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Papers

Advancing perspectives in geomorphology – An apotheosis to sustainable natural spaces and eudaemonic citizenry in the 21st century

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Abstract

Geomorphology deals with analysis of geo features that occur in a spatial array and develop over a temporal frame. In modern times investigations in geomorphology have progressed with the application of concrete theories of pure geomorphology and techniques of applied geomorphology for modelling future interpolations and projections affecting the Earth's natural systems. The scale and temporal frame of landform alteration by climate-induced processes (flowing water, glaciers, wind and marine processes) are important indicators of climate change. The integration of applied studies in natural processes and their probable impact on social milieu now requires greater accuracy. The subfields of geomorphology all have now developed multidisciplinary nature and effectively are being integrated in investigations with trans-disciplinary scope. The rapid progress in digital mapping capacities helps to monitor and assess geomorphic processes and estimate their impact on citizenry with precision. Digitization in cartography facilitates and mitigates disaster management in an integrated manner. Adequate planning and budgetary allocations for disaster management by planners and policy makers are simplified. This paper discusses the recent development of latest sub -disciplines in geomorphology, discussing how broad its scope has developed to cater to societal welfare that aims at millennium sustainable development and contented citizenry.

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INTRODUCTION

The growing concern in the millennium about a deteriorating natural environment, desertification, contamination and excessive extraction of groundwater, reduced groundwater recharge due to concretization, effect on food security as a result of reduction in arable land environment sustainability studies have gained critical attention. Previously in Earth studies, there was only a mono-disciplinary approach to investigate landforms and landscape genesis. It was common knowledge-all geomorphic features develop through physical processes operating on the lithosphere and these processes are driven by beneath and above the surface energy systems. The recent approaches to the subject of geomorphology have undergone a shift, integrating ideas and concepts from multiple disciplines. Geomorphology is useful not only for understanding the surface evolution of Earth, but of other solid planetary bodies as well (REALE, 2021). The emphasis now is on a multidisciplinary approach to address and solve problems in the environment that can slow down global warming and a host of environment-related problems on Earth. In common with other earth sciences, geomorphology has made rapid progress during the 1960s, greatly altering its techniques, concepts, and aims. (DRURY, 1972). Modern methods like geospatial technology and digitization in cartographic methods, precision techniques are employed to investigate processes and create prediction models. The areas covered are fluvial geomorphology (flood hazards, siltation, sediment load, changing river courses), arid zones (land degradation, desertification, dunes), semi-arid zones (land degradation, encroachment by desert sands, deforestation) the humid tropics (floods, rainfall prediction models for slope, runoff monitoring, gullying in laterite zones), peri glacial and glacial/glaciated areas (permafrost, retreat of glaciers due to global warming, flood hazards as a result in lower slopes) volcanic regions (lava runoff – spatial extent of lava flow and time taken to estimate evacuation) and disaster management on macro scales and many micro-region units. The modern applied geomorphological studies are involved in mapping the permafrost layers, the thickness of sediments, depth and areal expanse of talus slopes (figure 1), alluvial fans, block fields in peri glacial regions, the structures of sediment deposits in coastal regions and analyzing landslide models for mountainous regions in terms of assessment for velocity, composition of landslides and their expanse. As all these phenomena directly impact sustainability and affect our standards of living in terms of health.

Figure 1 - Eroded debris flow due to topsoil loosening on upper slopes aided by flowing ice – Dewal, Chamoli district Uttarakhand India

Source: The author (2019).

Sustainable Futures and UN SDGs 2030 for Eudaemonic Citizenry

The best solutions to sustainable futures can be found through multidisciplinary research and development (R&D). The biggest challenge looming over the globe is the subsequent changes in the Earth System – e.g. greenhouse gas levels, ocean acidification, deforestation and biodiversity deterioration due to climate change which lead to a chain of events that affects the environment, populations and the economy. In an effort to overcome challenges that encompass the natural environment affecting directly our quality of lives, there is a conscious effort from all stakeholders to create awareness and set goals for sustainability. The key to a eudaemonic state of life for all global citizens are sustainable futures and finding alternatives in order to limit resource extraction from the environment. The UN SDGs 2030 strives to attain sustainable futures through R&D, collaboration amongst scientific communities, multidisciplinary collaborations, the sustainable management of natural resources, including agriculture and land-use planning (DOWNS; BOOTH, 2011) finding alternatives to traditional natural resources like fossil fuels and wood, creating awareness among common citizenry. The four basic benefits of sustainable Earth are as follows:

i. It helps in ensuring a healthier life for all biota
ii. Creates the capacity for more resilience to epidemics.
iii. Lowers the extent of carbon footprint on the environment by reducing air, water, and soil pollution.
iv. It helps to achieve long-term economic growth as nations can focus more upon development, sustainable agriculture and bioengineered infrastructure that results in eudaemonic citizenry

AIMS AND OBJECTIVES OF THE STUDY

This essay attempts to trace the trends in millennium advancements in sub-disciplines of geomorphology that will gradually shape our policy-making by:

i. Utilizing their nature and capacities as demands of contemporary times;
ii. Understanding the scope which is there and will arise in the new millennium (industrialization leading to pollution of air, water & land, increase in size of settlements/built-up areas leading to shrinking of natural spaces, landslides in high altitude regions triggered by geomorphic wasting, tectonic triggers).

LITERATURE REVIEW

Geomorphology has grown rapidly to address quite a number of key issues which spearhead wellness in communities. It plays a direct role like in terrain evaluation, management or disaster prevention but indirectly in its scope and potential to be considered for delivery of goods and services to society or situations in perturbations due to natural events or episodes. The growth of applied geomorphology to accommodate terrain evaluation for infrastructure building has created renewed interest. Coates (1982) introduced it as part of Environmental Geology and published a book *"Applied geography: Selected perspectives"* along with his paper on Environmental geomorphology, Verstappen's (1983) reference to Environmental Geomorphology, Prasad (2005) in his book *Environmental Geomorphology*, Panizza (1996) as part of special issue: "*Planetary Geomorphology: Proceedings of the 45th Annual Binghamton Geomorphology Symposium*", held on 12-14 September 2014 in Knoxville, Tennessee, USA (in Geomorphology - Elsevier) have all envisaged and discussed the state of changing natural environments. The modern shift is more on sustainability and integrated management where communities, cities, scale and patterns of buildings and citizenry will benefit and there will be general welfare. A book titled "*Sustainable Futures in the Built Environment to 2050*": *"A Foresight Approach to Construction and Development"* by Dixon et al. (2018) covers very pertinent topics related to new professional practices with the future of a sustainable built environment. This book focuses on both construction and development issues, and examines how we can transition to a sustainable future by the year 2050 — bringing together leading research and practice at building, neighborhoods, and city levels. It deftly analyses how emerging socio-economic, technological, and environmental trends will influence the built environment of the future (DIXON et al., 2018).

The progressing trends of geomorphological research are explored in a book by Ronald M Reale (2021) titled *Recent Developments in Geomorphology Research* which has been featured in the January 2022 issue of *Lunar and Planetary Information Bulletin* as a "New and Noteworthy" item. The monograph has only three chapters each discussing the recent geomorphological research developments in specific details of volcanic activity, snow avalanche and planetary studies of the Martian surface and the impact of past fluvial erosion processes. There are numerous articles, monographs and books discussing geomorphology, its scope and future directions by stalwarts and academics. The final perceptions, speculations and estimations all border on climate change, sustainability and the impact on humankind.

