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Navigating Soil Erosion Challenges in Malaysia: Insights, Prospects, and Solutions

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ABSTRACT: The escalating global demand for forest products, driven by economic growth and a growing population, has led to increased forest conversion activities. Forest conversion involves transforming forested areas to meet industrial demands, resulting in severe ecological consequences. This review focuses on the state of soil erosion practices in Malaysia, which is a pressing issue with wide-ranging impacts on soil health, agricultural sustainability, and the environment. Malaysia's geographical location exposes it to the El Nino phenomenon, characterized by disrupted climate patterns and altered rainfall intensities, indirectly contributing to soil erosion. During El Nino events, diminished vegetation cover, primarily due to rainfall deficits, increases soil susceptibility to erosion, emphasizing the need for adaptive erosion control measures. Soil erosion poses a significant challenge to the sustainability of agriculture and terrestrial ecosystems. Malaysia has made efforts to address this issue by implementing soil and water conservation practices like terraces, grassed waterways, strip cropping, and conservation tillage, which effectively reduce erosion rates. However, these methods face challenges due to the variations in natural erosion rates driven by extreme events. Additionally, the conversion of natural forests to economic forests remains an underexplored concern in Malaysia, hindering the development of tailored soil erosion control strategies. Addressing soil erosion demands a comprehensive approach that includes research, policy support, and empowering farmers to adopt soil conservation practices. Soil erosion affects ecosystems, water resources, and urban development, necessitating multifaceted solutions to preserve both environmental sustainability and agricultural productivity in the face of evolving environmental challenges.

KEYWORDS: Soil erosion practices; ecological consequences; el nino phenomenon; soil conservation strategies; environmental sustainability

1. Introduction

The population of Southeast Asia has steadily increased over the years. In 1985, the region was home to approximately 401.7 million people, a number that rose to 633.5 million by 2015. Projections indicate that this population will further grow to reach 724.8 million by the year 2030. This remarkable population growth has been accompanied by a notable increase in urbanization throughout the region [1]. As the population has expanded exponentially, the demand for land has naturally followed suit. In Africa, Asia, and Europe, there exists a per capita shortage of arable land. This deficiency is primarily attributable to the loss of eroded land and the continued growth of the global population, which is approaching 6 billion [2]. Soil plays a pivotal role not only in providing nutrients for agriculture but also indirectly supporting the needs of the animal population. To offer a diverse and nutritionally adequate diet to the people, it is estimated that approximately 0.5 hectares of arable land per person is necessary. However, the current availability stands at only 0.27 hectares of arable land per person. Moreover, if the present trends persist, it is projected that within the next 40 years, the availability of arable land per person will decrease to a mere 0.14 hectares. This reduction is a consequence of both land loss and the rapid growth of the population [2].

El Nino is a climate phenomenon characterized by the periodic warming of sea surface temperatures in the central and eastern equatorial Pacific Ocean. This warming typically occurs every two to seven years and can have significant impacts on weather patterns around the world. El Niño is part of the larger El Nino-Southern Oscillation (ENSO) climate pattern, which also includes its counterpart, La Nina [3]. In addition to their crucial role in mitigating climate change by absorbing substantial amounts of carbon dioxide (CO_2) from the atmosphere, forest ecosystems play a vital part in global environmental sustainability. As the global economy expands and the human population continues to grow, there is an ever-increasing demand for forest products, which has, in turn, led to a surge in forest conversion activities. The practice of forest conversion, often referred to as "economic forest," involves transforming forested areas to meet the demands of various industries. This land use change can have far-reaching and detrimental ecological consequences, as supported by extensive research. Many countries, particularly those undergoing rapid development, have witnessed a surge in both land demand and the consumption of forest products. For instance, in Northeastern China, the rising demand for wood and other forest-related goods has led to a significant expansion of forested areas since the 1960s. However, this growth has come at a cost, resulting in a multitude of ecological and environmental issues, with soil erosion emerging as a major and widespread concern [4]. Soil erosion represents a significant and pressing threat to soil health and overall environmental sustainability. On a global scale, the annual loss of soil is estimated at approximately 2.8 metric tons per hectare. This rate of soil loss greatly outpaces the rate of soil formation, which stands at roughly 1.4 metric tons per hectare per year in Europe [5]. These concerning statistics underscore the urgency of addressing soil erosion and its associated impacts on the environment.

