinc, lead, cadmium, manganese, iron, and nickel, are non-biodegradable and have a negative impact on soil quality throughout the year [66-67]. Lead contamination is often associated with mining activities, while industrialization and urbanization have led to a widespread dispersion of cadmium, lead and chromium in the environment [68]. Although copper, zinc and chromium are required in small amounts by living organisms, arsenic and lead can adversely affect the physiological processes of plants and animals [69]. Even small amounts of these elements can have severe consequences for soil erosion, leading to a reduction in soil micro-organisms, a decline in biodiversity and ultimately, soil infertility.

Mercury, in particular, is a heavy metal used in gold extraction, which has a most negative impact on the ecosystems and public health [70]. It exists in various forms in the environment and is released from both natural and human-made sources, such as volcanic eruptions, rock weathering, forest fires, mining activites, burning of fossil fuels and waste incineration [71]. Once released, mercury can travel long distances through the atmosphere and can be deposited onto land or water surfaces through precipitation [72]. In aquatic ecosystems, micro-organisms convert mercury into methylmercury, a highly toxic agent that accumulates in the food chain. Methylmercury is primarily produced in sediments and is taken up by small aquatic organisms like plankton and small fish, which are then consumed by larger fish, birds, and mammals. As mercury moves up the food chain, its concentration increases through biomagnification [73-75]. Top predators, including predatory fish, raptors, and mammals, accumulate high levels of mercury in their bodies, resulting in toxic effects on their health and reproduction. Mercury enters terrestrial ecosystems through atmospheric deposition or runoff from contaminated water bodies. The mercury cycle in ecosystems is influenced by various factors, including the type and amount of mercury sources, the chemistry of the environment, the structure of the food web and the biological and physical processes that regulate mercury transformations and transport [76-79]. Overall, the mercury cycle in ecosystems is a complex procedure and mercury pollution has equally harmful effects on human health and the environment. It is crucial to manage and reduce mercury emissions, as well as monitor and control its levels in food and water sources in order to potect public health and the ecosystem (Figure 8a).

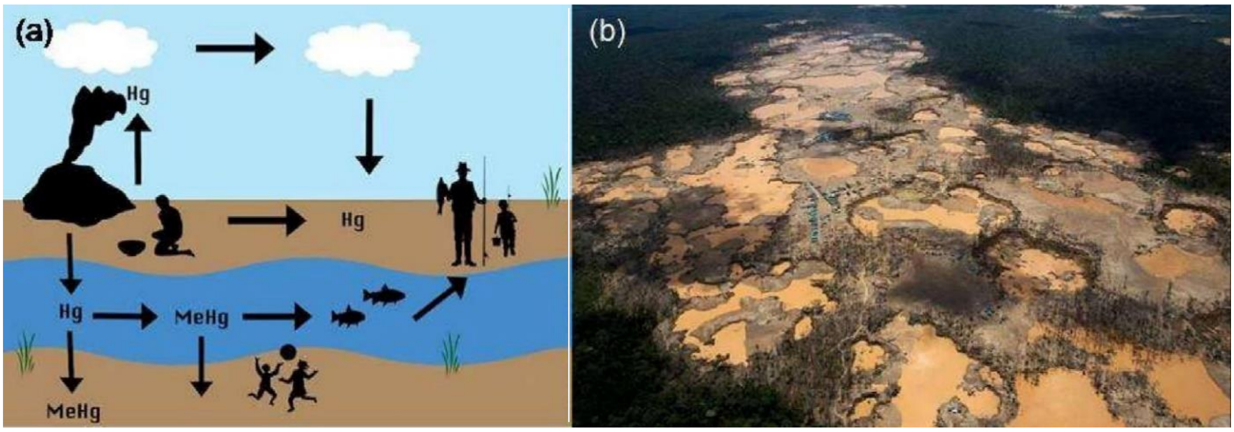

Figure 8. (a) Mercury cycle in the ecosystem and (b) post-gold mining process. Source: La Pampa, an illegal gold mining hub in the Peruvian Amazon, in 2014. (AP Photo / Rodrigo Abd, File)

Gold mining activities significantly and negatively impact soil erosion, especially in areas where techniques like open-pit mining, heap leaching and dredging are employed. These methods cause land disturbance, leading to the destruction of vegetation and wildlife habitats. Furthermore, the use of heavy machinery results in soil compaction, which increases the likelihood of erosion. Sedimentation in nearby water bodies also escalates due to gold mining, posing risks to aquatic ecosystems and the surrounding area [80-82]. Moreover, the utilization of toxic chemicals such as cyanide in certain mining techniques contaminates the environment [83].