DISCUSSIONS

Earth sciences contribute towards information about the surface, subsurface and the core of the Earth like Geography, geomorphology, geophysics, geochemistry, geology, climatology, hydrology, biology and glaciology all contribute significantly to Earth science that considers structures, geomaterials, geo processes, chronology of changing landforms and regions to understand and decipher external processes (gradation, degradation, weathering, mass movement, erosion, aggradation, running water, groundwater, waves, currents, tides and tsunamis, wind, glaciers and work of biotic elements i.e. both flora and fauna) and internal processes (diastrophism, volcanism, subduction of tectonic plates). The surficial structure and impressions upon the crust due to endogenetic and exogenetic mechanisms are witnessed all around us. These landforms have evolved as a result of plate movements, subsidence, upliftment and various erosional processes (MUKHERJEE; JHA, 2011). Notably, geomorphological modeling and correlating with form and process studies together with climate change - terrain modeling, feature extraction, terrain analysis, their applications in different fields of hydrology and climate, geomorphology, soil science, natural regions and planetary investigations have widened the scope of the discipline. Geomorphology is today on the threshold of a new millennium where it needs to accommodate geomorphologists, geo-biotechno scientists, geohydrologists, planetary geo morphologists and transcend its own boundaries to develop sustainable natural spaces and support eudemonic citizenry. Environment, planetary, climatic, regional, submarine, engineering geomorphology and anthropogeomorphology cater to the demands of the millennium welfare societies. "Geomorphologists have taken an increasing interest in how they can make an impact in the field of landscape conservation" (GOUDIE, 2020). The millennium has witnessed a rapidly growing interest in environment, worlds beyond our planets, regional landscapes, climate change, infrastructure development for sustainable societies and smart cities. Climate change impacts biodiversity, agriculture, water resource, natural resources and soil. The impact of climate change is vital in the shaping of the lesser topographies (KAPAT; JHA, 2009) and this change influence migration, society, food security, transport networks and spread of communicable disease that has stoked the need to create and nurture sustainable societies with clean air, soil and water for economic growth, citizen health, social inclusion and environmental protection as advocated by UNSDGs 2030. The goals for the millennium can be enumerated as:

i. Sustainable economic growth
ii. Encouraging sustainable livelihoods
iii. Living in harmony with nature and
iv. Modern technology (AI, geospatial techniques, digital cartography, geo morphometric) to assess and address risks and hazards related to climate change.

The general aim is to wisely manage the stumbling blocks encountered like droughts, floods, sea rise due to thermal expansion, loss of biodiversity, reduction in cropping areas, urban heat islands, groundwater depletion migrations and displacement of populace to escape regional impacts of climate change affecting food security and health. These pertinent issues are being tackled by worldwide associations like the United Nations and allied NGOs trying to bring about legislations and goals that support sustainability. The multidisciplinary vision that has developed gradually in the field of geomorphology to understand climatic variables, weathering processes and humanistic responses are explored further in this article.

APPLIED GEOMORPHOLOGY

"The acceptance of new ideas into the mainstream of geomorphological education is illustrated from the development of theories dealing with Earth history, glaciation, uniform flow, mass movement, continental mobility, cyclic erosion, and drainage networks" (ORME, 2002). Applied geomorphology incorporating quantitative techniques and principles of geomorphology with climatic approach offers an excellent scope for policy planners for all morpho climatic regions. This step is increasingly being translated to involve non-structural and structural methods of management, and to involve the economic valuation of non-use and recreational management benefits in addition to traditional economic use valuation (DOWNS; GREGORY, 2004; DOWNS; BOOTH, 2011). For example "buried pre-glacial and interglacial valleys may be sources of large volumes of groundwater. Recognition of their presence within an area depends upon a detailed study of the pre-glacial topography and geomorphic history of the area"– (THORNBURY, 1954-1986, p. 544).

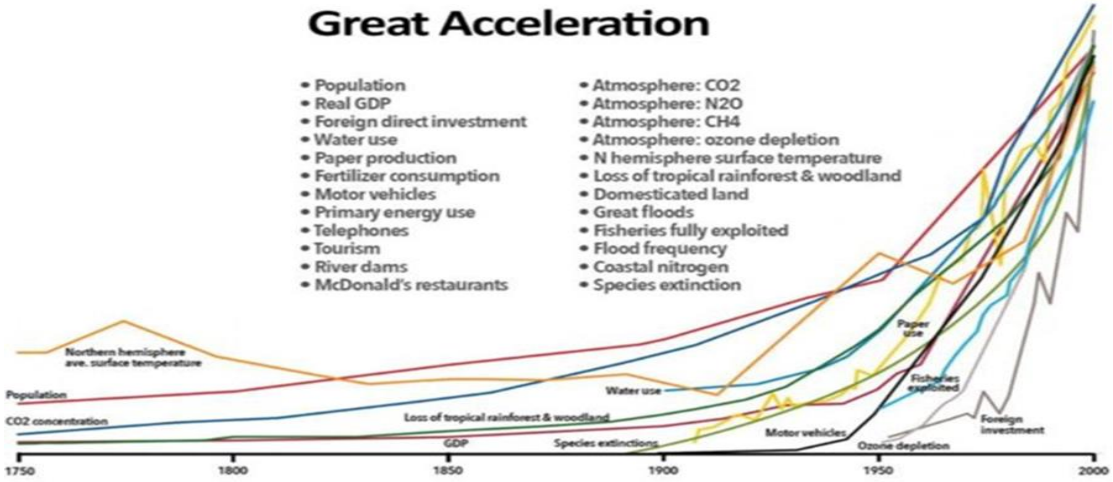
The scope for societal development through application of geomorphological intervention according to Goudie (2020) is:

i. Intellectual and policy-related;
ii. Technological developments that alter geomorphological processes;
iii. Demographic trends; and
iv. The proliferation of techniques for the study of landform and process change (GOUDIE, 2020).

The Great Acceleration

The analysis of natural and social trends, paradigms from 1795 to 2000 in a series of chronological evidences that have culminated in intensification of human activities on Earth in the mid-20th Century is termed as the Great Acceleration. The dominant feature of the socio-economic trends is that the economic activity of the human enterprise continues to grow at a rapid rate (STEFFEN et al., 2015). Human interventions primarily the economic system globally, is now the prime driver of change (Figure 2) of the Earth Systems — the sum of our planet's interacting physical, chemical, biological and human processes.

Figure 2 - The "Great Acceleration" of consumption that is stressing the earth's natural systems



Source: Prasad and Rao (2020).

Environmental geomorphology

Since the 1960s the growing awareness about environmental deterioration and its future impact on food security, living spaces and physical health which finally impact mental wellbeing led to growth of environmental geomorphology. Only beyond the mid-20th century is there clear evidence for fundamental shifts in the state and functioning of the Earth System that are beyond the range of variability of the Holocene and driven by human activities (STEFFEN et al., 2015). The growing interest in human-environment symbiosis developed post 1950s and the growth of multidisciplinary scope has equipped us to prepare for risks, hazards and disasters.