Erosion encompasses a set of surface processes involving factors like wind or water flow. These processes act to displace soil, rock, or dissolved materials from a specific area on the Earth's crust and subsequently transport them to different locations, where they are deposited as sediment [6]. Among the various forms of erosion, water-induced soil erosion stands out as a widely recognized and significant threat to soil quality and functionality [7]. Water-induced soil erosion is particularly concerning as it leads to the depletion of fertile soil from cropland. While the presence of vegetation can help alleviate this problem, various human activities have contributed to its exacerbation. Factors such as deforestation for urbanization, industrialization, and overgrazing have all played roles in the increased occurrence of soil erosion in recent years [8]. This has translated into a significant loss of valuable topsoil, which is essential for agriculture and maintaining soil health. It is worth noting that the impact of water-induced soil erosion is not limited to specific regions. Instead, it is a global issue that affects numerous countries, further highlighting the widespread nature of this problem and the urgency for effective conservation and soil management practices [9]. Addressing water-induced soil erosion is vital not only for safeguarding agriculture but also for maintaining the overall health and sustainability of our environment.

Furthermore, soil erosion is influenced not only by natural phenomena, such as wind and water flow but also by anthropogenic activities. As defined by Kuwabara et al. [10], soil erosion encompasses the loss of topsoil due to a combination of natural factors and human activities, often driven by socioeconomic development. In this context, Malaysia is currently experiencing a surge in large-scale physical developments, including land-clearing activities. Unregulated land clearing can lead to excessive erosion and sedimentation, particularly when soil surfaces remain exposed without adequate vegetation cover. Rapid urbanization and economic growth, which are key drivers of these development activities, can significantly exacerbate soil erosion. This issue is not unique to Malaysia; it is a prominent global environmental concern that the country also grapples with. Moreover, Malaysia's tropical rainforest climate makes water-induced soil erosion a critical form of soil degradation, particularly due to the frequent occurrence of heavy rainfall events [10]. The objective of this review is to provide a comprehensive assessment of the current status, future prospects, challenges, existing government policies, and other environmental considerations related to soil erosion practices in Malaysia.

2. Current Status

Important factors contributing to soil erosion in Malaysia is shown in Figure 1. Over the past four decades, approximately one-third of the world's arable land has been lost due to soil erosion, and this trend continues with a yearly loss rate of more than 10 million hectares [2]. The desire to decrease labour needs has been the driving factor behind the adoption of agricultural mechanization and the use of machines in agriculture has been a significant advancement in developed countries as the growing population requires a higher production of agricultural goods. Mechanization has not only reduced the physical strain of farm work, but also increased productivity per worker [11]). The cultivation of rice is prevalent throughout Malaysia, covering an extensive area of approximately 600,000 hectares. Over time, there has been an expansion in the area dedicated to rice cultivation by 3.8%, coupled with a rise in rice production by 19.6% [12]. The process of tillage involves using mechanical means to shape the soil for the purpose of creating an ideal surface structure for planting, irrigation, drainage, harvesting, and other related operations. Studies have shown that tillage can decrease the concentration of organic matter in the soil and increase the rate at which organic matter is broken down, although the extent of this effect can vary [13]. Moreover, conventional farming methods incur significant expenses related to multiple tillage operations, labor-intensive crop establishment, and frequent irrigation, resulting in poor returns on investment for farmers [14].

Soil erosion is considered to be a highly critical and prevalent type of soil degradation, and therefore, it presents a significant challenge to the sustainability and productivity of agriculture and terrestrial ecosystems. In order to minimize the environmental and social impacts of soil erosion on agricultural land, it is essential to provide farmers with policy options like technical support and educational resources to encourage them to adopt soil conservation practices [15]. Soil productivity decline due to erosion poses a significant obstacle to sustainable soil management on a global scale. Additionally, the redistribution of soil particles and nutrients can have adverse effects on neighbouring ecosystems. Soil erosion leads to additional economic burdens for farmers, such as higher fertilizer usage, which has been calculated to be around 115 billion US dollars per year for Nitrogen and Phosphorus fertilizers [7].

