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BLOCK 5: APPLIED GEOMORPHOLOGY

Applied geomorphology plays a crucial role in understanding and managing the dynamic interactions between Earth's surface processes and human activities. This interdisciplinary field utilises the principles of geology, geography, hydrology, and engineering to assess the morphological changes of landscapes and develop effective strategies for sustainable land use and hazard mitigation. By comprehending how natural processes shape the land, applied geomorphologists can provide valuable insights into issues such as soil erosion, sediment transport, and the formation of landforms. This knowledge is especially vital for planning infrastructure projects, urban development, and agricultural practices, as it helps mitigate the adverse effects of human interventions on natural landscapes. Additionally, applied geomorphology contributes significantly to disaster risk reduction by evaluating the susceptibility of areas to various natural hazards like landslides, floods, and coastal erosion. Through its holistic approach, applied geomorphology empowers decision-makers to make informed choices that balance environmental conservation with human needs.

Furthermore, the importance of applied geomorphology extends beyond immediate practical applications. It provides a historical perspective on Earth's ever-changing surface, offering insights into the long-term evolution of landscapes and the underlying geological processes that have shaped them. By studying past landforms and their formation, researchers can decipher the interactions between climate change, tectonic activity, and surface processes, contributing to our broader understanding of Earth's geological history. This knowledge can guide predictions about future landscape changes, especially in the face of ongoing climate variability and anthropogenic impacts. In essence, applied geomorphology bridges the gap between scientific exploration and real-world problem-solving, fostering a deeper connection between humanity and the dynamic natural systems that shape our world.

This block introduces you to the understanding of the basic of applied geomorphology with the understanding of slope processes, geomorphological mapping, geomorphic techniques, landforms, and environment management in detail in four units.

Unit 14: Slope Processes

This unit explains the slope processes, which are an essential factor in shaping the earth's surface and have significant implications for land-use planning, erosion control, and hazard management. Understanding the slope process is essential for developing effective strategies to manage and mitigate the risks associated with slope instability. We will also learn about hill development and evolution, measurement and description of slope, and different models of slope development.

Unit 15: Geomorphic Mapping

This unit discusses geomorphic mapping which is considered a basic unit of earth processes, generating valuable databases for surface processes and shaping the current earth structure. In this unit, we will also study about methods and Analysis of Geomorphic Data, Geomorphic Models, Geomorphic Mapping, and Application of Remote Sensing.

Unit 16: Geomorphic Techniques

This unit discusses the geomorphic techniques which are used to measure different landforms. You will be also learning about the hazard and risk assessment associated to land degradation

and soil degradation. The unit is also covering the problem of desertification which is an example of hazard and risk associated with land degradation.

Unit 17: Landforms and Environment Management

This unit discusses the issues related to landforms and environmental management. The unit discusses humans as geomorphic agents that how they are transforming the landforms. In the unit, we will also learn about surface and groundwater hydrology and also different types of land use planning.

We hope after studying this block, you will better understand the application of applied geomorphology for understanding the concepts of geomorphic processes, geomorphic tools and techniques, and issues of landforms and environment management. Our best wishes are with you in this endeavour.

We suggest for any assistance regarding this course, you can contact at: knrao@ignou.ac.in and dr.krishnakumar@ignou.ac.in



SLOPE PROCESSES |

Structure

14.1	Introduction		Slope Replacement Model
	Expected Learning Outcomes		Parallel Retreat Model
14.2	Hillslope Development and Evolution	14.5	Summary
		14.6	Terminal Questions
14.3	Measurement and Description of Slope	14.7	Answers
		14.8	References and Suggested Further Reading
14.4	Models of Slope Development		
	Slope Decline Model		

14.1 INTRODUCTION

In the previous Unit 13, we discussed the different coastal processes and landforms and now in this Unit 14 we will study the slope processes in detail. In section 14.2 we will study the hill slope development and evolution, and in section 14.3 we will study about measurement and description of the slope. In section 14.4 we will study models of slope development.

As we all know, Geomorphology is the study of landforms and the processes that shape them. One fundamental concept in geomorphology is the slope process, which refers to material movement down a hillside or slope due to the forces of gravity. The slope process is an essential factor in shaping the earth's surface and has significant implications for land-use planning, erosion control, and hazard management.

Slope processes can be classified into three categories: soil creep, landslides, and rockfalls. Soil creep is the slowest and most common form of slope movement, where soil particles move downhill in a slow, continuous manner. Landslides occur when a mass of soil, rock, or debris moves rapidly downslope, often triggered by natural events such as heavy rainfall or earthquakes. Rockfalls are similar to landslides but involve the sudden movement of individual rocks or boulders down a slope.

Understanding the slope process is essential for developing effective strategies to manage and mitigate the risks associated with slope instability. For example, the construction of structures such as retaining walls, stabilizing

vegetation, and drainage systems can help reduce the likelihood of landslides and other slope failures.

Among all the landforms, around 90% surface of the land occupied by slopes are the most unique landforms of the earth's surface and are mostly overlooked. The slopes are the most important and prerequisite to any land-use planning and development as the slopes aid in understanding the lithology of the region. Slopes are generally defined as the upward or downward inclination of the surface between Hills and valleys. The study of slopes mainly includes the thorough study development and evolution of hillslopes.

Expected Learning Outcomes

After studying this unit, you should be able to:

- elucidate the process involved in hillslope development and evolution;
- describe the form of slopes;
- explain the models of slope development.

14.2 HILL SLOPE DEVELOPMENT AND EVOLUTION

Hill slope development and evolution are fundamental processes in geomorphology, which involve the physical and chemical weathering of rock, soil erosion, and the transport of sediment downslope. The morphology and evolution of hill slopes are determined by a complex interplay between internal and external processes, including climate, topography, vegetation, soil properties, and geologic structure.

The development of hill slopes typically begins with the formation of a convex profile through the accumulation of sediment at the base of a slope. Over time, the slope profile becomes steeper and more concave as erosion and weathering processes remove material from the upper part of the slope and deposit it at the base. This results in a gradient of soil thickness and rock weathering from the top to the bottom of the slope.

The evolution of hill slopes is also influenced by the presence of vegetation, which plays a significant role in soil stabilization and erosion control. In humid and temperate regions, the growth of trees and other plants on hill slopes can help to maintain soil cohesion and slow down erosion by intercepting rainfall, reducing runoff, and enhancing infiltration. On the other hand, in arid and semi-arid regions, the absence of vegetation can lead to accelerated soil erosion and the formation of gullies and badlands.

The evolution of hill slopes is also influenced by human activities, such as agriculture, urbanization, and mining, which can significantly alter the hydrologic and sediment budgets of slopes, resulting in increased erosion, sedimentation, and slope instability.

Understanding the development and evolution of hill slopes is essential for managing natural resources, mitigating natural hazards, and maintaining ecosystem services. Researchers use a variety of field, laboratory, and

modeling techniques to investigate these processes and their interactions, including topographic analysis, soil and rock sampling, hydrologic and sediment transport measurements, and numerical simulations.

Generally, there are two types of hill slopes: one is the slopes, which are comprised of the surface between a drainage divide and valley floor, known as valley-side slopes and another is the slope comprised of the surface between an upper and lower erosion level, known as Scarps. The slope feature size varies and may range from the miniature slopes of badlands to the high mountains.

The landform study mainly focuses on two important aspects, which are the form and the process. The former represents the morphology of the land surface at a given period whereas, the latter indicates the actual procedures of various agents, which caused alternation in the physical form of the landform. There are two approaches to having a proper explanation of slope developments. They are (i) Historical Approach and (ii) Process form Approach.

i. Historical Approach: This method is also known as the theoretical approach, where various assumptions were made to understand slope development by considering the historical evolution of slopes from its point of origin to its present form. However, this approach is problematic to construct a proper theory, as there were no proper measurement techniques to verify the accurate reconstruction of the past and gave an actual explanation of the actual form of the slope of the past. Hence, tracing the accurate process of historical slope development is very difficult. Many researchers have an assumption that the present-day slope has been developed from a near-vertical cliff in a period of time has weathered back and modified to new forms and gradients. In nature, such conditions may occur but in most of the cases, the slopes appear to border the river valleys, which were never once vertical cliffs. Hence, it is an incorrect generalization, that the slopes evolved from the river erosion process, and it always produced steep vertical cliffs. There was another problem in this approach was the determination of slope age, as no standard method was available to measure the same. In case of this, an extensive field survey of slope profiles may give rather satisfying results than the other methods. Further, the current method of studying numerous slope profiles does not give a satisfying result. Although there was the above-mentioned problem, still many geomorphologists have formulated a different theory to understand the slope development process.

ii. The process-form approach: This approach is based on the form of the slope and its gradient, due to the interaction of different processes like weathering, erosion, transportation, and deposition. The denudation processes operate with varied combinations and varied rates, which resulted in varied of slopes with different steepness. The slopes are mainly categorized based on the variation in rock type, climate, and vegetation. Likely, the historical approach, this approach also has numerous complications. As the process of denudation is extremely slow, the observation of the slope processes is quite difficult. Thus, there requires special tools and accurate methods to record the processes acting on the slope and gave accurate results.

Further, it is problematic to state firmly that the slope processes have a direct bearing on the form of the denudational slope. This approach has another problem associated with it, that the present-day processes may not arrive at the present-day slope. There was a varied opinion among researchers about the relationship between the slope and climate. Also, if it is assumed that the slope process controls the slope alone, then it gives rise to varied slope forms in different regions. However, certain types of slopes will be formed due to climate is a wrong assumption and not always true.

From the above-discussed approaches, the historical approach reviews the sequences of past events whereas the process form approach studies the interrelationships among the processes, which gives rise to varied slope forms. Hence, both approaches are helpful in understanding the slopes and their evolution.

14.3 MEASUREMENT AND DESCRIPTION OF SLOPE

Measurement and description of slope are essential tasks in geomorphology and other earth sciences. The slope is defined as the inclination or steepness of a surface relative to the horizontal, and it is expressed in degrees, percentages, or gradients. The measurement of slope is critical for understanding and analyzing landforms, erosion processes, and stability of slopes.

Several methods can be used to measure and describe the slope of a surface. One of the most common methods is the use of topographic maps and digital elevation models (DEMs). Topographic maps provide contour lines that connect points of equal elevation, allowing researchers to estimate the slope angle and direction of the land surface. DEMs are digital representations of the Earth's surface, created from satellite or airborne remote sensing data, and can provide a high-resolution representation of the terrain's slope.

Another method of measuring slope is through field surveys. In the field, a clinometer can be used to measure the angle of the slope directly. A clinometer is an instrument that uses a spirit level and a graduated scale to measure the angle of inclination between the line of sight and the horizontal plane. This method is especially useful for measuring slopes in areas where topographic maps and DEMs are not available.

One of the important methods of slope analysis is Wentworth average slope analysis. The Wentworth average slope analysis is a method used in geomorphology to quantify the slope of a surface by measuring the lengths of a set of straight lines across the surface. This method was first proposed by Chester Wentworth in his paper "A scale of grade and class terms for clastic sediments" in 1922.

Wentworth proposed a method for measuring the average slope of a sedimentary surface by measuring the lengths of a set of lines drawn across the surface at regular intervals. The lengths of the lines were then used to calculate the average slope of the surface. Wentworth's method was based on the assumption that sedimentary surfaces are composed of a series of straight lines or planes that are inclined at various angles.

Now we will study that, the slopes of a landform are expressed basically in two ways i.e., i. Slope in percentage and ii. Slope in degree. To determine the slope in percentage, the difference between the elevation of two points (Rise) is divided by horizontal distance (Run), then multiplied by 100 (Figure 14.1). The formula of slope in percentage is as follows:

$$\text{Slope in \%} = \frac{\text{Difference in elevation (meter)}}{\text{Horizontal distance (meter)}} * 100$$

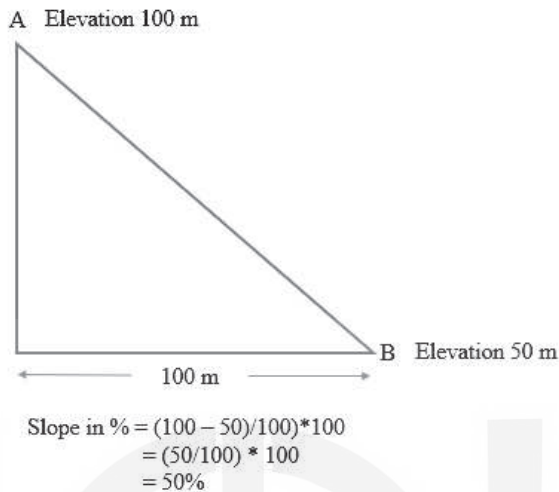


Fig. 14.1: Calculation of slope in percentage

To express the slope in degrees or slope angle, tangent of ratio between elevation difference and horizontal distance between the two points are taken in calculation. From, figure 14.2 slope in angle is opposite angle of the elevation difference. The formula is as follows

$$\text{Slope in degree} = \frac{\text{Difference in elevation (meter)}}{\text{Horizontal distance (meter)}}$$

SAQ I

What are the measurement unit of slope profile?

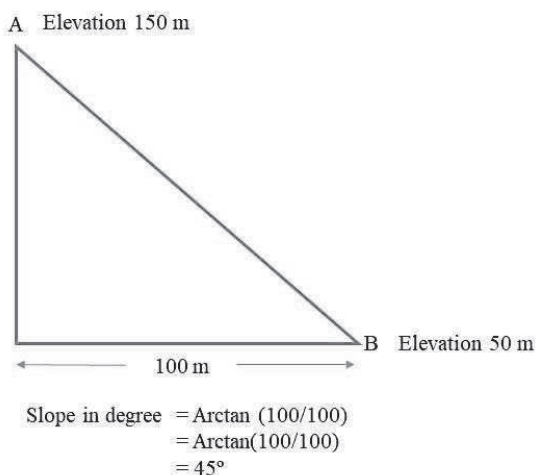


Fig. 14.2: Calculation of slope in degree

The hillslopes can be described in a various ways based on their characteristics or their dominant profile. Basically, the profile of slope comprises of convex, rectilinear, and concave slope forms. Generally, the convex slopes are found on the top of hillslopes whereas the concave slopes are found at the base of hillslopes. Further, as per L.C. King and A Wood's assumption, that slope may be of a composite form and comprises of four elements. These are (a) convex slope or crest (b) Scarp or free face (c) rectilinear slope (d) Concave slope. These profiles are most common in composite slopes, however, in nature, they may be varied with numerous combinations. All the elements may or may not be observed in a single profile. Followings are the major types of slope profiles

- **Convex Slope:** It is the formed by denudation process and is mainly found at the top or on the upper part of the hillslope. Convex slope is assumed to be characteristic of a humid temperature region. Chalk and limestones are mainly associated with a convex profile; however, it is always not true. The convex slopes are also known as crests at the upper part of the slope, and from the crest, the slope angle increases downslope. The two most active processes such as weathering and soil creep are behind the convex form slope (Figure 14.3.a).
- **Cliff of Free face:** Generally, the cliff of the free face is a steep wall-like slope. Due to its steepness, this type of slope is mostly bare in nature. Further, due to its steep slope, the debris or regolith cannot accumulate on it and falls and accumulate at the base of the cliff. Hence, many geomorphologists name it free face (Figure 14.3.b). Cliff or Free faces mainly developed in river valleys, glacial regions, faulted landscapes, and many other regions. If the debris deposited debris at the base of a cliff, does not come into contact with any transporting agents, then, the size of the debris deposition grows gradually, and the new form of slope developed and is referred to as Talus slope. Further, if there was a continuous supply of weathered material from cliff, then in the course of time the talus slope will cover the lower part of the cliff. The gradual increase of the talus slope caused a reduction in the length of free face and at some points of time, the entire cliff or free face would disappear and form a slope known as the aggradation slope.
- **Rectilinear Slope:** The straight slope profile formed below the cliff or free face is known as a rectilinear slope of constant slope, as the slope angle of this profile remains almost constant. The rectilinear slope may vary in dimension and dominate the whole slope. This slope section is mainly observed to spread downwards to the bottom of the valley from the summit. The rectilinear slope lies in the middle of the profile between the convex slope at the upper part and concave slope of the lower section. The repose angle of the weathered remains from the underlying rock and its occupying surface determined the angle of rectilinear slope. Many geomorphologists regarded that the aggradation only process that caused rectilinear slope, in many instances, it is not true. These slopes are also known as debris-controlled slope. The term 'Repose slope' was used by Strahler to name such slope (Figure 14.3.c).
- **Concave slope:** The lowest profile of the slope is referred as concave slope. It mainly lies at the bottom of a hillslope and spreads downwards to

the river valley (Figure 14.3.d). Usually, a layer of debris is deposited on it. The concavity is developed due to rain-wash, which caused the spread of finer particles farther than the coarse particle. Penck referred the term 'Waning' for such slopes. In arid and semi-arid conditions this slope develops a sharp break of gradient between the lower concave section and steeper slopes above in arid or semi-arid areas, however, in humid areas, the basal concavity grades smoothly into the higher slopes.

SAQ 2

Name major types of Slope profile.

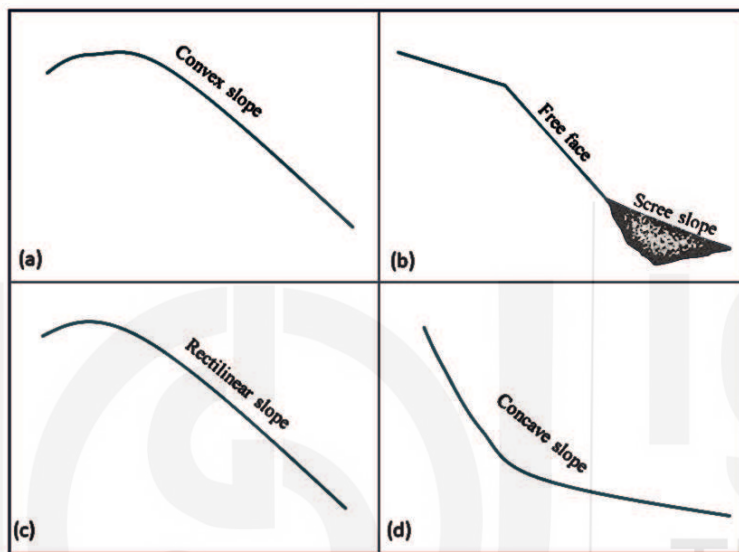


Fig. 14.3: Types of Slope form in Hillslope.

The above discussed slopes are the characteristics of hillslope as assumed by geomorphologists; however, many other geomorphologists have pointed out that all four slope types discussed earlier may not be observed in a single hillslope. It is observed that, one or more slopes are missing from the slope profile due to several reasons. Further, in nature, a hillslope may have several combinations of slope. This slope is referred to as a composite slope. The following are the most widely observed composite slope forms.

- Convexo-rectilinear-concave slope:** This type of slope has three different slope forms in a single slope profile, starting with a convex slope at the upper part, a rectilinear slope in the middle, and a concave slope at the lower part of the slope profile. A curving slope profile is developed as all three slope forms smoothly grade into each other. This type of slope profile is most common in areas having weak rock types. The different slope has different slope lengths. Whereas a very complex slope profile has been observed in areas having diverse rock types, hard and soft rock alternate, or regions with several rejuvenation.

It is observed that, if the region is characterized by alternate massive and thinly bedded rock strata, high relief, very deep valleys and active weathering, there, a very composite profile has been observed. The profile will have numerous combinations of free face and rectilinear slope whereas there was limited or no upper convexity and lower concavity. In the region where

massive strata were present that caused free face while weak and thinly bedded rock caused rectilinear slope.

The region with an arid condition, and hard crystalline rock characteristics, another composite slope develops in which, the upper part consists of a free face with a slope angle of 40 degree or more, and the middle part consists of a boulder-controlled slope with a slope angle of 25 degree or more followed by a concave or pediment slope at the lower part of slope profile with very gentle and angles is less than 7 degree slope.

Overall, the measurement and description of the slope are essential tasks in geomorphology. Accurate measurements of slope are necessary to understand and analyze landforms and processes that occur on slopes, including erosion and landslides.

SAQ 3

What are the two approaches for explanations of slope developments?

14.4 MODELS OF SLOPE DEVELOPMENT

There have been numerous models of slope development, which were advocated by various geomorphologists. However, among them, three basic models are the Down wearing model of slope development by W.M. Davis, the Slope replacement theory by Walter Penck, and the Parallel retreat model by L.C. King. These three models of the slope are of three different regions characterized by three different climates, tectonic settings, rock types, and processes where the study has been conducted. Hence, the models are not necessarily contradictory to each other. W.M. Davis has studied the slopes of New England where the region has a humid temperate climate and stable tectonic settings. L.C. King has studied in the semi-arid region of South Africa whereas W. Penck has studied in the Andes, which is tectonically active.

14.4.1 Slope Decline Model

Likely the cyclic landscape development, the hillslope, and valleys also have cyclic development in nature. This cyclic model of slope development was advocated by W.M. Davis, in the year of 1899, and is known as the 'Slope Decline theory'. As per this theory, because of a rapid rate of weathering at the upper slopes of hillslopes, there is a progressive decline in the slope angle of the slope profile and sequential changes in slope. The sequential change in slope has three distinct phases or stages. The first phase is known as the Youth stage and has a convex slope, the second phase is known as the mature stage and has a rectilinear slope and the third phase is known as the old stage, which has the concave slope form.

In each phase of slope development, the slope progressively decreases its slope angle and lessens its steepness, and gives rise to the concavity at the bottom of the hillslope, whereas the convexity at the upper section extends its length and develops a gentler slope.

In the youth stage of cyclic erosion, the steep convex slope develops due to the downcutting and causes the deepening of valleys and weathering processes. In this stage, there is limited slope retreat and no decline of slope angle. During the mature stage, lateral erosion dominates vertical erosion. Hence, down wasting of water reduces the slope angle, caused the slope to decline, and develops a smooth curve. At each point of the slope profile, the slope becomes graded. In the old stage of slope development, as the process of lateral erosion and down wasting of water continues, there observed a sharp decline in slope profile and hence general slope becomes concave (figure 14.4). The model described three aspects such as rounded convexity of hillslope and interfluvies, graded water sheets on slope profile and graded valley sides.

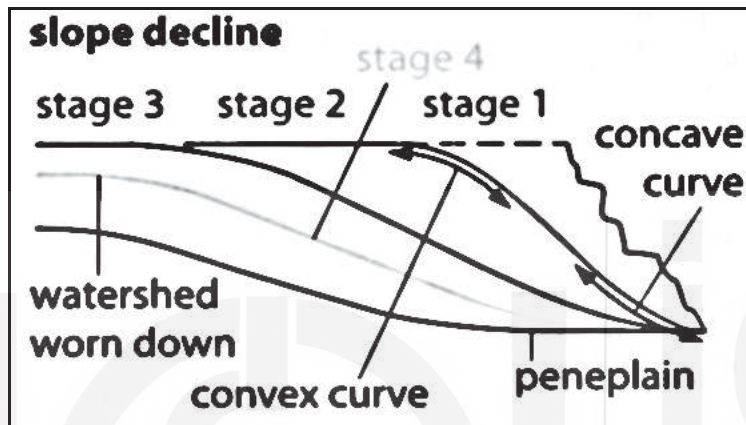


Fig. 14.4: Davis model of slope development.