Environmental resources, their spatial distribution, rates and volumes of precipitation, flooding frequencies soil properties, issues related to deforestation, crisis and management are the latest prospect for sustainability and are addressed with the following approaches:

i. Empirical (resources, their spatial organization and extent);
ii. Phenomenological (phenomenon of bio-systems interrelated with landforms &climate);
iii. Systems & structural (entropy, order, growth);
iv. Ecological (fragmentation, patch, corridor dynamics);
v. Evaluating (process, phenomena, impacts, modeling);
vi. Geospatial approach (aerial photographs, satellite imageries).

Prasad (2005) in his book Environmental Geomorphology described the discipline as "the scientific study of morphological process and landform with respect to nature". The estimation of man-environment relationship evaluated from geomorphological parameters has gained popularity in recent times. Coates (1982) introduced environmental issues as part of Environmental Geology and Panizza (1996) acknowledged Verstappen's (1983) reference to Environmental Geomorphology where the human – environment relation and also ecological perspective were considered in combination. In geomorphology, the first applications of homegrown phenomenological equations dealt with diffusion-like transport processes, such as soil creep, over hill slopes (e.g. CULLING, 1960; 1963; 1965; LUKE, 1972; HIRANO, 1968; 1975; HUGGET, 2007). The interaction of humans with nature through activities like grazing, hunting, mining, agriculture and exploitation of natural resources in the latter half of the eighteenth century and agricultural expansion due mechanization (industrial revolution) followed by rapid building of infrastructure, altering natural spaces in the twentieth century led to environmental deterioration, generation of huge amount of wastes in the urban areas which percolated and contaminated groundwater stores. The immediate impact witnessed is loss of biodiversity as a consequence of clearing of natural areas for increased industrial spaces, urban heat islands, subsidence due to uncontrolled extraction of groundwater in urban areas, contamination of soil due to excessive use of chemical fertilizers to artificially improve soil fertility and crop yields, extraction of crude oil, gas or water causing land surface subsidence.

Implication of Sustainable Development on citizenry and societal welfare

The 18th century witnessed the Industrial Revolution in Europe. Though it led to economic prosperity, it also increased the carbon dioxide levels as forested areas were cleared for urban spaces disrupting climate patterns by concentrating urban heat, as more and more areas were concretized. Concern with the human impact in Geomorphology has a long history. What is new is that since 1969 a number of developments have taken place that has led to an increasing realization of its importance (GOUDIE, 2020). Deterioration in air quality and environmental changes were intensified by ozone-depleting substances and burning of fossil fuels. Significant infrastructural developments and growing population led to the necessity of increased urban spaces and economical turn of events encouraged more extraction of natural resources causing irreversible damage to climate regimes. The most vital prerequisite for development is the concern for our natural environment which supports human existence. The decline in biodiversity on a regional scale like forest canopy depletion, removal of land cover and break in food chains threatens:

i. Nature's productivity, resilience and adaptability
ii. Biodiversity
iii. Carbon sequestration capacity
iv. Food security
v. Public health (affected by epidemics and uncontrolled pest proliferation)

Sustainability tackles issues or problems of the present natural environment simultaneously trying to safeguard future capacities of the people to solve their own crisis through alternate methods or products. Sustainable management can be defined in relation to the preservation or enhancement of the total stock of natural capital, zero or minimum net negative impact of management operations, and zero or minimum requirement for ongoing management intervention to uphold system values (CLARK, 2002; DOWNS; BOOTH, 2011). The modern developments in the millennium have led geomorphology to broaden its field of investigation beyond the common perspectives, methods and approaches for provisioning areal space, food and health.

Planetary geomorphology

The global perspective, the geological timescales, and the interdisciplinary relevance of planetary surface studies can open doors to newer understanding of the formation of landforms. Planetary geomorphology investigates evolutionary sequence of the relict landscapes, the relict landforms, the role played by cataclysmic events in creating such landforms on our distant planets and whether any similarities can be drawn to evolution of landforms on Earth, the differential rates of process operation, and the genesis history, which are all considered. The investigation into relief features of extraterrestrial planets is the subject of planetary geomorphology. The extraterrestrial landforms are evaluated and assessed by drawing comparisons to the same landform features on Earth. The agents and processes that sculpt land surfaces on Earth are considered to be operating on extraterrestrial planets as well. The chief two agents of erosion considered are water and wind whereby evidences are searched for meticulously. Reale (2021) in his book Recent Developments in Geomorphology Research incorporates a chapter – "*Geomorphological Analysis and Erosion Modeling of a Martian Fluvial System"* by Steinmann (2021). The use of SIMWE (Simulated Water Erosion) to construct a model recreating past fluvial activity on the Martian surface, investigate the genesis of present landforms and the paleo climate of the red planet has been done. The major areas that attract the attention of planetary geo morphologists are: impact cratering, tectonics, volcanism which initiates other geomorphic processes, including Aeolian, fluvial, lacustrine, and glacial/polar. "Moreover, geomorphology has a new role in contributing to the understanding of complex planetary landscapes that result from various processes operating over disparate timescales." (BAKER, 2003). Understanding paleo landscapes produced by geomorphic processes can explain significant aspects of planetary surface evolution in the solar system. As we explore worlds beyond our planet, it is to search for alternatives and discover new terrain that may be similar to ours and be able to host life. A whole area of R&D is devoted to this field with Governmental research institutions like NASA, ISRO, JXA, Roscosmos, CNSA and ESA to name a few.

Regional geomorphology

Region from the perspective of geomorphology can be explained as a spatial unit on the Earth's surface, having similar or homogeneous and composite units of landforms, with near similar origins and resulting in associated rock types and landform features. During the early part of this century, the study of regional-scale geomorphology was termed "physiography" (SALISBURY, 1907). The regional geomorphological approach here deals with precise evaluation of regional units on landform parameters. The expansiveness of regional landscapes results in multiple, complicated and prolonged temporal frames of the genesis processes. It is this complexity that brings about variety in landforms and processes in operation. A particular region has a particular set and patterns of landforms due to climate initiated processes that are operational there exclusively. Regional geomorphology attempts to divide an area into uniform or homogeneous geomorphic characteristics. This helps to quickly identify access and plan for those areas which are under duress (climatic, geo disasters or political conflicts which are operated over terrain). Scope for transfer along transport routes, dissemination of quick aid after appraisal and estimation is possible if proper landform units mapping is done. The purpose of regional planning and regional development based on theories of welfare regionalism and new regionalism for spatial planning should border on holistic growth, connectivity whereby keeping sustainability as the chief guiding factor.

