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REVIEW ARTICLE

EVALUATING THE IMPACT OF GEOLOGICAL FEATURES IN SHAPING BIODIVERSITY AND ECOSYSTEM HEALTH

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ABSTRACT

This review aims to critically examine perspectives on the impact of geological features and processes on the health of ecosystems and biodiversity in general. This is owing to the contextual evidence presented by several researchers that there is a significant correlation between geological features and the interactions and processes within ecological systems. To achieve this aim, the review seeks to answer some scholarly questions which are: how geological features influence the richness and distribution of species, how ecosystem processes are improved by geological features, and ways in which geological features serve as indicators of ecosystem and biodiversity health. The methodology adopted for this study was the desk research method, particularly the narrative review. Through this method, a total of 40 studies were identified from relevant databases. However, about 25 studies were finally selected for this narrative review. The studies reviewed unanimously examined ways through which geological features like landforms, tectonic and geomorphological barriers, and rock formations have significantly impacted species richness and distribution as well as ecosystem processes. The literature also indicates how these geological features reflect on the health of ecosystems. Finally, the study recommends that global environmental management experts and geoecologists should integrate geological knowledge into ecosystem management strides for improved outcomes. Specifically, this review proposes the adoption of GIS and remote sensing technologies, sensor systems and the innovation of soil spectroscopy to advance ecosystem management.

KEYWORDS

Geological, ecological systems, biodiversity health, geomorphological barriers

1. INTRODUCTION

1.1 Background to Study

According to a study by Spash and Aslaksen (2015), the discourses of biodiversity and ecosystem health are often made or proposed within climatological or biological frameworks. In fact, these frameworks usually provide the basis for which professionals tackle the issues of biodiversity change and ecosystem deterioration (Spash and Aslaksen, 2015). However, research by a group of researchers posits that geological features have a significant correlation with ecological interactions and systems (Hu et al., 2020). These features not only influence ecosystem processes but also provide the contextual basis for gaining understanding into ecological interactions. For instance, as Saidov et al. (2024) expounds the properties and composition of geological features like rocks and soil can determine the availability of nutrients and the degree of vegetation cover on such soil. In addition to this, Saidov et al. (2024) also cites that the topography or landforms of an area determines, to a significant extent, the climate system of the area as well as the species distribution within it. One important area of consideration by Hu et al. (2020) is that geological features significantly influence the richness and distribution of species. In Hawaii's volcanic islands, the mountainous terrain and the rain shadow effect of this area has led to several microclimates that support distinct plant and animal species like Nukupuu, Nene and Ko'oloa'ula, most of which are endemic to this area. These regimes thus authenticate the research findings in Perkins et al. (2018). Hu et al. (2020) equally underscores that geological features enhance ecosystem processes. This is why features such as soil profiles are responsible for enhancing ecological processes like nutrients cycling and root growth, or for determining others like erosion. Based on this understanding, this research is a review article that aims to investigate the significant impacts of geological features such as landforms and geomorphological barriers on biodiversity and ecosystem health and processes.

1.2 Research Questions

The following constitutes the research questions that this review attempts to provide answers to:

- How do geological features influence the richness and distribution of species?
- How are ecosystem processes improved categorically by geological features?
- In what unique ways can the health of ecosystems and biodiversity be measured using geological features?

1.3 Definition of Operational Terms

Some operational terms used within the context of this review paper are explained below:

Geological Features: These refers to physical and natural characteristics of the earth's surface and the layers beneath the surface. These features include landforms such as mountains, rocks and minerals like granite and gold, landscapes like forests, swamps and grasslands, and tectonic barriers such as faults, folds and canyons.

Biodiversity: Biological diversity, or biodiversity for short, are the variety of animal and plant species (otherwise called fauna and flora species) as well as the heterogeneity of ecosystems within which they flourish. Recent studies assert that biodiversity also includes the genetic diversity that exists within species (Díaz and Malhi, 2022).

