Chapter 1
An Introduction to Anthropogeomorphology and Geospatial Technology

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1.1 Introduction

Geomorphology is a scientific study of landforms, terrain and related processes that includes explanation of earth/planetary surfaces, substances, origins, nature and history. Geomorphological processes are the factors that alter the Earth, and others are the endogenetic mechanisms that reside inside the Earth; some forces placed beyond the Earth are the exogenetic processes. Moving water, wind, glaciers, karst and sea waves are powerful agents of degradation and aggradation that operate over a significant period of time and create gradual changes that lead to systematic development of landform. Landforms formed by dynamic anthropogenic processes are much less easy to identify, not smaller, but they do not require the introduction of a new path or strategies as much as the amplification of natural phenomena.

The concept of *anthropogeomorphology*, coined by Golomb and Eder (1964), is the study of the human role in forming landforms and changing the function of geomorphological processes. It therefore reflects throughout the Anthropocene on several key components of geomorphological processes. A significant aspect of the

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Anthropocene is physiographic modification, but its consequences can differ widely in space and time, and it is often underestimated in view on human interventions on the Earth's surface (Brown et al., 2013). Human behaviours impact the landscape and its natural features dramatically and cumulatively (Marsh, 1864). Geomorphological modifications arise from a variety of anthropogenic processes, namely, forest clearance, cultivation, ground drainage and filling, mining and quarrying, channelization, irrigation, and dam formation or other engineering development (Nir, 1983). Both the systematic erosion and accumulation of material and the unintended consequences of hydrological changes and the subsequent deforestation and sedimentation are implicated in these operations (Hooke, 2000).

1.2 Interaction Between Geomorphology and Human

The role of human being as a geomorphological agent is the topic of *anthropogeomorphology*. It has been presumed that the Earth's surface is a naturally occurring phenomenon capable of controlling human interaction, but that it is perhaps occasionally, if ever, strongly affected by human beings. Humans are now the most effective geomorphic entity in shaping and reforming the Earth's face, by transforming the physical climate. Exponentially the population growth has become faster, and the resources available for the demand has culminated in the widespread reworking of surface materials, which is projected to develop in the subsequent manner, at an even faster rate of population growth. In areas such as agriculture and mining, technological innovations will be designed and implemented, and growing population rates will result in more changes in land cover and in the utilization of natural resources. The early deforestation of the Neolithic slope in Central Europe, for example, may have been the most essential geomorphological process since the end of the Pleistocene, whereas in Dubai the coastline has altered during the last few centuries. Conversely, whenever significant anthropogenic modifications occurred, they have a direct global impact on the terrestrial ecosystem. Hooke et al. (2012) have estimated the terrestrial area amended by human activity in 2007 and recommend that more than 50% of the total area without ice has been altered by social existence. The Intergovernmental Panel on Climate Change (IPCC) has shown that global warming can dramatically alter biomes, contribute to major cryosphere modifications and enable sea levels to increase (IPCC, 2013). Wohl (2013) opines that geomorphologists can make a positive contribution to the management of what is now called the 'critical zone' in several contexts. This is the near-surface layer of the Earth from the tops of the trees down to the profoundest groundwater, with more and more human interactions with the surface of the Earth and the confluence of most geomorphological activity.

The dilemma of anthropogenic geomorphology is the identification of the broad and ever-expanding array of landforms on the surface, extremely varied in origin and function, generated by human activity. In a broader context, artificially generated landforms have diverse environmental effects (e.g. meso- and microclimate changes, morphology and so on) and alter natural processes. Natural environments that have been substantially changed as a result of direct management effects became anthropogenically varied systems. In geomorphology, a wide practice deals with the study of human impacts on river systems and other landscape structures (Thomas Jr., 1956). Direct anthropogenic practices, such as construction (e.g. spoil tips, embankments, sea walls), exploration (e.g. mining and quarrying), hydrological intervention (e.g. ponds and canals) and cultivation (e.g. terraces), generate numerous geomorphological features. The most common models of anthropogenic ecosystems involve agricultural fields, particularly cultivated land and pasture/grazing land and technological landscapes like urban landscapes and mining centre, etc. Slaymaker et al. (2009) pointed out the consequences of land cover modifications can be at least as significant as the changes that will be triggered by future climate change.

Nowadays, only in the sense of the impact of past human activities will the geomorphic consequences of continuing urban and suburban growth in the same communities be interpreted (Voli et al., 2013). Prolonged urbanisation is occurring globally and more quickly in the humid tropics' developing nations. The urban landscape features of LULC play a significant role in national, regional and local climate change. This accumulation will arise not only owing to variations in the patterns of susceptible and latent surface heat but also due to variation in surface albedo. The albedo is lower in an urban area in comparison to a rural region (Sailor, 2002). The lower albedo is recorded due to rooftops and asphalt roadways in the urban area. Much of the metropolitan landscape is marked by a large portion, or, if any, the proportion of urban surface coverage is disconcertingly low as a result of decreased supply of moisture. These elements of the urban landscape provide cities a much higher heat potential than natural surfaces.

Major driving forces of water, soil and air pollution are changes in land use/land cover characteristics. Mining activities can create contaminants from radioactive metals exposed in the operation. Agricultural pesticides are introduced into the soil and surface waters, including fertilizers, insecticides and pesticides, and, in some cases, persist as pollutants inside the region. Overtime, the deforestation degrades soil fertility and reduces soil suitability for potential agricultural use but also releases tremendous quantities of phosphate, nitrogen and sediments into waterways and other marine environments, with a kind of adverse effect (excessive sedimentation, turbidity, eutrophication and coastal hypoxia).