The floods have led to soil erosion, which will have a dual effect on natural resources. The erosion caused by the floods has resulted in environmental damage, and in most cases, it has led to a decline in water quality due to the deposition of sediment in various bodies of water, including waterways, streams, rivers, lakes, and reservoirs [16]. Approximately 60% of soil that undergoes erosion is transported into rivers, streams, and lakes, leading to increased risk of flooding and contamination of these bodies of water by fertilizers and pesticides. Besides, due to ongoing and future developments, Penang Island is facing pressure for agricultural and urban expansion, especially in hilly areas. As a consequence, various environmental problems such as deforestation, destruction of water catchments, endangered wildlife, soil erosion, landslides, water pollution, sedimentation, and downstream flooding have emerged. Furthermore, hill land development in Penang Island has resulted in high rates of soil erosion and landslides, posing environmental hazards in many parts of the hill slopes over the past few decades [17].

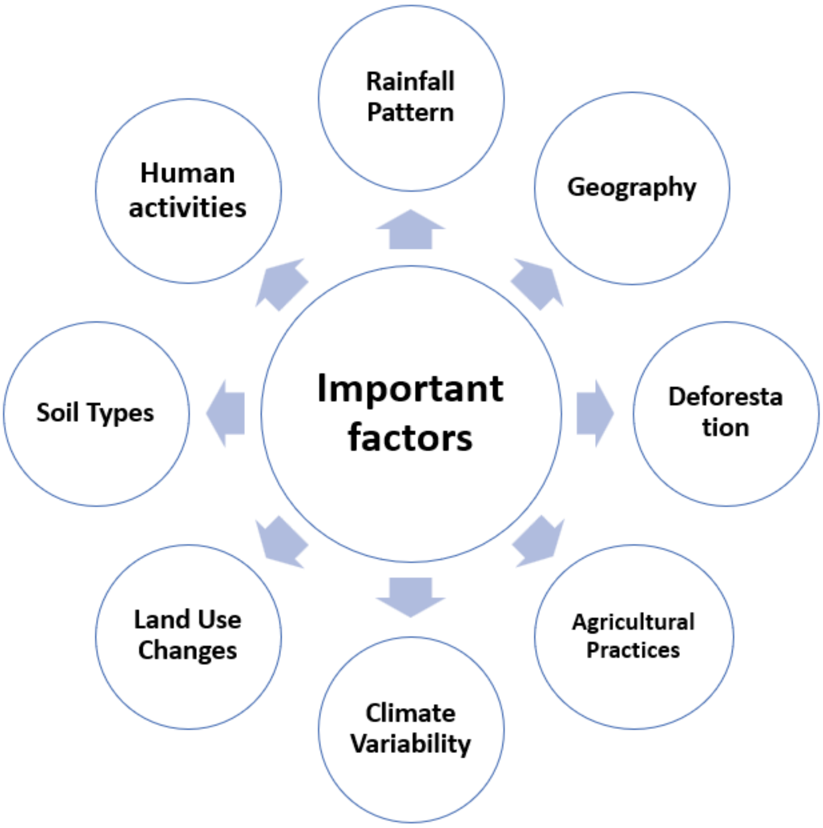

Figure 1. Important factors contributing to soil erosion in Malaysia.

3. Prospect and Challenge

Malaysia can enhance soil conservation by adopting modern practices like terracing, conservation agriculture, and no-tillage methods. These methods offer potential for reducing soil erosion and improving soil quality, promoting sustainable agriculture while mitigating environmental harm. The prospect and challenge of soil erosion control in Malaysia is shown in Figure 2.