Ecosystem Health: The health of an ecosystem denotes the total condition and status of such an ecosystem in its natural ability to enhance ecological

processes, support unique biodiversity, and provide essential services. Many scholars also describe ecosystem health as the capacity for an ecosystem to recover from disturbances from external forces (Giraudoux, 2022).

2. Methods Of Research

The research design adopted in this review paper is the desk research method, specifically the narrative review. According to a study, the desk research method is a research method that involves gathering insights and making inferences from existing studies or secondary sources (Topolewski et al., 2023). The justification for the use of this type of research method is that it offers access to existing data and research while helping to identify areas for further research (Topolewski et al., 2023). Through this method of research, the study identified and summarised existing literature that correlated with the research questions. To identify relevant studies, the research utilised keywords and combined them with boolean operators for search on several research databases including Google Scholar, ScienceDirect, ResearchGate, Springer and Web of Science. A total of 40 studies were identified from these databases. However, after the studies were evaluated against the inclusion and exclusion criteria, about 25 studies were selected for this review. The inclusion criteria involved articles that relate to the research variables and are published in the English language, from 2015 till date. The study also applied strict exclusion criteria to remove studies that were not published in the English language or that had poor methodology.

3. Impact Of Geological Features On Species Richness And Distribution

3.1 Landforms and Mountain Systems

According to a study by Salminen et al. (2023), mountain systems and other landforms like plateaus and valleys have a significant impact on the richness and distribution of species. To expound on this further, Salminen et al. (2023) asserts that these geological features create diverse habitats on different heights above sea level with differing climatic conditions. These diverse habitats support different species that can adapt to these varied conditions. For instance, mountain systems have vertical layering of thermal level, altitude and flora, and thus, support different species from its base to its peak. Research by Khalefa et al. (2024) explains that at the base of most mountain systems such as Mount Kilimanjaro, the elevation level and resulting climatic conditions supports tropical rainforest. However, 4,000 meters above sea level, close to the peak, there is an abundance of alpine desert zones (Khalefa et al., 2024). According to another study, during changes in climate such as in glacial periods, lowland fauna species tend to migrate to the upper lands of mountain systems to escape colder conditions (Salminen et al., 2023). Their migration, as Hughes and Atchison explains, creates isolated species at the base which may evolve into new species through a process called adaptive radiation (Hughes and Atchison, 2015). Other landforms like valleys, on the other hand, have diverse ecosystems with rich fertile soils and moderate climatic conditions to sustain grasses, crops and trees like willows and alders, among others (Khan et al., 2022). These landforms also support fauna species like primates, carnivores, ungulates and marsupials (Chester et al., 2015). The Kathmandu valley in Nepal demonstrates this heterogeneity since it supports diverse habitats and the different species within such habitats. Due to the dry and harsh conditions of plateaus, they often offer an ideal condition for drought-resistance species like cacti, desert-shrubs and camels, scorpions and horned lizards (Chester et al., 2015). This is because the extreme and changing temperatures, rocky and elevated terrain, and sparse vegetation of this type of landforms has caused these species to develop adaptive features for water conservation such as dormancy during dry conditions, specialised skin and deep roots for groundwater access (Hughes and Atchison, 2015; Khan et al., 2022).