1.3 Role of Remote Sensing and GIS in Geomorphological Application

Geomorphological mapping and the study of different structures using advanced tools including remote sensing and geographic information system (GIS) serve as conceptual tools for inventory, exploration and governance of land resources and geomorphological and geological risk mitigation, along with generating baseline knowledge for other environmental research areas, such as landscape ecology, soil science, hydrology and forestry, etc. In several geomorphological research, GIS and remote sensing have been implemented to measure surface processes and landmasses. Using post classification, comparative analysis, standard image differentiation, employing image ratio, image regression and manual on-screen digitization of variations, main components evaluation and multi-temporal image classification, there are several systems designed in the earlier research work. Geospatial technology has been extensively used for classifying land type and landscape units with the continuous advancement of GIS and RS technologies, extracting those landform characteristics, quantifying process-landform interactions and defining geomorphic variations.

Punkari's (1987) study shows how imagery beyond the visible spectrum can be helpful in landform recognition. In this research, inter-drumlin regions displayed higher proportion of moisture that influenced land cover, leading to a lower reflectance in visible-near-infrared (VNIR) bands and thus better separating drumlins. In conjunction with shaded relief derived through DEMs, Jansson and Glasser (2005) found false-colour composites integrating with near infrared and thermal infrared bands to be the most effective for identifying landscape. Marchese et al. (2019) used Multispectral Instrument (MSI), Operational Land Imager (OLI), Sentinel-2A/2B and Landsat 8 satellites sensors data to test an original multichannel algorithm (normalized hotspot indices and normalized thermal index), which aims at mapping volcanic thermal anomalies at a global scale. Sensors including the Advanced Very-High-Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS), which provide high temporal resolution data in the medium infrared (MIR) and thermal infrared (TIR) bands (up to 6 h in the case of AVHRR), have also been commonly used for operational monitoring of active volcanoes (Lombardo, 2016; Coppola & Cigolini, 2013). Thematic Mapper (TM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and image spectrometers such as Hyperion, providing medium-high spatial resolution near-infrared (NIR) and short-wave infrared (SWIR) data, are probably more useful for mapping lava flows and retrieving reliable volcanic feature information (Reath et al., 2019a, b; Davies et al., 2006). Satellite measurements of sparging, thermal variations and land breakage covering 17 years are used by Reath et al. (2019a) in 47 of the most active volcanoes in Latin America and associate these historical data with ground-based measurements documented by the Global Volcanism Program. This information offers to determine volcanic behaviour on a regional scale during, noneruptive, pre-eruptive, syneruptive and posteruptive periods. For the purpose of delineating overlapping lava flows near the summit through textural differences between flows, Smets et al. (2010) used individual SAR images and SAR pairs from ERS 1/ERS 2 (C-band), ENVISAT (C-band) and JERS (L-band: 23.5 cm) satellites. The snow has maximum reflectance accompanied by firn and ice as visible from the spectral response curve. Related reflectance of nearby rocks is observed in the debris layer on the glacier. An important remote sensing technique for distinguishing surface entities with various temperatures or emissivity is the thermal infrared (3–15 μm) (Lepparanta & Granberg, 2010).

The glacier's surface temperature is lower than that of the environment, and therefore the thermal data are being distinguished. The glacier is thermally active at a depth of just 10 m and can be detected throughout the season (Gareth & Pellikka, 2010). AVHRR, MODIS, Landsat and ASTER series are the most widely used thermal band sensors for the glaciological research. The key benefit of the microwave sensor in glacier tracking is the capability to encapsulate snow and ice at different depths through microwave signals and to provide information about the underlying configuration of the glacier. The L-band radar can be used to gather data about the inner stratigraphy of the glaciers. SAR data can be used for the evaluation of glacier faces, glacier stratigraphy and other metrics, including glacier thickness and acceleration, at high quality and high resolution. In particular, Landsat MSS, TM, AVHRR, MODIS, SPOT, ASTER and IRS VNIR bands are commonly used for mapping the snow cover zone worldwide. The Normalized Snow Difference Index (NDSI) is determined according to Dozier (1989) from a reflectance in band at wavelengths when the snow is bright (e.g. TM band 2 or MODIS band 1), where it is dark (e.g. TM band 5 or MODIS band 6) along with the band for threshold lights (e.g. TM band 4 or MODIS band 2). The Advanced Microwave Scanning System for Earth Observation (AMSR-E) is used since 2002 for providing a global Snow Water Equivalent (SWE) product (Nolin, 2010). SWE and snow depth recovery techniques use effective data from the microwave. SRTM and ASTER GDEM are the two global DEMs, publicly accessible and commonly used to build on the glaciers' topographical criteria. The glacier indices offer knowledge about the input of the avalanches from the adjacent to the glacier and impact the mass balance of the glacier. The glacier ratio is the proportional upsloping area and the downslope direction (Way et al., 2014).