Proper rehabilitation efforts are essential once mining activities cease in order to prevent ongoing soil erosion and address other environmental issues. Additionally, land degradation near mining areas and adjacent road networks used for transportation can lead to soil erosion, dust, pasture degradation and water shortage [84-85]. Furthermore, underground coal mining causes significant movement in surrounding rocks, resulting in surface subsidence and irreversible changes to surface morphology. These changes can give rise to geological disasters and environmental problems (Figure 8b). By implementing sustainable mining practices, including effective planning, management and monitoring of mining activities, it is possible to mitigate these impacts on soil erosion and promotes responsible resource extraction [86-87].

CONCLUSIONS

In summary, soil erosion is influenced by both natural and anthropogenic factors. Natural processes such as weathering and geological activities can initiate erosion, however anthropogenic factors intensify and accelerate the process, leading to more severe erosion. Moreover, anthropogenic factors like soil compaction, reduced soil fertility and increased runoff during rainfall events contribute to soil erosion. To address these issues, it is vitally important to implement effective erosion control techniques and adopt sustainable land use practices that prioritize the protection and enhancement of soil quality and productivity. These efforts are essential for preserving soil resources for future generations and ensuring the uninterrupted provision of vital ecosystem services.

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REFERENCES

1. Darkoh, M. B. K. (1998). The nature, causes and consequences of desertification in the drylands of Africa. Land Degrad Dev, 9(1), 1 pp. -20. https://doi.org/10.1002/(SICI)1099-145X(199801/02)9:1<1::AID-LDR263>3.0.CO;2-8
2. Hudson, N. W. (2015). Soil conservation. Scientific Publishers. eISBN: 978-93-88172-45-5.
3. Feng, Y., Wang, J., Bai, Z., and Reading, L. (2019). Effects of surface coal mining and land reclamation on soil properties: A review. Earth-Sci. Rev, 191, pp. 12-25. https://doi.org/10.1016/j.earscirev.2019.02.015
4. Yong, R. N., Fattah, E. A., and Skiadas, N. (2012). Vehicle traction mechanics. Elsevier. ISBN 0-444-41940-3 (series).
5. Liu, Q. Q., Chen, L., and Li, J. C. (2001). Influences of slope gradient on soil erosion. Appl. Math. Mech, 22, pp. 510-519. https://doi.org/10.1023/A:1016303213326
6. Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), pp. 5875-5895. https://doi.org/10.3390/su7055875
7. Sidiropoulos, P., Dalezios, N. R., Loukas, A., and Sakellariou, S. (2021). Quantitative classification of desertification severity for degraded aquifer based on remotely sensed drought assessment. Hydrology, 8(1), p. 47. https://doi.org/10.3390/hydrology8010047
8. Wang, S. J., Liu, Q. M., and Zhang, D. F. (2004). Karst rocky desertification in southwestern China: Geomorphology, landuse, impact and rehabilitation. Land Degrad Dev, 15(2), pp. 115-121. https://doi.org/10.1002/ldr.592
9. Zhang, C., Gao, R., Wu, J., and Yang, Z. (2020). Combating climate change, desertification and sandstorms: A collaborative approach. Annual Report on China's Response to Climate Change (2017) Implementing The Paris Agreement, pp. 145-153. ISBN : 978-981-13-9659-5.
10. Feng, Q., Ma, H., Jiang, X., Wang, X., and Cao, S. (2015). What has caused desertification in China? Sci. Rep, 5(1), pp. 1-8. https://doi.org/10.1038/srep15998
11. Dulamsuren, C., Khishigjargal, M., Leuschner, C., and Hauck, M. (2014). Response of tree-ring width to climate warming and selective logging in larch forests of the Mongolian Altai. J Plant Ecol, 7(1), pp. 24-38. https://doi.org/10.1093/jpe/rtt019
12. Zhang, J., Dong, W., and Fu, C. (2005). Impact of land surface degradation in northern China and southern Mongolia on regional climate. Sci. Bull, 50, pp. 75-81. https://doi.org/10.1360/04wd0054
13. Abdi, O. A., Glover, E. K., & Luukkanen, O. (2013). Causes and impacts of land degradation and desertification: Case study of the Sudan. International Journal of Agriculture and Forestry, 3(2), pp. 40-51. https://doi.org/10.5923/j.ijaf.20130302.03
14. Liang, X., Li, P., Wang, J., and Davaasuren, D. (2021). Research progress of desertification and its prevention in Mongolia. Sustainability, 13(12), p. 6861. https://doi.org/10.3390/su13126861
15. Yang, D., Kanae, S., Oki, T., Koike, T., and Musiake, K. (2003). Global potential soil