14.4.2 Slope Replacement Model

The slope replacement theory was advocated by Walter Penck. As per him, slope replacement refers to the replacement of the original slope by lower angle slopes, that extends upward from the base with a constant angle. The scree accumulates over the free face slope and buries slowly. Due to exposure of the free face to weathering, the scree accumulation gradually increases in height and at some point of time, it will replace the entire cliff to develop a gentle slope. The continuation of the process of weathering and removal leads to an upward extension of this upward slope. The entire slope has been replaced by a gentle slope because of this continuous process. To explain the slope evolution on the hillslope, Penck, choose a steep rock cliff with homogenous composition. The upper part of the slope profile is surmounted by a level surface, however, at the base of the slope profile, a river is present, which is neither eroding nor depositing but capable of the removal of material falling down from the upslope. The slope gradient is must great to failing down rock. Except for the lower face, other faces have this gradient. Hence, except for the lower face, all other slope face undergoes parallel retreat due to the constant rate of weathering and removal of material. A similar process is repeated during a second time interval. The development of concave slopes is due to the parallel retreat of all slopes except lower segments.

As per Penck, tectonic activity is mainly linked to the characteristics of the landform of a given region. He advocated that the geomorphic forms are an expression of the phase and rate of upliftment in relation to the rate of

degradation, where it is assumed that interaction between factors, uplift and degradation, is continuous.

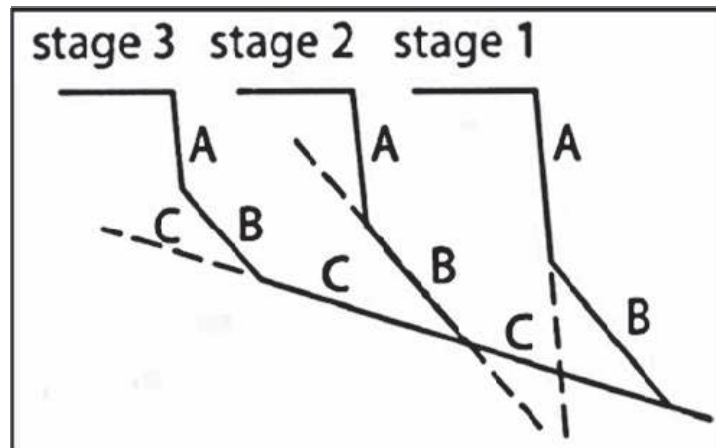


Fig. 14.5: Penck's slope development model of Slope Replacement.

14.3.3 Parallel Retreat Model

Geomorphologist L.C. King propounded this theory based on his studies of landform development in semi-arid regions. He asserted that "the landforms are developed uniformly in varied environmental conditions, and climate changes have insignificant influences on the development of fluvially originated landforms.

As per L.C. King, major landscapes have evolved due to the global tectonic events. There is continuous migration (retreat) of hillslope and such retreat is always in the form of parallel retreat. He asserted that the convexo-concave slopes are, by no means ubiquitous. King accepted Wood's view of hillslope development (1942) and stated that these elements are the product of hillslope evolution. The slope elements are Waxing slope, free face, debris or talus slope, and the pediments (Figure 14.6). The upper portion of each slope retreats similarly and continues with the same angle. Hence, all the slope profile has the same length.

The lower section spreads in length and develops a slightly gentler slope. As the slope retreats, the gently concave slope which spreads at the base extends laterally. The pediment at the base is concave, however, slopes are gentle with an angle of 3 to 5 degree and sometimes appears completely flat. A thin sheet of regolith covers the pediments. Due to the delayed chemical weathering in the arid region, the supply of regolith is limited, there is little supply of transported materials to the bottom of debris. This caused the debris slope to maintain a constant angle and subsequently caused a regular extension of pediments.

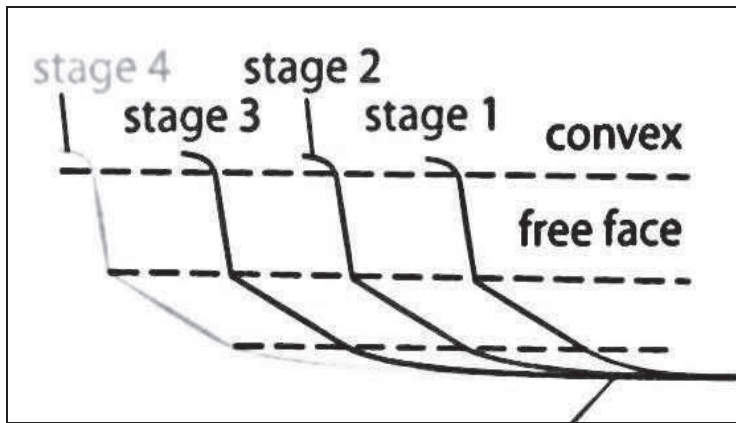


Fig. 14.6: L.C. King's slope development model of Slope Retreat.

King also advocated that these four slope elements are found in all regions regardless of their climatic conditions. As he accepted Wood's view of all the four elements, which are developed in a fully developed slope. However, complete slope development is influenced by other factors as well like a strong bedrock. If it fails, the free face disappears first and is followed by the debris slope, which caused a decadent Convexo-concave hillslope (King, 1957).

14.3.4 Slope Development Through Time

All these three models have formulated with time being an inherent component. There is either an abrupt, sudden, or slow upheaval of landmass, which is thereafter undergoes down wearing through denudational processes. While the landmass is removed the differential erosion between crest levels and valley floor levels create a generalized pattern of undulations and slope facets. All three scholars have visualized according to their geographical area of study and graphically their perceptions of landscape evolution through time are presented below (Fig. 14.7).

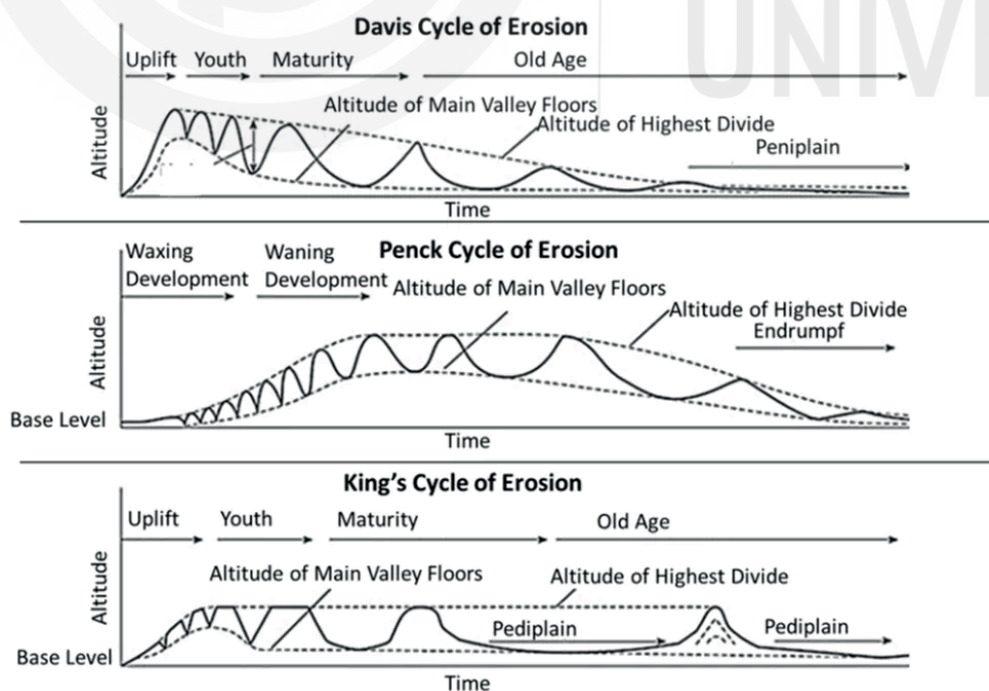


Fig. 14.7: Comparative view of landscape and slope evolution models

(Source: Thorn, C. E. (1988). *An introduction to theoretical geomorphology* (p. 247). Boston: Unwin Hyman.)

14.3.5 Comprehending the Slopes

So far it is understood that slopes are quantifiable entities, and evolve through denudational processes through time. It has its own characteristics and without slope no landform except flatlands can be conceived. The sequence of slopes in conjunction with altitude from top to bottom are not uniform and points to its legacy of genesis and development. The profile drawn from top to bottom is termed as slope profile. A simplified slope profile, also termed as hill-slope profile, as described as L C King is Four Unit Slope Model. It has: a Crest with convex slope (Cx), a Free Face (ff) with steep straight slope, a Debris Slope (Ds) with low angle straight slope and at the end a concave Slope (Cv) which is generally hydraulic controlled. All these slope elements allow different types of surface water movement and mass movement.

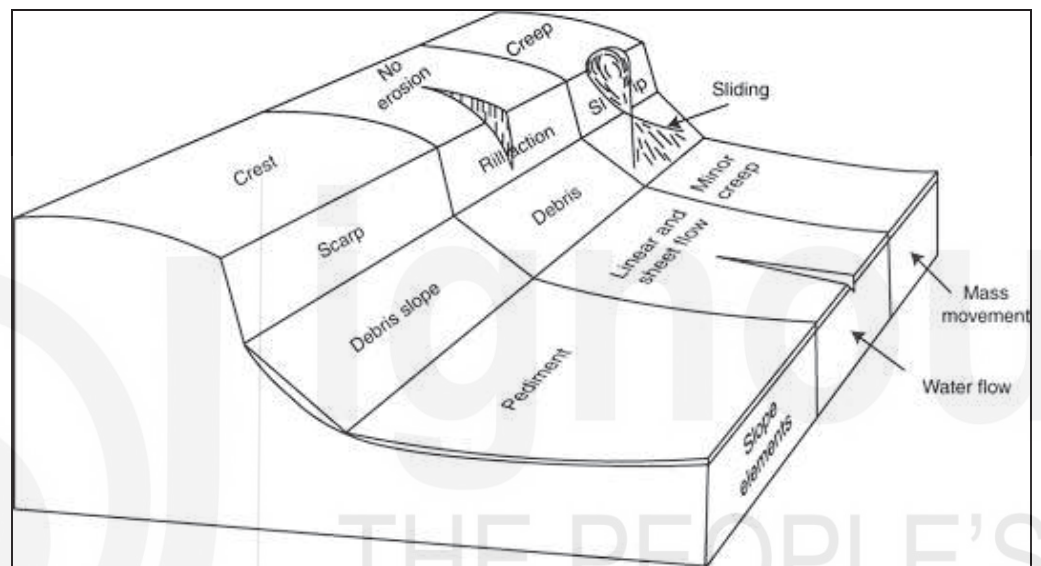


Fig. 14.8: L. C. King's Four Unit Slope-Profile

(Source: Adapted from LC King 1962)

A detailed slope classification with nine distinct units has been presented by Dalrymple. The waxing slope or the crest is divided into two segments on the basis of slope angle and another functional part that acts as mass movement termed as a creep. Likewise, the debris slope is further divided into the transitional mid-slope and a lower part with an accumulation of colluvium termed as colluvial footslope. The channel wall or the river bank is considered as one unit before it terminates at the Thalweg point of the channel. This classification explains more about the slope processes: seepage, creep, concentrated flow, deposition, and sorting of detritus.

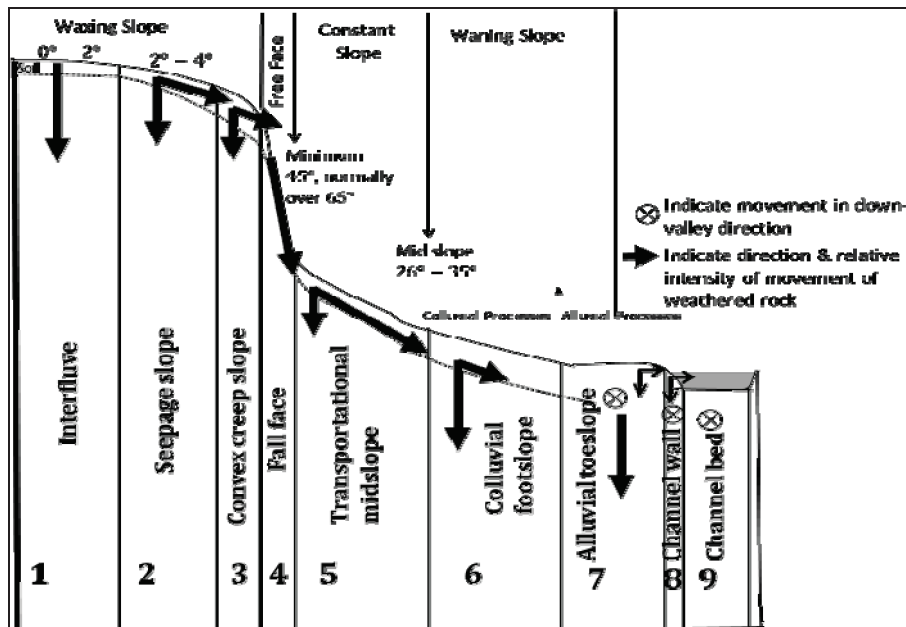


Fig. 14.9: Dalrymple's nine-unit slope profile.

(Source: Parsons, A. J. (2002). *Hillslope form*. Routledge.)

SAQ 4

Which slope models are given by L.C. King and Walter Penk?

14.5 SUMMARY

In this unit, you have studied so far:

- As a result of weathering and transportation of loose rock material slips downwards to give rise slope on a landscape. The slope may change in course of time. The change of slope form from past to present is known as slope evolution.
- A slope profile basically comprises three slope elements, which are convex slope (Crest), free face (Cliff), rectilinear slope, and concave slope forms.
- No single model of slope development is completely correct and can't be applied to every slope. As slope evolution mainly depends on their locations' rock structure and climatic conditions.
- Slope decline process started at the upper part of the slope profile and caused steep slopes to decrease their slope angle gradually giving rise to a shallower, gentle slope profile. The slope decline model resulted in a profile with a convex slope at the upper segment above the lower concave slope develops at the base, where material transported from the upper segment is deposited near the base of the slope. The slope declines are mainly observed in temperate and humid regions with soil-mantled slopes.
- The slope replacement process occurred in all the climates. Here a gentler slope at lower segment of the slope profile extends uphill as steeper upper angle retreats and talus accumulates on it. This is due to material falls from the cliff cannot be removed from the base.

- In the Parallel retreat process, as the slope retreats of the ground surface cut back into the bedrock, the slope maintains a constant angle. The Parallel retreat is mainly found in arid and semi-arid regions with bedrock slopes.
- In this unit, we have studied the slope evolution process, and measurement of slope, description of slope, and three basic slope development models. For further study about the slope development and evolution processes following references can be referred.

14.6 TERMINAL QUESTIONS

1. Explain the type of slope developed due to the Slope decline process?
2. Why are the different methods of slope analysis? Explain the process of measurement of slope analysis?
3. Describe the end product of the Parallel retreat process?
4. Compare the geomorphological significance of four unit and nine unit slope models.

14.7 ANSWERS

Self-Assessment Questions (SAQ)

1. Percentage and Degree are the units of slope measurement.
2. Convex Slope, Cliff of Free Face, Rectilinear Slope and Concave Slope
3. Historical approach and Process-form-approach
4. Parallel Retreat Model given by L.C. King and Slope Replacement given by Walter Penk.

Terminal Questions

1. Slope decline process has three distinct phases or stages. The first phase is known as the Youth stage and has the convex slope, the second phase is known as the mature stage, and has a rectilinear slope and the third phase is known as the old stage, which has the concave slope form. For further reading refer to section 14.4.1.
2. Several methods can be used to measure and describe the slope of a surface. One of the most common methods is the use of topographic maps and digital elevation models (DEMs). Topographic maps provide contour lines that connect points of equal elevation, allowing researchers to estimate the slope angle and direction of the land surface. DEMs are digital representations of the Earth's surface, created from satellite or airborne remote sensing data, and can provide a high-resolution representation of the terrain's slope. For further reading refer to section 14.3.
3. Waxing slope, free face, debris or talus slope, and the pediments. For further reading refer to section 14.3.3.
4. Slopes are quantifiable entities, and evolve through denudational processes through time. It has its own characteristics and without slope

no landform except flatlands can be conceived. The sequence of slopes in conjunction with altitude from top to bottom are not uniform and points to its legacy of genesis and development. For further reading refer to section 14.3.5.

14.8 REFERENCES AND FURTHER READING

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GEOMORPHIC MAPPING|

Structure

15.1	Introduction		Legend
	Expected Learning Outcomes		Classification
15.2	Methods and Analysis of	15.5	Application of Remote
	Geomorphic Data		Sensing
	Data Requirements	15.6	Summary
	Methodology	15.7	Terminal Questions
	Final Output	15.8	Answers
15.3	Geomorphic Models	15.9	References and Suggested
15.4	Geomorphological Mapping		Further Reading
	Scale		

15.1 INTRODUCTION

Applied geography can be considered as "the use of geographic content, principles, and methods in research and other activities designed to aid in the resolution of human problems with a strong geographic dimension." (Boehm & Harrison, 1989). In Unit 14 of this block, you have learned about the development, evolution, measurement, and description of all the hill slope aspects. In the present unit 15, you will learn about geomorphic mapping. Geomorphic mapping is considered a basic unit of earth processes, generating valuable databases for surface processes and shaping the current earth structure. A well-thought-out graphical list of landscapes showing landforms, surface, and subsurface materials is known as geomorphic map.

The first geomorphic map was prepared in 1914 with the beginning of World War I but the greatest need for maps came from planners and agronomists after World War II. A formal mapping system was subsequently designed in the 1950s. Many European countries such as France, Poland, and Russia had developed several mapping systems but the International Geographical Union's Sub-commission on geomorphological mapping was established in 1960 to standardize legends for mapping.

For the analysis of landforms, geomorphic mapping is a key means of providing geographical data. This mapping method uses five basic concepts - morphology, morphometry, morphogenesis, morpho-chronology and morpho-dynamics. This method critically helps in understanding the processes of the earth's surface, the formation of relief, the emergence of landscape, and the

composition of the underground surface. Geomorphic maps are needed in geomorphological research and practice along with other fields involving environmental research and professionals dealing with landforms and evolution of the landscape, managers of natural hazards and geological risks, land conservation managers, soil and forest scientists, urban planners as well as construction engineers.

International Institute for Geo-information Science and Earth Observation (ITC) has evolved the most comprehensive geomorphic survey method that led to three different types of maps: synthetic geomorphic map, analytical geomorphic map, and pragmatic (applied) geomorphic map.

The maps that are useful for mapping on all scales and consequently serve as the basis for the use of applied geomorphic mapping are known as analytical geomorphic maps. These maps include the following information-

- i) morpho structure/lithology: The underlying structure and bedrock usually exercise a significant impact on the landform (for example, structural hill and granitic residual hill, etc.);
- ii) morphometry: the quantitative information about the relief (for example, the height of the terrace and slope angle, etc.);
- iii) morphogenesis: the process/gneisses (for example, alluvial fan, piedmont);
- iv) morpho-chronology: the ages of landforms whenever such relevant information is available.

In addition to these 4 levels of terrain mapping components, Synthetic geomorphic maps contain environmental details needed for every terrain mapping component collected subsequently from various site observations, for example, soil, hydrology, vegetation/land use/land cover, and topography in every unit.

Analytical and synthetic maps have given birth to pragmatic or applied geomorphic maps. Maps concerning natural hazard assessment and mitigation are becoming more useful, as hazard zoning is directly related to geomorphology and is also possible in all cases. Some common examples of pragmatic geomorphic maps include mountain hazard zoning, flood hazard zoning, earthquake hazard zoning, drought hazard zoning, cyclone hazard zoning, and volcanic hazard zoning maps. Maps for hydrocarbon and mineral exploration, that contain geomorphic anomalies which indicate suitable subsurface structures are other examples.

In Section 15.2, you will study how geomorphic maps are prepared and data are analyzed. You will also study which type of data is needed to prepare geomorphic maps and how geomorphic maps will be prepared and the final output will be generated using the given data. In Section 15.3 you will learn about what is a geomorphic model and what its various types are. In Sec. 15.4 you will study different components of geomorphological mapping i.e., scale, legend, and classification in detail. At last in Sec. 15.5 you will learn about the Remote Sensing technique and how this technique is helpful to prepare geomorphic maps.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define and classify the geomorphic map;
- describe how geomorphic maps are prepared and data are analyzed Karst processes;
- describe the geomorphic model and its various types of global distribution of karst topography; and
- explain the different components of geomorphological mapping; and
- describe how the remote sensing technique is helpful to prepare geomorphic maps.

15.2 METHODS AND ANALYSIS OF GEOMORPHIC DATA

Traditionally, information obtained from the field along with the interpretation of topographic maps and aerial photographs has been the source of geomorphic mapping. Recent technology such as remote sensing and geographic information systems (GIS) have brought about a revolution in the field of geomorphic mapping and remote sensing data has become the main source of geomorphic data. An increasing number of novel space and air sensors now provide data on geographical distribution, topography, terrain, and the appearance of underground characteristics at higher temporal, spatial, and spectral resolutions. This, coupled with expanded GIS capabilities and geospatial analysis, greatly enhances the capabilities of geomorphic mapping.

The methods and analysis of geomorphic maps include data requirements i.e., the data which are required to prepare geomorphic maps, methodology i.e., how geomorphic maps will be prepared using the given data, and final output i.e. the map that one will get based on the above two.

15.2.1 Data Requirements

Satellite images taken during the summer season and the Survey of India toposheets are the main input data for the preparation of the geomorphic maps. However, in desert/arid regions like Rajasthan, parts of Haryana, and Gujarat, the summer season image may lead to incorrect interpretation due to the impact of dust storms and the consequent haze and therefore, satellite images of Kharif or Rabi season as available are used.

15.2.2 Methodology

The geomorphic units need to be delineated according to the image characteristics like texture, tone, colour, shape, background, association, etc. Furthermore, Rabi season's images have to be referred for better details and appropriate correlation. It is advantageous to use base maps prepared on transparent tracing films that are placed over geocoded false colour composite (FCC) images. Next, with the help of a light table, the geomorphic units and forms along with the structural information like faults, fractures, folds, lineaments, structural trend lines, and lithology are incorporated.

Available published literature and geological maps along with other information are used to enhance the geomorphological details. Whenever some doubtful units are encountered during the interpretation, they are noted for a ground check. The legend is classified and included in the map based on the origin and chronology. In the legend, the units with the youngest geomorphic origin are placed at the top whereas the oldest ones are kept at the bottom. All the details of geomorphic units, lithology, and structure need to be described coherently. Usually, it takes approximately 5 man-days to prepare a pre-field geomorphic map for one toposheet area scaled at 1:50,000. Wherever the digital image analysis system facility is available, the enhanced image product can be used for delineating more details. At this stage, before going to the field, the map will be reviewed by the Quality Assurance and Standardization (QAS) team.