GIS-based geomorphological applications span the entire spectrum of process fields and related landforms. On a range of spatial scales, anthropogenic landforms are generated. Under the general heading of 'engineering mapping', Fookes et al. (2007) aggregated several applied geomorphological mapping issues. Comparative maps of morphography, morphochronology, morphogenesis, tools and hazards made it possible to understand the important mapping criteria. More applications analyse the space-time patterns of geomorphic environments, multiscale characteristics and processes, scenarios of landscape transition, changes in disorder regimes and land destruction associated with natural and human forces, often in images or scientific visualization techniques. The convergence of GIS and RS with digital elevation models (DEMs) has, especially with the development of the early twenty-first century in LiDAR (light detection and ranging) and UAV (unmanned aerial vehicle) to get high-resolution DEMs, becomes one of the most prevalent strategies for geomorphologic exploration. Both the systematic extraction and accumulation of material and the unintended consequences of hydrological changes and subsequent degradation and sedimentation are implicated in these processes (Hooke, 2000). Geomorphological modifications arise from a variety of anthropogenic processes, involving forest clearance, agriculture, land mining and excavation, mining and quarrying, infusing, irrigation and dam building or other infrastructure properties (Nir, 1983). Global satellite positioning (GPS) technology is common in defining and incorporation of different data on geographical positions of landscape features and specific patterns. These emerging capabilities represent a significant improvement relative to conventional cartography in geomorphology. Conceptual and functional challenges that have a potential for geospatial solutions also need to be understood (Table 1.1).

1.4 Anthropogenic Landform and Intervention of Geospatial Technology

On a number of spatial scales, anthropogenic landforms are formed. Human activities like excavation, mining and quarrying have brought about dramatic changes in the landscape. Landforms of local scale emerge from excavation, cutting and levelling to change slopes and channel morphology and establish flat land for infrastructure for construction and transport infrastructure. Broader landforms of size are produced by mining and quarrying, as well as subsidence due to the exploitation of water or mineral resources. Many of the researchers warned about the destructions have been caused by human activity, but perhaps more harmful to life and property are disturbances induced by these practices (wastelands, scars arising from strip mining and open-pit quarrying). In regions with concentrated human occupation (e.g. in urban areas), the combined geomorphologic impacts of human activities are more prominent and arise mainly in the early-urban to mid-urban stages of growth (Chirico et al., 2020). Some of the human actions have induced slope displacement by steeping slopes, removing the support, removing protective cover, surplus stacking, drainage blockage, increased soil moisture and vibration. Geoscientific knowledge plays a critical role in evaluating resource capacity and suitability for urban planning, defining risks and advising management policies with increasing demand on urban areas (Fookes et al., 2005).

1.4.1 Mining, Quarrying and Geomorphological Change and Application of Geospatial Technology

Remote sensing methods have been successfully used globally in mineral extraction research (Fig. 1.1). While fine-resolution data has been used to analyse improvements in the scale of surface mining, owing to its global coverage, a vast number of studies are focused on Landsat imagery (Maxwell et al., 2014). Studies integrating mine recognition with multitemporal analysis can also be strengthened by using fine-resolution data to classify and establish mine borders while doing change analysis based on medium-resolution imagery (Koruyan et al., 2012). In semiarid areas, Schimmer (2008) used normalized difference vegetation index (NDVI), wetness and grain size homogeneity to establish a new metric unique to the detection of

Table 1.1 Spatiotemporal characteristics of geomorphological features

Order	Relief type	Spatial extension (km^2)	Temporal characteristics (in year)	Landforms	Satellite/sensor
0	Mega relief	$5.098*10^8$	$5*10^9$	Lithosphere, cryosphere, hydrosphere, atmosphere, ecosphere	Gravity Recovery and Climate Experiment, MODIS, NOAA-AVHRR, Landsat, ASTER, ESA's satellite SMOS, MIRAS
1		10^7–10^8	10^9–10^8	Continents, ocean basins and tectonic plates	InSAR, SPOT, ERS-2 radar, TERRASAR-X, JERS-1, ALOS, MOSART, IRS, AIRS
2	Macrorelief	10^7–10^5	10^8	Physiographic provinces, shields, large volcanoes, mountain ranges	AVHRR, MODIS, Landsat, ASTER, SPOT, CORONA, Sentinel-2, SEVIRI
3		10^5–10^3	10^8–10^7	Medium-scale tectonic units, mountain massifs, fault blocks, grabens	Landsat TM, ASTER, WorldView-2
4	Mesorelief	10^3–10^2	10^7	Small-scale tectonic units, fault blocks, sacking	
5	Microrelief	10^2–10^1	10^7–10^6	Large-scale erosional/depositional landforms, major valleys, piedmonts, deltas, landslides	SRTM, aerial photography, Landsat (MSS, TM, ETM+), SPOT, IRS, Radarsat, JERS-1, LDAR, CORONA satellite, RapidEye, Pleiades
6		10^1–10^{-1}	10^6–10^5	Medium-scale erosional/depositional landforms, cirques, moraines, floodplains, alluvial fans	ETM$^+$, LiDAR, SRTM, IRS, IKONOS, Digital Globe
7	Nanorelief	10^{-1}–10^{-3}	10^5–10^4	Small-scale erosion/depositional landforms, ridges, terraces, dunes, slump blocks, talus	MODIS – Terra/Aqua, ASTER, Landsat TM, ETM$^+$, aerial LiDAR, UAV, IKONOS, InSAR, IRS-1C PAN, SPOT-4, AVIRIS, RADARSAT
8	Picrorelief		10^4–10^3		

(continued)

Table 1.1 (continued)

