PREFACE

In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. *core, generic, discipline specific general elective, ability and skill enhancement* for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility of choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the University has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A".

UGC Open and Distance Learning (ODL) Regulations, 2017 have mandated compliance with CBCS for U. G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Bachelors Degree Programme (BDP) level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme.

Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English/Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs.

I wish the venture a grand success.

Professor (Dr.) Subha Sankar Sarkar

Vice-Chancellor

Netaji Subhas Open University
Under Graduate Degree Programme
Choice Based Credit System (CBCS)
Subject : UG Honours in Geography (HGR)
Course : HYDROLOGY AND OCEANOGRAPHY
Course Code : CC-GR-09

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Notification

UG. Geography
(HGR)

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Honours in Geography (HGR)

Course Code : CC–GR-09

Course : HYDROLOGY AND OCEANOGRAPHY

Module - 1 : Hydrology

Module - 2 : Oceanography

Module 1

Hydrology

Introduction

Etymologically Hydrology is the science that relates to water. It is the scientific study of the movement, distribution and management of water on the earth including the water resource as a whole, its cycle and environmental watershed sustainability. By using various analytical methods and scientific techniques, the hydrologists collect and analyse data to help solve water related problems such as environmental preservation, natural disasters and water management.

Objectives

- to have a comprehensive idea of the study of Hydrology and the Global Hydrological Cycle
- to gather knowledge on the process of Runoff and its cycle
- to study the processes of water infiltration and evapo-transpiration
- to examine why a drainage basin is known as a hydrological unit
- to assume the principles of water harvesting and watershed management
- to assess the facts relating to the groundwater occurrence, its storage and the controlling factors

Unit - 1 ❑ Systems Approach in Hydrology. Global Hydrological Cycle : Its Physical and Biological Role

Structure

1.1 Introduction

Hydrology is an very significant branch of physical geography, that is studied in under-graduate and post-graduate course of geography discipline. In broad sense, hydrology relates to all the waters of the earth, but for practical reasons it has been limited in several respects. We all know that certainly the greatest reservoir of water on the earth is the ocean. The science relating to the ocean is however, called oceanography, and is not generally included in hydrology except as to the relations of the ocean to the waters of the land. The study of the water in the interstices of the rocks, even the water at comparatively great depths below the land surface, belongs to the science of hydrology. From time to time some of this internal water reaches the surface or the rock interstices near the surface, it also at one of the fringes of the science of hydrology. In this unit, the learners came to know about all these elaborately.

1.2 Objectives

- To know the system approach in hydrology.
- To know the components of Hydrological Cycle.
- To know the pattern of the Hydrological Cycle.
- To know the physical and biological role of Hydrological Cycle.

1.3 Concept

The main concept in the science of hydrology is the so called hydrologic cycle, a convenient term to describe the circulation of the water from the sea, through the atmosphere, to the land; and thence with numerous process of exchanges, back to there by overland and subterranean routes, and in part, by the way of the atmosphere. Also there are many additional processes of the water that is returned to the atmosphere without reaching the sea.

The study of hydrology is especially concerned with the second phase of this cycle, that is, with the water in its course from the time it is precipitated upon the land until it discharged into the sea or returned to the atmosphere. It involves the measurement of the quantities and rates of movement of water at all times and at every stage of its course. Rain and snow gauging helps determine both the quantities and rates of rainfall and snowfall in all parts of the earth; snow surveying to determine the quantities of water stored as snow on the surface and the rates of its accumulation and disappearance; observations of the advance and retreat of glaciers and surveys the glaciers to determine the quantities of water that they contain and their rates of gain or loss; the gauging of streams, both large and small, to obtain records of their flow at many points and during long periods. It measures quantities of water lost by evaporation and the rates of loss from the lakes, ponds, swamps and streams, from the land surface and from the soil, and the quantities lost by transpiration from the leaves of growing plants. Hydrology is concerned with the development of accurate and acceptable methods of making these measurements of diverse kinds, and with the accumulation and compilation of the great mass of quantitative data.

1.4 Kinds of water included in the study of Hydrology

In its broadest sense, hydrology relates to all the waters of the earth, but for practical reasons it has been limited in several respects. Certainly the greatest reservoir of water on the earth is the ocean. The science relating to the ocean is however, called oceanography, and is not generally included in hydrology except as to the relations of the ocean to the waters of the land

The study of the water in the interstices of the rocks, even the water at comparatively great depths below the land surface, belongs to the science of hydrology. From time to time some of this internal water reaches the surface or the rock interstices near the surface, it also at one of the fringes of the science of hydrology. A small but very active and important part of water of the earth occurs in the atmosphere. Hydrology deals entirely with the water of atmospheric origin. Hence it is concerned with the geographic distribution of the quantity of water precipitated on each place. It is concerned with the source of the atmospheric water, whether from the sea or from the land with movements from the points of origin to the points of precipitation. It is also concerned with the return of the water to the atmosphere.