Climatic geomorphology

Shift in geomorphological studies approach initiated by climate change has led to increased interest in desertification and land degradation investigations. It was Julius Büdel of Germany who advanced climatic geomorphology to be the cause for all relief-forming processes on the surface thereby having a spatio-temporal dimension. Climatic geo morphologists explain that systematic morpho climatic zones on the globe provide relief-forming mechanisms which differ as a function of climate. "An appreciation of world climates is necessary to a proper understanding of the varying importance of the different geomorphic processes." (THORNBURY, 1954; p. 28). Concepts and notions about climate change developed in the 18th century. The scientific analysis of former ice ages, collection of climatic data from ice core samples, pollen analysis, dendrochronology and geological evidences from sediments and fossils helped to understand climatic regimes and morphoclimatic mechanisms that operated and gave rise to certain sets of landforms. The morphogenetic concept explains that under a particular climatic regime, certain geomorphic processes will be dominant and produce a set pattern of land features which are characteristic topographic expressions of that particular climatic regime. The concept of morphogenetic regions as "The complex of geomorphic processes and agents which operates under a particular set of climatic conditions has been termed a morphogenetic system - Tricart and Cailleux (1955) and Thornbury (1954, p. 21) relates to a theoretical area developed by geo morphologists to assess interconnections between climate, geomorphic processes, and landforms. It evaluates and analyzes all changes brought about by catastrophic or diastrophic events over time. In tropical regions like eastern India, the Rarh region is predominantly composed of detrital laterites. The lateritic soil scapes are mostly affected by water erosion induced, vegetal and anthropogenic degradation attaining severe and very severe degradation (JHA;KAPAT, 2011) that is gradually reducing the net sown area. The interest in global warming that has developed since the early 1980s has created considerable interest in its consequences for a range of geomorphological phenomena (GOUDIE, 2020). Climate change has brought about acceleration in rates of melting of ice sheets in the Pleistocene, exposed landmasses were subjected to denudation, desertification of forested regions and simultaneously initiated geomorphic processes. The records of glacial and interglacial phases give evidence of both global warming and cooling. The various themes of climatic geomorphology deal with specific regional climate-induced landform changes, challenges that support populations adapting themselves to that particular climatic regime and the hazards that are cropping up due to climate change. The focused scope of the study is:

i. Arid geomorphology (Tropical and Temperate).
ii. Peri glacial geomorphology.
iii. Tropical geomorphology

The transition zones for life forms are very critical for adaptation to changing habitat conditions caused by climate change. Arid, peri-glacial and tropical zones tolerate both extreme and minimal changes in temperature and moisture conditions and though only less than 1% of the world's population live here. They have a distinct way of living, when disrupted due to irreversible effects of climate change can lead to their obliteration or migration and intermingling with people of other ethnicity. Notwithstanding the importance of some of these changes in prehistoric and historic times, recent researches have demonstrated that humans have become an increasingly important agent of geomorphological change during the period of the Great Acceleration of the past five or six decades (GOUDIE, 2020). The pertinent question that looms before us is how much rise in sea levels is likely to take place, which are the coastal areas that will be inundated or are at risk, how will change in carbonate percentage of the oceans affect the tropical coral reefs and marine life forms, landforms in terms of rates of erosion and how will it impact developed and underdeveloped nations? The beginning of the Great Acceleration is by far the most convincing from an Earth System science perspective (STEFFEN et al., 2015). Applying regional-scale; risk-based, ecosystem services-oriented approaches to environmental management would significantly enhance the potential for geomorphology application. (DOWNS; BOOTH, 2011).

Engineering geomorphology

Landscape dynamics study using engineering geomorphological approach and quantitative methods to determine terrain stability is a meticulous and precise exercise in the millennium for planning and management. It draws examples from geomorphology, engineering geology and geotechnical engineering to plan for integrated environmental management, development planning, infrastructural planning and engineering. Engineering geomorphology has been a recognized sub-discipline for more than 20 years and it continues to expand today. (GIARDINO, 1999). Given the large-scale alterations of natural landscapes by human activities the professional partnership between geomorphology and engineering can significantly minimize environmental damage (COATES, 1982, p. 1).

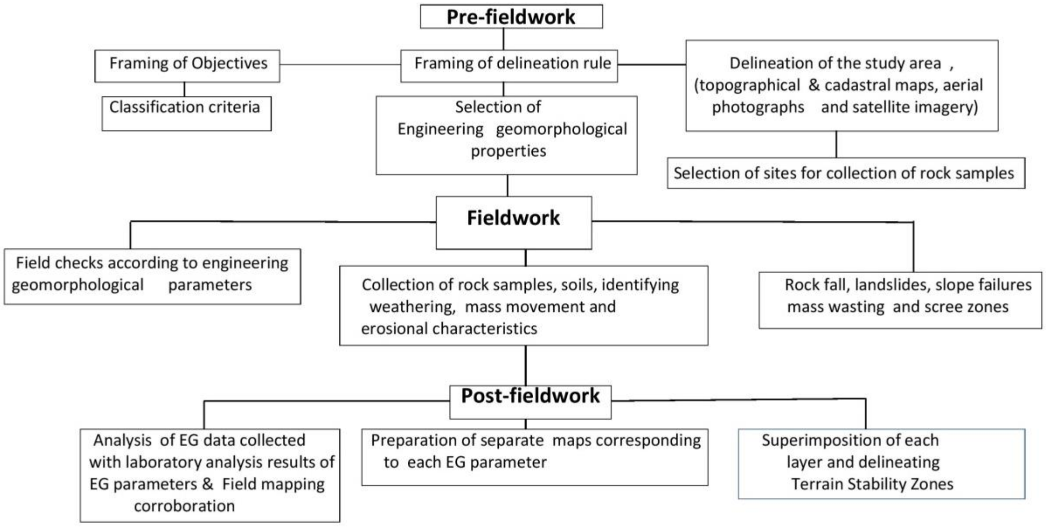
Engineering geomorphology chiefly deals with landforms and processes by:

i. Mode of descriptions of landforms as derived from pure geomorphology
ii. Mode of formation and temporal change which alter landscapes
iii. Mode of operation of geomorphic processes which influence landscapes
iv. Types and characteristics of geomaterials and their assessment

v. Use of landforms to benefit society and construct infrastructure

The strong potential of this sub-discipline is determined by the combination of geomorphological site evaluation and description of dynamic processes with engineering characterization of deformation, strength, and hydrological properties of the involved materials (KLIMES; BLAHUT, 2017, p. 1). Risk, hazards and disaster assessment, mitigation and management using engineering geomorphological approach for solving terrain stability situations that are related to settlements and the connectivity between them, roadways, railways, freight corridors (transport communication lines). Geomorphological mapping (Figure 3) is a new approach along with engineering geology to deal with disasters especially those that are related to stability of terrain and arise from episodes of tectonic disequilibrium, The "technique of geomorphological mapping is the most familiar geomorphological tool known to the civil engineer and the valid and often cost-effective contributions that geomorphologists can make to other civil engineering studies using different techniques" (GRIFFITHS; HEARNS, 1990) for assessing risks like mapping of landslide-prone zones for road construction projects, buildings and any infrastructure construction (dams, roads, bridges, etc.) In order to assess landslide hazards correctly, it is necessary to carry out in-depth investigations on the spatial and temporal occurrence of mass movements in the study area (PANIZZA, 1996).

Figure 3 - The methodology for carrying out an Engineering Geomorphological Analysis to prepare Terrain Stability Zones



Source: The author (2022); adapted from Jha (2002; 2004).

Jha (2002) explains that an Engineering geomorphological map preparation follows the pattern of creating layers and superimposition as in GIS by addressing each physical parameters - topography; rock units; tectonics; soil units; weathering; mass movement; and erosion at the designated site independently. The final EGM will specifically deal with laboratory analysis of rock samples pertaining to strength of intact rock; joint spacing; width of joints; bedding planes; gauge or infilling; the materials and water movements within the rock; point load range; water retention capacity; and compaction bearing strength. The selected area can then be categorized into four categories post layering of information on the base map to exhibit rock mass strength of the selected area and determine stability classes (Figure 4).