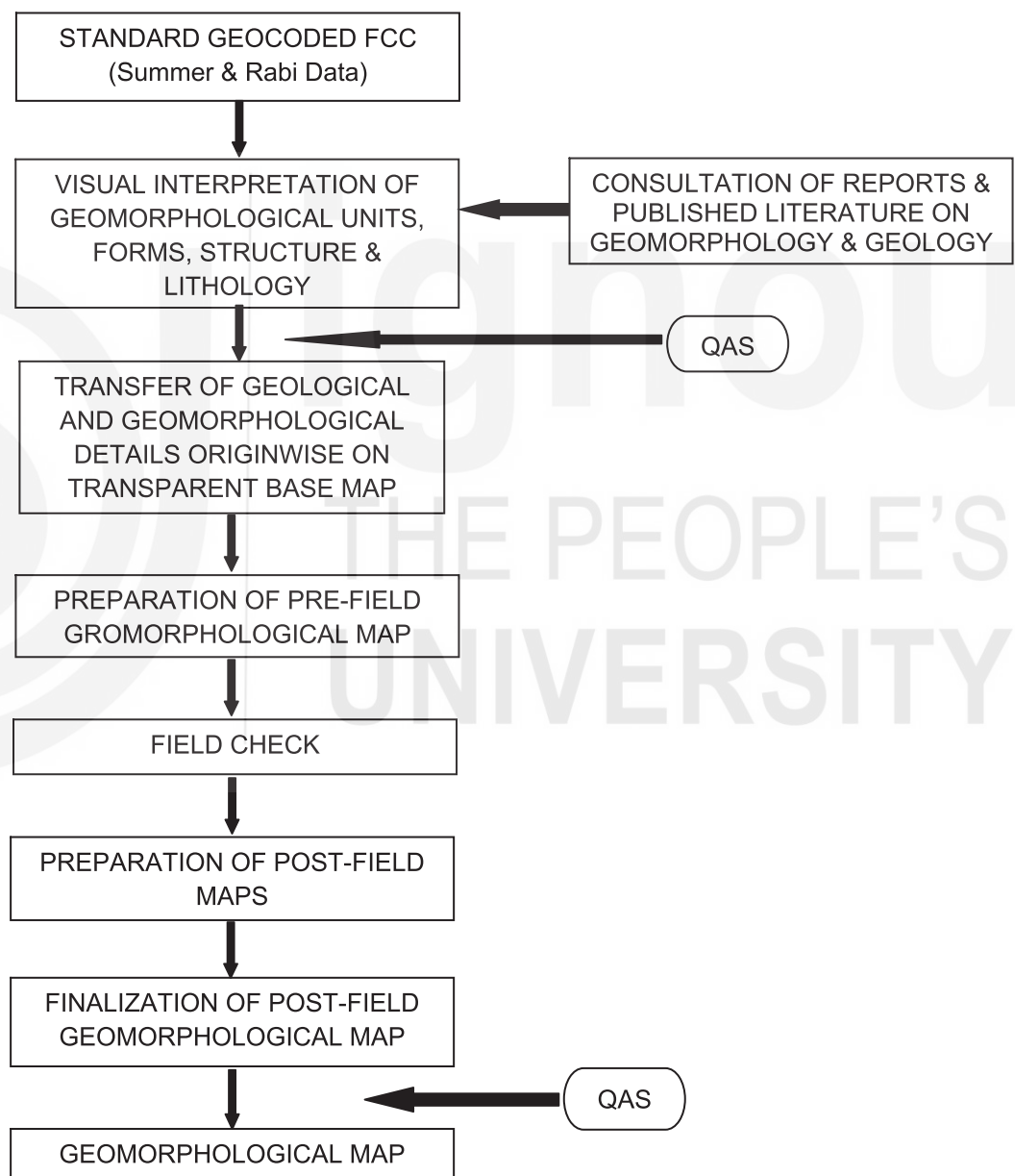


Fig. 15.1: Procedure for Preparation of Geomorphological Map.

(Source: IMSD Technical Guideline, (1995) National Remote Sensing Agency, Department of Space, Government of India, Balanagar Hyderabad).

Based on the pre-determined traverse plans, the ground truth is undertaken. The doubtful units encountered during the pre-field interpretation are verified and properly incorporated on the map. Efforts should be put in to verify all the geomorphic units and geological features during the ground truth assessment to enhance accuracy. The data are available from central and state departments can be referred to for this purpose. One toposheet area on a 1:50,000 scale which is roughly about 700 km sq, requires 5 to 7 man-days to complete the ground truth. Required changes should be incorporated carefully on the map based on ground observation.

It is required to check these maps in the field by the DOS QAS team along with the respective theme specialists of the work center before the same is finalized/fair drawn. Normally two days are required by the QAS team to have the sample checked in the field for a toposheet area. Fig. 15.1 shows the steps involved in the preparation of geomorphic.

15.2.3 Final Output

The final output has to be drawn with neat and quality cartographic accuracy. To minimize the time on drawing the alphabetic letters should be used as symbols for geomorphic units. However, the important forms, structural trends, fractures, lineaments, and faults should be marked by line symbols. Each categories' area statistics are computed and presented as part of the report.

SAQ I

What are the data requirements for geomorphic mapping?

15.3 GEOMORPHIC MODELS

Geomorphic models represent the external reality of the Earth's surface processes and landforms. Primary distinctions can be established between (i) conceptual models, (ii) scale models or analogs, and (iii) quantitative models (e.g., Huggett 1985).

15.3.1 Conceptual Models

They are visual or verbal representations of a process or system. They may range right from a sequence of relationship statements or a "story" of a geomorphic system to schematics and flow diagrams, often in a graphical form. Many famous geomorphic models, and indeed paradigms, can be classified into this kind, such as Davis's (1899) Geographical Cycle, often represented in a sequence of landscape cartoons, or the general systems framework by Chorley (1962) and Strahler (1980), usually drawn as detailed and elaborate flow schemes resembling electronic circuitry diagrams. This kind of modeling is referred to as an activity of conception in Haggett and Chorley's (1967) taxonomy, representing a geomorphic system as an integrated whole synthetically (e.g., as a flow scheme), or as a black-box model where the precise details of constituent parts are not further elaborated.

Geomorphic models show the external facts of the existence of Earth's surface processes and landforms. The prime difference can be made between (i) conceptual models, (ii) scale models or analogs, and (iii) quantitative models.

15.3.2 Scale Models and Analogs

Represent a geomorphic system on a (sometimes reduced) physical or temporal scale to mimic or replicate the processes and forms in a reproducible and observable form. This includes hardware models or physical analogs such as wind tunnels (e.g., White, 1996), water flumes (e.g., Peakall et al., 1996), and wave tanks, where processes or properties are scaled in terms of their geometry (sizes), dynamics (forces) or kinematics (velocities), relative to the real-world system. As an example, we may consider the investigation of subaqueous bed form development on moveable sand trays in small water tanks as an analog for understanding desert dune formation in the atmospheric boundary layer. This type of modeling heavily relies on the equivalence of dimensionless similarity parameters, such as the Froude number or the Reynolds number (e.g., White 1996). This type of scientific activity is referred to, by Haggett and Chorley (1967), as *translation*. It includes natural analogs as models, i.e., observable real-world systems that exhibit characteristics or behaviour that is similar to (and thereby an explanation of) another geomorphic system. In other words, using a known geomorphic phenomenon from a historical time sequence or from within a spatial hierarchy (e.g., a landform unit) as a model to understand another landscape or subset.

15.3.3 Quantitative models

Quantify objects, features, and processes of a geomorphic system numerically as parameters, variables, and coefficients, representing the relationships between them as mathematical expressions. Such models range from single equations, such as the Universal Soil Loss Equation (USLE), to coded algorithms of different levels of complexity running on computers. These models are usually developed from initial conceptual models and often (partly) parameterized or tested against scale models and analogs. Malamud and Baas (2013) emphasize three key distinctions in contemporary quantitative models of geomorphology that include: (i) traditional physically based computer models, (ii) cellular automata models, and (iii) statistical models of observations or simulated data.

SAQ 2

Mark the following statements as True or False:

- a) Davis's Geographical Cycle is a scale model.
 - b) A geomorphic system on a physical or temporal scale is represented by scale models and analogs.
 - c) Three key distinctions are recognized by Malamud and Baas in quantitative models of geomorphology.
 - d) Universal Soil Loss Equation (USLE) is a quantitative model.
-

15.4 GEOMORPHOLOGICAL MAPPING

We have already discussed what is a geomorphological map and its types in Section 15.1 and how a geomorphological map is prepared means about data requirements, methodology, and final output in Section 15.2. Now we will discuss three important components of geomorphological mapping i.e., scale

on which geomorphological maps will be prepared, legend, and classification of geomorphological units.

15.4.1 Scale

Geomorphological mapping, as described by Lee (2001), can be considered as one of the groups of techniques under the general category of "terrain evaluation" employed to systematically record the morphology (shape) of ground, landscape, landforms forming processes and materials that make the surface of the earth.

The following three forms of geomorphic mapping were identified by Lee (2001).

1. General geomorphological investigation by a regional survey of terrain conditions, land use planning, or baseline studies for environmental impact assessment. (e.g., 1:25,000 scale maps).
2. General assessment of resources or geo hazards at a scale between 1:50,000 & 1:10,000.
3. Large-scale surveys for specific purposes to delineate and characterize particular landforms. (e.g., 1:500).

Geomorphological maps are one of the best tools that help in understanding the physical context of the surface of the earth. They provide a completely objective description of landforms (morphology) that are identified with precise names and depicted with their right shape or if not allowed by the map scale, by symbols as found appropriate.

Geomorphological maps should include information about the spatial characteristics (slope, dimension, relief, curvature) of landforms (morphometry); their origin and evolution concerning endogenous/exogenous genetic processes and agents (morphogenesis) also taking into account the effects of bedrock lithology/structure control; their absolute/relative age (morpho-chronology); their activity status and the rate of genetic processes (morpho-dynamics) and the type of bedrock and near-surface deposits present.

These data collected at different scales for the purposes of the investigation, from systematic field surveys and the interpretation of aerial photographs and/or satellite imagery are commonly reported on toposheets to highlight their spatial distribution with mutual relationship.

15.4.2 Legend

The legend of the geomorphological map should consist of three parts namely geomorphic units, landforms, and topographic symbols. A sample legend for the geomorphological map is given in Table 15.1.

1. The first part should contain the details regarding the map symbol, geomorphological units, and description in column number 1, 2, and 3 respectively.

The three important components of geomorphological mapping are scale, legend and classification.

Legend of a geomorphological map consists of three parts namely geomorphic units, landforms, and topographic symbols.

- 1.1. Map symbol should come as per the technical guidelines against each geomorphic unit (i.e., the alphabets) e.g., AP, VF, EP, etc. (Column 1)
- 1.2. Name of the geomorphic unit (expansion) will appear in the second column e.g., Alluvial Plain, Valley Fill, Flood Plain, etc.
- 1.3. The third column should contain the description of the geomorphic units in which the material, composition, lithology, age of the deposits/parent rock, structural details, and the association of landforms should be described in detail.
2. The second part of the reference contains landform symbols and names.
 - 2.1. Landform symbols should come as per the technical guidelines against each landform (line symbols).
 - 2.2. The appropriate name of the landform will appear against the landform symbol e.g., Old Meander, Dyke, Beach Ridge, etc.
 - 2.3. In case more types of landforms are encountered in the study area which is not mentioned, the same can be added under respective origin.
3. The third part of the reference will have topographic symbols and other common geological and geomorphological symbols.

Table 15.1: Geomorphological Map

S. No.	Topographic Symbols	Geomorphic Units	Landforms Description
1.	<i>Fluvial Origin</i>		
	AP	Alluvial Plain	Quaternary deposits of unconsolidated sand, silt, and clay sediments.
	APO/APU	Older/ Upper Alluvial Plain	Quaternary deposits of sand, silt, and clay. Old meander, natural levee, and back swamp noticed.
	APY/APL	Younger/ Lower Alluvial Plain	Recent deposits of sand silt and clay. Oxbow lakes, and palaeo channels are seen.
	FP	Flood Plain	Recent deposits of gravel, sand, and silt having the width of few meters.
	VF	Valley Fill	Quaternary, unconsolidated sand, silt, and gravel occupy a narrow stretch of alluvium 1-9 meters deep along ... streams/rivers.
2.	<i>Denudational Origin</i>		
	PI	Pediment Inselberg Complex.	Peninsular genesis and granites with criss-cross well-knitted fractures as lineaments.
	BPP-S	Shallow Weathered Pediplain.	Dharwarischists with highly foliated gently undulating plain with 0.5m weathered thickness.
	BPP-M	Moderately Weathered Pediplain.	Dharwarischists with highly foliated plain with 5-20m weathered rock.
3.	<i>Structural Origin</i>		
	DPP	Dissected Plateau	Srisailem Quartzite: Rocks with prominent gully erosion varying the depth up to several meters. Very gently dipping beds

			with faults and fractures. The flat top is bounded by an escarpment and steep slope.
	MS	Mesa	Banganapally Quartzites of flat-topped hills bounded by escarpments. Gently dipping beds with occasional faults and fractures. Buttes are also seen.

(Source: IMSD Technical Guideline, (1995) National Remote Sensing Agency, Department of Space, Government of India, Balanagar Hyderabad).

15.4.3 Classification

Geomorphological maps are prepared by distinguishing the geomorphic forms and units. All available geomorphic forms and units are listed after interpreting the study area. All the geomorphic units and landform details listed are classified according to their origin like aeolian, fluvial, structural, etc. An extensive list of geomorphological units belonging to different origins is given in Table 15.2 with a brief description of each geomorphic unit and landform. Furthermore, the geological details like the type of lithology or rock and other structural details are also delineated using the available geological/geomorphological maps of the area under study.

Table 15.2: Description of Geomorphic Units and Symbols for Geomorphological Mapping

15.2.1a: Forms of Denudational Origin

S. No.	Map Symbols	Geomorphic Units/ Forms	Structure	Materials/Lithology	Description
1	DH	Denudational Hill	Joints, fractures, lineaments, etc.	Varying lithology.	Formed due to differential erosion and weathering so that a more resistant formation or intrusion stands as mountains/ hills.
2	RH	Residual Hill	Joints, fractures, lineaments, etc.	Varying lithology.	Isolated rock, isolated low relief formed due to differential erosion so that a more resistant formation stands as residue like small hills.
3	IV	Intermontane Valley	Sometimes fracture controlled.	Constitutes colluvial deposits of varying lithology.	The broad depression between mountains is normally filled with colluvial deposits.
4	P	Pediment	Sometimes fracture controlled.	Varying lithology.	Gentle sloping, smooth surface of erosional bedrock between the hill and plain with the veneer of detritus.
5	PI	Pediment-Inselbergs	Sometimes controlled by joints,	Varying lithology.	Isolated low relief/hill surrounded

		Complex	fracture lineaments, etc.		by gently sloping smooth, erosional bedrock with the veneer of detritus.
6	PP	Pediplain	-do-	Varying lithology.	Coalescence of pediments marked by a large area.
7	BP	Buried Pediment	Fractures may be present.	Unconsolidated weathered material of varying lithology.	Pediment covered with thick alluvial/ colluvial material or weathered rock.
8	BPP	Buried Pediplain	Crisscrossed by fractures/faults etc.	With the varying thick overburden of weathered material of varying lithology.	Coalescence of buried pediments where a thick overburden of weathered materials occur.
9	BPP-S/BP-S	Buried Pediplain/ Buried Pediment Shallow	Maybe crisscrossed by lineaments/ fractures.	With shallow overburden of weathered material of varying lithology.	The flat and smooth surface of buried pediplain/ pediment with (0-5 m thickness) shallow overburden.
10	BPP-M/BP-M	Buried Pediplain/ Buried Pediment Medium	-do-	With moderate thickness overburden of weathered material of varying lithology.	Flat and smooth buried pediplane/ pediment with moderately thick (0-20 m) overburden.
11	BPP-D/BP-D	Buried Pediplain/ Buried Pediment Deep	-do-	With very thick overburden of weathered material of varying lithology.	Flat and smooth buried pediplain/ pediment with very thick (more than 20m) overburden.
12	LU	Lateritic Upland	Present along rivers/stream channels in ravenous or gullied region.	Mainly laterites as capping over granite, metasediments.	Higher elevated flat land with lateritic capping.
13	DLU	Dissected Lateritic Uplands	A specific type of landscape or terrain characterized by certain geological and topographical features.	-do-	Higher elevated land with lateritic capping with extensive dissections marked by gullies and broad shallow valleys.
14	PD	Piedmont	Transitional areas between the higher elevations of mountains and the lower-lying coastal plains or valleys.	Constitutes boulders, cobbles pebbles, gravels, sand silt, and clay of varying lithology.	Formed by the coalescence of several alluvial fans by streams covering a large area at the foothills, with gentle slopes, in humid to sub-humid regions. (Upper humid to sub-humid regions). Upper and

					lower units are marked by variations in slopes and thickness of sediments.
15	BJ	Bajada	A fan-shaped deposits of sediment and debris that are created by the action of water flowing.	Comprises detrital materials of varying grains size and lithology.	Coalescence of alluvial fans at the foothills in arid and semi-arid region having gentle slopes. (Upper and lower units are marked by variation in slope and thickness).

15.2.1b: Geomorphic Features of Denudational Landforms

S. No.	Map Symbols	Geomorphic Units/Forms	Materials/Lithology	Description
1		Dyke	Various basic and acidic intrusive like dolerite, basalts, pegmatite, etc.	A discordant mass of consolidated series of intrusions that cut across the country rock. It may act as barrier as well as carrier and control the flow of groundwater depending upon the topography and local hydrology conditions.
2		Inselberg	Varying lithology.	A residual isolated hill stands above the ground level of the surrounding pediplain: normally barren and rocky.
3		Talus Cone	Comprises scree or rock fragments.	Rock debris accumulated at the foot of steep slopes and cliffs which have originated from the parent rock mass under the influence of gravity.

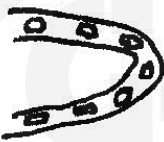
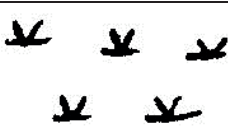
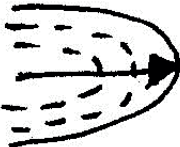
15.2.2a: Forms of Fluvial origin

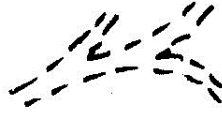
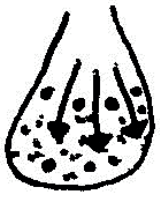
S. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1	AP	Alluvial Plain	A flat or gently sloping land area formed by the deposition of sediment carried.	Constitutes gravels, sand, silt, and clay of varying lithology; silt dominates.	Formed by extensive deposition of alluvium by major river systems. This unit is normally flat, gently undulating surface.
2	APO/APU	Older/upper alluvial plane	A type of alluvial	Predominantly of gravel, sand, silt, and	Flat/gently undulating surface

			plain that has been in existence for a significant period of time, often over geological timescales.	clay of varying lithology.	formed by river action; older refers to the earliest cycle of deposition and upper occupies a higher elevation.
3	APY/APL	Younger/lower alluvial plane	A recently formed or relatively new alluvial plain that has developed over a shorter period of time.	Predominantly of gravel, sand, silt, and clay of varying lithology.	Like older alluvial plains; younger refers to the late cycle of deposition and lower refers to lower elevation.
4	FP	Flood plain	A relatively flat and low-lying area adjacent to a river, stream, or other water body that is prone to flooding.	Primarily comprises unconsolidated materials like gravels, sand, and silt; sand dominates.	A flat surface adjacent to a stream/river composed of unconsolidated fluvial sediments. Normally subject to periodic flooding by parent stream/river.
5	VF	Valley fill	Valleys are mostly fracture controlled.	Constitutes boulders, cobbles, pebbles, gravels, sand, and silt.	The unconsolidated sediments deposited by streams/ivers normally in a narrow fluvial valley.
6	DP(DPO/DPU)	Deltaic plain (older/upper)	A type of landform that forms at the mouth of a river where it flows into a larger body of water.	Consists of material from river-borne sediments; mostly alluvium.	Flat to gently sloping plain of the large aerial extent of thick sediments with fan shape formed at the end of river cycle (older/younger refers to respective age/time of deposition;

					upper/lower refers to elevation.
7		Wadi	A dry riverbed or stream channel that only carries water during periods of heavy rainfall.	Mainly sand.	Wide river beds devoid of water; seen in semi-arid areas.

15.2.2b: Geomorphic Features of Fluvial Landforms

S. No.	Map Symbols	Geomorphic Units/Forms	Materials/Lithology
1		River terraces	Comprises gravels, sand, and silt of river-borne deposits.
2		Ravines	Comprises of fine-grained semi consolidated alluvium.
3		Old meanders	Sand, gravel, pebble, and silt.
4		Palaeo channel	Comprises fluvial deposits of varying grain size and lithology.
5		Ox-bow Lake	Composed of fluvial deposits of varying grain size and lithology.
6		Meander scar	Composed of alluvial deposits, mostly silt, and clay.
7		Natural levee	Constitutes mostly sand and silt.
8		Back swamp	Comprises of alluvial deposits: predominantly of clay and silt.
9		Point bar	Comprises alluvial deposits predominantly by sand and silt.

10		River bed with water	composed of a mix of sedimentary rocks and unconsolidated sediments, including sand, gravel, and silt.
11		River bed without water	composed of a mix of sedimentary rocks and unconsolidated sediments, such as sand, gravel, and silt.
12		Alluvial fans	Constitutes mainly colluvial material such as gravels, sand, silt, clay, etc. of varying lithology. Alluvial fans are sometimes characteristic of the tectonically active region.

15.2.3a: Forms of Structural Origin

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/ Lithology	Description
1	SH	Structural hills	Associated with folding, faulting etc.	Varying lithology.	Linear to arcuate hills showing definite trend lines.
2	LR	Linear ridges	May be strike controlled.	Varying lithology.	Linear, narrow, low-lying relief generally barren.
3	SV	Structural valley	Linear/curvilinear fracture formed as a result of faulting/fracturing etc.	Form over various lithology.	A linear or arcuate valley between the high relief controlled by the structure.
4	PT	Plateau	Maybe crisscrossed by fractures/joints lineaments.	Form over various litho units.	Essentially formed over horizontally layered rocks. Marked by the extensive flat top and steep slopes.
5	DPT	Dissected plateau	-do-	Varying lithology.	Deep valleys/ gullies with gently sloping land developed due to stream/ river erosion on the plateau.
6	MS	Mesa	Characterised by erosion and weathering processes.	May consist of volcanic/sedimentary rocks.	Formed over horizontally layered rocks. Flat topped, isolated relief with gentle side slope at the base and steep at the top.