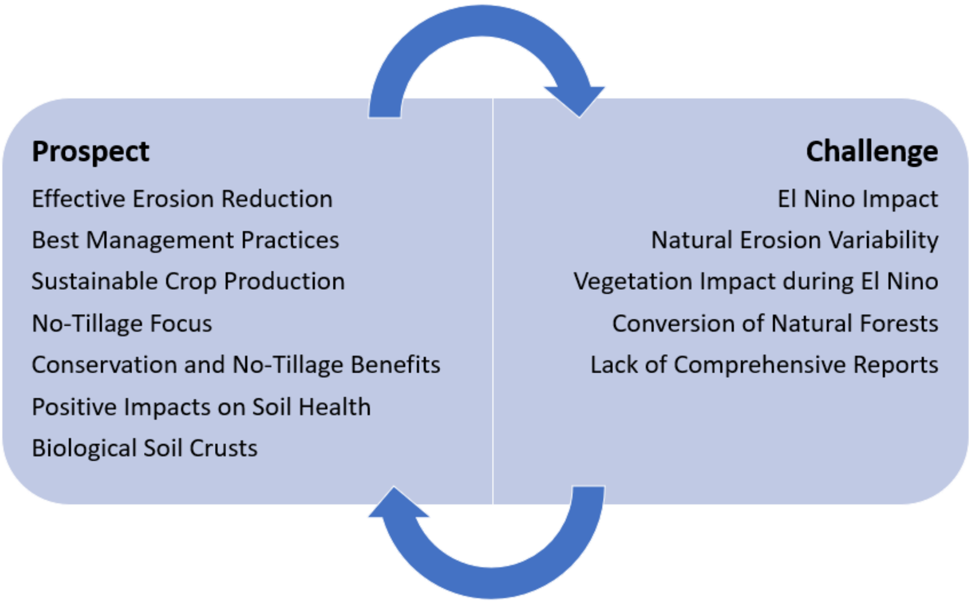

Figure 2. Prospect and challenge of soil erosion control in Malaysia.

3.1.Prospect.

The implementation of numerous soil and water conservation and management practices, including terraces, grassed waterways, strip cropping with fewer row crops in the rotation, and conservation tillage methods such as no tillage, can effectively reduce soil erosion [16]. The existing Best Management Practices for soil erosion control comprise of techniques such as ground covers, slope drains, silt fence, blankets, and plastic covers. These methods can be effective if implemented and designed appropriately. However, they can be costly, environmentally unfriendly, and temporary in certain cases [10]. Research findings indicate that alterations in land use, haphazard urban development, and unsustainable agricultural practices have contributed significantly to the degradation of river water quality in the Cameron Highlands. It is imperative to enhance the enforcement of existing laws and regulations to mitigate the impact of intensive agricultural activities on the pristine landscapes of the highlands while simultaneously safeguarding the welfare and productivity of local farmers. The natural areas in the highlands play a pivotal role in providing essential ecological services for both humans and the environment. Therefore, prioritizing environmental conservation is essential to guarantee the long-term sustainability of the region and prevent the depletion of valuable ecological resources [18].

Conventional farming practices involving excessive tillage have been found to cause soil and environmental degradation. As an alternative and sustainable crop production system, conservation agriculture has emerged [18]. Conservation agriculture aims to prevent the decline in soil quality, crop productivity, and resource use efficiency. Numerous experiments from various regions have indicated that conservation agriculture can provide short-term benefits such as lower production costs, reduced erosion, stabilized crop yield, improved water productivity, and adaptation to climatic variability, as well as long-term benefits such as higher soil organic carbon and enhanced soil quality. Implementing diverse agricultural practices, such as crop diversification, agroforestry, and water-efficient technologies, can enhance resilience to fluctuating climatic conditions. Robust early warning systems, farmer education, and community engagement are essential. These strategies collectively bolster adaptive capacity, ensuring agricultural sustainability and productivity in the face of climate variability [14].