The categories are as below:

i. Low rock mass strength unit (Rlo)
ii. Medium rock mass strength unit (Rme)
iii. High rock mass strength unit (Rhi)
iv. Very high rock mass strength unit (Rvhi).

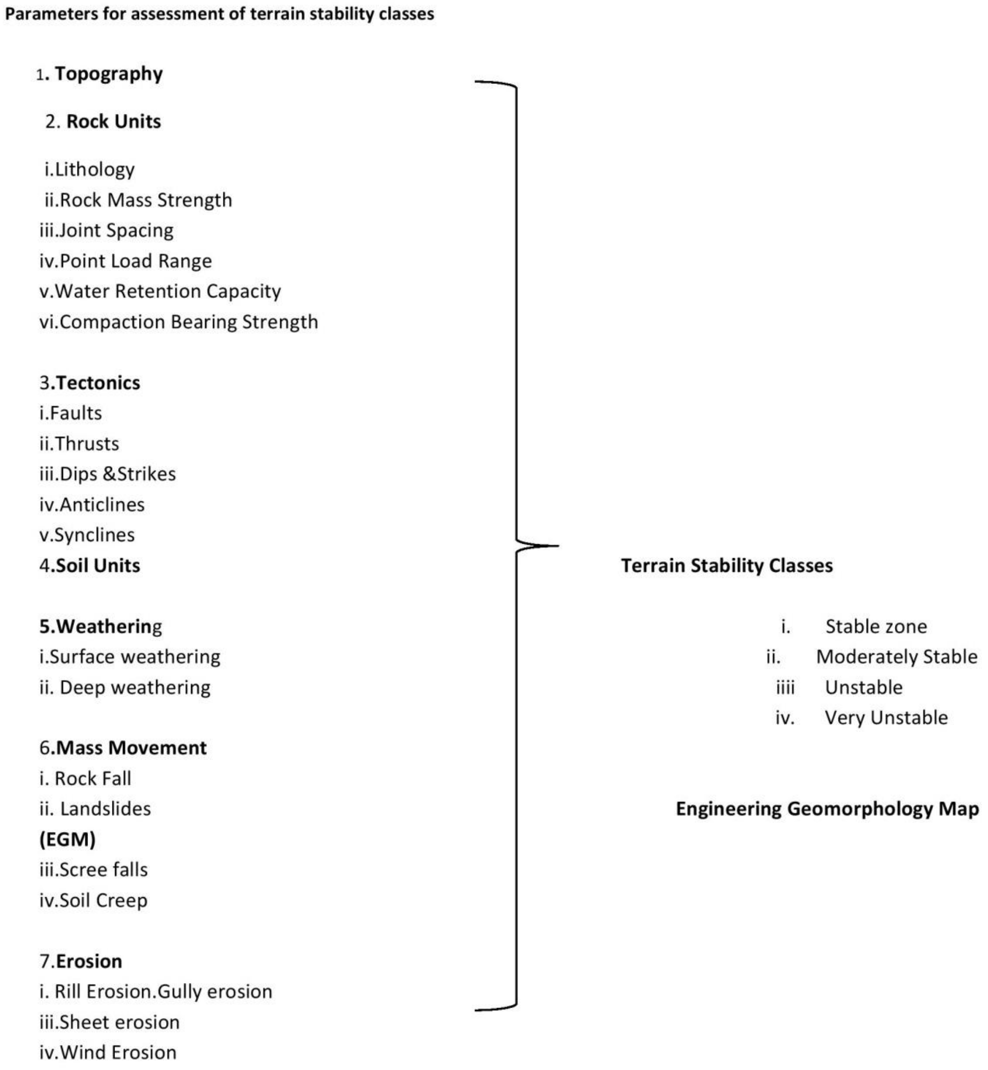
Where: R = Rock mass; lo = low; me = medium; hi = high; vhi = very high

4 (four) terrain stability classes (JHA, 2002; 2004; MUKHERJEE, 2012; 2019) are designated as

i. Stable zone
ii. Moderately stable
iii. Unstable
iv. Very Unstable

Landforms and landscapes also have strong appeal to the general public, as evidenced by the heavy visitation of public lands where the landforms are spectacular, interesting, attractive, and instructive (KNEUPFER;PETERSEN, 2002, p. 99) therefore requiring suitable management and adaptations also. The geomorphological approaches include landform mapping combining field surveys with interpretation of remotely sensed images (KLIMES; BLAHUT, 2017). The exercise carries out zone mapping by preparing an engineering geomorphological map, upon the designated region selected for urban planning, infrastructure building and constructing all-weather roads in difficult terrain and on mountain slopes, promoting disaster-resilient structures. The methodology followed in engineering geomorphology to prepare EGM as proposed by Jha (2002) in "*Encyclopedia of Geomorphology"* edited by A. Goudie (2004) is outlined in the flow chart (Figure 4) GIS is providing engineering geo morphologists with a system to efficiently map, measure, monitor, and model engineering geomorphological data (GIARDINO, 1999).

Figure 4 - Engineering Geomorphological Planning Units



Source: The author (2022); adapted from Jha (2002) and Mukherjee (2012; 2019).

Submarine Geomorphology

The terrain below marine waters is an extension of the terrestrial land but remotely accessible under special conditions. The exploration and investigation of submarine landscapes – form, process and evaluation of submarine terrain have gained interest as humankind looks towards a blue economy. Submarine topography, like its terrestrial counterpart, can be interpreted in classical geomorphological terms: structure, process and time (or stage) (HEEZEN; WILSON, 1968). The marine floor is mapped on the basis of its physiographic nature i.e. structures like ridges, canyons, continental margins, continental shelves, ocean floors, seamounts and more landform features. The rate of sediment deposits washed down from continents, underground volcanic eruptions, seafloor spreading, glacial deposits, turbidity currents, wave action and slumping of shorelines all reflect the amount of temporal span for submarine sedimentation. Sedimentation is controlled by sediment supply from continents, ocean bottom contour currents, the growth of organisms (hence temperature, salinity), and many other factors (HEEZEN; WILSON, 1968). Changes during Pleistocene climatic regimes and sediment transfer can be assessed through marine topography which affects marine habitats and marine biodiversity. They also emphasize potential conservation concerns, because areas of high marine biodiversity often have greater velocities of climate change and seasonal shifts (BURROWS et al., 2011). Changes in sea level due to thermal expansion of water as temperatures increase rise in seawater acidity due to increased carbonation and dying out of coral reefs are of concern and needs to be explored, analyzed and understood to combat submerging coastlines, disappearing mangroves leading to biodiversity loss.