Order	Relief type	Spatial extension (km^2)	Temporal characteristics (in year)	Landforms	Satellite/sensor
		10^{-3}–10^{-5}		Larger geomorphic process units, hillslopes, stream channel reaches, talus, small debris flows	Low-altitude unmanned aerial vehicle (UAV), terrestrial laser scanning (TLS), 3D Point Cloud (3DPC), aerial photograph, IKONOS, Quickbird, WorldView and GeoEye
9		10^{-5}–10^{-7}	10^3–10^2	Medium geomorphic process units, riffles/pools, river bars, slope facets, solution pits, gullies	SRTM, ASTER, RADAR, LiDAR, Google Map
10		10^{-7}–10^{-9}	$<10^2$	Smaller geomorphic process units, ripple marks, glacial striae, rills, raindrop impact pits	ICESat, CryoSat
11		10^{-9}–10^{-12}		Clast grain morphologies, clay mineral structure	

AIRS Atmospheric Infrared Sounder, *ASTER* Advanced Spaceborne Thermal Emission and Reflection Radiometer, *AVHRR* Advanced Very High Resolution Radiometer, *MIRAS* Microwave Imaging Radiometer with Aperture Synthesis, *InSAR* Interferometric Synthetic Aperture Radar, *MODIS* Moderate Resolution Imaging Spectroradiometer, *MOSART* Monitoring of Surface Deformation in Active Tectonic Zones, *GRACE* Gravity Recovery and Climate Experiment, Tropical Rainfall Measuring Mission, *SEVIRI* Spinning Enhanced Visible InfraRed Imager, *UAV* unmanned aerial vehicle

Source: modified after Napieralski et al. (2013)

copper mill tailings. In order to quantify changes in vegetation stemming from marble quarry expansion in a densely vegetated area, Koruyan et al. (2012) also used NDVI. To identify mining areas and assess recent mining expansion in Myanmar, LaJeunesse Connette et al. (2016) used freely available data (such as Google Earth) and open-source software. Open-cast mining causes piles of manure, tailings, solid waste and other issues impacting land use (Ozdemir & Kumral, 2019). Slope stability has introduced secret risks to mining areas (MA) of open-cast mines with a rise in mining depth and mining angle. The dynamic acquisition of multiple variables through UAVs equipped with different sensors at different phases in mining areas is an efficient method to provide constant monitoring of risk sources after quarrying and land reclamation planning (Jackisch et al., 2018; Xiao et al., 2019).

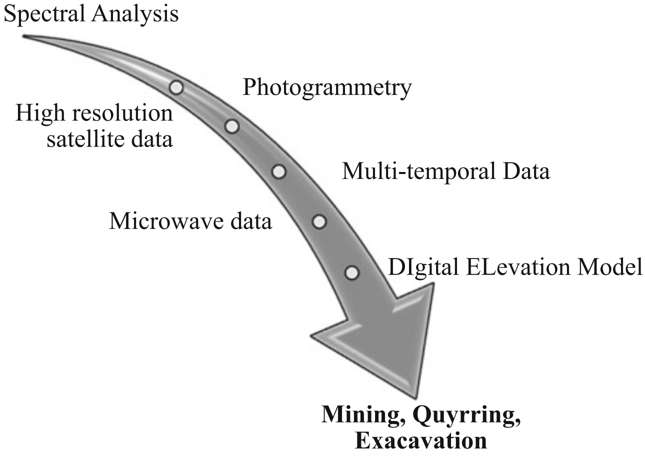
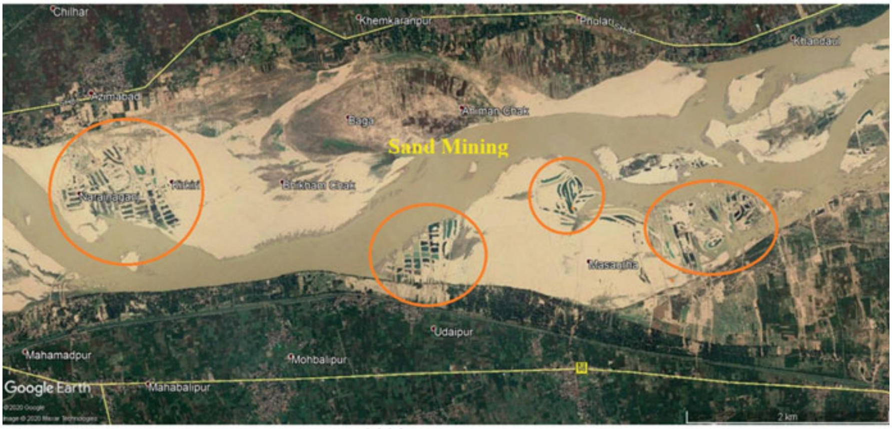


Fig. 1.1 Role of geospatial technology in mining, quarrying and excavation

1.4.2 *Riverine Geomorphology and Human Intervention and Application of Geospatial Technology*