Currently, greater attention is being placed on implementing no-tillage methods in order to preserve soil and water resources and sustain soil productivity. The type of tillage system used can have significant impacts on the process of ammonia volatilization [18]. Conservation and no-tillage practices have been shown to be more effective than conventional tillage methods in conserving soil organic matter, reducing soil erosion, increasing soil infiltration, enhancing aggregate stability, and promoting microbial biomass [19]. Based on Yasnolob et al. [20], outlined several benefits of minimum tillage, including the enhancement of soil structure and firmness, the prevention of soil compaction and plough pan formation, the reduction of soil aeration that can disturb humus, the promotion of soil microorganisms and dew worms, the reduction of waterlogging and surface runoff, the improvement of water filtration during heavy rainfall, and the protection against rain and wind. In addition, it facilitates water supply from deeper soil layers in arid conditions. The implementation of conservation tillage practices presents a favorable chance to mitigate soil depletion and enhance soil productivity [14]. Conservation tillage is a form of tillage that causes minimal disturbance to the soil. Conservation tillage is frequently employed in expansive farming operations that require the use of machinery for cultivation. With rising fuel expenses, as well as an emphasis on sustainable agriculture, farmers are seeking to transition from traditional tillage methods and explore more cost-efficient alternatives [21]. Conservation tillage provides several advantages, such as increased retention of surface water, higher organic matter concentration in soil, improved fertilizer utilization, and protection against soil erosion due to wind and water [22]. The practice of conservation tillage can aid in preserving soil moisture as the soil is denser, allowing for less water and soil nutrient leaching, resulting in improved crop growth. In light of the pressing concerns of erosion prevention and water preservation in different parts of the world, conservation tillage has gained significant attention in recent times [21]. Utilizing conservation tillage techniques for crop establishment and retaining crop residues are viable and sustainable methods to increase the productivity and profitability of crop rotations based on rice [14].

Besides, one of the approaches of soil erosion control practice in Malaysia is through the creation of a biological soil crust (BSC or biocrust) in the specific area, which consists of diverse organisms such as algae and fungi that live on the soil surface. The development of BSC can aid in the stabilization of soil, protection of topsoil from erosion caused by water and wind, as well as maintenance of soil moisture. While biological soil crusts can be found on every continent, research on their occurrence in tropical environments is still scarce [10]. Based on Yoshitake et al., the biological soil crust, which is a community of various organisms including cyanobacteria, algae, lichens, mosses, fungi, and bacteria, is present on soil surfaces around the world, particularly in arid and semi-arid areas. Biological soil crusts (BSCs) typically comprise initial organisms that colonize the surface and subsurface of the soil. They play an essential role in stabilizing otherwise mobile surfaces by binding soil surface particles and providing protection from erosion due to wind and water, as well as cryoturbation [23]. Aside from their physical roles, BSCs also have significant contributions to ecological processes in regions with warm and temperate climates. One instance of the functions of BSCs is that in desert ecosystems, nitrogen fixation carried out by cyanobacteria and cyanolichens found in the biological soil crusts (also called microbiotic, cryptobiotic, or microphytic crusts) can be the primary source of nitrogen [24]. Biological soil crusts (BSCs) have been identified as having significant photosynthetic ability and are considered a significant carbon reservoir [23]. The presence of a large number of photosynthetic organisms, even if in a thin layer, can significantly contribute to carbon fixation, particularly in regions such as the Negev desert where primary productivity is limited [25]. Besides, the formation of BSC during the initial stages of primary succession provides a favorable environment for the growth and establishment of plants by enhancing the moisture and nutrient levels of the soil, thus promoting vascular plant succession. For example, biological soil crusts contain organisms that improve soil water retention and nutrient content, and studies in temperate deserts have shown that they can increase the uptake of specific essential elements by plants. [26].

3.2.Challenge.