Anthropo-geomorphology

The interactions between humans and nature are directly upon the regolith zone which covers all types of terrain. It is also becoming apparent that anthropogenic geomorphological change is having an impact on the Earth System as a whole (GOUDIE, 2020). It is not related to only landforms of first order as categorized in geomorphology but the local landscapes (egg hills, valleys, coastal regions, gorges, caves) which are of the third order and can be easily accessed. The present concern with landform elements and landform processes are due to the vulnerability and impact upon large population masses that are at risk. For example, Tsunamis are created due to movement of plates on the ocean floor, yet the impact is felt upon inhabited coastlines, destroying settlements and disrupting normal lives. Periglacial regions develop Pingos where water accumulates and freezes beneath layers of grass. This melts during warmer months leaving unstable surfaces unfit for cultivation (Figure 5). Similar is the instance of all natural disasters (earthquakes, volcanic eruptions, GLOFs) which manifest in regions of human settlements. Urban planning, infrastructure development resource management, SWAT and defense studies refer to human-induced landform alterations which impact sustainability. The human nature dichotomy makes a deep mark in the geological time scale of the Earth and may be referred to as a new phase in the enumeration of the geological time scale.

Geo-biotechnology and geomorphology

Geo biotechnology is regarded as a multidisciplinary research area that draws from allied disciplines of biology, biotechnology, geology and geochemistry mineralogy. It explores the intertwined effects of biological and geological processes that impact landforms. The impact of climate change has led to colder areas experiencing more ice melts as a result of warmer temperatures and hot regions becoming drier with lack of atmospheric moisture. Biotic factors with the aid of moisture initiate varied geomorphic and biogeochemical processes that influence mechanical and chemical processes of weathering leading to formation of soil and its erosion. The near future will gradually witness the shift from multidisciplinary to a trans-disciplinary nature drawing experts from multiple disciplines to explore solutions as global concern for sustainable societies with economic prosperity and reduced or zero carbon footprint grows. Zero emissions and increased carbon sequestration globally demand increasing green cover and sustainable agriculture. The nature of slopes, how best they can be afforested and extrapolations for possible risks and hazards that remove forest covers can be best addressed by a geomorphologist. Attempts to regulate the flow of water from the atmosphere to the surface or below and stabilize the terrain from slope failure to minimize soil erosion can be assigned to geo morphologists. A geomorphologist can offer techniques to reduce or control erosion, model future extrapolations of climate that can affect the land and soil and biotechnologists can relate such data to apply in major fields: Industry, healthcare, crop production and agriculture, industrial uses of crop and crop wastes for products like biodegradable plastics, vegetable oil and biofuels, environmental engineering for landscape modifications. The management of terrestrial surfaces using biological products and engineering techniques to facilitate human activities and prevent risks, hazards and disaster is the basis for geo-biotechnology. Environmental management is both a multi-layered social construct, in which environmental managers interact with the environment and each other, and a field of study emphasizing the need for interdisciplinary understanding of human–environment interactions (WILSON; BRYANT, 1997; DOWNS; BOOTH, 2011). The emphasis on sustainability and harmonious interaction with the environment yet at the same time drawing resources in a controlled manner to prevent their rapid depletion, searching for alternatives have led to increased awareness and integrated management. The most popular methods are:

i. Growth of vegetation on denuded slopes to prevent landslides (Figure 6);
ii. Restriction on extracting trees from forests to maintain biodiversity, preserve food chains and ecosystems;
iii. Laws for controlling deforestation to prevent reduction in carbon sinks and biodiversity;

iv. Replacement of forest tree species cut down with suitable varieties to entrap atmospheric moisture;
v. Alternate taller varieties with shorter shrubs to maintain soil cover and encourage organic content of the soil;
vi. Use local materials to build infrastructure to facilitate humans and protect habitats egg., living root bridges of Meghalaya – India, where tree branches and roots are trained and guided, intertwined over a period of many years to build bridges over swift-flowing streams and gorges within the forest.

Figure 5 - A layer of frozen ground pushed up by accumulation of ice does not support Vegetation after ice melts in the warmer month. Hat-Kalyani Chamoli Uttarakhand India

Source: The author (2019).

Figure 6 - Control of slope failure by supplemental vegetation can prevent landslides Wan (Chamoli District). Uttarakhand- India

Source: The author (2019).

Scope of biotechnology in the purview of geomorphology

The major objectives of geomorphology can be combined with biotechnology to address sustainable societies estimate EIA and live in harmony with nature. The future holds enormous opportunities for continuing to expand the role of geomorphology in environmental problem-solving, particularly if geomorphologists can embrace temporal and spatial scales of problem-solving more closely allied to geomorphology's scientific origins, and better integrate concerns for environmental conservation and social justice to gain improved understanding of the mutual vulnerability and dependence of society and landscape (SLAYMAKER, 2009; DOWNS; BOOTH, 2011). Natural regions around the world are all undergoing the perils of climate change with reduced groundwater recharge (urbanization, lesser precipitation), desertification, land degradation, top soil loss and reduced carbon sequestration due to a reduction in green cover (Figure 7), and rising temperatures.

Figure 7 - Cleared slopes for cultivation when left fallow accelerates topsoil erosion aided by rainfall and gravity. Village of Dewal Chamoli district Uttarakhand

Source: The author (2019).

It is a vicious cycle and a thorough understanding of landforms, processes that are operative and modeling of future changes are important. Geomorphology can suitably offer to tackle the crisis along with engineering and biotechnology as it helps to understand landforms in the following manner:

i. Mode of Descriptions – Describes landforms which are typical to particular regions egg, glacial, arid, fluvial, marine and karst have distinct forms.
ii. Mode of Formation and Temporal Change –Describes the methods and sequences that lead to the formation of landforms (macro or minor) that create unique landscapes under different climatic regimes.
iii. Mode of Operation of Processes – Describes the operation of geomorphic processes and the agents that initiate those processes in particular climatic regions.
iv. Types and Characteristics of Materials – Investigates the type of geomorphic waste which have distinct shapes and forms in separate climatic regimes egg., moraines in glacial regions, dreikanters in arid and periglacial regions, cobbles in fluvial eroded regions, gloups are formed due to marine action. Biotic elements that aid disintegration.
v. Use of Landforms – Describes how landforms respond to key drivers as climate and can be geo-engineered and utilized to the best advantage of humankind for infrastructure development using landforms, slopes and rocks.

The geomorphologist should be capable of contributing as part of the project team to discussions about how the landscape should function in the future (MONTGOMERY et al., 1995, DOWNS; BOOTH, 2011).

Prevalent environmental issues that geomorphologists can address with geo biotechnology

Another significant opportunity for geomorphology in the coming decades will result from efforts worldwide to redefine environmental management in terms of the services to humans provided by functioning ecosystems (DOWNS; BOOTHS, 2011). Environment sustainability concerns the advancements in planning and integrated management of our present ecosystems without jeopardizing the ability of humankind to draw resources, fresh drinking water, fresh air and judiciously prevent depletion of these vital resources for future generations

i. Land degradation – Control of slope failure by supplemental vegetation placing iron nets, rocks and planting shrubbery. This aids slope stabilization;
ii. Environmental degradation - Gully Erosion & management in tropical lands to maintain land cover (Figure 8);
iii. Geomorphic Hazards - Soil erosion and conservation to prevent degradation and depletion of biotic elements within an ecosystem (Figure 9).

Figure 8 - Gully erosion in tropical laterite due to rainfall initiates break (Sriniketan Birbhum India)

Source: The author (2021).

Figure 9 - Formation of duri crusts in tropical laterite regions prevents growth of vegetation cover. Sriniketan Birbhum India

Source: The author (2021).