Unintended side effects and future long-term legacies that can cause new complications in upstream or downstream sections are always taken into account in human interventions in riverine ecosystems (Hohensinner et al., 2018). Natural channel changes are superimposed by disruptions induced by humans that further enhance or curtail fluvial dynamics. A river channel's geometry represents the equilibrium or imbalance of erosion and depositional factors that configure the riverbed and the banks, respectively. Bandyopadhyay et al. (2013) reported that the elevation differences between narrow dried-up channels for brick factories to supply raw materials also cause the river course to change, alter the natural dynamics and eventually make the Haora River sick (Tripura, India). From the human viewpoint, the valley slope probably remains the same, and the supply of sediments are more susceptible and over shorter time frames respond to natural or human effects. Apart from specific impacts on human beings, such as changes in land cover or sand mining (Fig. 1.2), the fluvial morphology of the river rises to the most direct changes in river channelization. As the texture of the sand is very fine and it is of high demand for its manufacturing purposes, brick fields and some other building industries obtain sand from the riverbed. This sand extraction from both the riverbed and the riverbank induces numerous forms of hydrological changes within the river system (Saviour, 2012). Sediment quarrying from the riverbed is generally treated as a good activity that eliminates a river's dilemma of sedimentation. However, the sediments are randomly quarried, it poses another challenge for the flow, leaving the riverbed uneven and porous and generating more sedimentation to the lower river reaches (Bandyopadhyay & De, 2018). Most of the brick fields in this river basin accumulate mud by clumsily destroying the nearby low-elevated denudational uplands and

2017



2020

Fig. 1.2 Temporal view of anthropogenic intervention (sand mining) along the Sone river course in Bihar, India

transferring the left out loose debris to the river and creating unnecessary sedimentation (Fig. 1.3).

Moreover, brick fields situated along the river do not have sufficient road access in most instances. So, they have to move their goods over the river across those brick fields. Any temporary bridges across the river have been built by most of the brick fields, and they also often use the riverbed itself as their means of transport by dumping particles of bricks. This brick dumping inside the riverbed made the bed rough and affected the rugosity of the river.

Mining operations exacerbate coastal erosion not only by extracting sand directly but also by disrupting the sediment budget, frequently depriving regions of their sand input in the down-current direction. Despite the limited spatial scope of operations, the combination of optical images and Interferometric Synthetic Aperture Radar (InSAR) can be used to determine the environmental effects of black sand

Fig. 1.3 Temporal view of development of brick industry along Rupsa River course

mining (Chaussard & Kerosky, 2016). The L-band sensor on board the ALOS-2 and future NiSAR satellites will be especially suitable for ongoing surveillance and impact monitoring of mining activities.

The river's normal behaviour has been disrupted because of the unscientific development around the river. The river adjusts its behaviour to readjust the situation and has a great strain on those building systems that end with the fall of most of them. Bridge pier structures have certain morphological effects on rivers (Lane, 1955). Pier scouring happens as water levels discharge is raised and significant quantities of surface materials next to the bridge piers are swept away (Heidarnejad et al., 2010). Any of the removed soil particles are surrounded by turbidity currents along the bridge piers (Pasiok & Stilger-Szydło, 2010) and are accumulated as bars immediately downstream of the bridge.

Aher et al. (2012) describes the 35-year changes in the Pravara riverbank due to numerous natural and manmade activities such as floods, water intensity, sand extraction, plant cover destruction and rich soil excavation for the different proposals of the inhabitants of the immediate surrounding area using remote sensing data (SRTM) and GIS technology. Five different years (2010, 2003, 1989, 1980 and 1973) of Landsat Enhanced Thematic Mapper Plus (ETM+), Thematic Mapper (TM) and Multispectral Scanner (MSS) image and topographic maps of 1947 were used to identify and analysed vulnerability and morphological changes of Jamuna river course by Uddin et al. (2011).

1.4.3 Coastal Geomorphology and Human Intervention and Application of Geospatial Technology

At a global scale, delta morphologies are easily modified by the direct and indirect influences of human behaviour (Hoitink et al., 2020). Delta dynamics are largely governed by the availability of riverside sediments and subsequent reworking by tidal and wave driven, and variations in average sea level and in the distribution of sediments are influenced over longer periods of time. These environmental dynamics are detrimental to human activity, for example, the development of reservoirs in catchments on rivers has left many deltas starving (Kondolf et al., 2014; Schmitt et al., 2017). Delta planforms have been completely resolved by embankments (engineered levees) for purposes of land reclamation and flood control, thus competing between alternate land use categories (Giosan et al., 2013). Delta distribution channels usually terminate in mouth bar structures, where depths are limited, whether restricted by embankment or not (Fagherazzi et al., 2015). Erosion activities contribute to the emergence of deep pits in the channel beds in deltas of interconnected subsoil lithology, placing covered embankments at risk (Sloff et al., 2013). As a consequence of flow reconfiguration caused by human changes, vulnerable earthen dikes will explicitly collapse, including in the Ganges-Brahmaputra delta (Bain et al., 2019). In view of the projected rise in sea level, sand mining, groundwater extraction and human impact on delta soil, traditional delta landscape control approaches may become unsustainable (Schmitt et al., 2017).

High-resolution satellite data helps in continuos tracking of hydrodynamic and morphodynamic reactions to sudden and incremental shifts in boundary conditions (Fig. 1.4). A modern strategy to persistent flow and discharge control, for example, takes advantage of measurements from a horizontal acoustic Doppler profiler that can gather horizontal flow profiles through complex delta channels (Kästner et al., 2018). Particularly, under the surface of the water, airborne remote sensing techniques in turbid conditions associated with river deltas are confined. In shallow coastal and deltaic systems, this is a regular phenomenon. High-resolution digital elevation models (DEMs) interpolated from over 1000 measurements per square metre can be created by extensive use of light detection and ranging (LiDAR), motion structure and other techniques in terrestrial environments (Passalacqua et al., 2015). In clearwater systems, LiDAR and multispectral techniques will also work well to quantify bathymetric surfaces where measurements of up to 70-m depth are possible (Brock & Purkis, 2009; Wedding et al., 2008). The need to build automated software capable of collecting sensitive information without or with minimal user interaction is intensified by the vast data sources from remote sensing.