erosion with reference to land use and climate changes. Hydrological processes, 17(14), pp. 2913-2928. https://doi.org/10.1002/hyp.1441

16. Visser, S. M., Sterk, G., and Ribolzi, O. (2004). Techniques for simultaneous quantification of wind and water erosion in semi-arid regions. J. Arid Environ, 59(4), pp. 699-717. https://doi.org/10.1016/j.jaridenv.2004.02.005
17. Zuazo, V. H. D., and Pleguezuelo, C. R. R. (2009). Soil-erosion and runoff prevention by plant covers: A review. Sustain. Agric, pp. 785-811. ISBN : 978-90-481-2665-1.
18. Kosmas, C., Gerontidis, S., and Marathianou, M. (2000). The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece). Catena, 40(1), pp. 51-68. https://doi.org/10.1016/S0341-8162(99)00064-8
19. Hoffmann, C., Funk, R., Reiche, M., and Li, Y. (2011). Assessment of extreme wind erosion and its impacts in Inner Mongolia, China. Aeolian Res, 3(3), pp. 343-351. https://doi.org/10.1016/j.aeolia.2011.07.007
20. Ochoa, P. A. A., Fries, A., Mejía, D., Burneo, J.I., Ruíz-Sinoga, J. D., and Cerdà, A. (2016). Effects of climate, land cover and topography on soil erosion risk in a semi-arid basin of the Andes. Catena, 140, pp. 31-42. https://doi.org/10.1016/j.catena.2016.01.011
21. Zhang, Y. M., Wang, H. L., Wang, X. Q., Yang, W. K., and Zhang, D. Y. (2006). The microstructure of microbiotic crust and its influence on wind erosion for a sandy soil surface in the Gurbantunggut Desert of Northwestern China. Geoderma, 132(3-4), pp. 441-449. https://doi.org/10.1016/j.geoderma.2005.06.008
22. Veihmeyer, F. J., and Hendrickson, A. H. (1955). Does transpiration decrease as the soil moisture decreases? Eos, Transactions American Geophysical Union, 36(3), pp. 425-448. https://doi.org/10.1029/TR036i003p00425
23. Duniway, M. C., Pfennigwerth, A. A., Fick, S. E., Nauman, T. W., Belnap, J., and Barger, N. N. (2019). Wind erosion and dust from US drylands: a review of causes, consequences, and solutions in a changing world. Ecosphere, 10(3), e02650. https://doi.org/10.1002/ecs2.2650
24. Kok, J. F., and Renno, N. O. (2008). Electrostatics in wind-blown sand. Physical review letters, 100(1), 014501. https://doi.org/10.1103/PhysRevLett.100.014501
25. Mander, S. (2017). Slow steaming and a new dawn for wind propulsion: A multi-level analysis of two low carbon shipping transitions. Marine Policy, 75, pp. 210-216. https://doi.org/10.1016/j.marpol.2016.03.018
26. Alkhayer, M., Eghbal, M. K., and Hamzehpour, N. (2019). Geomorphic surfaces of eastern lake Urmia Playa and their influence on dust storms. J Appl. SCI. Environ. Manag, 23(8), pp. 1511-1520. https://doi.org/10.4314/jasem.v23i8.15
27. García-Orenes, F., Roldán, A., Mataix-Solera, J., Cerdà, A., Campoy, M., Arcenegui, V., and Caravaca, F. (2012). Soil structural stability and erosion rates influenced by agricultural management practices in a semi-arid Mediterranean agro-ecosystem. Soil Use Manag, 28(4), pp. 571-579. https://doi.org/10.1111/j.1475-2743.2012.00451.x
28. Chepil, W. S. (1945). Dynamics of wind erosion: I. Nature of movement of soil by wind. Soil Sci, 60(4), pp. 305-320. WS Chepil - Soil Science, 1945 - journals.lww.com. https://doi.org/10.1097/00010694-194510000-00004
29. Vermeire, L. T., Wester, D. B., Mitchell, R. B., and Fuhlendorf, S. D. (2005). Fire and grazing effects on wind erosion, soil water content, and soil temperature. J. Environ. Qual, 34(5), pp. 1559-1565. https://doi.org/10.2134/jeq2005.0006
30. Pettit, R. E. (2004). Organic matter, humus, humate, humic acid, fulvic acid and humin: their importance in soil fertility and plant health. CTI Research, 10, pp. 1-7. RE Pettit - CTI Research, 2004 - harvestgrow.com.
31. Weeraratna, S. (2022). Factors causing land degradation. In understanding land degradation: An overview (pp. 5-22). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-12138-8_2