15.2.3b: Structural Elements of Tectonism and Geomorphic Features of Structural Landforms

Sl. No.	Map Symbols	Geomorphologic Units/Forms	Structure	Materials/Lithology	Description
1		Lineaments	Faults/fractures of varying length and breadth.	Linear features associated with tectonic or geologic processes.	Can be observed in a variety of geologic settings, including mountain ranges, rift zones, and volcanic regions.
2		Fault	Definite linear features with displacement. It may cut across various litho units.	A geological fracture or zone of discontinuity in the Earth's crust where rocks on either side have moved relative to each other.	Fracture in the earth's crust along the plane of which there has been displacement of rock on one side related to the other either horizontal/vertical/oblique.
3		Fault – inferred	Linear features with displacements. It may cut across various litho units.	A fault that is not directly visible on the Earth's surface but is deduced or hypothesized based on geological evidence, features, and the behaviour of surrounding rock formations.	The possibility of faulting/fracturing is from surface feature.
4		Fracture	Cuts across various litho units as minor linear features.	Refers to a crack or break in the Earth's crust or in rock formations.	Cracks developed in the country rock.
5		Fracture/fault line valley	Valleys formed along fractures/faults.	A type of valley that forms along the course of a fault, where movement has occurred along a geological fault line.	Fracture/fault line controlled valley with or without valley fills.
6		Structural trends	Litho units may be folded/faulted/fractured.	The dominant directions along which geological features, are aligned within a particular region.	A structural feature that is accurate/circular/folded.
7		Butte	A prominent isolated hill or mountain with steep, often vertical sides and	May consist of volcanic/sedimentary rocks.	Flat-topped isolated relief with steep sides. Smaller in dimension when compared to Mesa.

			a flat or gently sloping top.		
8		Dip/Strike (field, image)	Describe the orientation and characteristics of rock layers, beds, and geological structures within the Earth's crust.	Sedimentary, Igneous, and metamorphic rocks.	Dip refers to the angle at which a rock layer or geological structure inclines from the horizontal plane. Strike is the intersection of the rock layer with a horizontal plane.
9		Escarpment	Varies from cliff to scrap face to terrace to waterfalls, etc. depending on different geological setting.	Characterized by a steep slope or cliff that exposes a variety of rock layers.	Characterized by a long, steep slope or cliff that separates two different elevation levels.
10		Hog back	A ridge of land formed by the outcropping edges of tilted strata.	A long sharply crested ridge, generally formed of steeply inclined strata that are especially resistant to erosion.	In sedimentary formation, hog backs are formed when the formation is tilted and when there is a softer layer of rock underneath a harder layer on the top.
11		Cuesta	Elongated in shape and can extend for many kilometres.	Associated with alternating layers of hard and soft rock.	A type of ridge or hill with a gentle slope on one side and a steep slope on the other.
12		Fold axis	Anticlines and synclines are two common types of folds that have different structures.	Folded sedimentary rocks, which often consist of alternating layers of different sedimentary rock types, such as sandstone, shale, and limestone.	Represents the hinge line of the fold, where the curvature is greatest, and separates the limbs of the fold on either side.

15.2.4a: Forms of Aeolian Origin

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1	EP	Aeolian plain	Flat or gently sloping surface.	Mainly composed of fine to medium-grained sand and silt.	Flat to undulating plain in arid/semi-arid regions with sheet-to-sand/sand dunes marked by xerophytic vegetation.
2	DC	Dune complex.	Collection of dunes of	Comprises wind-blown sand.	Colony of sand dunes of a type/

			various sizes and shapes that are arranged in a particular pattern based on prevailing wind direction and other environmental factors.		types, generally of undulating surface in arid or coastal areas.
3	ID	Inter dunal depressions	The low-lying, flat or gently sloping area that is bounded on either side by sand dunes.	Comprises wind-blown material.	Shallow depressional between two sand dunes in arid regions.
4	DEP	Desert pavement	Layer of gravel or stones that is several centimetres to several meters thick, and that covers an underlying layer of finer sediments or bedrock.	Mainly composed of gravel.	Occur as nearly level or very gently sloping surface developed by removal of fine sediments resulting in concentration of rounded/ sub rounded/ angular pebbles in desertic area.
5		Playa	Closed basin, which means that it has no natural outlets for water to flow out of the basin.	Comprises clay silt or sand and soluble salts.	Flat topped bottom of an interior desert basin or a dry lake covered by a thin sheet of clastic sediments, in arid regions.

15.2.4b: Geomorphic Feature of Aeolian Landform

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1		Sand dunes	Mound or hill of loose sand, with a distinctive shape and orientation.	Comprises wind blown material.	Area of low mounds, rich of loose stabilized blown granular material.

15.2.5a: Forms of Marine Origin

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1	CP	Coastal plain	Broad, relatively flat plain that extends inland from the coastline for a distance.	Sand, silt, clay.	Regional land of low relief bounded seaward by the shore and landward by highlands mainly formed by coastal action.
2	SF	Salt flat	Flat, featureless plain that extends for miles in all directions.	Fine-grained material like clay dominates.	Flat land bordering the sea/ estuaries with a thin veneer of salt.
3	MF	Mud flat	Relatively flat and featureless expanse of soft mud, which is exposed at low tide and submerged at high tide.	Fine silt and clay.	A muddy flat area along a shore or around an island, covered during high tide, uncovered during low tide, and devoid of vegetation.
4		Beach	Sloping strip of sand, gravel, or pebbles that extends from the shore out into the water.	Comprises sand and silt.	Narrow strip of land along sea shore generally consisting of sand or unconsolidated material. Sometimes it can be formed of boulders or shingles.

15.2.5b: Geomorphic Features of Marine Landforms

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1		Beach ridge	Consists of a series of linear ridges or mounds.	Comprises sand and gravel.	Subparallel ridges of sand, shell, or pebble varying in amplitude from a few inches to several feet normally parallel to the coastline.

2		Spit	Narrow, elongated landform.	Comprises sand.	An elongated accumulation of sand or shingle or both as a bar attached to the coast at one end and extending out to sea.
3		Offshore bar	Parallel to the shoreline of several kilometres having a gently sloping top, with steeper sides that drop off into deeper water.	Comprises sand.	An elongated body of sediments such as sand or shingle occurring in the sea more or less parallel with the coastline and is partially or completely submerged beyond the wave breaker zone.
4		Lagoon	Irregularly shaped, depending on the underlying geology and topography.	Composed of sediment, rock, or coral, and may be covered by seagrass, algae, or other aquatic plants.	Lagoons are important habitats for a variety of marine life, including fish, shellfish, and other aquatic organisms. They may also provide important breeding grounds for sea turtles and other marine animals.
5		Water logged area/ wetlands	Largely dependent on its location, water source, and the types of plants and animals that live there.	The water in a wetland may be sourced from rainwater, groundwater, or surface water such as rivers and streams.	Characterized by the presence of water-tolerant vegetation such as cattails, bulrushes, and other marsh plants.

15.2.6a: Forms of Glacial Origin

Sl. No.	Map Symbols	Geomorphic Units/Forms	Structure	Materials/Lithology	Description
1	GV	Glacial valley	Sometimes fracture controlled	Comprises sediments of glacial origin	'U' shaped wide valley in the glaciated mountain area

2	MP	Morainous plain	A type of landscape formed by the deposition of glacial moraines.	Comprises unsorted angular material ranging from clay-sized particles to huge boulders.	A plain formed of unsorted sediments of glacial origin,
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(Source: IMSD Technical Guideline, (1995) National Remote Sensing Agency, Department of Space, Government of India, Balanagar Hyderabad.)

SAQ 3

Match the following?

- | | |
|---|--------------------------------|
| a. Regional Survey | 1. 1:50,000 |
| b. General assessment of resources | 2. AP, VF, EP etc. |
| c. Specific purpose large scale surveys | 3. 1:25,000 |
| d. Map symbol | 4. Alluvial Plain, Valley Fill |
| e. Geomorphic unit | 5. 1:500 |

15.5 APPLICATION OF REMOTE SENSING

Remote sensing is the art and science of obtaining information regarding an entity or phenomenon without coming in physical contact with it. Observations obtained from Remote Sensing space and aerial platforms which are currently operational give a synoptic picture of terrain features in images that are interpreted and analyzed by thematic specialists in order to extract information and understand data of specific interest to the application. Satellites generate two-dimensional images since they record their data in digital form without stereoscopic coverage. A direct form of interpretation from space images includes the geomorphological analysis of surface forms of the earth. The third dimension of height is usually provided by aerial photos with required forward overlap, which in turn adds to interpretation precision including morphometry.

Given that aerospace images have integrated information of early everything on the surface including the landforms, ecology, and the resources present in areas along with the effect of human actions on their natural landscape, remote sensing becomes an effective tool for their analysis. The repeated coverage of the same area at various times effectively brings out the dynamism with which changes may occur in the landscape. Images convey a lot of things, even to an untrained individual, not to mention they convey much more for professionals including features unseen on the ground. Some specific advantages of satellite imagery for obtaining information about the features on the ground are discussed below.

Multi-Temporal Capability

Indian Remote Sensing satellite (IRS) revisits the same site every 22 days, stationed at a height of nearly 800 km. Moreover, any change taking place between two successive visits to the same location becomes evident in the images captured. On the one hand, no significant change is found to take place in major landforms in the short period of 22 days, on the other hand, the changes that are brought about by natural disasters like cyclones, floods,

landslides, erosion of the river banks and change in river courses can be automatically and efficiently detected. Moreover, changes in land use/ land cover, which are rather dynamic, may emphasize some landforms during some seasons of the year.

Multi-Spectral Capability

Remote sensing satellites usually have specialized sensors that are capable of recording both in the visible band and in the NIR, SWIR, and MIR bands making them different from other satellites that record in the thermal band. On the other hand, microwave recording requires specialized efforts and their satellites are usually exclusive. The fact that certain bands or a combination of bands provide better contrast for image interpretation than other bands gives a critical advantage in multispectral capability. Furthermore, digital analysis is quicker and more apt in the identification and delineation of crops and land use as each land use/land cover may have a unique signature. Moreover, landforms may be best interpreted by analyzing basic elements like tone, size, shape, texture, slope, drainage, relief, land use, and other association of features. Verstappen (1977) has described the following four phases of image interpretation:

(i) detection, (ii) identification and recognition, (iii) analysis, and (iv) classification of observable features in terms of landform and genesis. In order to derive maximum information from an image, a good reference level in the subject coupled with formal training in interpretation may be essential.

Multi Spatial Capability

Satellite sensors have progressed decently over the years, specifically in terms of spatial resolution and multiple other improvements. As of today, data of resolution 1m are available from satellites launched by space-faring nations apart from other resolutions ranging from 2 m to 1000 m or more. Although this provides an opportunity to have multispatial capabilities, at the same time choosing the appropriate resolution becomes necessary. Generally speaking, low-resolution data are usually sufficient for regional mapping whereas higher resolution is needed when the landscape ecology of a small area is to be studied. Moreover, time, economy and the purpose of the study have to be taken into account to determine the optimal spatial resolution data.

Microwave Remote Sensing in Geomorphic Analysis

Radar is an active sensor that provides all-weather including night and day capabilities, in contrast to optical remote sensing. Properties like slope, surface roughness, and dielectric property of surface material are considered sensitively by the radar backscatter. A radar image has its own unique characteristics. For example, the shadow effect is useful for terrain analysis whereas the subtle elevation differences, that are not directly seen in optical remote-sensing images, are also perceived in radar images. These subtle relief changes may have some significance in neotectonics or may even represent a boundary condition. Topographic position, texture and pattern, pseudo-3D presentation of the form (slope), and regional geomorphic context are key factors that determine the interpretation of radar images. The mapping of flood and cyclone-affected areas in India is one of the most common applications of radar imagery. Some good examples include the

change brought about by devastating floods in the Brahmaputra River and change in the coastal configuration of Orissa coast in the aftermath of the super cyclone in Orissa in October 1998.

Examples of Application of Remote Sensing in Geomorphological Mapping

Some examples of the application of remote sensing in geomorphological mapping are given below.

Landforms of Denudational Origin

Landform of denudational origin forms where the denudation process dominates over other processes. Mechanical and chemical weathering together affects most of the landform resulting due to this process. Ice, water, and wind are the major agents whereas the major factors affecting denudation are climate, tectonics, geology, and anthropogenic effects. Important denudational landforms are bajada, butte, badland, colluvial fan, dissected denudational hill, dome, inselberg, mesa monadnock, pediment, pedimentinselberg complex, pediplain, piedmont slope, plateau, residual hill, rolling plain, talus/scree, tor, and valley fill. Some examples of the application of remote sensing in landforms are given below:

Landforms of Denudational origin



Fig. 15.2: Highly dissected denudational hills (HDDH) and moderately dissected denudational hills (MDDH) within the Plateau-Ridge-Valley Complex of Hoshangabad district, Madhya Pradesh state. The density of drainage lines is relatively moderate and therefore moderate dissection in case of MDDH, whereas, the density of drainage lines is relatively high and therefore high dissection in case of HDDH.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

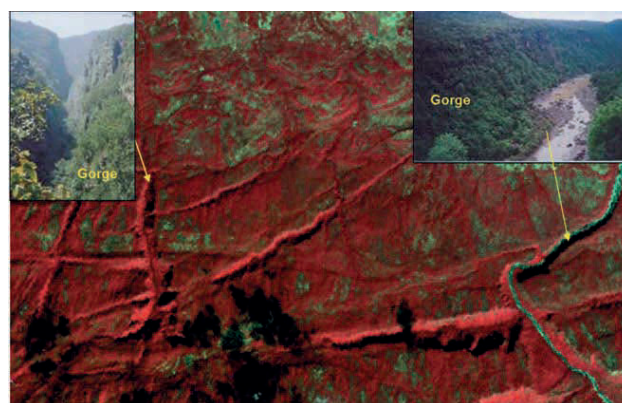


Fig. 15.3: Gorges along Denwa River and its tributaries in the Plateau-Ridge-Valley Complex, Hoshangabad district. These are deep valleys with nearly vertical rocky walls, enclosed among mountains, smaller than a canyon.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

Landforms of Fluvial Origin

Landforms produced by running water are called fluvial landforms. They can be classified as either depositional landforms or erosional landforms. Mechanical and chemical weathering together affects most of the landform resulting due to this process. Important fluvial landforms are abandoned channel, alluvial plain, alluvial fan, terrace, braided bar, paleochannel, channel bar, flood plain, levee / natural levee, meander, meander scar, meander scroll, oxbow lake and point bar. Some examples of the application of remote sensing in landforms of fluvial origin are given below.

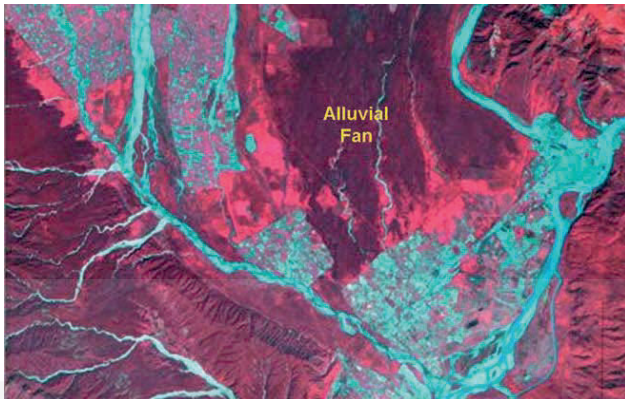


Fig. 15.4: Alluvial fan seen in the foothills of the Himalayas. The bifurcating drainage from the foothill is clearly seen. The Yamuna River is seen in the extreme east.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

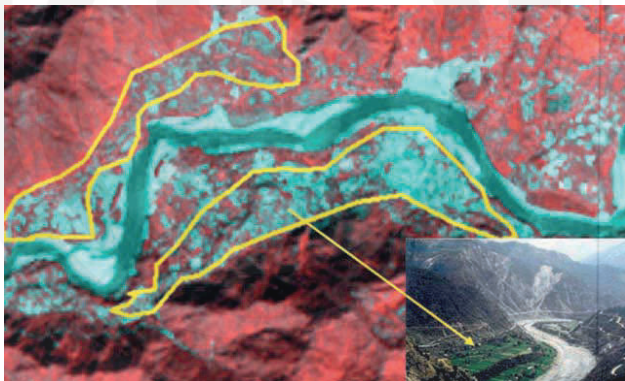


Fig. 15.5: River terrace seen on either side of the Bhagirathi River in the Himalayas.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

They are elevated fluvial deposition zones, which can be clearly demarcated from the hill boundary. They are mostly cultivated forming either paired or unpaired terrace.

Landforms of Structural Origin

The landform of structural origin is related to the structural aspect of the area. Structure plays an important role in reducing the resistance of rock which manifests itself in different geomorphic forms. Some of the variations are minor and some are on a mega-scale. The mega-scale structural features like fault and fold depending on their type play an important role in the genesis of structural landforms.



Fig. 15.6: Hogback in the Low dissected structural hills and valleys in Hoshangabad district, Madhya Pradesh state. Ridge with a sharp summit and steep slopes of nearly equal inclination on both flanks and resembling in outline the back of a hog.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

Important structural landforms are antiformal hills/valleys, basin, cuesta, dome, dissected structural hills and valleys, dyke and sill ridge, hogback, intermontane valleys, homoclinic, monocline, rift valleys, synformal hill/valley, strath terrace and scarp (escarpment). Some examples of the application of remote sensing in landforms of structural origin are given below.

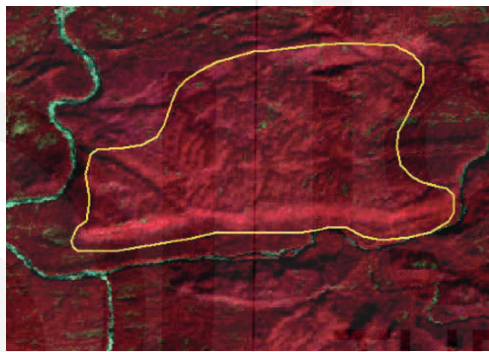


Fig. 15.7: Cuesta in the moderately dissected structural hills and valleys in Hoshangabad district, Madhya Pradesh state. It is seen as a hill or a ridge with a gentle slope on one side and a steep slope on the other.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

Landforms of Aeolian Origin

The wind is an important geological agent playing a dominant role in the origin of Aeolian landforms. Important aeolian landforms are barchan, deflation plain, desert pavement, dissected dune complex, dune complex, interdunal depression, loess, longitudinal dune, parabolic dune, playa, sand dune, sand sheet, star dune, transverse dune, and wadies. Some examples of the application of remote sensing in landforms of Aeolian origin are given below.

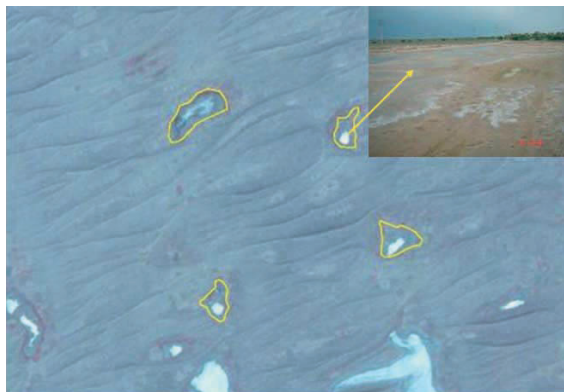


Fig. 15.8: Playa in the desert north of Rann of Kutch, Gujarat. These are depressions in the desert, where seasonal water is stored. Playas are good for groundwater in desert environments.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

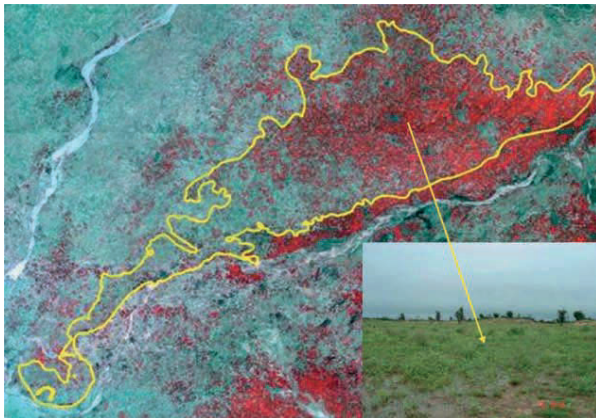


Fig. 15.9: Aeolian plains in Jalor district, Rajasthan. These plains are created due to wind action and are sometimes good for cultivation.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

Landforms of Coastal Origin

Coasts are also the loci of a unique assemblage of erosional and depositional processes. The various landforms of coastal areas are almost exclusively the result of the action of ocean waves. Using multi-temporal satellite data can bring out the dynamics of the coast. Important coastal landforms are beach, coastal plain, coral reefs, tidal creek network, delta, backwater, estuarine islands, delta plain, offshore island, longitudinal bars, lagoon, inter distributary marsh, offshore bars/islands, dune and swale complex, spit, sea cliff, sea stacks and tidal flat. Some examples of the application of remote sensing in landforms of coastal origin are given below.

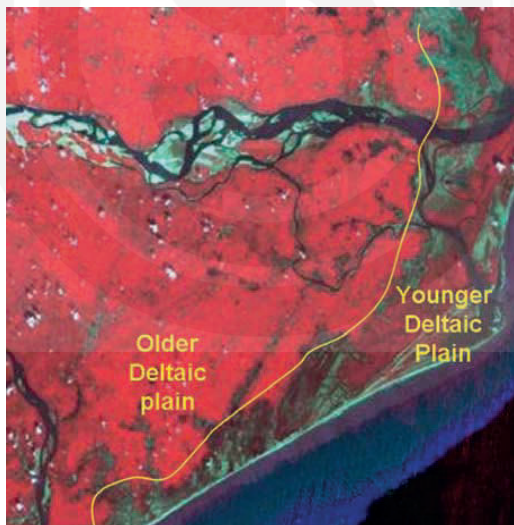


Fig. 15.10: The boundary between older and younger deltaic plains can be clearly seen in the Godavari Delta. The Younger deltaic plain is characterised by some coastal landforms like beach ridges, swale, etc. The river has broadened after entering this plain. Such features are not seen in the older deltaic plain. Fluvial landform dominates and some of the old traces of palaeo beach ridge can be traced in this plain. Salinity problems are relatively less as compared to the younger deltaic plain. The older deltaic plains are intensively cultivated as compared to younger deltaic plains as seen in this false colour composite.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

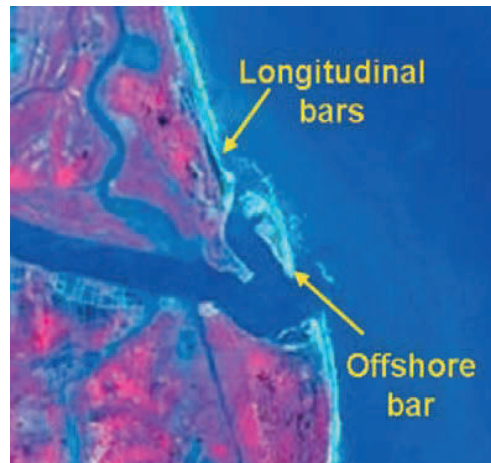


Fig. 15.11: Two different types of coastal depositional landform are seen in Tamil Nadu coast in the mouth Vellar River. The sediment brought by this river especially the coarse sand gets modified by the littoral current for depositional of these two bars. Longitudinal bars are of recent origin and they are generally seen where the wave breaks and are parallel to coast whereas the offshore bars are slightly interior and more stabilized. Mostly formed by sand deposition and they are not much disturbed due to wave action.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

Landforms of Glacial Origin

Glaciers play an important role in the shaping of landscapes in the middle and high latitudes and low-temperature alpine environments. Their ability to erode soil and rock, transportation of sediment, and deposition of sediment is extraordinary. Glaciers are known for a few characteristic landforms each is a result of the processes associated with glacial erosion or deposition. These landforms are varying in size and occur locally or regionally. During the last glacial period, more than 50 million square kilometres of the land surface were geomorphically influenced by the presence of glaciers. Important glacial landforms are arete, avalanche chute/track, cirque, esker, glacial stairway/crevasse, glacial valley, hanging valley (glacial), horn, kame terrace, lake, lateral moraine, medial moraine, nunatak, outwash plain, terminal moraine and till. Some examples of the application of remote sensing in landforms of glacial origin are given below.