1.4.4 Human Intervention in Mountainous Region and Application of Geospatial Technology

Humans are able to preserve certain ecological resources. Therefore, effective interdisciplinary cooperation is required, requiring shared data sources that are open and clear to all interested populations. In the coupling of the ecological and human facets of delta processes, social sciences play an increasingly important role. Study activities have to become not just interdisciplinary but also transdisciplinary, that is, including stakeholders, for an efficient interface between delta science and delta management. A normal morphodynamic equilibrium usually no longer occurs,

Fig. 1.4 Temporal view (2004–2020) of Mahanadi river delta

and deltas cannot achieve morphodynamic equilibrium as long as human actions take place due to continuous interventions. In addition to these, the stratigraphic record offers an extensive database of pristine delta behaviour that should be further studied in order to uncover unexplained natural morphological resilience mechanisms.

Anthropogenic triggering factors may decrease forest resistance to landslides through deforestation, forestry and mining or may increase vulnerability of forest areas to landslides through fragmentation caused by infrastructure construction, including extension of the transport network with the results of mass movements and slope failures (Shirvani, 2020). In the meantime, the impact of anthropogenic behaviour on the vulnerability of degraded forests to landslides can be revealed by a distinction between the influence of conditioning and triggering factors in protected and non-protected forests. Change in land use is a significant factor in the creation and movement of landslides caused by rainfall (Karsli et al., 2009). Landslides are specifically correlated to land use variations (Glade, 2003). The larger the volume of land cover, the less soil is destroyed by the rains. Since to recover a natural slope takes 30–35 years or more (Hung, 2009), slope land growth can enable a slope to drop its equilibrium, causing slope collapse during heavy downpours. Anthropogenic practises in mountain regions typically create volatile areas on hillsides in the Earth's material (Nefeslioglu et al., 2011). Human activities including deforestation have been described as a primary preparatory factor in a study area in Ethiopia for shallow landslides (> 3-m deep) by eliminating the stabilising forest greenery (Broothaerts et al., 2012). Recent scholars have investigated the existing generated mapping of landslide vulnerability in terms of applying common geo-environmental variables across various regions and periods (Reichenbach et al., 2018), taking into account fixed effects of a variable (Xiao et al., 2018) such as road distance and land use/land cover generated from the latest available images without analysing their dynamic changes. Shirvani (2020) investigated the significant conditioning and triggering factors that control the susceptibility of landslide using Landsat 8 multispectral images and digital elevation model (DEM) data.

1.4.5 Soil, Gully Erosion and Application of Geospatial Solution

Naturally, soil erosion happens by wind or extreme climatic conditions, but overgrazing, overcropping and deforestation are man-made practices, influencing soil erosion. *Overgrazing* happens when farmers store too many animals on their property, such as horses, cattle or goats. By chewing the plants and then scratching into damp soil or compacting dry soil with their hooves, the animals destroy the soil surface. *Overcropping* happens as the soil is continually harvested, and between crops it is not permitted to lay fallow. When it is continuously ploughed or stripped for crop growth, this continuous cultivation of the land decreases the capacity of the soils to provide useful humus for soil fertility. *Deforestation* is the chopping down of an open, uncovered ecosystem of vast tracts of trees. By leaving large areas vulnerable to excessive rainfall (which can cause leaching or flash floods) or wind erosion, deforestation accelerates soil erosion. When humans intervene with building, gardening, forestry and mining operations on the earth, the result is a deterioration of the Earth's surface layer, contributing to excessive wear and erosion. The eroded material is taken away or transferred and ultimately deposited by water, wind, etc. When water flows over land, it takes sand and other types of natural debris with it.