32. Blanco, H., and Lal, R. (2008). Principles of soil conservation and management (Vol. 167169). New York: Springer.
33. An, J., Wu, Y., Wu, X., Wang, L., and Xiao, P. (2021). Soil aggregate loss affected by raindrop impact and runoff under surface hydrologic conditions within contour ridge systems. Soil Tillage Res, p. 209, 104937. https://doi.org/10.1016/j.still.2021.104937
34. Gabriels, D., Horn, R., Villagra, M. M., and Hartmann, R. (2020). Assessment, prevention, and rehabilitation of soil structure caused by soil surface sealing, crusting, and compaction. In Methods for assessment of soil degradation (pp. 129-165). CRC Press. eISBN 9781003068716. https://doi.org/10.1201/9781003068716-7
35. Han, M., Wang, Q., Han, Y., Fu, H., Shen, J., and Liu, Y. (2022). Description of different cracking processes affecting dispersive saline soil slopes subjected to the effects of frost and consequences for the stability of low slopes. Bull. Eng. Geol. Environ, 81(2), p. 75. https://doi.org/10.1007/s10064-022-02570-w
36. Rodríguez-Caballero, E., Cantón, Y., Chamizo, S., Lázaro, R., and Escudero, A. (2013). Soil loss and runoff in semiarid ecosystems: a complex interaction between biological soil crusts, micro-topography, and hydrological drivers. Ecosyst, 16, pp. 529-546. https://doi.org/10.1007/s10021-012-9626-z.
37. Abdul, R. S., Muhammad, S. P., Patanduk, J., and Harianto, T. (2014). Experimental study of rainfall intensity effects on the slope erosion rate for silty sand soil with different solpe gradient. Int. J. Eng. Technol, 4(1), 58-63. ISSN: pp. 2049-3444. IJET Publications UK.
38. Pimentel, D. (2006). Soil erosion: a food and environmental threat. Environ. Dev, 8, pp. 119-137. https://doi.org/10.1007/s10668-005-1262-8
39. Huang, B., Yuan, Z., Li, D., Zheng, M., Nie, X., and Liao, Y. (2020). Effects of soil particle size on the adsorption, distribution, and migration behaviors of heavy metal (loid) s in soil: A review. Environ. Sci: Processes Impacts, 22(8), pp. 1596-1615. https://doi.org/10.1039/D0EM00189A
40. Su, W., Gao, Y., Gao, P., Dong, X., Wang, G., Dun, X., and Xu, J. (2022). Effects of different vegetation restoration types on the fractal characteristics of soil particles in earthy-rocky mountain area of Northern China. Forests, 13(8), p. 1246. https://doi.org/10.3390/f13081246
41. Vaezi, A. R., Abbasi, M., Keesstra, S., and Cerdà, A. (2017). Assessment of soil particle erodibility and sediment trapping using check dams in small semi-arid catchments. Catena, 157, pp. 227-240. https://doi.org/10.1016/j.catena.2017.05.021.
42. Bathrellos, G. D., Gaki-Papanastassiou, K., Skilodimou, H. D., Papanastassiou, D., and Chousianitis, K. G. (2012). Potential suitability for urban planning and industry development using natural hazard maps and geological–geomorphological parameters. Environ. Earth Sci, 66, pp. 537-548. https://doi.org/10.1007/s12665-011-1263-x
43. Obiakor, M. O., Ezeonyejiaku, C. D., and Mogbo, T. C. (2012). Effects of vegetated and synthetic (impervious) surfaces on the microclimate of urban area. J. Appl. SCI. Environ. Manag, 16(1), pp. 85-94. eISSN: 2659-1502.
44. Zhao, L., Huang, C., and Wu, F. (2016). Effect of microrelief on water erosion and their changes during rainfall. Earth Surf., 41(5), pp. 579-586. https://doi.org/10.1002/esp.3844
45. Ferreira, C. S. S., Kalantari, Z., Salvati, L., Canfora, L., Zambon, I., and Walsh, R. P. D (2019). Chapter Six - Urban areas. in: Pereira, P. (Ed.), Advances in Chemical Pollution, Environmental Management and Protection. Elsevier: Vol 4, pp. 207–249. https://doi.org/10.1016/bs.apmp.2019.07.004
46. Leh, M., Bajwa, S., and Chaubey, I. (2013). Impact of land use change on erosion risk: an integrated remote sensing, geographic information system and modeling methodology. Land Degrad Dev, 24(5), pp. 409-421. https://doi.org/10.1002/ldr.1137
47. Zhu, X., Liu, W., Chen, J., et al. (2020). Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: A review of evidence and