CONCLUSION

The present trends in modern times demand a trans-disciplinary acumen (Table 1) which will accommodate integrated practices from other disciplines, formulating an action plan or approach to address environmental crisis, resulting socio-economic disparities and perturbations growing worldwide. It goes without mention that landform and processes are always envisaged with a set of separate, interdependent relations or interactions which needs to be suitably analyzed to develop sustainable multidimensional welfare space and practices for sustainable societies. Geomorphologists can offer their full potential only if they are given adequate opportunity and representations in decision-making and policy formulation by planners in providing solutions to landform processes for sustainable natural spaces for societal benefit.

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Table 1 - Core skills and techniques required by the early 21st century applied geomorphologist

Service	Skills	Example methods
Project Orientation	1.Background Information Assembly 2.Terrain Modelling using GIS 3.Development of Conceptual Models	• Assimilation of geology, soils, vegetation, precipitation, population history, land management history, prior geomorphology reports • Empirical modelling for expected conditions • Development of process domains/landscape units
Determination of current conditions	4. Mapping and Inventorying 5. Baseline data collection 6.Field interpretation of current morphology and process 7.Classification and characterization of landscape units 8.Monitoring of site dynamics 9.Determine regional sediment flux(also for past conditions)	• Expert interpretation using known site details and accepted process–form linkages in academic literature • Survey, aerial photographic interpretation • Field reconnaissance using rapid assessment protocols • Collation of existing data records • Collection of additional data to supplement existing records (e.g. transects and cross-sections, grain size determination) • Field reconnaissance using rapid assessment protocols • Expert judgement • Application of a priori classification hierarchy • • Characterization via statistical analysis of attributes • Repeat measurements (tracer studies, repeat transects/cross sections) over a designated interval or following large forcing events such as high intensity rainfall, floods. storm surges). • Estimate of sediment yield, budget for coastal or watershed zone.
Investigation of past conditions	10.Reconstruction of historical data series 11. Palaeo-environmental reconstruction for pre-historical conditions	• Air photo/map/survey overlay • Reconstruction of sediment flux from historical records • Use of narrative accounts, ground photographs • Vegetation composition and age • Stratigraphic analysis and interpretation of sedimentary deposits • Geochronology dating methods, e.g. radiocarbon, lead 210, 237 • Erosion estimates using short-lived radionuclides
Prediction of future conditions	12. Sensitivity analysis of potential for change 13. Computer and physical model simulations	• According to measured potential for changes related to threshold: e.g. stream power • Interpretation of departure from ‘expected’conditions: e.g. using hydraulic geometry comparisons, discriminant bi-variate plots

		• Positioning of units in expected sequence of change: e.g. channel evolution model • Statistical deterministic or probabilistic analysis • Using hydrological and sediment transport models • Computer modelling of hillslope stability • Computer modelling of river bank stability • Computer modelling of sediment transport in rivers, and near shore • Modelling of plan form change • Physical modelling using scale models or generic experiment in flume
Problem solution/Design	14. Expert interpretation and integration 15. Contribution to project objectives for sustainable / minimum maintenance/ impact 16.Project siting 17.Project design 18.Project implementation oversight	• Based on the geomorphologist's experience and mental models, project perception • Ability to determine and contextualize the historical legacy on contemporary geomorphological processes • Contribution via problem-solving forum of technical specialists, government • agency representatives, other stakeholders • Interpretation or risk analyses to determine minimum conflict point or maximum benefit between natural process and project requirements • Use of empirical and numerical models to propose process-based dimensions suitable to contemporary forcing mechanisms • Experience with implementation methods and techniques • Design of adaptive monitoring and evaluation programmes, experience in hypotheses setting • In assistance to project engineer
Post-project monitoring and evaluation	19. Determination of measurable success criteria 20. Development of monitoring and evaluation plan 21. Adaptive management response to outcomes of post-project appraisal	• Expert knowledge of geomorphological system relationships (analytical references) • Identification of primary variables, methods, locations and frequency of monitoring • Suggestions for suitable analyses • Ability to interpret evaluation in context of implemented project to determine success and next steps
Expert advisory	22. Data provision 23.Cross - examination capability	• Analytical expertise to provide data for open use or to bolster case • Expert knowledge of specific geomorphological system and related systems to answer questions in deposition and in court.

Source: adapted Downs and Booth (2011).

REFERENCES

ANTHROPOCENE REVIEW, 2015 Available: https://www.anthropocene.info/great-acceleration.php. Accessed on: May 07, 2023.

BAKER, V. R. **Encyclopedia of Physical Science and Technology.** 3. ed. Geomorphology; Planetary Geomorphology. Massachusetts: Elsevier Science Ltd, 2003. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/planetary-geomorphology

BURROWS, M. T.; SCHOEMAN, D. S. BUCKLEY, LAUREN B, MOORE, PIPPA POLOCZANSKA, ELVIRA S BRANDER, KEITH M BROWN, CHRIS. BRUNO, JOHN F DUARTE, CARLOS M, HALPERN, BENJAMIN S, HOLDING, JOHNNA KAPPEL, CARRIE V KIESSLING, WOLGANG, O'CONNOR, MARY I, PANDOLFI, JOHN M PARMESAN, CAMILLE SCHWING, FRANKLIN B SYDEMAN, WILLIAM J, RICHARDSON ANTHONY J. The pace of shifting climate in marine and terrestrial ecosystems. **Science**, v. 334, n. 6056, p. 652-655, 2011. https://doi.org/10.1126/science.1210288 Accessed on : April 22 2023

CLARK, M. J. Dealing with uncertainty: adaptive approaches to sustainable river management. **Aquatic Conservation: Marine and Freshwater Ecosystems**, v. 12, n. 4, p. 347-363, 2002. https://doi.org/10.1002/aqc.531

COATES, D. R. Geomorphology and Engineering. *In:* Binghamton Geomorphology Symposium 7, 1982.

CULLING, W. E H. Analytical theory of erosion. **Journal of Geology**, v. 68, p. 336-44, 1960. https://doi.org/10.1086/626663

CULLING W. E. H. Soil creep and the development of hill-side slopes. **Journal of Geology**, v. 71, p. 127-61, 1963. https://doi.org/10.1086/626891

CULLING, W. E. H. Theory of erosion on soil-covered slopes. **Journal of Geology**, v. 73, p. 230-54, 1965. https://doi.org/10.1086/627060

CULLING, W. E. H. Equifinality: Chaos, Dimension and Pat-tern. the Concepts of Non-linear Dynamical Systems Theory and their Potential for Physical Geography. London School of Economics, 1985.

CULLING, W. E .H. Equifinality: modern approaches to dynamical systems and their potential for geographical thought. Transactions of the Institute of British Geographers ,12, 57-72, 1987. https://doi.org/10.2307/622577

DOWNS, P.W. and GREGORY K.J. River Channel Management: Towards Sustainable Catchment Hydrosystems. London: Arnold, 2004.