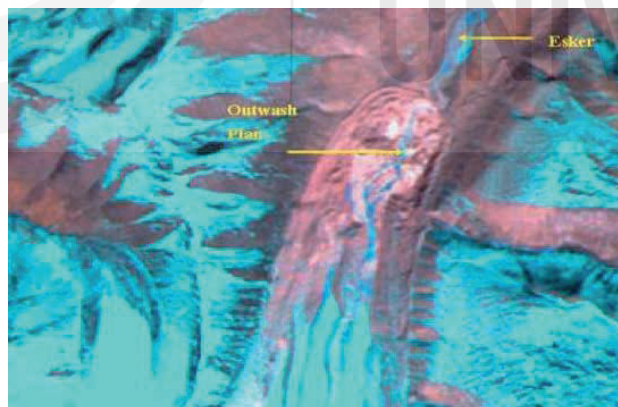


Fig.15.12: Outwash plains and Eskers are seen in the downstream mouth of glacial where epiglacial streams are originated. Esker is low elevated ridge formed due to the result of deposition of sand, gravel, etc. by melt water and generally surrounded by riverine system. Outwash plains formed at the mouth of glacier where fans coalesce.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

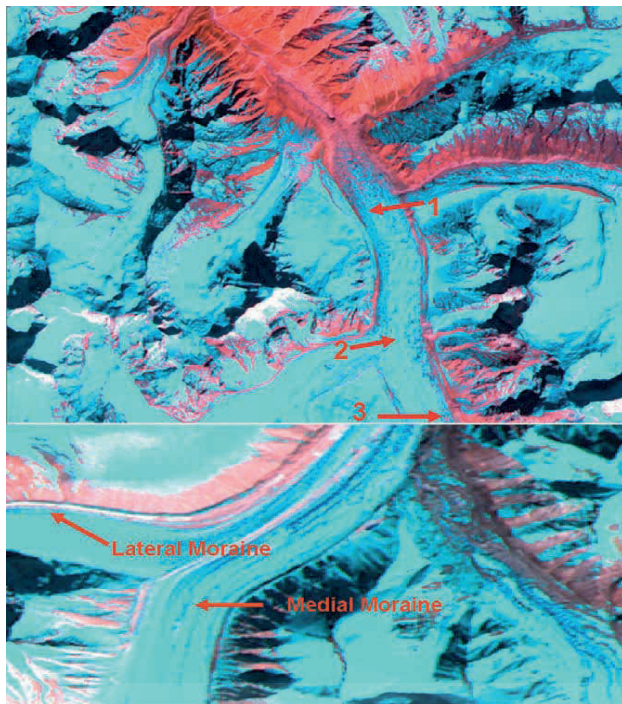


Fig. 15.13: Glacial moraines are the erosional rock debris that occurs in a glacial channel. With reference to their relative place occurrence in the glacial channel, they can be subdivided in three subcategories. Lateral moraines (shown by arrow with 1) are depositing at the edge of the glacier channel while medial moraines (shown by arrow with 2) and terminal moraines (shown by arrow with 3) occupy the central portion and downstream portion of the glacier channel respectively.

(Source: Manual for National Geomorphological and Lineament Mapping on 1:50,000 scale (2010) A Project under National (Natural) Resources Census (NRC), Indian Space Research Organisation, Department of Space, Government of India.)

SAQ 4

What is Remote Sensing and in which geomorphological areas this technology is applicable?

15.6 SUMMARY

Applied geography can be considered as "the use of geographic content, principles, and methods in research and other activities designed to aid in the resolution of human problems with a strong geographic dimension." For the analysis of landforms, geomorphic mapping is a key means of providing geographical data. The mapping method uses five basic concepts — morphology, morphometry, morphogenesis, morphochronology, and morphodynamics.

International Institute for Geo-information Science and Earth Observation (ITC) has evolved as the most comprehensive geomorphic survey method that led to three different types of mapping structure: analytical geomorphological map, synthetic geomorphological map, and pragmatic (applied) geomorphological map.

Remote sensing is the science and art of acquiring information about an object or phenomenon without physically coming in contact with it. With the development of the new Remote Sensing technique, the information about the geographical distribution, topography, terrain, and the appearance of underground characteristics have got at higher spectral, temporal, and spatial resolutions. This, with the expanded GIS capabilities and geospatial analysis, has enhanced the capacity of geomorphic mapping which is applicable in the

areas of denudational landforms, fluvial landforms, structural landforms, aeolian landforms, coastal landforms, glacial landforms and many more.

The methods and analysis of geomorphic maps include data requirements i.e., the data which are required to prepare geomorphic maps, methodology i.e., how geomorphic maps will be prepared using the given data, and final output i.e., the map that one will get on the basis of the above two. There are three important components of geomorphological mapping i.e., scale on which geomorphological maps will be prepared, legend, and classification of geomorphological units.

Geomorphological models show the external facts of the existence of Earth's surface processes and landforms. A primary distinction can be made between (i) conceptual models, (ii) scale models or analogs, and (iii) quantitative models (for instance, Huggett 1985). You will learn about Tools of geomorphology for measuring landforms, hazard and risk assessment in Unit 16 of this block.

15.7 TERMINAL QUESTIONS

1. What do you mean by geomorphic mapping?
2. Explain how geomorphic maps are prepared?

15.8 ANSWERS

Self-Assessment Questions (SAQ)

1. a) To get in depth information about the geomorphic map the summer season satellite images and the Survey of India toposheets are the main inputs. However, in desert/arid regions like Rajasthan, parts of Haryana, and Gujarat, summer season images may lead to incorrect interpretation due to the impact of dust storms and the consequent haze and therefore, satellite images of Kharif or Rabi season as available are used.
2. a) False; b) True; c) True; d) True
3. (a-3), (b-1), (c-5), (d-2), (e-4)
4. Remote sensing is the science and art of procuring data about an object or peculiarities on the earth's surface without actually interacting with it. This technology is applicable in the areas of denudational landforms, fluvial landforms, structural landforms, aeolian landforms, coastal landforms, glacial landforms, and many more.

Terminal Questions

1. Geomorphic mapping is considered a basic unit of earth processes, generating valuable databases for surface processes and shaping the current earth structure. A well-thought-out graphical list of landscapes showing landforms, surface, and subsurface materials are known as geomorphic maps.

- 2 The methods and analysis of geomorphic maps include data requirements i.e., the data which are required to prepare geomorphic maps, methodology i.e., how geomorphic maps will be prepared using the given data, and final output i.e., the map that one will get on the basis of above two. Apart from these, we should also know about three important components of geomorphological mapping i.e., scale on which geomorphological maps will be prepared, legend, and classification of geomorphological units. For complete details refer to the sections 15.2 and 15.4.

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GEOMORPHIC TECHNIQUES |

Structure

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16.2	Tools and Techniques of Geomorphology for Measuring Land Forms Changing Nature of Geomorphic Tools and Techniques The Current Major Tools and Techniques of Geomorphology	16.4	Desertification
		16.5	Summary
		16.6	Terminal Questions
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16.1 INTRODUCTION

In the previous Unit, you learned about geomorphic mapping and its uses. You have also studied the different methods and analyses of geomorphic data, geomorphic models, and geomorphological mapping scales. You have also learned how the application of Remote Sensing and GIS is helping the study of geomorphic mapping. In this Unit, you will be learning about different geomorphic tools and techniques which are used to measure different landforms. You will be also learning the hazard and risk assessment of land degradation and soil degradation.

As now you know Geomorphology is basically an earth science that deals with the study of geological structures culminating into geomorphic landforms through interactive processes of various geomorphic agents under varying climatic regimes. A true landform is a function of structure, process, and time as put forth by W.M. Davis. The study of the landforms varies with respect to the spatial resolution with which they are analysed or investigated. They can vary from the global continental level to, Meso level regional physiographic land system to micro process dominated geomorphic forms.

It will be interesting to learn that the study of these forms and processes is really essential and extremely relevant as they will reveal the true dynamism of surficial transformations, due to either degradational or aggradational processes. The degradational processes whether passive under natural

forces or active under anthropogenic processes are equally accountable for the morpho dynamics and altering surficial forms. In a true sense, Delta accretion (Aggrading Delta), floodplain expansion: constricted natural channels due to encroachment constructional processes; glacial fluvial forms under the influence of melting glaciers; undercut mountain and hillslope fronts; receding rapids and waterfalls; migrating dunes, are all the changing forms and processes which are confronted and debated repeatedly. In fact, geomorphic forms are the true indicators of environmental changes. For example, fossil dunes or palaeo channels are indicative of former wind directions and precipitation levels, as is the case of misfit valleys, which are indicative of erratic discharge levels. A variety of anomalous forms reveal the true nature of evolution.

Leading further, the variety of landforms are enormous, especially in the Indian sub-continent. India is endowed with one of the oldest archaen-based Deccan shields juxtaposed with Tertiary and Pleistocene-based Himalayan mountains. Between these two major forms is the vast Indo-Gangetic plain with khaddar and bhangar alluvial tracts with varying climatic conditions of extreme wetness in the east to extremely arid conditions in the west. Further to this, the variety of landforms cutting across the whole width and length of the Indian subcontinent can be witnessed in the form of fluvial landforms (Valleys, Meanders, Flood plains, Deltas) Glacial forms (Cirques, Troughs, Moraines, Outwash plains) coastal forms (Cut benches, Terraces, Bars, Beaches, lagoons, etc.), Arid Eolian forms (Cut slopes and Rocks, Dunes, Intermontane Basins, Intermittent Stream Valleys, etc.); which are all possible through the continuous interactive exogenic denudational and endogenic tectonic processes.

The base structural components of landforms are overlaid with surficial regolith cover, and transformed into soil cover through interactive processes of organic and inorganic elements. The peninsular plateau region is overlaid with Red, Black, Laterite, and Mixed soils followed by arid soils in the west and mountainous soils in the north. These soils are overlaid with evergreen forests with rainfall greater than 250 cm, Moist and dry deciduous forests with rainfall ranging between 100-250 cm and shrubs and grasslands with 50-100 cms, and dry scrub and desert with Rainfall less than 50 cms. With such a wide range of physiographic regions, the techniques available for studying, analyzing, and planning are equally varied. A variety of data-generating tools and analytical techniques are available and used which is dealt with in forthcoming section.

Expected Learning Outcomes

After studying this unit, you should be able to:

- identify the tools of geomorphology for measuring landforms;
- identify natural hazards and study risk assessment;
- discuss in detail land degradation as a major hazard;
- describe desertification as a result of advanced or accelerated degradation.

16.2 TOOLS AND TECHNIQUES OF GEOMORPHOLOGY FOR MEASURING LAND FORMS

As of now, you have already studied the different forms of geomorphology so in this section now you will study about the tools of geomorphology for measuring different landforms.

Geomorphology is the study of the physical features of the Earth's surface, including landforms, and the processes that shape them. Although, an understanding of geological structures along with geomorphic processes is essential for applied geomorphic studies. However, tools used for geological structures and landforms are basically associated with the detailed investigation of petrological, lithological, and clinometric characteristics of rocks and how they are patterned on the earth's surface. The techniques involved in identifying geomorphic processes, basically involve a detailed understanding of erosional, transportational, and depositional mechanisms by various geomorphic agents.

There are various tools and techniques used in geomorphology to measure and analyze landforms, including:

- **Topographic maps:** These maps show the elevations of landforms by using contour lines to indicate changes in height. They can be used to identify and measure landforms such as valleys, ridges, and mountains.
- **Aerial photography:** This involves taking photographs of the Earth's surface from the air. Aerial photos can provide detailed information on the shape, size, and location of landforms.
- **Geographic Information Systems (GIS):** GIS is a computer-based tool that allows the collection, storage, analysis, and visualization of geographic data. It can be used to map and analyze landforms, including their distribution, shape, and size.
- **Global Positioning System (GPS):** This is a satellite-based navigation system that can be used to accurately determine the location of landforms. GPS can provide information on the height, length, and width of landforms.
- **LiDAR (Light Detection and Ranging):** LiDAR is a remote sensing technique that uses laser beams to measure the distance between the Earth's surface and the sensor. It can be used to create highly accurate digital elevation models (DEMs) of landforms.
- **Ground Penetrating Radar (GPR):** This is a geophysical technique that uses radar pulses to image the subsurface of the Earth. GPR can be used to identify buried landforms such as buried valleys or buried channels.
- **Field surveys:** Field surveys involve physically measuring landforms using instruments such as clinometers, compasses, and tape measures. Field surveys can provide detailed information on the size, shape, and location of landforms.

It will be also very interesting to know how the nature of geomorphic tools is changing over time period with the advancement of technology and their needs. In the coming sub-sections, we will be also learning about the geomorphological tools which are in current use.

16.2.1 Changing Nature of Geomorphic Tools

The nature of geomorphic tools has changed from the past to the present. The focus from Davisian times, which was mainly on the cyclic development of landforms based on observations of structural changes, changed to an emphasis on contemporary processes, making use of quantitative techniques as propounded mainly by Horton, Strahler, Morisawa, etc.

Two processes - namely, inductive nature based on experiment and observational data leading to a classification scheme and a deductive approach based on cause-and-effect analysis have taken over in recent times. This has also given scope for micro-analysis whereby first-order drainage basins and hill slope facets can be studied in a more effective way. This has also led to simulated models to study process - responses in a more meaningful way. This is mainly dependent on quantifying the predictable variables of various sets of landforms.

Measurement of variables should be consistent, precise, and rigorous. One has to have the data from various sources from primary field measurements to secondary sources like maps, photographs, and satellite images providing high resolution from the micrometer scale to thousands of km² of the earth's surface. Maps, photographs, satellite images, and field data rarely exist independently of one another, since maps are derived from remotely sensed imagery and field surveys, and ground truth for imagery is provided on the field through the latest GIS tool available and used widely.

16.2.2 The Current Major Tools of Geomorphology

Below mentioned are the current major tools of Geomorphology:

- 1) Primary data, based on field investigation and Derived digital data from images
 - a) Field observations include measurements on altitude, slope, water quality, water flow, based on sediment characters, depth of soil, properties of soil, Base rock and soil profile, etc. Field-based soil and water testing kits and (depth of water table).
 - b) Questionnaire-based field information of changed land characters, dynamic soil properties, processes, floods, and droughts, etc.
 - c) Survey of India Topo sheets on 1:1000000, 1:250000, 1:50000, 1:25000, 1:10000 scale etc.
 - d) Remote sensing-based Aerial Photographs on 1: 10,000, 1:20,000, 1:50,000, 1:2,50,000 scale, etc.
 - e) Satellite images of IRS series, Landsat series, NOAA, MODIS, SPOT, Quick Bird, CARTOSAT, METOSAT and recently launched vehicles by ISRO.
 - f) Advanced GIS-based digital data creation and analysis.

- 2) Secondary data from published reports
 - a) Secondary published Reports on climate, forest cover, land use, land cover, and land management practices, etc.
 - b) Laboratory-based soil and water testing tools, techniques, and analysis.

SAQ I

What are the various tools of geomorphic tools used for measuring landforms?

16.3 HAZARD AND RISK ASSESSMENT

Hazard and risk assessment are important components of geomorphology, which is the study of landforms and the processes that shape them. In geomorphology, hazard assessment refers to the identification and assessment of potential hazards that can arise from natural processes such as landslides, floods, earthquakes, and volcanic eruptions. Risk assessment, on the other hand, involves the estimation of the likelihood and potential consequences of such hazards.

Hazard and risk assessment in geomorphology typically involves the use of a range of techniques and tools, including remote sensing, field surveys, and computer modeling. These methods are used to identify and analyze the factors that contribute to the occurrence and severity of natural hazards. Factors that are commonly considered include the slope and topography of the land, the geology of the area, and the climatic conditions.

Hazard and Risk are two interrelated words that are triggered by natural imbalances creating resource loss or depletion, making that section of the populace highly vulnerable which are dependent on that particular resource. In this section, we will be studying land degradation and desertification to understand the hazard and risk assessment.

According to UN statistics due to natural hazards about 1,00,000 persons are killed and property loss is about 20,000 crores of rupees every year. Many natural hazards are interrelated. One type of hazard can lead to many disasters, especially impacting the human population. Hazard is defined as “a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. (UNISDR 2009) (*United Nations International Strategy for Disaster Reduction*). Similarly, disaster is defined as a sudden event, *such as an accident or natural catastrophe that causes great damage or loss of life*. UNISDR defines a disaster as a “serious disruption of the functioning of a community or a society causing widespread human, material economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources”. Risk is the combination of the probability of an event and its negative consequences.

Natural hazards are classified into (1) Geological hazards (Earthquakes, volcanic eruptions, Avalanches, Landslides, mudflows, Lahars, subsidence, and crustal displacements, Tsunamis, and wildfires). (2) Climatic and Atmospheric hazards (Floods due to excessive rainfall, Droughts due to excessive evaporational losses and erratic and scant rainfall, hail storms, thunderstorms, heat waves, Erratic oscillation of rainfall due to climatic changes leading to glacier melting and sea level changes, dust storms, wildfires). (3) Hydrologic hazards (Floods due to change in channel geometry leading to carrying capacity of the rivers as in urban floods, water logging and clogging, groundwater changes, etc.). (4) Space disasters and hazards (Solar flares and Meteor falls). (5) Biological Hazards (epidemics and pest infestations) (6) Anthropogenic hazards (Faulty land use land cover practices and policies resulting in intensive degradation, toxic waste disposal, air and water pollution, gas flaring, artisanal and small-scale mining, etc.).

Natural hazards lead to heavy destruction and displacement of people impacting their livelihoods. It can be mentioned here that hazard leads to resource loss and people are put at risk. The assessment of the type of loss can be of both short and long ranges. The loss can never be only physical in nature but equally socio-economic in nature. The real problem arises in estimating the total loss and subsequently engaging in ameliorative measures to combat such adversaries which crop up as hazards. One such major hazard is land degradation which is universal in nature and impacts the agrarian sector the most, which contributes to greater GDP of the world economy and is also the true food basket and the backbone of living and survival of the human race.

The results of hazard and risk assessments can be used to inform land use planning, emergency preparedness, and infrastructure development. For example, hazard and risk assessments can be used to identify areas that are at high risk of landslides or floods, and to develop strategies to mitigate or manage these risks. They can also be used to identify areas that are suitable for development, and to determine the type and scale of infrastructure that is appropriate for the area.

Overall, hazard and risk assessment are important tools in the field of geomorphology, as they enable scientists and planners to better understand and manage the risks associated with natural hazards, and to develop strategies that can help to reduce the impact of these hazards on communities and the environment.

16.3.1 Land Degradation

Land degradation is a composite term involving all the land resources like rocks, relief, soils, water, and vegetation, as these have changed for the worse over a period of time. Approximately 15% of the World's Population is affected by land Degradation. As per the UN/FAO definition, "Land degradation generally signifies the temporary or permanent decline in the productive capacity of the land. Under the land degradation process, eight processes are recognized-water erosion, wind erosion, water logging, salinisation/ alkalization, acidification, glacial, anthropogenic, and others.

Similarly, land degradation types include - Sheet erosion, rills, gullies, ravines, stabilized/partially stabilized dunes, unstabilised dunes, surface ponding,

saline soils, sodic soils, saline-sodic soils, acidic soils, frost heaving, snow-covered areas, mining areas, brick kiln areas, industrial effluent affected areas, mass movement/ mass wastage, barren rocky/ stony waste and miscellaneous (Manual-NRSC LDM).

Causes of Degradation: Land degradation is caused by excessive pressure on land to meet the competing demands of the growing population for food, fodder, and fiber. Various human activities such as the introduction of large-scale irrigation canals, and deforestation lead to accelerated soil degradation through salinisation, flooding, drought, erosion, and waterlogging. These processes, in turn, reduce agriculture productivity leading to social insecurity. The emission of greenhouse gases to the atmosphere resulting in global warming could be a major reason for soil degradation. Direct and indirect causes as the older man pointed out as deforestation, overgrazing, agriculture-related activities, over-exploitation of vegetation for domestic use, increase in population and livestock density leading to mechanization, agriculture expansion, fertilizer use, etc. can lead to intensive land degradation.

From the above, it is clear that the above processes of land degradation are more in occurrence where the region has steep slopes, high intensity of rainfall, and less soil organic matter. Identification of such environments which have the potential for land degradation has to be made through detailed mapping and identifying those attributes responsible for land degradation. To derive this, four major types of soil surveys are conducted such as (i) Reconnaissance (ii) Semi detailed (iii) Detailed (iv) Detailed reconnaissance. These are mainly carried out for agricultural and irrigational planning by various government institutes.

In many ways, the soil is held synonymous with the land as it is the most vulnerable resource having a direct interface with not only climate changes but also anthropogenic processes and degenerating on a regular basis impacting the livelihood options of a majority of the population. Degraded lands are also akin to wastelands. Whilst soil degradation is recognised as a major aspect of land degradation, other processes which affect the productive capacity of cropland, rangeland, and forests, such as lowering of the water table and deforestation are captured by the concepts of land degradation.

16.3.2 Soil Degradation

Soil Degradation leading to wastelands is defined as “Degraded land which can be brought under vegetation cover with reasonable effort and which is currently underutilized land which is deteriorating for lack of appropriate water and soil management or on account of natural causes”. Soil degradation can basically be classified into 3 types physical, chemical, and biological nature (Fig. 16.1).