processes. Plant Soil, 453, pp. 45-86. https://doi.org/10.1007/s11104-019-04377-3

48. Wang, L. Y., Xiao, Y., Rao, E. M., et al. (2018). An assessment of the impact of urbanization on soil erosion in Inner Mongolia. Int. J. Environ. Res. Public Health, 15(3), p. 550; https://doi.org/10.3390/ijerph15030550
49. Maciejczyk, P., Chen, L.C., and Thurston, G. (2021). The role of fossil fuel combustion metals in PM2.5 air pollution health associations. Atmosphere, 12(9), p. 1086. https://doi.org/10.3390/atmos12091086.
50. Toy, T. J., Foster, G. R., and Renard, K. G. (2002). Soil erosion: processes, prediction, measurement, and control. John Wiley & Sons.
51. Tiecher, T., Minella, J.P.G., Caner, L., and Dos Santos, D.R. (2017). Quantifying land use contributions to suspended sediment in a large cultivated catchment of Southern Brazil (Guaporé River, Rio Grande do Sul). Agric. Ecosyst. Environ, 237, pp. 95-108. https://doi.org/10.1016/j.agee.2016.12.004
52. Seutloali, K. E., and Beckedahl, H. R. (2015). A review of road-related soil erosion: an assessment of causes, evaluation techniques and available control measures. Earth Sci. Res J, 19(1), pp. 73-80. https://doi.org/10.15446/esrj.v19n1.43841
53. Jiang, F. S., Huang, Y. H., Wang, M. K., and Ge, H. L. (2014). Effects of rainfall intensity and slope gradient on steep colluvial deposit erosion in southeast China. Soil Sci Soc Am J, 78(5), pp. 1741-1752. https://doi.org/10.2136/sssaj2014.04.0132
54. Justin, M. G., Bergen, J. M., Emmanuel, M. S., and Roderick, K. G. (2018). Mapping the gap of water and erosion control measures in the rapidly urbanizing Mbezi river catchment of Dar es Salaam. Water, 10(1), p. 64. https://doi.org/10.3390/w10010064
55. Fay, L., and Shi, X. (2012). Environmental impacts of chemicals for snow and ice control: state of the knowledge. Wat, Air, and Soil Poll, 223, pp. 2751-2770. https://doi.org/10.1007/s11270-011-1064-6
56. Wang, X., Dong, S., Yang, B., Li, Y., and Su, X. (2014). The effects of grassland degradation on plant diversity, primary productivity, and soil fertility in the alpine region of Asia's headwaters. Environ. Monit. Assess, 186, pp. 6903-6917. https://doi.org/10.1007/s10661-014-3898-z
57. Nunes, A. N., De Almeida, A. C., and Coelho, C. O. (2011). Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Appl. Geogr, 31(2), pp. 687-699. https://doi.org/10.1016/j.apgeog.2010.12.006
58. Xie, Y., and Wittig, R. (2004). The impact of grazing intensity on soil characteristics of Stipa grandis and Stipa bungeana steppe in northern China (autonomous region of Ningxia). Acta Oecol, 25(3), pp. 197-204. https://doi.org/10.1016/j.actao.2004.01.004
59. Dunne, T., Western, D., and Dietrich, W. E. (2011). Effects of cattle trampling on vegetation, infiltration, and erosion in a tropical rangeland. J. Arid Environ, 75(1), pp. 58-69. https://doi.org/10.1016/j.jaridenv.2010.09.001
60. Tudi, M., Daniel, R. H., Wang, L., and Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. Int. J. Environ. Res. Public Health, 18(3), p. 1112. https://doi.org/10.3390/ijerph18031112
61. Damalas, C. A., and Eleftherohorinos, I. G. (2011). Pesticide exposure, safety issues, and risk assessment indicators. Int. J. Environ. Res. Public Health, 8(5), pp. 1402-1419. https://doi.org/10.3390/ijerph8051402
62. Hasanuzzaman, M., Rahman, M. A., and Salam, M. A. (2017). Identification and quantification of pesticide residues in water samples of Dhamrai Upazila, Bangladesh. Appl. Water Sci, 7, pp. 2681-2688. https://doi.org/10.1007/s13201-016-0485-1.
63. Gandhar, A., Tiwari, M., Tiwari, T., Gupta, S., and Rehalia, A. (2022). Internet of things based pest and growth management system using natural pesticides & fertilizers for small scale organic farming. J. Pharm Negat Results, pp. 8654-8665.