1.5 Global Hydrological Cycle

Elements of Hydrological Cycle : The elements that influence hydrological cycle are: (1) Evaporation, (2) Condensation, (3) Precipitation, (4) Interception, (5) Absorption, (6) Evapo-transpiration, (7) Infiltration, (8) Capillary Action, (9) Ground Water, (10) Soil-water, and (11) Surface Water.

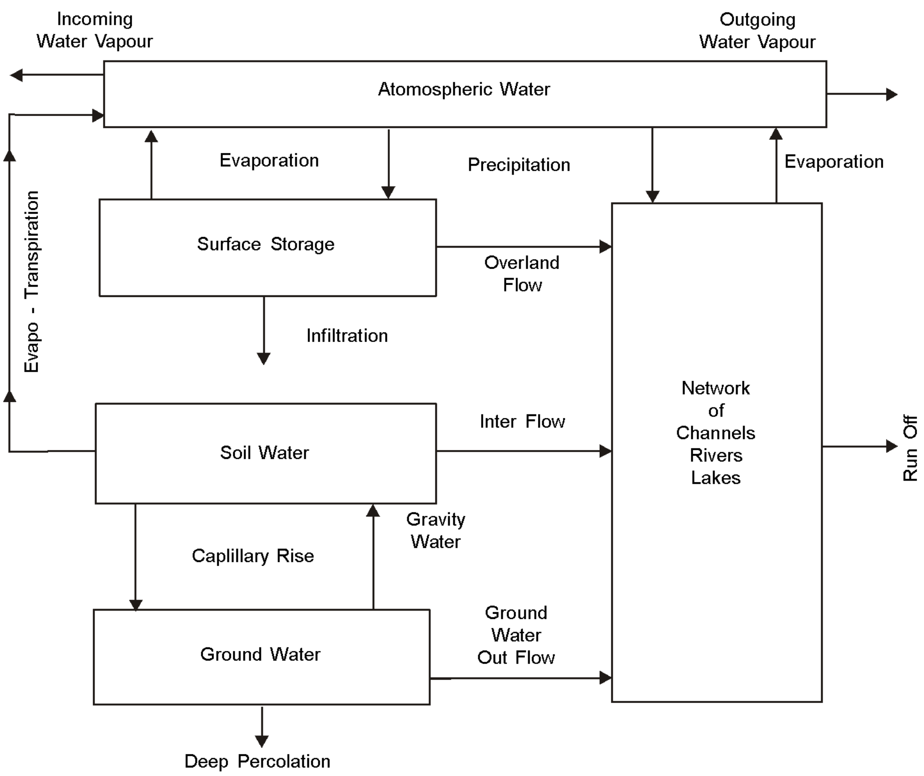

Fig. 1 : Elements of hydrological cycle

(1) Evaporation : Hydrological cycle begins with evaporation. The water vapour is considered as the reservoir of hydrological cycle. By the rays of the sun the waters of the ocean, rivers, canals etc. evaporate and it moves into the atmosphere. The process by which water evaporates is called evaporation. The water-vapours are lighter than all other elements and so they can rise above easily and speedily, and then, they get cool, condensed and create the sprays of water. At present, with the rise of heat in the atmosphere the amount of evaporation is getting increased.

(2) Condensation : The water vapour rises above and gets condensed by adiabatic cooling turning ultimately into drops of water or ice. This process is known as condensation. Again the amount of the water vapour in the atmosphere and the warmth of the atmosphere are closely related with each other. The Importance of Hydrological Cycle on Earth down in the form of rain that means this time floating particles of vapour get bigger and assume the form of rain and it is quite impossible for the atmosphere to carry them. Thus they fall down on earth as rain-drops.

(3) Precipitation : When the condensed water-vapour of the atmosphere turns hard or liquid, and falls on the ground by gravitation, it is called precipitation. The water-vapour of the atmosphere, fog or frost does not belong to precipitation. The rainwater, ice-fall and hail-storm do certainly belong to precipitation.

(4) Interception : At the time of rain, the whole amount of water does not reach the earth directly, because of the fact that the vegetation world, atmosphere and the sun-rays evaporate some amount of rain. When it rains, it is obstructed by a number of things. This is called interception, by which though some amount of water gets evaporated, the rest amount flows over the surface of the earth and augments the volume of external water level.

(5) Absorption : Some amount of rain-water enters underground and is absorbed and make s the soil wet, and it is called the soil moisture. This process sometimes fails to wet the earth completely. Often the water level underground rises and wets the soil and as a result beyond the monsoon period, the soil is found wet in drier seasons as well.