By raindrop splash, eroded soil is transported downslope. The erosion is termed rill erosion as drainage water focuses and passes into finger-like channels (rills) from upland areas containing soil particles, and the soil eroded from between rills is referred to as inter-rill erosion. When rill erosion starts, a sequence of deeply erodible head cuts usually advances up the slope (Shit et al., 2020). Gully is referred to as areas where accumulated drainage from a slope is adequate in volume and velocity to dig deep trenches or where concentrated water tends to cut in the same groove (such as rill) creating a deep incision of the surface. In terms of high-spatial-resolution satellite imagery and geographic object-based image analysis (GEOBIA) (Fourie, 2011), the development of remote sensing technologies provides the ability to map gullies with less effort, time and precision at an appropriate level. Previous experiments have shown that because of the spectral similarity with other non-erosion characteristics, supervised classification methods such as the maximum likelihood classification (MLC) algorithm do not express water erosion characteristics at an appropriate degree of precision (Pirie, 2009). Some human actions, such as agricultural practices, forest conversion to agriculture, etc., will increase the rate of erosion. Latest studies suggest that gully erosion is one of the most severe risks to agricultural lands and is an essential aspect of sediment in a number of environments, and gullies are effective connections for the transport of runoff and sediment from uplands to valley bottoms and permanent channels where the consequences of river erosion are exacerbated off-site. The prevalence and behaviour of gully erosion, however, has been constrained, and the geographical distribution of soil loss has been identified due to the constraints of small datasets in dynamic situations. Integrated erosion prediction models using remote sensing (RS) and geographical information system (GIS) not only provide estimated soil depletion but also provide spatial erosion distributions (Okalp, 2005). Through their drainage pattern, form, scale, colour and tone, gullies have been visually identified from multispectral remote sensing data. In the red and infrared (IR) bands, gullies with no vegetation appears bright. Pirie (2009) suggested that since they get embedded with the pixels, gullies smaller than 10 m cannot be observed using SPOT 5 imagery. It is also recommended that IO techniques, such as Quickbird, TerraSAR-X and IKONOS, be checked with better higher-spatial-resolution images. Bouaziz et al. (2011) investigated the possible contribution of the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) data and geomorphological parameters to the discernment of MER gully erosion trends and characteristics. In order to remove various gull shapes and patterns, maximum likelihood classification (MLC), support vector machine (SVM) and minimum distance (MD) classifiers have been used. The most productive data is provided by very-high-resolution satellite images (Desprats et al., 2013), traditional aerial photography (Maugnard et al., 2014) and nowadays also by images collected using unmanned aerial vehicles (UAVs) for precise tracking of damage in individual catchments or in agricultural fields (Eltner et al., 2014). Photogrammetry, primarily close-range photogrammetry (Wells et al., 2016) or UAV-based photogrammetry (Carollo et al., 2015) and terrestrial laser scanning (TLS) are the most frequently used noncontact techniques (Vinci et al., 2015). High-resolution data, such as point clouds, which enable digital surface models (DSMs) to be created and orthophotos of observed objects, such as erosion rills and gullies, to be acquired for more volumetric study, are an advantage of modern indirect methods. Gessesse et al. (2010) have used photogrammetric DSM time series to measure the change in tillage-induced microtopography on field plots due to inter-rill and rill erosion. Razavi-Termeh et al. (2020) have investigated the gully erosion susceptibility map (GESM) for the Abdanan region, Ilam province, Iran, using frequency ratio (FR), logistic regression (LR), an ensemble of radial basis function (RBF) and imperialist competitive algorithm (ICA) models. In a GIS platform, 12 factors influencing gully erosion were defined and planned to model the GESM, including height, slope angle, slope part, plan curvature, topographical wetness index (TWI), standardised differential vegetation index (NDVI), soil type, precipitation, river distance, road distance, lithology and land use in the study region. Thus, such strategies are effective where there has been great geomorphic change and high-quality historical evidence.

1.4.6 Urban Geomorphology and Application of Geospatial Solution

Urban growth is one of the world's biggest challenges. Urbanisation and the subsequent development of infrastructure have a high effect and often disrupt landforms completely (Reynard et al., 2017). Landform often borders between two geomorphological contexts that prohibit urbanisation in some directions, such as the borders of river or plateau. Some unique geomorphological backgrounds often contribute to significant urban development limitations. The slope is also a barrier to urbanisation and causes natural threats, such as landslides, rockslides or debris flows, particularly dangerous for settlements built without preparation on precarious slopes in humid climate conditions. Processes of geomorphology can lead to natural threats. Owing to the distribution of communities that maximise risk, damages and casualties in urban areas are significantly higher than in rural areas. Urbanization is a transformative vector of relief. This produces artificial types of land. These are often infills intended to remove pathways and make movement simpler. There are also hills made up of different waste materials. Finally, urbanisation is the aspect that affects landforms, like degradation. Many landforms, especially separate fillings,

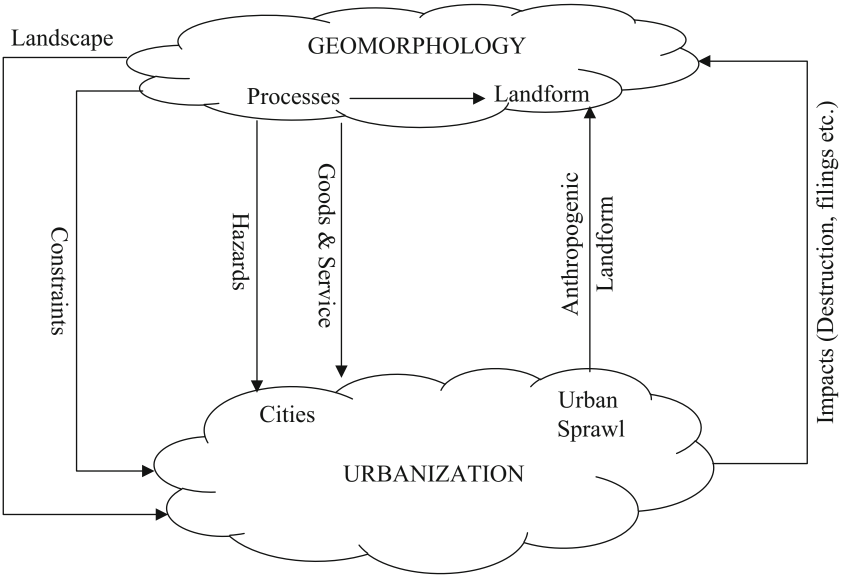


Fig. 1.5 Association between geomorphology and urbanization (Source: Reynard et al., 2017)

perforations (tunnels) or abrasions, are influenced by city planning. It contributes to the partial or complete invisibility of lands and sediments protected or degraded by urban facilities. As the urbanisation takes place, the formerly forested land is supplanted with impervious surface, distorting the size of waste and the sediment delivery to the stream network (Booth & Jackson, 1997).