https://doi.org/10.47750/pnr.2022.13.S09.1017

64. Mahmood, I., Imadi, S. R., Shazadi, K., Gul, A., and Hakeem, K. R. (2016). Effects of Pesticides on Environment. In: Hakeem, K., Akhtar, M., Abdullah, S. (eds) Plant, Soil and Microbes. Springer, Cham. https://doi.org/10.1007/978-3-319-27455-3_13
65. Singh, R. L., and Singh, P. K. (2017). Global environmental problems. Principles and applications of environmental biotechnology for a sustainable future, pp. 13-41. Applied Environmental Science and Engineering for a Sustainable Future book series (AESE). https://doi.org/10.1007/978-981-10-1866-4_2
66. Chonokhuu, S., Batbold, C., Chuluunpurev, B., and Byambaa, B. (2019). Contamination and health risk assessment of heavy metals in the soil of major cities in Mongolia. Int. J. Environ. Res. Public Health, 16(14), p. 2552. https://doi.org/10.3390/ijerph16142552
67. Khanna, P. (2011). Assessment of heavy metal contamination in different vegetables grown in and around urban areas. Res. J. Environ. Toxicol, 5(3), pp. 162-179. https://doi.org/10.3923/rjet.2011.162.179
68. Li, H., Li, Y., Lee, M. K., Liu, Z., and Miao, C. (2015). Spatiotemporal analysis of heavy metal water pollution in transitional China. Sustainability, 7(7), pp. 9067-9087. https://doi.org/10.3390/su7079067
69. Nagajyoti, P. C., Lee, K. D., and Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: A review. Environ. Chemistry Lett, 8, pp. 199-216. https://doi.org/10.1007/s10311-010-0297-8
70. Fashola, M. O., Ngole-Jeme, V. M., and Babalola, O. O. (2016). Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. Int. J. Environ. Res. Public Health, 13(11), p. 1047. https://doi.org/10.3390/ijerph13111047
71. Candeias, C., Ávila, P., Coelho, P., and Teixeira, J. P. (2018). Mining activities: health impacts. Reference Module in Earth Systems and Environmental Sciences, pp. 1-21. https://doi.org/10.1016/B978-0-12-409548-9.11056-5
72. Lindberg, S., Bullock, R., Ebinghaus, R., and Seigneur, C. (2007). A synthesis of progress and uncertainties in attributing the sources of mercury in deposition. AMBIO: J. Hum. Environ, 36(1), pp. 19-33. https://doi.org/10.1579/0044-7447(2007)36[19:ASOPAU]2.0.CO;2
73. Chumchal, M. M., Rainwater, T. R., Osborn, S. C., and Bailey, F. C. (2011). Mercury speciation and biomagnification in the food web of Caddo Lake, Texas and Louisiana, USA, a subtropical freshwater ecosystem. Environ. Toxicol. Chem, 30(5), pp. 1153-1162. https://doi.org/10.1002/etc.477
74. Cao, L., Liu, J., Dou, S., and Huang, W. (2020). Biomagnification of methylmercury in a marine food web in Laizhou Bay (North China) and associated potential risks to public health. Mar. Pollut. Bull, p. 150, 110762. https://doi.org/10.1016/j.marpolbul.2019.110762
75. Ward, D. M., Nislow, K. H., and Folt, C. L. (2010). Bioaccumulation syndrome: identifying factors that make some stream food webs prone to elevated mercury bioaccumulation. Ann. N. Y. Acad. Sci, 1195(1), pp. 62-83. https://doi.org/10.1111/j.1749-6632.2010.05456.x
76. Scheuhammer, A. M., Meyer, M. W., Sandheinrich, M. B., and Murray, M. W. (2007). Effects of environmental methylmercury on the health of wild birds, mammals, and fish. AMBIO: J. Hum. Environ, 36(1), pp. 12-19. https://doi.org/10.1579/0044-7447(2007)36[12:EOEMOT]2.0.CO;2
77. Obrist, D., Kirk, J. L., Zhang, L., Sunderland, E. M., Jiskra, M., and Selin, N. E. (2018). A review of global environmental mercury processes in response to human and natural perturbations: Changes of emissions, climate, and land use. Ambio, 47, pp. 116-140. https://doi.org/10.1007/s13280-017-1004-9
78. Gnamuš, A., Byrne, A. R., and Horvat, M. (2000). Mercury in the soil-plant-deer-predator food chain of a temperate forest in Slovenia. Environ. Sci. and Tech, 34(16), pp. 3337-3345. https://doi.org/10.1021/es991419w