DOWNS, P. W., BOOTH, D. B. Geomorphology in Environmental Management .The SAGE Handbook of Geomorphology Edited by A.Goudie chap 5, p. 81-85, 2011. https://doi.org/10.4135/9781446201053.n5

DRURY, G. H. Some Current Trends in Geomorphology **Earth Science Reviews**, v. 8, n. 1, p. 45-72, 1972. https://doi.org/10.1016/0012-8252(72)90034-7

DIXON, T; CONNAUGHTON, J. GREEN, S. **Sustainable Futures in the Built Environment to 2050**: A Foresight Approach to Construction and Development. New York: Wiley-Blackwell, 2018. https://doi.org/10.1002/9781119063834.ch1

GIARDINO, J. MARSTON R.A. MORISAWA, M. Engineering geomorphology: an overview of changing the face of earth. **Geomorphology**, v. 31, n. 1–4, p. 1-11, 1999 https://doi.org/10.1016/S0169-555X(99)00069-0.

GOUDIE, A. Encyclopaedia of Geomorphology. London: Routledge, 2004.

GOUDIE, A. Geomorphology: The human impact in geomorphology – 50 years of change. **Geomorphology**, v. 366, p. 106601, 2020. https://doi.org/10.1016/j.geomorph.2018.12.002

GREGORY, K. J., GOUDIE, A.S. **The SAGE Handbook of Geomorphology**, 2010. https://doi.org/10.4135/9781446201053.n1

GRIFFITHS, J. S.; HEARN, G. J. Engineering geomorphology: A UK perspective. **Bulletin of the International Association of Engineering Geology**, v. 42, p. 39–44, 1990. https://doi.org/10.1007/BF02592618

HEEZEN, B. C.; WILSON, L. Submarine geomorphology In: Geomorphology. Encyclopedia of Earth Science. Berlin, Heidelberg: Springer, 1968, p. 1079–1097. https://doi.org/10.1007/3-540-31060-6_360

HIRANO M. A mathematical model of slope development– an approach to the analytical theory of erosional topography. **Journal of Geosciences Osaka City University,** v. 2, p. 13-52, 1968.

HIRANO, M. Simulation of developmental process of inter-fluvial slopes with reference to graded form. **Journal of Geology** v. 83, p. 113-23, 1975. https://doi.org/10.1086/628048

HUGGETT, R. A history of the systems approach in geomorphology. **Géomorphologie: relief, processes, environnment**, v. 13, n. 2, p. 145-158, 2007. https://doi.org/10.4000/geomorphologie.1031

JHA, V.C. Engineering Geomorphology. **Encyclopaedia of Geomorphology pub Routledge**, p: 316-318, 2002.

JHA V. Encyclopaedia Of Geomorphology. Pub Routledgep. 316-318, 2004

JHA, V. C.; KAPAT, S. Degraded lateritic soils cape and land uses in Birbhum district, West Bengal, India. **Sociedade & Natureza**, Uberlândia, v. 23, p. 545-558, 2011. https://doi.org/10.1590/S1982-45132011000300013

KAPAT, S.; JHA, V. C. Rill and gully erosion risk of lateritic terrain in south-western Birbhum District, West Bengal, India / Risco a erosão em ravinas e voçorocas nos terrenos lateríticos de South-Western Birbhum District, West Bengal, India. **Sociedade & Natureza**, Uberlândia, v. 21, 2009. https://doi.org/10.14393/SN-v21-2009-9821

KLIMES J.; BLAHUT, J. Engineering Geomorphology. In: Bobrowsky P., Marker B. (eds) Encyclopedia of Engineering Geology. Encyclopedia of Earth Sciences Series. Cham: Springer, 2017. https://doi.org/10.1007/978-3-319-12127-7_109-2

KNUEPFER, P.; PETERSEN, J. Geomorphology in the public eye: policy issues, education, and the public. **Geomorphology**, v. 47. p. 95-105, 2002. https://doi.org/10.1016/S0169-555X(02)00089-2

LIST OF GOVERNMENT SPACE AGENCIES. In: WIKIPEDIA: the free encyclopedia. [San Francisco, CA: Wikimed ia Foundation, 2010]. Available: https://en.wikipedia.org/wiki/List_of_government_space_agencies. Accessed on: May 01, 2023.

LUKE, J. C. Mathematical models for landform evolution. **Journal of Geophysical Research** v. 77, p. 2460-2464, 1972. https://doi.org/10.1029/JB077i014p02460

MUKHERJEE, S.; JHA, V. C. Morphotectonics and Resultant Features in Kaliani River Basin (Assam). **Sociedade & Natureza**, Uberlândia, v. 23, p. 285 – 294, 2011. https://doi.org/10.1590/S1982-45132011000200011

MUKHERJEE, S. Kalyani River Basin, Assam: A Study in Engineering Geomorphology Visva Bharati (A Central University) Santiniketan India shodhganga, 2012. Available: http://hdl.handle.net/10603/103424. Accessed on Jan. 18,2023

MUKHERJEE, S. Engineering Geography: Principles and Applications, Pub Manav Prakashan Kolkata India 2019

MONTGOMERY, D. R.; GRANT, G. E.; SULLIVAN, K. Watershed analysis as a framework for implementing ecosystem management. **Water Resources Bulletin** v. 31, p. 369–85, 1995. https://doi.org/10.1111/j.1752-1688.1995.tb04026.x

ORME, A. R. Shifting paradigms in geomorphology: The fate of research ideas in an educational context. **Geomorphology**, v. 47, n. 2, p. 325-342, 2002. https://doi.org/10.1016/S0169-555X(02)00092-2

PANIZZA, M. Environmental geomorphology, **Developments in Earth Surface Processes**. v. 4, p. 1-8, 1996. https://doi.org/10.1016/S0928-2025(96)80018-6

PRASAD, K. **Environmental Geography**. Shree Publishers & Distributors, 2005.

PRASAD, R.; RAO, B. C. Embracing our Larger Role: Family Physicians as Catalysts of Social and Planetary Well-Being. **Journal of the Indian Institute of Science**, v. 102, n. 2, 2020. https://doi.org/10.1007/s41745-022-00324-x

REALE R. M. **Recent Developments in Geomorphology Research Series**. NOVA Science, 2021.

SALISBURY, R. D. **Physiography**. New York: Holt, 1907.

SLAYMAKER O. The future of geomorphology. **Geography Compass**, v. 3, 329–49. https://doi.org/10.1111/j.1749-8198.2008.00178.x

STEFFEN, W., BROADGATE, W., DEUTSCH, L., GAFFNEY, O., & LUDWIG, C. (2015). The trajectory of the Anthropocene: The Great Acceleration. **The Anthropocene Review**, v. 2, n. 1, 81–98. https://doi.org/10.1177/2053019614564785

STEINMANN, V. Geomorphological Analysis and Erosion Modelling of a Martian Fluvial System in Recent Developments in Geomorphology Research Series: Earth Sciences in the 21st Century BISAC. NOVA Science, 2021.

THORNBURY, W. D. Principles of Geomorphology, 2 ed.John Wiley & Sons Inc., 1954-1986. https://doi.org/10.1097/00010694-195408000-00023

TRICART, J.; CAILLEUX, A. Introduction a la Geomorphologie Climatique. Cours De Geomorphologie, Centre De Documentation Universitaire, Paris, p. 228, 1955

VERSTAPPEN, H. T: Applied geomorphology: geomorphological surveys for environmental development. Amsterdam: Elsevier. p. 487, 1983.

WILSON, G. A.; BRYANT, R. L. **Environmental Management**: New Directions for the Twenty-First Century. London: UCL Press, 1997.

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