Urban geomorphosites are places that illustrate the connections between geomorphology and urban growth in a classic sense (Fig. 1.5). Urban geomorphosites as well as other types of geomorphosites found in rural areas and natural areas should be considered, evaluated and controlled. They can be alone, or group of property, of complex type or geomorphological structures like all kinds of geomorphosites. Numerous settlements, with different systems, are in dynamic geomorphological settings, and the town site itself can be used as a geomorphosite (geomorphological system). Urban geomorphosites may be either dynamic (active geomorphosites) or inactive (i.e. indicative of no longer current historical morphodynamic conditions); others may be static geomorphosites emerging (Pelfini & Bollati, 2014). Urban geotourism has recently been developed. Urban areas also have fascinating contextual conditions depending upon geo-interpretation (Hose, 2012) for the production of geotouristic services (Pica et al., 2017).

The complex relationship between various facets of urban development, such as build-up area expansion, construction activities on natural features causing the diversion and depletion of aquifers and the unique geomorphic characteristics of the urban area, needs to be understood (Wolman, 1967). Sediments overload the waterways and thus modify the courses. The availability of groundwater from the urbanised region also declines and the frequency of runoff increases (Sala & Inbar, 1992). The growth and development of a city over the years are steadily altering the local topography. Ultimately, such changes impact geomorphic processes such as weathering and erosion (Viles, 1993). Mohapatra et al. (2014) used Landsat satellite image to evaluate the effects of urban expansion on geomorphology in the historical town of Gwalior in central India. Results initially revealed that residual hills are transformed and the denudational hills are progressively influenced. Most of the denudational hills will be impacted in the future with growing demands for urban space and nonavailability of plain regions. Results also revealed that two streams of the Swarnarekha and Morar Rivers flowed south to north through the city's western and eastern portions, respectively. The rain water from the catchment area is obtained by the Morar River by numerous nallas. Due to the dumping of solid waste materials that obstructs the carrying ability of the sediments, siltation is evident along its course within the region. In the low-lying areas, waterlogging issues have also been seen. The destruction of riparian habitats and the disconnection of stream channels to their floodplains are another detrimental effect of urbanisation (Segura & Booth, 2010). Haldar and Satpati (2018) enhanced the concept of urban geoforms in Kolkata Megacity (West Bengal, India) situated in humid tropics. They have highlighted surface deformations due to urban hazards like waterlogging and subsidence and also accidents due to uneven surfaces. However, numerous anthropogenic processes act to alter the topography of metropolitan environments. This may involve digging underground lines or pipes, cutting and filling surfaces, shifting of building materials and laying of roads and floors. In addition, indirect improvements include waste disposal, construction material disintegration, failure, shrinking or surface layer and the sedimentation degenerative streams/canals.

The developments in remote sensing and GIS technology have created a forum for space and time analysing landscape transformations (Estoque & Murayama, 2016). Landscape changes are regulated by anthropogenic behaviours in urban areas and are profoundly affected by spatial extension of built-up lands (Estoque & Murayama, 2015, 2016). LISS-III, Landsat TM, MSS and ETM+ satellite data have been used for 25 years (1977–2002) to study the urban structure of Ajmer city of Rajasthan, India (Jat et al., 2008). The spatial analysis of urban geography of Ranchi town, India, was studied by Ahmad and Goparaju (2016) using Landsat data from 1976, 2002 to 2015 and reported the prerequisite for unplanned urban growth tracking and sustainable urban development. Taubenböck et al. (2009) detected the temporal and spatial sprawl in cities, while Abd El-Kawy et al. (2011) proved the responsibility for land loss practices due to human activities. Geomorphology remains a major and productive method in allowing developers and policymakers to prepare for low-cost environmental planning and sustainable growth. In recent decades, for example, 68% of the coast of New England and the Central Atlantic region of the USA have suffered erosion for many reasons, mostly linked to anthropogenic influences (Goudie & Viles, 2016). In addition, it is a possible disaster, involving loss of life, to build and urbanise in/near sand dunes or in places where any other geomorphic risk, such as a base, being undermined by fragile bedrock. Therefore, the use of both high-spatial-resolution remote sensing (Unmanned aerial vehicles UAVs for 3D imaging) data and field research (ground truthing) to detect land use and land cover changes, such as the use of sample analysis of historical sites and soils to trace evidence and create/update a geomorphological map and the construction of a spatial database, can lead to the generation of an effective urban planning system.

1.5 Conclusion

Geomorphological maps are required on a wide range of scales, as various chemical, biological, meteorological and lithospheric processes are restricted and regulated by surface materials and topography. The most advanced approach to generate detailed geomorphological maps on multiple scales is still human analysis, even though subjectivity, reproductivity and validity continue to be a concern. Theoretical and philosophical advances propel advancement in research. Geomorphologists can now navigate a host of new data and technological features and can modify and interpret data using multifaceted processing sequences. The most powerful geomorphic entity of the universe is now human beings to shape and reform the surface by modifying the physical landscape. However, the advancements to digital geomorphologic mapping protocols in the current state of geospatial technology would rely upon combining geomorphological and GIS science expertise and on the person, who wants to cross the gap between two disciplines and contribute to computational geomorphology. This strategy often collectively acts as a way to create uniform forms of geographical territories. With global DEMs and satellite images accessible, geomorphologists must concentrate on map information material, vocabulary, setting the appropriate mapping requirements, evaluating objective methods and repeatable outcomes.

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