79. Mason, R. P., Abbott, M. L., Bodaly, R. A., and Swain, E. B. (2005). Monitoring the response to changing mercury deposition. Environ. Sci. and Tech, 39(1), 14A-22A. https://doi.org/10.1021/es053155l
80. Hagos, G., Sisay, W., Alem, Z., Niguse, G., and Mekonen, A. (2016). Participation on traditional gold mining and its impact on natural resources, the case of Asgede Tsimbla, Tigray, Northern Ethiopia. Journal of Earth Sciences and Geotechnical Engineering, 6(1), pp. 89-97. ISSN: 1792-9040 (print), 1792-9660 (online).
81. Troldborg, M., Aalders, I., Towers, W., and Hough, R. L. (2013). Application of Bayesian Belief Networks to quantify and map areas at risk to soil threats: Using soil compaction as an example. Soil tillage res, 132, pp. 56-68. https://doi.org/10.1016/j.still.2013.05.005
82. Li, J., Song, L., Chen, H., Wu, J., and Teng, Y. (2020). Source apportionment of potential ecological risk posed by trace metals in the sediment of the Le'an River, China. J. Soils Sediments, 20, pp. 2460-2470. https://doi.org/10.1007/s11368-020-02604-4
83. Razanamahandry, L. C., Karoui, H., Andrianisa, H. A., and Yacouba, H. (2017). Bioremediation of soil and water polluted by cyanide: A review. Afr. J. Environ. Sci.Technol, 11(6), pp. 272-291. https://doi.org/10.5897/AJEST2016.2264
84. Brown, S., and Lugo, A. E. (1994). Rehabilitation of tropical lands: a key to sustaining development. Restor. Ecol, 2(2), pp. 97-111. https://doi.org/10.1111/j.1526-100X.1994.tb00047.x
85. Wang, Y. (2004). Environmental degradation and environmental threats in China. Environ. Monit. Assess, 90. https://doi.org/10.1023/b:emas.0000003576.36834.c9
86. Ning, L., Xiao-Guang, Z., Shi-Jie, S., and Wen-Fu, Z. (2019). Effect of underground coal mining on slope morphology and soil erosion. Math. Probl. Eng, 2019, pp. 1-12. https://doi.org/10.1155/2019/5285126
87. Aryee, B. N., Ntibery, B. K., and Atorkui, E. (2003). Trends in the small-scale mining of precious minerals in Ghana: a perspective on its environmental impact. J. Clean. Prod, 11(2), pp. 131-140. https://doi.org/10.1016/S0959-6526(02)00043-4