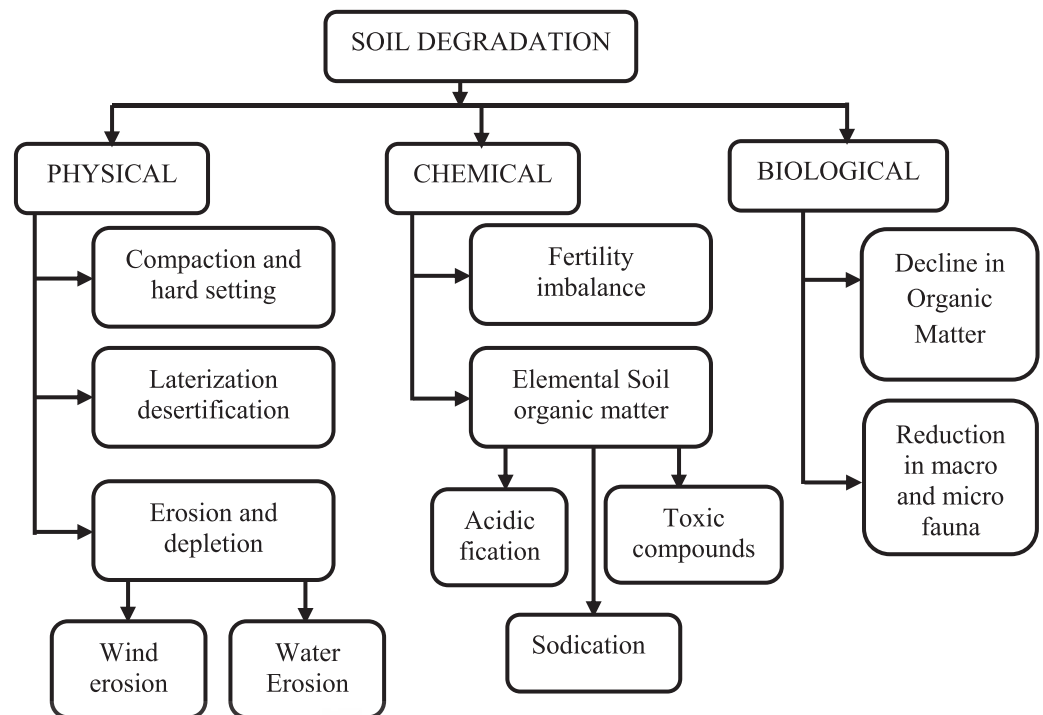


Fig. 16.1: Kinds of Soil Degradation.

Pedogenesis is soil forming process comprising of following processes under varying climates

1. Podzolisation (Cool climates)
2. Calcification (Warm climates)
3. Laterisation (Warm & humid)
4. Salinisation (Hot climate)
5. Gleization (over drained wet cold climates).

Physical Degradation: Physical degradation includes *compaction and hard setting of soils* either due to less rainfall or less moisture content. Compaction, crusting, and sealing are usually caused by the use of heavy farm machinery. Due to slaking, clogging occurs which retards infiltration. Upon drying the surface becomes harder impeding root penetration.

Land degradation: Laterisation mainly occurs in humid and sub-humid areas with alternate wet and dry seasons. When climatic uncertainties increase, leaching is impeded and the minerals get encrusted within subsoils leading to laterisation. Laterites are the soils that result from this process. If the rainfall becomes scarcer, subsequently it will lead to desert-like conditions which is known as desertification. Laterites are acidic soils with a heavy concentration of sesquioxides.

Erosion and Depletion: Soil erosion is the major factor responsible for soil degradation. Approximately 430m ha of land or 30% of the presently cultivated area of the world has been impacted by this process. This can occur by both water and wind. Erosion is more in mountainous (1.5 – 7 t/ha) areas compared to low-lying areas (0.1 – 7 t/ha). This is also expected to reach 600 ppm by 2070 due to global warming's impact. (Yadav and Singh 2000)

Soil Erosion by Water: Erosion by water is the most serious degradation problem not only in the world but also in the Indian context. It is estimated that 5334 tonnes per year are the loss. This ranges from 5t/ha per year in hilly regions to 80t/ha/yr along the banks and ravines of rivers like Yamuna, Chambal, Mahi, and Tapti, to 40t/ha/yr due to shifting cultivation in regions of Orissa and northeastern states to 20-30 t/ha/yr on western coasts of India (Yadav and Singh 2000).

Basically, soil erosion by water is the removal of soil particles by the action of water usually seen as Splash erosion by falling raindrops; sheet erosion is a more or less uniform removal of a thin layer of topsoil; rill erosion by small

channels in the field or gully erosion by large channels like incised rivers which are a result of localized surface runoff affecting the unconsolidated material resulting in the formation of perceptible channels causing undulating terrain. In a way, these are developed from rills commonly found in sloping lands due to headward erosional recession by channels. Ravine Erosion is associated with an extensive and intricate network of gullies over the deep alluvium of a river flowing at a lower level than the surrounding tablelands as is the case in the famous Chambal Ravines.

Soil Erosion by Wind: This type of erosion is common in arid, Semiarid, and coastal regions, due to the removal of soil particles by deflation activities of wind. Wind cannot only lift the top fine **fertile** particles but also can erode the land by forming hollows and blowouts, which are uncultivable.

Chemical Deterioration of Soils: This occurs either through loss of nutrients or organic matter and accumulation of salts and pollutants in the soils. This occurs mainly due to mismanagement owing to over-cultivation due to increasing demand against the carrying capacity of soils. 3.7m ha of land is under this category. Reduction in organic matter, with an associated decline in soil biological activity leading to less water-holding capacity and aeration of the soils is witnessed. Loss of nutrients and increase in toxic levels also lead to soil fertility loss. Incorrect application of fertilizers and pollutants from industrial and urban origin can also lead to soil quality loss. The heavy concentration of nitrates due to groundwater pollution is also one of the other reasons for soil degradation

Waterlogging is caused by a rise in groundwater close to the soil surface or inadequate drainage of surface water, often resulting from poor irrigation management, leading to oxygen deficiency in the soils. Water logging can also be due to changes in hydrologic regime, landscape developmental activities, silting of river beds, etc. Repeated flooding in flood plain and natural levees and coastal areas due to deforestation and changed land use conditions often can lead to water-logged conditions. Flooding may also take place due to an increase in sedimentation and a reduction in the carrying capacity of the channels. 5.7 M ha land seems to have been affected by this problem.

Salinization and alkalization: The main culprit for this type of soil loss is cultivation (farming) through irrigation means especially through canals. There has been a huge increase in irrigated areas. When the groundwater reaches nearer to the surface evaporation occurs leaving out the salts (chloride, sulfates of sodium, calcium magnesium). Uttar Pradesh, Haryana, Punjab, Rajasthan, Maharashtra, and Karnataka have a higher proportion of these types of soils. Salinization (excessive salts in soils) occurs not only due to brackish groundwater, but also due to intrusion of seawater into inland areas due to excessive extractions of groundwater in coastal areas. Alkalization is a process of increase in carbonates and bicarbonates in soils with higher pH values. Wherever there is a marked fluctuation in the water table, sodication tends to occur naturally increasing carbonate (bicarbonates) content in the soils.

Sedimentation or Soil Burial: This may occur through flooding, where fertile soil is buried under less fertile sediments, or the wind blows where sand inundates grazing lands. Other types of degradation include.

- a) Lowering of the water table due to over-extraction of groundwater exceeding the natural recharge capacity of the water table.
- b) Loss of vegetation cover: Vegetation is important in many ways. It protects the soil from both wind and water erosion. It provides organic matter to maintain nutrient levels in the soil and facilitate water infiltration. Where the organic matter content of soil falls below 2%, the soil is more prone to erosion because dislodgement may be more.
- c) Increased stoniness and rock cover of the land: this would usually be associated with extreme levels of soil erosion causing the exhumation of stones and rock.

Table 16.1: Land Degradation Status in India (Area in lakh ha.)

S. No.	Type of degradation	MOA, 1985 Assessment	MOA, 1994) Assessment
1.	Water Erosion	1071.96	571.55
2.	Wind Erosion	177.96	104.60
3.	Ravines	39.75	26.78
4.	Salt Affected	76.16	63.23
5.	Waterlogging	85.26	31.97
6.	Mines & Quarry Wastes	--	2.53
7.	Shifting Cultivation	49.12	23.78
8.	Degraded Forests	194.94	248.97
9.	Spl. Problems Coastal Sandy Areas	27.30	0.89
	*Included In Other Type	14.65	--
	TOTAL	1736.40 lakh.ha or 173.64 M. ha	1074.30 Lakh.ha or 107.43 M. ha

(Source: Sagal and Abrol (1994))

Table 16.1 depicts that water erosion is the dominant degradation type accounting for 148.9M ha (Table 16.1), and 571.55 Lakh.ha (Table 16.2). Wind erosion accounts for 13.5Mha (Table 16.1) and 104.6 Lakh.ha (Table 16.2). These tables clearly reflect the fact that there is no similarity in the data as per the values shown above but there is a definite similarity in the nature of degradation type. Both the tables reflect more or less identical degradation types.

SAQ 2

Fill in the following

- a) Gully erosion occurs due to _____.
- b) Salinisation occurs in _____.
- c) Usar and reh in Uttar Pradesh are examples of _____ soils.
- d) Migrating dunes cause _____ of soils.

16.4 DESERTIFICATION

Land degradation in arid, semiarid, and dry sub-humid regions, resulting from various factors including climatic variations and human activities is called desertification (Anonymous 1992). The deserts prevail basically in hyper-arid areas, but desertification leading to desert-like conditions can be caused due

to both climatic aberrations and more so due to human activities such as deforestation, overgrazing, over-cultivation, and over-irrigation.

Desertification in contrast to land degradation is the permanent decrease in biological productivity of dryland areas. The causes of desertification are both natural and man-made. Desertification is a systematic phenomenon involving climate, soils, flora, fauna, and man. Three major desertification processes, namely degradation of the vegetation, soil erosion by water and wind, salinisation/alkalization, and water logging impact major land uses, namely pastoralism on rangeland, rainfed cropland, and irrigated agriculture in the arid and semiarid regions. Salinisation/alkalization and water logging are the principal desertification processes on irrigated land. Population growth, agriculture technologies, and unsustainable policies are the other main causes. Human activities were overgrazing making the relation between vegetation, albedo, temperature, precipitation, soil moisture, wind, and water erosion unbalanced.

Increased population pressure leading to more human activities affects the surface characteristics and atmospheric composition including a breakdown in soil structure, accelerated soil loss by wind and water erosion, increasing salinisation, and a reduction in soil moisture retention. An increase in particulate and trace gas emissions from biomass burning can increase in atmosphere dust load leading to changes in energy balances between the atmospheric and earth's surface.

Desertification is a phenomena which is a continuous and cumulative process of soil loss leading to complete and excessive salinisaion making the soil to be expansive along with loss in the vegetal cover is termed as desertification. These lands can be completely wasted lands, affecting billion of people, and covering 40% of the earth's surface.

Measures to reduce land degradation are: 1) Proper land use policies, for better land management. 2) Check on population density to reduce pressure on land resources 3) Measures to ameliorate salted /Alkaline soils. With proper treatment techniques.

Causes of Desertification

There are many causes of desertification. Some of the important causes of desertification are mentioned below:

- Climate Variability and Drought

Climate variability and drought are natural causes of desertification. They can cause soil moisture deficits, reduce vegetation cover, and increase the susceptibility of the land to erosion. For example, in the Sahel region of West Africa, drought and erratic rainfall have contributed to the loss of vegetation cover and the degradation of soil (Nicholson, 2014).

- Overgrazing

Overgrazing by livestock is a significant cause of desertification in many regions of the world. It can lead to the loss of vegetation cover, soil erosion, and the degradation of soil fertility. For example, in Mongolia, overgrazing by livestock has contributed to the expansion of desertification (Jargalsaikhan et al., 2019).

- Deforestation

Deforestation is a human-caused factor that can contribute to desertification. When forests are cleared, the land becomes more vulnerable to soil erosion, loss of soil fertility, and reduced water-holding capacity. For example, in the Amazon Basin, deforestation has led to soil degradation and reduced vegetation cover, contributing to desertification (Aragão et al., 2018).

- Unsustainable Agricultural Practices

Unsustainable agricultural practices, such as monoculture farming, excessive use of fertilizers, and inappropriate irrigation, can also contribute to desertification. They can lead to soil degradation, loss of soil fertility, and reduced water-holding capacity. For example, in the Loess Plateau of China, inappropriate agricultural practices have contributed to soil erosion and desertification (Liu et al., 2018).

Consequences of Desertification

Desertification can have severe consequences for both the environment and the people who depend on it. Some of the consequences are mentioned below:

- Loss of Biodiversity

Desertification can lead to a loss of biodiversity, as the land becomes less able to support diverse plant and animal communities. For example, in the Sahel region of West Africa, desertification has contributed to a decline in plant species and wildlife populations (UNEP, 2016).

- Soil Erosion and Reduced Soil Fertility

Desertification can cause soil erosion and reduce soil fertility, making it more difficult to grow crops and support vegetation. For example, in the Loess Plateau of China, desertification has caused soil erosion and reduced soil fertility, making it difficult for farmers to grow crops (Liu et al., 2018).

- Water Scarcity

Desertification can lead to a reduction in water availability, as vegetation cover decreases and soil becomes less able to retain moisture. For example, in the African Sahel, desertification has led to a decline in water availability for both people and wildlife (UNEP, 2016).

- Food Insecurity

Desertification can lead to food insecurity, as the land becomes less able to support agricultural production. For example, in the Horn of Africa, desertification has contributed to food insecurity and malnutrition (UNEP, 2016).

- Migration and Conflict

Desertification can contribute to migration and conflict, as people are forced to leave their homes in search of food and water. For example, in the Darfur region of Sudan, desertification has contributed to conflict between farmers and herders over access to land and resources (UNEP, 2016).

Measures for Mitigating Desertification

Mitigating desertification involves taking measures to prevent further degradation of land and to restore degraded lands. Mentioned below are some examples of mitigation measures for desertification.

- Agroforestry

Agroforestry involves planting trees and shrubs alongside crops, which can help to improve soil fertility, reduce soil erosion, and increase the water-holding capacity of the soil. For example, in Niger, farmers have used agroforestry techniques to restore degraded lands and increase crop yields (Bayala et al., 2015).

- Conservation Agriculture

Conservation agriculture involves minimizing soil disturbance, maintaining soil cover, and rotating crops to improve soil health and reduce erosion. For example, in Zambia, conservation agriculture has helped to improve soil fertility and increase crop yields, while also reducing erosion (Kwazira et al., 2017).

- Sustainable Land Management

Sustainable land management involves using land in a way that is sustainable over the long term, taking into account the needs of both people and the environment. This can include measures such as reducing overgrazing, planting vegetation to reduce erosion, and improving water management. For example, in Ethiopia, sustainable land management practices have helped to restore degraded lands and increase agricultural productivity (Amsalu et al., 2020).

- Rehabilitation of Degraded Lands

Rehabilitation of degraded lands involves restoring degraded lands to their original state or to a state where they can support sustainable land use. This can include measures such as planting vegetation, improving soil fertility, and managing water resources. For example, in China, the "Grain for Green" program has involved planting trees and shrubs on degraded lands to reduce erosion and improve soil fertility (Wang et al., 2015).

Overall, mitigating desertification requires a range of measures that address the underlying causes of land degradation and promote sustainable land use. By taking appropriate measures, we can help to protect the environment and ensure the well-being of people who depend on it.

SAQ 3

What are the measures to check desertification?

16.5 SUMMARY

In this unit you have studied so far:

- Geomorphic tools and techniques have changed from past to present. The focus has shifted from cyclic development of landforms to contemporary

processes. Quantitative techniques are being used, as propounded by Horton, Strahler, Morisawa, etc.

- Two processes, inductive and deductive, have taken over in recent times. Inductive process leads to a classification scheme, while the deductive approach is based on cause-and-effect analysis
- There is a scope for micro-analysis of first-order drainage basins and hill slope facets. Simulated models are being used to study process responses more effectively. The success of modern techniques depends on quantifying predictable variables of different landforms.
- To gather data for precise, and rigorous measurement of variables, one needs to use various sources, including primary field measurements and secondary sources like maps, photographs, and satellite images. These sources provide data at different scales, from micrometers to thousands of km² of the Earth's surface.
- Maps, photographs, satellite images, and field data are interconnected and rarely exist independently of one another, as maps are created from remotely sensed imagery and field surveys, and ground truth for imagery is provided using the latest GIS tool available and used widely.
- Land degradation and desertification are natural hazards that often get intensified due to gross mismanagement of the land and water resources by man. Erosion by water and wind increases due to a lack of ameliorative measures to check deforestation, overgrazing, and intensive irrigation. Land and soil are major resources forming the backbone of the agriculture economy, a constant monitoring and mapping of natural resource bases along with their prime characters are required on a priority basis to reduce and minimize the land degradation.

16.6 TERMINAL QUESTIONS

1. Discuss the changing nature of Geomorphic tools and their importance in land measurement.
2. Discuss land degradation in the context of hazard and risk.
3. What do you mean by hazard and risk assessment? Discuss how soil degradation is posing a hazard to the environment.
4. What do you mean by desertification? Discuss the mitigation processes to check desertification.

16.7 ANSWERS

Self-Assessment Questions (SAQ)

1. There are various tools and techniques used in geomorphology to measure and analyze landforms are Topographic maps, Aerial photography, Geographic Information Systems (GIS), Global Positioning System (GPS), LiDAR, Ground Penetrating Radar (GPR), and Field survey (For a detailed answer, see the section 16.2).
2. a) Water erosion, b) Arid, c) Saline soils, d) Desertification

3. Agroforestry, conservation agriculture, sustainable land management, and rehabilitation of degradation (For a detailed answer, see the section 16.4).

Terminal Questions

1. Geomorphology is the study of the physical features of the Earth's surface, including landforms, and the processes that shape them. Although, an understanding of geological structures along with geomorphic processes is essential for applied geomorphic studies. However, tools used for geological structures and landforms are basically associated with the detailed investigation of petrological, lithological, and clinometric characteristics of rocks and how they are patterned on the earth's surface. The techniques involved in identifying geomorphic processes, basically involve a detailed understanding of erosional, transportational, and depositional mechanisms by various geomorphic agents. (For a detailed answer, see the section 16.2, subsection 16.2.1 and 16.2.2).
2. Land degradation is a composite term involving all the land resources like rocks, relief, soils, water, and vegetation, as these have changed for the worse over a period of time. Approximately 15% of the World's Population is affected by land Degradation. (For a detailed answer, see the section 16.3, subsection 16.3.1).
3. Hazard and Risk are two interrelated words that are triggered by natural imbalances creating resource loss or depletion, making that section of the populace highly vulnerable which are dependent on that particular resource. In this section, we will be studying land degradation and desertification to understand the hazard and risk assessment. (For a detailed answer, see the section 16.3, subsection 16.3.2).
4. Desertification in contrast to land degradation is the permanent decrease in biological productivity of dryland areas. The causes of desertification are both natural and man-made. Desertification is a systematic phenomenon involving climate, soils, flora, fauna, and man. (For a detailed answer, see the section 16.4).

16.8 REFERENCES AND SUGGESTED FURTHER READINGS

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LANDFORMS AND ENVIRONMENT MANAGEMENT

Structure

17.1	Introduction		Key Principles and Strategies for
	Expected Learning Outcomes		Land Use Planning
17.2	Human as a Geomorphic Agent		Land Use Planning and Environment Management
17.3	Surface and Groundwater Hydrology	17.5	Summary
	Surface Hydrology	17.6	Terminal Questions
	Groundwater Hydrology	17.7	Answers
17.4	Landuse Planning	17.8	References and Suggested Further Readings

17.1 INTRODUCTION

In the previous Unit 16, you have learnt that, geomorphology utilises various tools to measure landforms, and these tools have evolved over time. In the present, remote sensing and Geographic Information Systems (GIS) play a significant role in measuring and analysing landforms on different scales. However, you have also studied that despite technological advancements, land degradation and desertification remain pressing natural hazards. These hazards are often intensified by the mismanagement of land and water resources by humans, posing risks to both the environment and mankind. Deforestation, overgrazing, and unsustainable agricultural practices are among the contributing factors to these hazards, resulting in the disruption of ecosystems and threatening the well-being of communities. To address these issues, sustainable land and water management practices are crucial, along with initiatives such as reforestation, erosion control, and community education. By implementing effective measures, we can mitigate the impacts of land degradation and desertification, ensuring the preservation of the environment and the well-being of both nature and human populations.

In this Unit, you will learn about the human as a geomorphic agent in section 17.2. In section 17.3, you will learn about surface and groundwater hydrology while in section 17.4, you will learn about the different types of landuse planning.

Expected Learning Outcomes

After completing this Unit, you should be able to:

- explain humans as a geomorphic agent
- define surface and groundwater hydrology and their importance
- describe the different types of land use planning

17.2 HUMAN AS A GEOMORPHIC AGENT

Geomorphic agents are agents of change that contribute to the formation, modification, or destruction of landforms through their actions. Both nature and human beings are acting as geomorphic agents and shaping different landforms of our earth's surface. We all have learned in our previous units that how nature acts as geomorphic agents and makes and transforms landforms like sand dunes, beaches, moraines, plateaus, lakes, etc. But it will be interesting to know that how human beings, through their land use practices, engineering interventions, and resource extraction activities, have emerged as significant geomorphic agents since immemorable which are also shaping the Earth's surface processes and landforms.

Throughout its civilization, human interactions with the environment have led to transformative impacts on landscapes. From deforestation to urbanization, agriculture to mining, human activities have had profound consequences for the natural geomorphic systems. These interactions have altered the balance of physical processes that shape landforms and landscapes.

Human beings have a significant impact on the Earth's surface processes and landforms, acting as geomorphic agents through their activities. Here are some examples of how human actions influence landforms and geomorphic processes:

- **Soil Erosion due to Agriculture:** Intensive agricultural practices, such as improper land management, overgrazing, and extensive tilling, can accelerate soil erosion rates (Montgomery, 2007). The removal of vegetation cover and the disruption of soil structure through plowing leave the land more susceptible to erosion by wind and water, leading to the loss of fertile topsoil and changes in landforms (Boardman & Poesen, 2006).
- **Dam Construction and Reservoirs:** The construction of dams and the creation of reservoirs for hydropower, irrigation, or water supply purposes significantly modify river systems and associated landforms. Dams alter natural flow regimes, trapping sediments, and reducing downstream sediment supply, which can lead to erosion or deposition in certain areas (Williams, 2013). Reservoirs also inundate valleys, altering the shape of river valleys and creating new landforms.
- **Deforestation and Slope Instability:** Clearing forests without appropriate management practices can increase the likelihood of slope instability, such as landslides and debris flows (Crozier, 2010). Forests provide stability to slopes by their root systems and intercepting rainfall, reducing

surface runoff. Deforestation weakens the slopes, leading to increased erosion, soil mass movement, and changes in the landscape.