3.2 Tectonic and Geomorphological Barriers

According to Blenkinsop and Moore (2013), tectonic and geomorphological barriers are natural obstacles or features that are created by plate movements, volcanic activities or even faulting. These processes, from Blenkinsop and Moore's (2013) description, lead to the formation of canyons, islands, fault lines and glaciers. Research reveals that tectonic and geomorphological barriers have a significant impact on the richness and distribution of both flora and fauna species (Couvreur et al., 2021). A group researcher observes that tectonic landforms like islands isolate its species populations from those of the mainland, thus initiating the process of speciation (Pellissier et al., 2018). Through this process, species on the islands become endemic to the landform, evolve smaller or bigger body size, develop specialised traits and loose traits that are no longer necessary for their survival (Pellissier et al., 2018). An example of this is the Galápagos Islands where there are several endemic and giant tortoises that are sustained within the unique ecosystems. A study by Couvreur et al. (2021) asserts that geomorphological barriers like canyons and fault lines restrict the migration of species, therefore shaping species patterns within the geographic area. By restricting gene flow and causing habitat fragmentation, canyons lead to genetic differences and species divergence on both sides of the divide (Pellissier et al., 2018). This is true for some geomorphological features like the Grand Canyon in the US where experts claim that the Kaibab squirrel evolved on one side of the canyon as a subspecies of the Albert's squirrel after thousands of years of geographical isolation by the barrier (Bono et al., 2018).

3.3 Geological Substrates and Rock Formations

According to Nitzu et al. (2018), geological substrates, which refers to the underlying rock or soil constituting an area, has a significant influence on the richness and distribution of species in a given geographical region. For the first part, research asserts that sedimentary rocks and soils in limestone regions often host highly alkaline soils that are quite ideal for the growth and richness of certain specialised flora species like fig trees, cherry trees, lavender and even asparagus (Nitzu et al., 2018; Sharma et al., 2025). This resulting flora attracts an abundance and a distribution of fauna like fruit bats, white-tailed deer, finches and various insects (Sharma et al., 2025). Studies also note that islands in Hawaii and the Galápagos Islands that are made up of rocks formed by volcanic activities have been observed to release high amounts of nutrients like potassium and calcium (Perkins et al., 2018; Mihai et al., 2023). The soils of these islands have high fertility because of these nutrients and are able to host diverse vegetation such as ferns, orchids and several other kinds of flora (Mihai et al., 2023). A group researcher also agrees that several species of iguanas and lizards like skinks are also endemic to these geological features because of the type of vegetation that are common there (Arteaga et al., 2019).

4. Impact Of Geological Features On Ecosystem Processes

4.1 Nutrient and Watercycle Regulation

Research by Rempe and Dietrich (2018) indicates that geological features have a significant impact on the availability and composition of nutrients, as well as the distribution of water within an ecosystem. In fact, the type of rocks determines the nutrient composition and water retention capacity to a great extent (Rempe and Dietrich, 2018). Volcanic rocks, for example, are rocks that are generally rich in nutrients such as potassium and calcium because the alkaline and calc-alkaline magmas that feed volcanic eruptions are rich in these nutrients (Mihai et al., 2023). Thus, islands like the Galápagos with this type of rocks have highly fertile soils. According to Zimmer and Gannon (2018), geological features like mountains and hills also regulate ecosystem processes like water cycles by affecting the patterns of surface runoff, often allowing rainwater to settle in the valleys and provide water for downstream ecosystems. Moreover, as moist air rises from downstream along mountain slopes on the windward side over the top to descend on the leeward side, it results in orographic rainfall (Zimmer and Gannon, 2018). This way, these landforms cause intense precipitation which ensures availability of water. It is also important to note that water infiltration in soils with underlying impermeable rocks may be limited due to the nature of the rocks, thus inhibiting soil moisture level (Rempe and Dietrich, 2018).

4.2 Modulation of Hydrological and Biogeochemical Balance

According to the empirical study by Rempe and Dietrich (2018), geological features have a strong influence on the modulation of biogeochemical and hydrological balance in the ecosystem. In fact, this impact, according to a study by Smith et al. (2015), is as a result of the interaction between these geological features and some processes of biological nature. An example of this is how certain types of soils can impact the oxygen cycle in an ecosystem. As described by Kotiyal and Gupta (2024), some soils in certain areas are made up of granite rocks and substrates. The fertility of these soils are considerably very low due to the high level of acids deposited in it by the rocks. This in turn leads to low vegetation cover which causes low rate of photosynthesis and reduced production of oxygen within the ecosystem (Kotiyal and Gupta, 2024). Rempe and Dietrich (2018) earlier cited also posits that geological features have a direct impact on the modulation of hydrological processes like infiltration and percolation. According to this study, porous rocks facilitate percolation from rainfall and increase filtration as well as groundwater volume (Rempe and Dietrich, 2018). On the other hand, non-porous and compacted rocks restrict infiltration, causing increased erosion and limited groundwater recharge (Smith et al., 2015).