Malaysia's geographical location in the western part of the Pacific Ocean makes it susceptible to the El Nino phenomenon. El Nino, characterized by weakened trade winds and warmer sea surface temperatures, disrupts normal climate patterns [3]. It indirectly contributes to soil erosion by altering rainfall patterns and intensities. The increased likelihood and severity of erosion during El Nino events pose a significant challenge for soil erosion control practices in Malaysia. Soil erosion is influenced by natural factors and is typically at its lowest in hyper-arid and arid regions. However, this does not make Malaysia immune to erosion. The rates of natural erosion can vary significantly due to extreme events, including warm El Nino-Southern Oscillation (ENSO) conditions or earthquakes [27]. These variations in natural erosion rates can complicate soil erosion control efforts. During El Nino events, Malaysia experiences reduced vegetation coverage and vegetation stress, primarily due to a lack of rainfall. El Niño events in Malaysia exert distinct impacts on vegetation cover and soil conditions, primarily through altered precipitation patterns and elevated temperatures. During El Niño, the country experiences reduced rainfall, leading to water stress for vegetation and diminished soil moisture content. This water deficit adversely affects the health and growth of both natural ecosystems and agricultural crops. Increased temperatures exacerbate evaporation, further contributing to soil desiccation and reduced fertility. The combination of these factors often results in a decline in overall vegetation cover, impacting forests, grasslands, and cultivated areas. Prolonged dry conditions heighten the risk of wildfires, posing threats to biodiversity and agricultural productivity. Localized variations in topography and land use patterns contribute to diverse impacts, necessitating region-specific assessments and adaptive measures. Addressing the consequences of El Niño on vegetation and soil conditions is crucial for sustainable land management and agricultural resilience in Malaysia [28]. Reduced vegetation cover can make soils more susceptible to erosion. This challenge underscores the need for effective erosion control measures, especially during El Nino events.

The conversion of natural forests to economic forests can result in significant environmental consequences. However, comprehensive reports quantifying the specific impacts on soil erosion, soil organic carbon (SOC), and total nitrogen (TN) in Malaysia are notably absent [3]. This knowledge gap is a challenge because it hinders the development of targeted soil erosion control strategies in areas affected by such land-use changes. The lack of comprehensive studies quantifying the effects of land-use changes on soil erosion, SOC, and TN makes it difficult to assess the full extent of the problem and develop tailored soil erosion control practices. It highlights the need for more research and data collection to address this environmental concern. The El Nino phenomenon often occurs every few years in the tropical Pacific Ocean region and Malaysia is also affected due to its location in the western part of the Pacific Ocean. The El Nino phenomenon is an extraordinary cycle of atmosphere and ocean characterized by weakened trade winds, warmer than normal sea surface temperatures moving towards the eastern equatorial Pacific [3]. This phenomenon can contribute to soil erosion indirectly by altering rainfall patterns and intensities, which can increase the likelihood and severity of erosion. The rates of natural erosion are typically the lowest in hyper-arid and arid regions, but they can still fluctuate significantly due to extreme events, particularly warm El Niño-Southern Oscillation (ENSO) conditions or earthquakes [27]. Besides, based on Juan et al., reduced vegetation coverage and vegetation stress was seen during El Nino events due to the absence of rain [28]. There is a notable absence of comprehensive reports that have quantified the effects of converting natural forests to economic forests on soil erosion, soil organic carbon (SOC), and total nitrogen (TN) [4]. This is a significant environmental concern that requires further attention and investigation.

4. Conclusion

Malaysia's experience with soil erosion offers insights into the prospects and challenges of managing this global issue. While the adoption of modern soil conservation practices, such as terracing and conservation agriculture, holds promise for mitigating erosion and enhancing soil quality, it's not without challenges. The recurring El Nino phenomenon disrupts rainfall patterns and intensifies soil erosion in Malaysia, highlighting the need for adaptive control measures. Furthermore, the conversion of natural forests to economic forests remains an understudied environmental concern, hindering the development of tailored erosion control strategies. Nonetheless, addressing soil erosion is crucial for agricultural and environmental sustainability. Measures like terracing and conservation tillage are valuable tools, and a data-driven approach with research and policy support is essential. Soil erosion affects ecosystems, water resources, and urban development, making it a multifaceted concern demanding multifaceted solutions. Malaysia's investment in effective erosion control practices and research is crucial for sustainable soil management in the face of evolving environmental challenges. Research should focus on understanding the specific impacts of El Niño on soil erosion patterns in different Malaysian regions, developing adaptive strategies and early warning systems. Policy interventions should address the understudied issue of natural forest conversion to economic forests, with a focus on balancing economic interests and environmental sustainability. Educational programs should target farmers and local communities to promote the adoption of conservation practices, emphasizing the importance of terracing and conservation tillage. These multifaceted efforts, supported by a data-driven approach, are crucial for Malaysia's sustainable soil management amidst evolving environmental challenges.

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