- **Urbanization and Artificial Drainage:** Urban development involves extensive modification of land surfaces through the construction of buildings, roads, and drainage systems. Impermeable surfaces and artificial drainage networks alter natural hydrological processes, increasing surface runoff and the frequency and magnitude of floods (Arnold & Gibbons, 1996). These changes affect the geomorphology of urban areas and downstream watercourses.
- **Coastal Land Reclamation:** Human activities involve reclaiming land from coastal areas for various purposes, including infrastructure development and urban expansion. Land reclamation alters natural coastal landforms and ecosystems, leading to changes in sediment transport, shoreline dynamics, and coastal erosion (Nicholls & Cazenave, 2010). Coastal land reclamation projects often involve the construction of dikes, breakwaters, and seawalls, which further modify natural coastal processes.
- **Land Use Change:** Human activities such as deforestation for agriculture, urbanization, and infrastructure development lead to significant modifications of landforms. For example, the conversion of forests into agricultural fields alters the natural vegetation cover and affects soil erosion rates (Ellison et al., 2012). Similarly, urbanization involves the clearing of land, construction of buildings, and paving, which can disrupt natural drainage patterns and increase surface runoff (Trimble & Mendel, 1995).
- **Mining and Quarrying:** Extraction of minerals, coal, and other resources through mining and quarrying directly modifies landforms. These activities involve the removal of soil and rock, leading to the creation of excavated pits, waste dumps, and altered topography (Montgomery, 2010). Mining operations can result in changes in drainage patterns, increased erosion, and the creation of landforms such as tailing ponds and spoil heaps (Sengupta, 2007).
- **River Channel Modification:** Humans frequently modify river channels for various purposes, including navigation, flood control, and water supply. Channelization, dredging, and construction of levees and embankments alter natural river flow patterns, affecting sediment transport, erosion, and deposition processes (Rinaldi et al., 2005). For instance, straightening river channels for navigation purposes can lead to increased erosion downstream and the loss of floodplain habitats (Darby et al., 2016).
- **Coastal Modifications:** Human activities along coastlines significantly influence coastal landforms. Construction of coastal infrastructure such as ports, harbors, and seawalls can alter natural sediment transport processes, leading to coastal erosion in some areas and accretion in others (Pethick & Orford, 2014). Beach nourishment, the addition of sand to beaches, is another example of human-induced coastal modification that aims to combat erosion and maintain recreational areas (Dean & Houston, 2016).

From the above examples, it is evident that various human act as geomorphic agents and have significant impacts on landforms and geomorphological processes. These human-induced modifications have far-reaching consequences on the landscape, erosion rates, sediment transport, and the overall geomorphology of any areas.

SAQ I

Give two examples of human as geomorphic agents.

17.3 SURFACE AND GROUNDWATER HYDROLOGY

Before we study surface and groundwater hydrology, we will learn briefly about surface and groundwater and their importance. Surface water is vital for meeting the basic needs of human populations, such as drinking water, sanitation, and hygiene. It is also essential for irrigation, which is the mainstay of agricultural production in many parts of the world, including Asia, Africa, and South America. Additionally, surface water is an important source of hydropower, which is a clean and renewable source of energy. Moreover, surface water is necessary to maintain the health and productivity of aquatic ecosystems, which provide various ecosystem services, including nutrient cycling, water purification, and habitat for aquatic plants and animals.

Whereas, groundwater is also an important source of water for drinking, irrigation, and industry, especially in arid and semi-arid regions, where surface water resources are limited. It is also an essential source of water for maintaining the health of ecosystems, especially wetlands, streams, and lakes, which depend on groundwater for maintaining their water levels and flows. Moreover, groundwater is an important source of thermal energy, which can be harnessed through geothermal energy systems.

Now, we will study about surface and groundwater hydrology. Both surface and groundwater hydrology are two interconnected branches of hydrology that focus on the study of water on and below the Earth's surface. They play a crucial role in understanding and managing water resources, predicting and mitigating floods, and sustaining ecosystems and human activities.

Surface and groundwater hydrology are fundamental components of the broader field of hydrology, which is concerned with the study of water in all its forms, distribution, movement, and interactions with the environment. Surface hydrology and groundwater hydrology specifically focus on water on and below the Earth's surface, respectively.

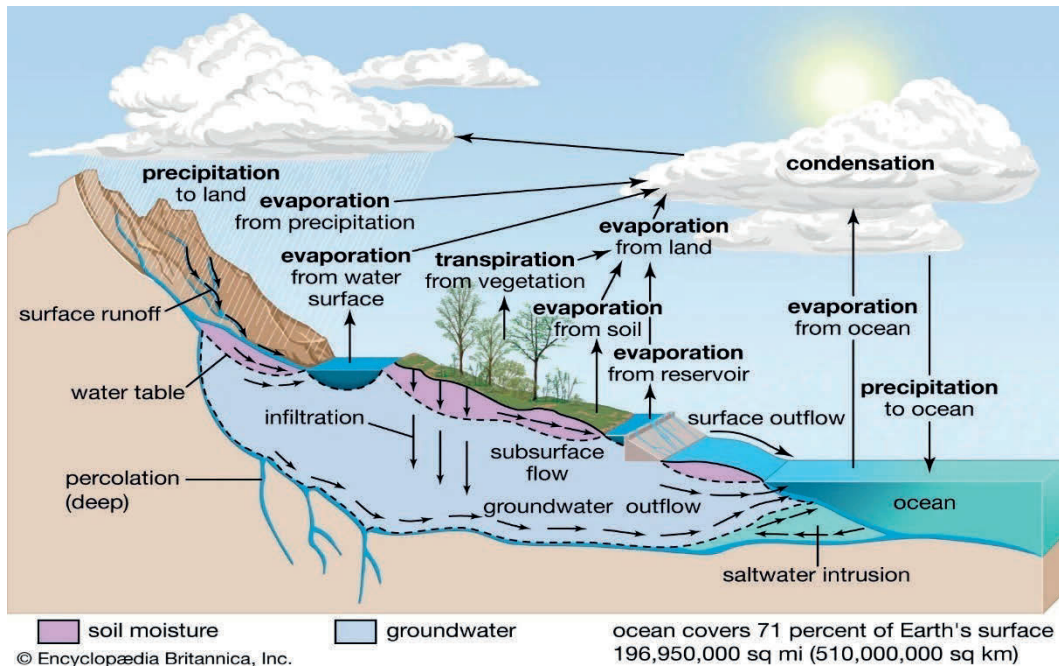


Fig. 17.1: Surface and Groundwater.

(Source: water-hydrologic-cycle-land-surface-atmosphere-ocean.jpg (1600×1160) (britannica.com))

17.3.1 Surface Hydrology

Surface hydrology deals with the study of water movement on the Earth's surface, including the processes of precipitation, evaporation, infiltration, runoff, and stream flow. It involves understanding how water interacts with various elements of the landscape, such as vegetation, soil, and landforms. Surface hydrology plays a crucial role in managing water resources, as it helps in assessing water availability, designing and operating irrigation systems, and predicting and mitigating the impacts of floods and droughts. It also contributes to the understanding of the water cycle, energy balance, and the dynamics of ecosystems. There are many key aspects of surface hydrology which include precipitation, infiltration, runoff, stream flow, floods, etc. which we will discuss below in brief:

- i. **Precipitation:** Precipitation is a crucial aspect of the hydrological cycle, playing a significant role in providing water to the Earth's land surface. It occurs through various mechanisms that can be classified into three main types: convective, cyclonic or frontal, and orographic precipitation.
 - **Convective Precipitation:** Convective precipitation is often associated with localized thunderstorms and occurs when there is rapid vertical motion of air. It typically happens in warm and unstable atmospheric conditions, where the air near the ground becomes heated and rises, forming cumulus clouds. As the air rises, it cools, leading to condensation and the formation of raindrops. Eventually, these raindrops become large enough to overcome the updrafts and fall to the surface as rain.
 - **Cyclonic or Frontal Precipitation:** Cyclonic or frontal precipitation occurs in association with large-scale weather systems, such as low-pressure systems or fronts. It is more widespread and generally occurs over a larger area compared to convective precipitation. In this type of precipitation, warm and moist air masses collide with colder air masses, leading to the

formation of frontal boundaries. As the warm air is forced to rise over the colder air, it cools and condenses, resulting in the formation of clouds and precipitation. The duration and intensity of cyclonic or frontal precipitation depend on the speed and movement of the weather system.

- **Orographic Precipitation:** Orographic precipitation is related to the topography of the land. When moist air encounters a mountain or elevated terrain, it is forced to rise and undergoes adiabatic cooling. As the air cools, its capacity to hold moisture decreases, leading to condensation and precipitation. The side of the mountain that faces the prevailing winds, known as the windward side, experiences more significant amounts of precipitation, while the opposite side, called the leeward side or rain shadow, tends to be drier. This phenomenon is responsible for the formation of lush, rainy areas on the windward side and arid regions on the leeward side of mountains.

In addition to these primary mechanisms, other forms of precipitation include orographic enhancement, where the presence of mountains enhances rainfall on the windward side, and graupel or snow pellets, which occur in freezing temperatures when supercooled water droplets freeze onto ice nuclei.

The amount and distribution of precipitation are influenced by various factors, including atmospheric moisture content, temperature, wind patterns, topography, and global climate patterns such as El Niño and La Niña. Precipitation measurements are vital for understanding regional water resources, agriculture, hydroelectric power generation, and managing water supplies for human and ecological needs.

- ii. **Infiltration:** Infiltration is an essential process in the movement of water within the hydrological cycle. It refers to the entry of precipitation, such as rain or snow, into the soil through its pores and spaces. The mechanism of infiltration involves several factors that influence the rate and extent of water penetration into the soil like soil type, vegetation cover, slope, and initial soil moisture content.

Different soil types have varying characteristics that affect their ability to absorb water, with coarse-textured soils like sandy soils having larger pores and allowing for quick infiltration, while fine-textured soils like clay soils have smaller pores and lower infiltration rates. Additionally, vegetation cover on the soil surface plays a crucial role in infiltration by intercepting and slowing down the movement of precipitation, enabling water to infiltrate more gradually and deeply. Vegetation also enhances soil structure, increases organic matter content, and improves water-holding capacity. Furthermore, the slope or gradient of the land influences infiltration rates, as steep slopes tend to result in faster runoff, while gentle slopes promote better infiltration.

Moreover, the initial moisture content of the soil impacts infiltration, as dry soils have a higher capacity to absorb water, facilitating faster infiltration, whereas saturated or already wet soils may have reduced infiltration rates due to water occupying the soil pores. The rate of infiltration is commonly measured as the amount of water per unit area that enters the soil in a given time, usually expressed in millimeters per hour. Factors such as soil compaction, presence

of impermeable layers, and human activities (e.g., land development, land use changes) can significantly impact infiltration rates.

Meanwhile, the mechanism of infiltration involves three main processes, which are discussed below:

- **Entry:** When precipitation reaches the soil surface, it encounters various obstacles such as vegetation, litter, or rocks. These obstacles can delay or obstruct the direct entry of water into the soil, causing some water to be temporarily held on the surface before infiltration occurs.
- **Vertical Movement:** Once the water enters the soil, it moves vertically downward under the influence of gravity. The water fills the soil pores and continues to move deeper into the soil until it encounters obstacles or reaches the groundwater table.
- **Redistribution:** As water infiltrates the soil, it undergoes redistribution due to differences in soil texture, structure, and water-holding capacity. Water moves from areas of higher moisture content to drier areas, ensuring a more uniform distribution of water within the soil profile.

SAQ 2

List the key mechanism of Precipitation.

iii. Runoff: Runoff is an important process in surface hydrology that occurs when precipitation exceeds the infiltration capacity of the soil or when the ground is already saturated. It refers to the portion of precipitation that does not infiltrate into the soil but instead flows over the land surface, eventually collecting in streams, rivers, lakes, or other water bodies. The mechanism of runoff involves several factors and processes that influence its generation and movement. Let's discuss these in detail:

- **Infiltration Excess:** When precipitation intensity exceeds the soil's infiltration capacity, the excess water cannot infiltrate into the soil fast enough and begins to accumulate on the surface. This leads to the formation of surface runoff. Factors such as soil type, slope, vegetation cover, and antecedent soil moisture conditions influence the infiltration capacity and can affect the onset of runoff.
- **Saturation Excess:** In cases where the soil is already saturated due to prolonged rainfall or high groundwater levels, the additional precipitation cannot infiltrate into the soil and results in immediate surface runoff. Saturation excess runoff commonly occurs in areas with poor drainage or in low-lying regions where water accumulates due to limited vertical infiltration.
- **Overland Flow:** Overland flow is the movement of water across the land surface in response to gravity. It occurs when the rainfall rate exceeds the infiltration capacity, or when the soil is impermeable, such as in urbanized areas with pavement or compacted soils. Overland flow can be sheet flow,

where water spreads out evenly over a plane, or concentrated flow, where water accumulates into channels or depressions.

- **Channelized Flow:** As runoff accumulates and concentrates into natural or man-made channels, it forms channelized flow. These channels can be small streams, creeks, or larger rivers. Channelized flow occurs when the volume of runoff exceeds the storage and infiltration capacity of the land surface. It transports runoff downstream and ultimately discharges into larger water bodies like lakes or oceans.

Factors that influence the generation and movement of runoff include rainfall intensity, duration, and spatial distribution, as well as characteristics of the watershed, such as topography, soil properties, and land cover. Human activities, such as urbanization, deforestation, and land-use changes, can alter surface conditions and significantly impact the runoff process.

iv. Streamflow: Streamflow refers to the movement of water within a defined channel or stream. It is the result of both surface runoff and groundwater discharge into the stream. Streamflow can vary depending on precipitation patterns, land use, geology, and the shape and characteristics of the stream channel. Let's discuss its mechanism in detail:

- **Surface Runoff:** Surface runoff contributes to streamflow when excess precipitation or snowmelt flows over the land surface and enters the stream channel directly. This runoff occurs when the soil becomes saturated, the infiltration capacity is exceeded, or the precipitation intensity exceeds the soil's ability to absorb water. Surface runoff is influenced by factors such as rainfall intensity, duration, and distribution, as well as characteristics of the watershed, such as slope, soil type, vegetation cover, and land use practices.
- **Groundwater Discharge:** Groundwater discharge also contributes to streamflow. It occurs when water from the subsurface, stored in aquifers, emerges into the stream channel through springs or seepage. Groundwater can flow laterally through permeable layers of soil or rock and eventually intersect the stream channel. The amount of groundwater discharge depends on the water table elevation, hydraulic conductivity of the subsurface materials, and the connectivity between aquifers and the stream network.
- **Baseflow:** Baseflow is the portion of streamflow that comes from groundwater discharge and sustains streamflow between rainfall events or periods of low precipitation. It represents the slow and steady contribution of water from aquifers to the stream channel. Baseflow is crucial for maintaining streamflow during dry periods and supports ecosystems that depend on a continuous water supply.
- **Stormflow:** Stormflow is the component of streamflow that occurs in response to precipitation events. It includes both the initial rise in streamflow caused by surface runoff and the subsequent increase due to groundwater discharge. Stormflow can be rapid and intense during storms or heavy rainfall events, leading to temporary increases in streamflow levels.

The mechanism of streamflow is influenced by various factors, including the characteristics of the watershed, such as its size, shape, and slope, which determine the speed and volume of water reaching the stream channel. The geology of the area, including the permeability of the soil and rock layers, affects the movement of water through the subsurface and its contribution to streamflow. Land use practices, such as urbanization or deforestation, can alter surface conditions, increase runoff, and modify the streamflow regime.

v. Floods: Floods occur due to a combination of factors and mechanisms in surface water hydrology. Let's discuss the mechanism of floods in detail:

- **Intense Rainfall:** Heavy or prolonged rainfall is a primary cause of floods. When the precipitation rate exceeds the capacity of the land to absorb or infiltrate the water, the excess water accumulates on the surface, leading to runoff. If the rainfall intensity is high enough, it can overwhelm the drainage capacity of rivers, streams, and stormwater systems, resulting in flood conditions.
- **Rapid Snowmelt:** During periods of rapid snowmelt, large amounts of water are released as snow and ice melt. If the rate of melting exceeds the capacity of the soil to absorb the water, or if the ground is still frozen, the water flows over the surface, contributing to increased runoff and potentially causing floods.
- **River Channel Capacity:** Rivers and streams have a limited capacity to carry water. When the volume of water exceeds the channel's capacity due to intense rainfall, rapid snowmelt, or a combination of both, the water spills over the banks, inundating adjacent areas and causing riverine flooding. The capacity of the river channel is influenced by its size, shape, slope, and the presence of any obstructions.
- **Dam or Levee Failure:** Failures of dams or levees can also lead to flooding. Dam failures can occur due to structural defects, excessive inflows, or overtopping during heavy rainfall events. Similarly, levees can be breached or overtopped, allowing water to flow into areas protected by the levee system, resulting in floodwaters spreading beyond their natural boundaries.
- **Coastal Storm Surges:** Along coastal areas, storm surges caused by tropical cyclones, hurricanes, or severe storms can lead to coastal flooding. These surges occur when strong winds and low atmospheric pressure push seawater towards the coast, causing a rise in sea level. The combination of storm surge, high tides, and intense rainfall can result in significant coastal flooding.

The mechanism of floods is influenced by factors such as topography, land cover, soil conditions, and the hydrological characteristics of the area. Watersheds with steep slopes, limited vegetation cover, or impermeable surfaces are more prone to flash floods, where water accumulates rapidly and flows with great force. Urbanization and changes in land use patterns can also exacerbate flooding by increasing the amount of impervious surfaces and altering natural drainage patterns.

vi. Evapotranspiration: It is a vital process in the hydrological cycle that involves the movement of water from the Earth's surface, including water bodies and vegetation, into the atmosphere in the form of water vapor. It consists of two main components: evaporation and transpiration. Let's discuss the mechanism of evapotranspiration in detail:

- **Evaporation:** Evaporation is the process by which liquid water changes into water vapor and enters the atmosphere. It occurs primarily from the Earth's surface, such as open water bodies like lakes, rivers, and oceans, as well as from wet soil surfaces and the leaves of plants. The driving force behind evaporation is the energy from the sun, which provides the necessary heat to convert liquid water into vapor. Factors influencing evaporation include temperature, humidity, wind speed, and the availability of water.
- **Transpiration:** Transpiration is the process by which water is absorbed by plant roots, transported through the plant, and released into the atmosphere through tiny pores called stomata present on the leaves. It is an essential physiological process for plants, as it allows them to uptake water and nutrients from the soil. Transpiration is influenced by various factors, including plant type, leaf surface area, stomatal conductance, and environmental conditions such as temperature, humidity, and light intensity. It is also influenced by the availability of water in the soil, as plants regulate their transpiration rates to avoid water stress.

The movement of water from the Earth's surface to the atmosphere through evaporation and transpiration is driven by a combination of physical processes. Energy from the sun heats the Earth's surface, causing water molecules to gain enough energy to escape into the atmosphere as water vapor. The water vapor then diffuses through the air, moving from areas of high vapor concentration to lower concentration, until it reaches the atmosphere. In the case of transpiration, water is absorbed by plant roots, transported through the plant's vascular system, and released through stomata on the leaves.

Evapotranspiration plays a vital role in regulating weather patterns and climate by releasing water vapor into the atmosphere through evaporation and transpiration. This moisture contributes to atmospheric moisture content, cloud formation, and precipitation. The release of latent heat during condensation affects atmospheric stability and circulation patterns. Evapotranspiration rates depend on factors like temperature, humidity, solar radiation, wind speed, vegetation type, and water availability. Accurate estimation of evapotranspiration is essential for water balance calculations, irrigation management, and understanding the water cycle's dynamics. It is also crucial for managing water resources, agricultural practices, and predicting the impacts of climate change on water availability.

17.3.2 Groundwater Hydrology

Groundwater hydrology focuses on the study of water that exists beneath the Earth's surface in saturated zones known as aquifers. It involves the understanding of groundwater flow, storage, recharge, and discharge processes. Key aspects of groundwater hydrology include:

- i. **Aquifers:** Aquifers, being underground geological formations, are critical components of the water cycle, and they fulfill various functions that impact water availability and sustainability. Firstly, they act as natural underground reservoirs, storing significant amounts of water over extended periods. This storage capacity enables them to regulate the movement and availability of water, ensuring a continuous supply even during dry periods, and maintaining a balance in the hydrological cycle.

Aquifers receive water through recharge, which occurs when precipitation infiltrates the ground and replenishes the groundwater. Unconfined aquifers, in particular, are recharged as precipitation percolates through the soil and reaches the water table. Confined aquifers, on the other hand, can be recharged from distant areas where precipitation infiltrates and percolates downward. In terms of their contribution to the hydrological cycle, aquifers play a vital role in discharging water. This discharge occurs through natural springs, seepage into streams and lakes, and baseflow to rivers. By sustaining surface water bodies during dry periods and maintaining streamflow, aquifers support ecosystems and provide essential water resources for various human activities. Aquifers also serve as crucial sources of freshwater for human consumption, irrigation, and industrial use. Groundwater extracted from aquifers offers a reliable and sustainable water supply, particularly in regions where surface water may be limited or unreliable. Furthermore, as water moves through aquifers, it undergoes natural filtration processes. These processes effectively filter out impurities and contaminants, resulting in improved water quality. Aquifers act as natural filters, enhancing the quality of groundwater extracted for drinking water supply and other purposes.

There are basically two types of aquifers which are mentioned below:

- **Unconfined (Water Table) Aquifers:** Unconfined aquifers are located near the Earth's surface and are not confined by impermeable layers above them. They interact directly with the water table, which is the upper boundary of the aquifer. Unconfined aquifers receive water from precipitation that infiltrates the ground and recharges the aquifer. They contribute to the hydrological cycle by storing and releasing water through processes like evapotranspiration, groundwater discharge to streams, and groundwater seepage to the surface. Unconfined aquifers play a significant role in sustaining streamflow and maintaining water availability for vegetation and ecosystems.
- **Confined (Artesian) Aquifers:** Confined aquifers are situated between impermeable layers of rock or clay, which confine the water within the aquifer. They are under pressure, and when a well is drilled into a confined aquifer, the water may rise to the surface without pumping, forming an artesian well. Confined aquifers are often recharged in areas distant from where they are tapped, and their water movement is influenced by regional geological structures. They contribute to the hydrological cycle by storing large volumes of water over long periods, releasing water through natural springs, and providing a sustainable source of groundwater for human consumption, agriculture, and ecosystem support.

ii. **Groundwater Recharge:** Groundwater recharge is a fundamental process in the hydrological cycle that involves the replenishment of groundwater reservoirs through the infiltration of water into the subsurface. It plays a crucial role in sustaining groundwater resources and maintaining the balance of the water cycle. Groundwater recharge encompasses several processes and mechanisms which are also mentioned below.