4.3 Ecosystem Renewal and Resilience

In a study by Ma (2024), it is explained that ecosystems undergo regular and consistent renewals to enhance their resilience. These renewals are

demonstrated through the regeneration of soils, emergence of disturbance-adaptive species and habitat resuscitation (Ma, 2024). There is considerable evidence that proves that geological features have a significant influence on the renewal and resilience of ecosystems. According to Mihai et al. (2023), geological features like landforms created by volcanic eruptions and massive landslides are noted to contain introduced but rich nutrients and minerals that support the growth and development of certain plants. Thus, through the growth and richness of these plants, the ecosystem gradually repairs itself and restores its functions (Mihai et al., 2023). The process of erosion and sedimentation is another geological process that ensures that ecosystems are renewed. According to Rathburn et al. (2018), through this process, particles of soil alongside its nutrients are carried by erosion agents such as wind, water and ice etc, and redistributed into other areas. Constant erosion and sedimentation means that the soils in such areas are continuously renewed (Rathburn et al., 2018). Moreover, it is important to understand that geological heterogeneity, evident in the variations of rocks and landforms within a given ecosystem, provide protection, habitat and ideal ecological conditions for resisting the shock of environmental stressors.

5. Geological Features And Processes As Indicators Of Ecosystem Health

5.1 Geophysical Parameters as Ecological Indicators

In the aspect of ecosystem health, research suggests that geological features like geophysical parameters are significant indicators. A critical consideration of research by Raza et al. (2015) and Gatica-Saavedra et al. (2017) proves that such geophysical parameters like groundwater levels, mineral and nutrient composition of soils, acidity of soils and temperature, among others, can accurately point to the condition of an ecosystem. Thus, in this direction, soils rich in nutrients and organic matter as well as high levels of groundwater are actually indicators of good ecosystem health. On the other side, soils with crustings and cracks or low water levels could indicate that an ecological system is experiencing drought stress (Gatica-Saavedra et al., 2017). Further research also concurs to this empirical perspective that geophysical parameters are ecological indicators (Raza et al., 2015). In like manner, Bello et al. (2025) maintains that within wetland ecosystems, stable groundwater levels are necessary for maintaining the ecological conditions of these ecosystems and shows that ecological processes are functioning properly. However, reduced levels of groundwater could well indicate an imbalance in the hydrological system of such ecosystems (Bello et al., 2025). This can help to identify underlying issues within the environment.

5.2 Sedimentation and Erosion Patterns as Ecological Indicators

According to research, it is important to mention that patterns of sedimentation and erosion are geological processes that can be used as indicators to determine the health of the ecosystem (Jiang et al., 2025). Firstly, it is worth mentioning that the intensity and factors of these geological processes can provide insights into an ecosystem's quality of water, habitat, changes in climate and changes in water cycle, which all have a bearing on the health of the ecosystem (Owens, 2020). Secondly, group researcher postulates that when anthropogenic factors like deforestation and urbanism act on these geological processes, the equilibrium within which they occur could be disrupted, and the ecosystem could be affected (Jiang et al., 2025).