- **Infiltration:** Infiltration refers to the process by which water enters the soil through the surface. When precipitation, such as rain or snow, falls onto the ground, a portion of it is not immediately lost through runoff or evaporation. Instead, it infiltrates the soil, moving downward through the unsaturated zone.
- **Percolation:** Once water enters the soil, it percolates downward under the influence of gravity. Percolation occurs as water moves through the unsaturated zone, also known as the vadose zone. The rate and extent of percolation depend on various factors, including soil properties (e.g., texture, structure, permeability), vegetation cover, land use, and the intensity and duration of precipitation events.
- **Soil Moisture Storage:** As water percolates through the soil, it is temporarily stored in the soil moisture zone. This zone represents the region where water is held between soil particles and is available for plant uptake or further percolation. The soil's capacity to store water depends on its texture, porosity, and initial moisture content.
- **Recharge to the Water Table:** As water continues to percolate downward, it eventually reaches the water table, which marks the upper surface of the saturated zone. The water table represents the boundary between the unsaturated zone above, where air and water fill the pore spaces, and the saturated zone below, where all the pore spaces are filled with water. Recharge occurs when water infiltrates below the water table, increasing the water content in the saturated zone.
- **Natural Recharge:** Natural recharge refers to the direct or indirect replenishment of groundwater by precipitation. Direct natural recharge occurs when rainfall directly infiltrates the ground and reaches the water table. Indirect natural recharge occurs when surface water bodies, such as rivers or lakes, contribute to groundwater replenishment through seepage or infiltration into the subsurface.
- **Lateral Recharge:** Lateral recharge involves the movement of water from one area to another, horizontally along the subsurface. It occurs when water from higher elevations or distant recharge zones flows laterally and infiltrates the ground, recharging groundwater in a different location. Lateral recharge can be important in areas with complex hydrogeological settings or where the topography and geology facilitate the flow of water.
- **Seasonal and Spatial Variability:** Groundwater recharge rates can vary spatially and seasonally. Factors such as climate, precipitation patterns, vegetation cover, soil properties, and land use influence the spatial and temporal distribution of recharge. Areas with high rainfall, low evapotranspiration, and permeable soils tend to have higher recharge

rates compared to arid regions with low precipitation and high evapotranspiration.

- iii. **Groundwater Discharge:** Groundwater discharge is a crucial process in the hydrological cycle that involves the release of groundwater back to the surface or its contribution to the flow of rivers, lakes, wetlands, and springs. It plays a significant role in maintaining the overall water balance and sustaining surface water bodies. The concept of groundwater discharge encompasses several processes and mechanisms.
- **Springs:** Springs are locations where groundwater naturally emerges at the Earth's surface. They occur where the water table intersects the ground surface, resulting in the upward flow of groundwater. Springs can range from small seeps to large, flowing outlets and are often important sources of freshwater. The discharge from springs contributes directly to streamflow and helps sustain aquatic ecosystems.
 - **Seepage into Surface Water Bodies:** Groundwater can discharge into surface water bodies such as rivers, lakes, and wetlands through seepage. This occurs when the water table intersects the bed of a water body, allowing groundwater to flow laterally and emerge into the surface water system. The seepage of groundwater into surface water bodies can provide a continuous supply of water, particularly during dry periods or in regions with intermittent flow.
 - **Baseflow:** Baseflow refers to the portion of streamflow that is sustained by groundwater discharge. It represents the slow and steady contribution of groundwater to rivers and streams, even when there is no direct precipitation or runoff occurring. Baseflow helps maintain streamflow during periods of low rainfall or when surface runoff is limited. It plays a crucial role in supporting aquatic habitats, water supply, and ecosystem functioning.
 - **Wetlands:** Wetlands are areas where the water table is at or near the land surface, resulting in saturated conditions. Groundwater discharge is a vital process in wetlands, as it continuously supplies water to maintain the wetland ecosystem. Wetlands act as natural filters, purifying water as it passes through their soil and vegetation. They also provide habitat for diverse plant and animal species and play a role in flood mitigation and water storage.
 - **Submarine Groundwater Discharge:** Submarine groundwater discharge (SGD) refers to the discharge of groundwater into coastal or marine environments. It occurs where the water table extends below the land-sea interface, allowing groundwater to seep into the ocean or other bodies of water. SGD can contribute significant amounts of freshwater and dissolved substances to coastal areas, influencing water chemistry, nutrient cycling, and coastal ecosystems.
 - **Evapotranspiration:** Although not a direct discharge process, evapotranspiration plays an indirect role in groundwater discharge. Evapotranspiration refers to the combined loss of water through evaporation from the land surface and transpiration from plants. As plants take up water from the soil and release it through their leaves, it eventually

returns to the atmosphere. This water loss from the land surface reduces groundwater levels, potentially leading to increased groundwater flow and discharge in areas where the water table is shallow.

- iv. **Groundwater Flow:** Groundwater flow is a fundamental process in the hydrological cycle that refers to the movement of water within aquifers, underground geological formations that store and transmit water. It plays a crucial role in maintaining the overall water balance, sustaining groundwater availability, and influencing the behavior of surface water bodies. The concept of groundwater flow involves several processes and mechanisms and are discussed below:
- **Porosity and Permeability:** The movement of groundwater is influenced by the characteristics of the aquifer, particularly its porosity and permeability. Porosity refers to the percentage of void spaces or openings in the aquifer material, while permeability refers to the ability of the material to transmit water. Highly porous and permeable materials, such as gravel or sand, allow water to flow more easily, promoting faster groundwater flow. In contrast, less porous and permeable materials, such as clay, hinder groundwater movement.
 - **Hydraulic Gradient:** Groundwater flows from areas of higher hydraulic head (elevation of the water table) to areas of lower hydraulic head. The hydraulic gradient represents the change in hydraulic head over a given distance and determines the direction and rate of groundwater flow. Water naturally moves downhill under the influence of gravity, and the slope of the water table controls the hydraulic gradient.
 - **Darcy's Law:** Darcy's Law describes the flow of groundwater through porous media. It states that the rate of groundwater flow is proportional to the hydraulic gradient and the permeability of the aquifer. According to Darcy's Law, groundwater flow can be quantified using mathematical equations that consider the properties of the aquifer and the driving forces of flow.
 - **Recharge and Discharge:** Groundwater flow is driven by the processes of recharge and discharge. Recharge refers to the addition of water to the aquifer, typically through infiltration of precipitation or surface water. It replenishes the groundwater and sustains its availability. Discharge, on the other hand, represents the outlets or losses of groundwater from the aquifer, including springs, seepage into surface water bodies, and baseflow to rivers. Recharge and discharge are interconnected processes that maintain the movement and balance of groundwater.
 - **Aquifer Heterogeneity:** Aquifers are often characterized by spatial heterogeneity, meaning that the properties of the aquifer (such as porosity and permeability) can vary across space. This heterogeneity influences groundwater flow patterns, creating preferential flow paths and areas of groundwater convergence or divergence. The presence of geologic structures, such as faults or fractures, can also impact groundwater flow, creating conduits or barriers to flow.
 - **Groundwater Velocity and Travel Time:** Groundwater velocity refers to the speed at which groundwater moves through the aquifer. It can vary

depending on factors such as hydraulic conductivity, aquifer properties, and hydraulic gradient. Groundwater flow velocities can range from centimeters to meters per day. Travel time represents the duration it takes for groundwater to travel from one point to another within the aquifer. Travel times can range from weeks to thousands of years, depending on the distance and flow characteristics.

Groundwater hydrology and surface water hydrology are interconnected and essential for understanding and managing water resources effectively. Groundwater hydrology utilizes techniques such as monitoring wells and geophysical methods to assess aquifer characteristics and groundwater availability. This information is crucial for sustainable groundwater management and understanding the interactions between surface water and groundwater systems.

Surface water and groundwater interact through processes like infiltration and baseflow, influencing each other's availability and quality. Integrated water resources management relies on understanding these interactions to ensure sustainable development and protect ecosystems.

SAQ 3

What are the two types of aquifers?

17.4 LANDUSE PLANNING

Land use planning is a crucial tool for effective environmental management. It involves the systematic assessment, allocation, and regulation of land resources to achieve sustainable development goals while minimising negative impacts on the environment. Land use planning provides a structured approach to managing land resources in a way that promotes environmental sustainability. It helps protect natural resources, mitigate environmental impacts, support sustainable development, and adapt to climate change. By considering environmental factors alongside social and economic considerations, land use planning contributes to effective environmental management.

By carefully considering the environmental factors and incorporating them into land use decisions, planners and environmentalists can help ensure the long-term ecological health and resilience of an area. Now you will study some key principles and strategies of land use planning in the below-mentioned sub-sections.

17.4.1 Key Principles and Strategies for Land Use Planning

- **Sustainability:** The principle of sustainability underpins land use planning for environmental management. It emphasizes meeting the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable land use planning seeks to achieve a balance between economic development, social well-being, and

environmental protection, aiming for long-term environmental sustainability.

- **Integration and Coordination:** Effective land use planning requires integration and coordination among various stakeholders, sectors, and levels of government. It involves collaboration between planners, policymakers, environmental experts, community members, and other relevant parties. Integration ensures that environmental considerations are incorporated into land use decisions and that multiple perspectives are taken into account.
- **Conservation and Protection of Natural Resources:** Land use planning should prioritize the conservation and protection of natural resources such as forests, wetlands, rivers, and biodiversity. It identifies areas of ecological significance and establishes measures to safeguard them, including designating protected areas, buffer zones, and wildlife corridors. This principle ensures the sustainable management of natural resources and the preservation of ecosystem services.
- **Environmental Impact Assessment:** Land use planning incorporates environmental impact assessment processes to evaluate the potential environmental effects of proposed development projects or land uses. It involves identifying and assessing potential impacts on air quality, water resources, soil health, ecosystems, and biodiversity. This principle ensures that potential environmental risks and concerns are identified and addressed in the decision-making process.
- **Land-Use Zoning and Designation:** Land use planning involves zoning and designating different areas for specific land uses based on their environmental suitability and capacity. This includes allocating areas for residential development, industrial zones, agricultural lands, protected areas, and green spaces. Zoning helps prevent incompatible land uses, minimize conflicts, and ensure the appropriate use of land resources while considering environmental factors.
- **Sustainable Urban Development:** Land use planning in urban areas focuses on promoting sustainable urban development. It aims to create compact, well-designed, and walkable cities that minimize urban sprawl, reduce the reliance on private vehicles, and optimize the use of infrastructure. This principle includes integrating green spaces, promoting mixed land uses, and prioritizing public transportation and active transportation options.
- **Stakeholder Participation and Public Engagement:** Land use planning for environmental management emphasizes the involvement of stakeholders and the public in decision-making processes. It encourages active participation, consultation, and collaboration with local communities, interest groups, and individuals affected by land use decisions. This principle ensures that diverse perspectives, including environmental concerns, are considered, leading to more inclusive and informed land use plans.
- **Adaptive Management and Monitoring:** Land use planning recognizes the need for adaptive management and continuous monitoring of land use decisions and their environmental impacts. It involves regular monitoring,

evaluation, and review of land use plans to assess their effectiveness and make necessary adjustments. This principle allows for adaptive responses to changing environmental conditions and new knowledge.

These principles provide a framework for land use planning that promotes sustainable and responsible environmental management. By adhering to these principles, land use planners and environmentalists can achieve a balance between development goals and environmental protection, fostering long-term sustainability and resilience.

SAQ 4

List five key elements for land use planning.

17.4.2 Land Use Planning and Environment Management

The role of land use planning in environmental management is crucial as it helps prevent or mitigate the negative impacts of human activities on the environment. Below mentioned are some examples that highlight the importance of land use planning in environmental management:

- **Conservation of Natural Areas:** The establishment of protected areas, such as national parks and wildlife reserves, through land use planning contributes to the conservation of biodiversity and ecosystems (World Commission on Protected Areas, 2021). Protected areas play a vital role in safeguarding plant and animal species, preserving natural habitats, and maintaining ecological processes. Land use planning ensures that specific areas are designated for conservation, minimizing the negative impacts of human activities on biodiversity. Protected areas serve as refuges for rare and endangered species, support ecosystem conservation, and protect key ecological processes. They also provide opportunities for scientific research and monitoring, allowing academic institutions to contribute to understanding natural ecosystems. Additionally, protected areas offer ecosystem services, attract tourists, and create economic opportunities for local communities. Overall, the establishment of protected areas through land use planning is essential for biodiversity conservation and sustainable development.
- **Sustainable Urban Development:** Land use planning promotes compact and mixed-use development, preserving green spaces, reducing sprawl, and promoting sustainable transportation options (United Nations Human Settlements Programme, 2019). It focuses on compact and mixed-use development, preservation of green spaces, reduction of urban sprawl, and promotion of sustainable transportation options. This approach aims to create efficient, livable, and environmentally friendly cities. By integrating green spaces, supporting sustainable transportation modes, and considering the environmental, social, and economic aspects of development, land use planning contributes to the creation of resilient and sustainable urban environments.
- **Floodplain Management:** Land use planning considers flood-prone areas and restricts development in these zones, reducing the risk of flood

damage and protecting human lives and properties (Federal Emergency Management Agency, 2021). By considering the risk of flooding, land use planning helps to protect human lives and properties from potential flood damage. It ensures that land use activities are appropriately located, taking into account the natural floodplain dynamics and the potential impacts of flooding. This proactive approach minimizes the vulnerability of communities to floods, reduces the need for costly post-disaster recovery efforts, and promotes long-term resilience in flood-prone areas.

- **Sustainable Agriculture and Rural Land Use:** Land use planning supports sustainable farming practices, protects agricultural lands from conversion, and promotes the preservation of rural landscapes (Food and Agriculture Organization of the United Nations, 2017). It helps to protect agricultural lands from conversion to non-agricultural uses, ensuring their long-term availability for food production. By designating areas for agricultural activities and implementing zoning regulations, land use planning helps to maintain the viability of farming operations and supports sustainable farming practices. It also promotes the preservation of rural landscapes, including scenic vistas, cultural heritage sites, and ecological corridors. Through strategic planning and collaboration with agricultural stakeholders, land use planning fosters the integration of agricultural activities with environmental conservation, economic development, and community well-being in rural areas.
- **Environmental Impact Assessment:** Land use planning incorporates the assessment of potential environmental impacts of proposed developments or projects through Environmental Impact Assessments (EIAs), helping identify and mitigate adverse effects (International Association for Impact Assessment, 2021). Through the use of EIAs, land use planners can identify and evaluate the potential environmental effects of proposed developments or projects. This includes assessing impacts on air and water quality, biodiversity, ecosystems, cultural heritage, and social well-being. By considering these impacts early in the planning process, land use planning allows for the identification of mitigation measures and the incorporation of sustainable design principles to minimize negative environmental effects. Environmental impact assessment ensures that land use decisions are made in an informed and sustainable manner, balancing development needs with environmental protection and conservation goals. It helps to ensure the long-term sustainability of projects, minimize risks, and promote responsible and environmentally sensitive development practices.
- **Protection of Sensitive Areas:** Land use planning identifies and protects environmentally sensitive areas, such as coastal zones or critical habitats, through regulations and zoning restrictions (Coastal Zone Management Act, 1972). By identifying and designating these areas, land use planners can implement regulations and zoning restrictions to ensure their preservation and minimize potential negative impacts. For example, coastal zone management plans may restrict certain types of development or require setback requirements to protect fragile coastal ecosystems and mitigate the risks of erosion, storm surge, and sea-level rise. Similarly, wetland protection regulations may prohibit or limit activities that could

harm these valuable ecosystems, such as draining or filling wetlands for development purposes. By integrating the protection of sensitive areas into land use planning, we can safeguard biodiversity, maintain ecosystem services, and promote sustainable development practices that balance human needs with environmental conservation. This approach helps to maintain the ecological integrity of these areas and supports the long-term resilience and sustainability of our natural environment.

- **Coastal Zone Management:** Land use planning in coastal areas considers the vulnerability to sea-level rise, storms, and erosion, and applies measures such as setback requirements and coastal adaptation strategies to protect coastal ecosystems and communities (Coastal Zone Management Act, 1972). It employs strategies such as setback requirements and coastal adaptation measures to protect coastal ecosystems and communities. Setback requirements establish minimum distances between development and the shoreline, reducing exposure to erosion and storm damage while preserving natural coastal processes and habitats. Coastal adaptation strategies like beach nourishment and dune restoration enhance coastal resilience. Integrating coastal zone management into land use planning ensures sustainable development practices that balance economic, social, and environmental considerations for the long-term viability of coastal areas.
- **Land Conservation and Restoration:** Land use planning identifies areas for land conservation and restoration, including wetlands, forests, and natural habitats, to safeguard biodiversity, improve ecosystem services, and promote ecological resilience. It ensures the preservation of wetlands, forests, and natural habitats, safeguarding biodiversity and improving ecosystem services. Land use planning also facilitates the restoration of degraded areas, promoting the recovery of ecosystem functions and the re-establishment of native vegetation. By integrating land conservation and restoration into planning processes, a balance can be achieved between human development and the protection of natural landscapes.
- **Renewable Energy Development:** Land use planning designates suitable areas for renewable energy projects, such as wind farms or solar installations, to encourage the transition to clean energy sources while minimizing impacts on sensitive ecosystems and landscapes (National Renewable Energy Laboratory, 2021). Through careful consideration of environmental factors and community needs, land use planning ensures that renewable energy projects are sited in areas that maximize energy generation while minimizing negative impacts on sensitive ecosystems and landscapes. By integrating renewable energy into land use plans, communities can transition to sustainable energy sources and contribute to the reduction of greenhouse gas emissions.
- **Urban Greening and Tree Canopy Enhancement:** Land use planning incorporates urban greening strategies, including the promotion of tree planting and the development of green spaces, to improve air quality, reduce heat island effects, and enhance the overall urban environment (United Nations Human Settlements Programme, 2019). By incorporating strategies like tree planting programs and the development of green spaces, land use planning improves air quality, mitigates the urban heat

island effect, and enhances the overall urban environment. These efforts support ecosystem services, carbon sequestration, and biodiversity conservation, creating healthier and more sustainable cities for residents.

17.5 SUMMARY

In this Unit, you have studied that,

- Human beings, through their land use practices, engineering interventions, and resource extraction activities, have emerged as significant geomorphic agents since immemorial which are also shaping the Earth's surface processes and landforms.
- Groundwater hydrology and surface water hydrology are interconnected and essential for understanding and managing water resources effectively. Ground and surface water interact through processes like infiltration and baseflow, influencing each other's availability and quality. Integrated water resources management relies on understanding these interactions to ensure sustainable development and protect ecosystems.
- Land use planning provides a structured approach to managing land resources in a way that promotes environmental sustainability. It helps protect natural resources, mitigate environmental impacts, support sustainable development, and adapt to climate change. By considering environmental factors alongside social and economic considerations, land use planning contributes to effective environmental management.

17.6 TERMINAL QUESTIONS

1. Explain how humans are acting as geomorphic agent.
2. Discuss the key aspects of surface hydrology.
3. Explain the role of land use planning in environmental management.

17.7 ANSWERS

Self-Assessment Questions (SAQ)

1. (i) Dam Construction and Reservoirs and, (ii) Deforestation for agriculture
2. Convective Precipitation, Cyclonic or Frontal Precipitation, and Orographic Precipitation:
3. Unconfined Aquifers and Confined Aquifers
4. Sustainability, Conservation, and Protection of Natural Resources, Environmental Impact Assessment, Land-Use Zoning and Designation, and Sustainable Urban Development.

Terminal Questions

1. Human beings have a significant impact on the Earth's surface processes and landforms, acting as geomorphic agents through their activities. (Refer to section 17.2).

2. There are many key aspects of surface hydrology which include precipitation, infiltration, runoff, streamflow, floods, etc. (Refer to section 17.3.1).
3. The role of land use planning in environmental management is crucial as it helps prevent or mitigate the negative impacts of human activities on the environment (17.4.2).

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GLOSSARY

Agroforestry	: Planting trees and shrubs alongside crops, which can help to improve soil fertility, reduce soil erosion, and increase the water-holding capacity of the soil.
Alkalisiation	: It is a process of increase in carbonates and bicarbonates in soils with higher pH values.
Baseflow	: It refers to the portion of streamflow that is sustained by groundwater discharge. It represents the slow and steady contribution of groundwater to rivers and streams, even when there is no direct precipitation or runoff occurring.
Darcy's Law	: It describes the flow of groundwater through porous media. It states that the rate of groundwater flow is proportional to the hydraulic gradient and the permeability of the aquifer.
False Colour Composite (FCC)	: An artificially generated colour image in which blue, green, and red colours are assigned to the wavelength regions to which they do not belong in nature.
Flood plain	: A flat surface adjacent to a stream/river composed of unconsolidated fluvial sediments. Normally subject to periodic flooding by parent stream/river.
Geocoded image	: A geocoded image is an image that is associated with a geographical location. A geocoded image can be associated with geographical coordinates such as latitude, longitude, and altitude, or a street address.
Ground Penetrating Radar (GPR)	: It is a geophysical technique that uses radar pulses to image the subsurface of the Earth. GPR can be used to identify buried landforms such as buried valleys or buried channels.
Groundwater Flow	: It is a fundamental process in the hydrological cycle that refers to the movement of water within aquifers, underground geological formations that store and transmit water.
Hydraulic Gradient	: It represents the change in hydraulic head over a given distance and determines the direction and rate of groundwater flow.
Land degradation	: Land degradation generally signifies the temporary or permanent decline in the productive capacity of the land.
LiDAR (Light Detection and Ranging)	: LiDAR is a remote sensing technique that uses laser beams to measure the distance between the Earth's surface and the sensor. It can be used to create highly accurate digital elevation models (DEMs) of landforms.
Morphodynamics	: The land-forming processes presently active on the landscape or those that may become active in the

future.

- Morphometry** : The process of measuring the external shape and dimensions of landforms, living organisms, or other objects.
- Morphostructure** : A geological feature of the landscape typically caused by tectonic activity and climate.
- Rectilinear Slope** : The straight slope profile formed below the cliff or free face is known as a rectilinear slope of constant slope, as the slope angle of this profile remains almost constant.
- Resolution** : The resolution of an image refers to the potential detail provided by the imagery. In remote sensing, we refer to three types of resolution: spatial, spectral, and temporal.
- Risk** : It is the combination of the probability of an event and its negative consequences.
- Runoff** : Runoff is an important process in surface hydrology that occurs when precipitation exceeds the infiltration capacity of the soil or when the ground is already saturated
- Stereoscopic coverage** : The three-dimensional view that results when two overlapping photos (called a stereo pair), are viewed using a stereoscope. Each photograph of the stereo pair provides a slightly different view of the same area, which the brain combines and interprets as a 3-D view.
- Submarine Groundwater Discharge** : It refers to the discharge of groundwater into coastal or marine environments.
- Surface hydrology** : It deals with the study of water movement on the Earth's surface, including the processes of precipitation, evaporation, infiltration, runoff, and streamflow.
- Thematic map** : A thematic map is also called a special-purpose, single-topic, or statistical map. A thematic map focuses on the spatial variability of a specific distribution or theme (such as population density or average annual income).
- Topographic maps** : A topographic map or topographic sheet is a type of map characterized by large-scale detail and quantitative representation of relief features, usually using contour lines (connecting points of equal elevation), but historically using a variety of methods.
- Universal Soil Loss Equation (USLE)** : Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system, and management practices.

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