Thus, these processes directly reflect on the health of the ecosystem. A study by Zhang et confirms that excessive sedimentation of rock particles within an ecosystem's bodies of water can indicate poor quality of water. This is because the rate of deposition of particles within the stream or river is high, and these particles may be pollutants that can harm the aquatic diversity in the water (Zhang et al., 2021). In the same direction, an inquiry by Owens (2020) also maintains that frequent and intense erosion within an ecosystem may be proof of land degradation. Of course, this is clearly because erosion can directly instigate the removal of fertile soil, the loss of vegetation cover and other negative effects (Owens, 2020). All these can indicate the health of the ecosystem.

5.3 Geological Alterations as Ecological Indicators

Some researchers apprise that geological alterations like volcanic eruptions, earthquakes and weathering can indicate a lot about an ecosystem and its health (Carrillo and Díaz-Villanueva, 2021). Volcanic activities, according to such researchers indicate that there is a high level of nutrient or geochemical cycling phenomena going on within a mountain ecosystem (Carrillo and Díaz-Villanueva, 2021). This is largely because volcanic eruptions release certain minerals and nutrients like nitrogen, magnesium, phosphorus, iron and potassium into surrounding areas (Blenkinsop and Moore, 2013). Thus, such volcanic activities indicate that an ecosystem will have an abundance of minerals to support plant growth, and thus, impacts on the fertility of such an ecosystem. According to a study by Jafarpour et al. (2024), earthquakes can also indicate geological instability within the crust of an ecological system. Such insights on the dynamic nature of an ecosystem's crust can emphasise the possibility of reoccurrence and continuous disruptions of ecosystem functions (Jafarpour et al., 2024). Moreover, the occurrence of earthquakes can mean that an ecosystem's soil is quite unstable and would indicate the possibility of erosions and landslides happening often. Therefore, these studies attest to the significant role that geological alterations play as indicators of ecosystem health.

6. Conclusion And Recommendations

6.1 Summary of Key Findings

This study has critically investigated the significant impacts of some geological features on biodiversity and ecosystem health and processes. As shown within this review, several studies have agreed with the understanding that specific geological features like landforms, mountain systems, tectonic and geomorphological barriers, geological substrates and even rock formations have a significant impact on the richness and distribution of different species within diverse ecological systems. Research reviewed within this study has also adequately indicated that these geological features significantly impacts ecosystem processes like renewal and restoration of habitats and systems, the modulation of hydrological and biogeochemical processes as well as nutrient and water cycle regulation. Finally, the study has analysed the perspectives of existing literature on how geological features and processes serve as natural indicators of ecosystem health. Thus, this review confirms categorically that geological knowledge is instrumental for the management of these ecological systems.

6.2 Directions for Further Research

This research has clearly discussed literature on the impact of geological features on ecosystem health and processes. However, future studies and research should focus on providing empirical knowledge on how geological principles should be integrated into ecological management strides for ecosystem protection. There is also a need for longitudinal studies to consider how current geological features and processes affect the ecosystem over an extended period of time. Such studies will help geoecologists to track ecosystem changes caused by geological features and processes over a period of time in order to more effectively reverse negative ecosystem changes. It is also imperative that future researchers explore how geological and ecological knowledge can be combined to restore unique habitats, prevent soil degradation and mitigate the impacts of natural hazards.

6.3 Integrating Geology into Ecosystem Monitoring: Recommendations for Environmental Management

As highlighted within this review, geological knowledge can be integrated efficiently into ecosystem monitoring frameworks for sustainable environmental management. To that extent, this review recommends the following for environmental stakeholders and geoecologists;

- Remote sensing and geological modelling technology should be adopted for use by ecosystem experts to map and monitor geological features and processes and determine their impacts on ecosystem health and processes. This will help to reverse negative ecosystem changes on time.
- The use of soil spectroscopy should be encouraged globally to help geoecologists and other environmental experts to conduct rapid soil analysis to detect nutrients availability and any presence of pollutants.
- Sensor systems should be installed across dynamic geological features like volcanic mountains and unstable landscapes to help with real-time monitoring of these parameters. This will give experts the opportunity to detect anomalies on time and respond immediately to ecosystem threats.

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