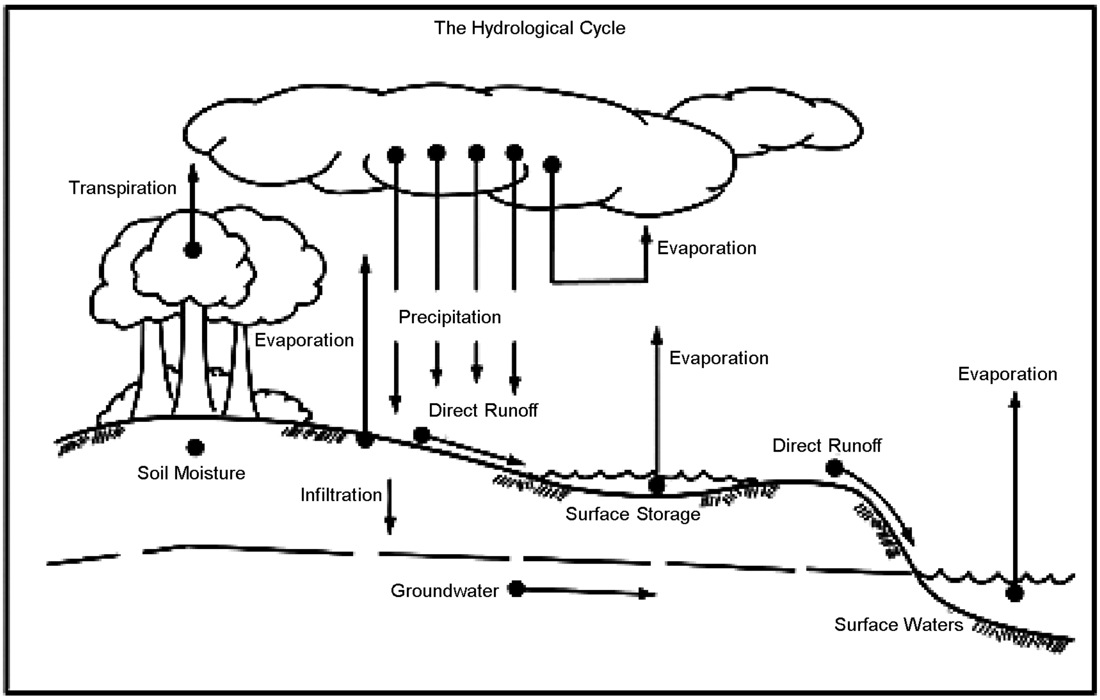

Fig. 2 : Hydrological cycle

(6) **Evapo-transpiration :** Plants suck salty mineral water from the earth through their roots. After Carbon assimilation, when the extra-water is emitted through the pores of the leaves, it is called evapo-transpiration. This vapour supplies additional vapour to the atmosphere and increases the moisture of it. So in the regions blanketed with trees and bushes, it rains more heavily than in other regions.

(7) **Infiltration :** In some regions of the world, the water flowing over the earth and the ice-born water control the collection of water underground. The process through which meteoric water, by capillary strength, enters underground is regarded as infiltration. The infiltration of water underground depends on natural characteristics. Variation occurs in the entrance of water into the deeper part of stones, the blowing of wind underground, the amount of rain, the change of seasons and the nature of the plants etc. These directly or indirectly control the amount of water deposited on the surface of the earth.

(8) **Capillary Action :** The rain water enters into the ground by leaching process. The moisture of the earth and the water underground, both increase by degrees. When the surface of the earth becomes dry by the rays of the sun, the water underground rises above through the pores of the soil and returns to the atmosphere in the form of water vapour. This process is called capillary action. In the Hydrological Cycle, thus supplies water-vapours to the atmosphere and helps in the process of condensation.

(9) **Ground Water :** The water collected upon the impassable layers of the rocks underground is called ground water. This ground water is formed out of the entrance of water inside the ground. Infiltration of water increases during the heavy rains and the water-level on the earth's surface rises. While in dry seasons, it decreases and the water level goes downwards. The number of springs or fountains and the volume of the water are controlled by the upward rise and down-ward descent When the surface of the ground water remains above the surface of the river water, the supply of water continues in the river bed and thus the river water increases. So during the dry seasons, the flow of ground water helps in maintaining the volume of river water. The flow of ground water takes place slowly and pass through rivers, ultimately falls into the sea. In the Hydrological Cycle, the ground water plays a vital role.

(10) **Soil-water :** When the rain-water mixes with the particles of dust and the soil gets wet through capillary action, the water of the earth is formed. The main source of the soil water is the rain. Some amount of this rain-water is

laid down in the ocean as it flows over the surface of the earth; some amount gets evaporated, and the rest enters underground through percolation.

(11) Surface Water : When the rain water and other waters flow in the form of the stream of water, it is called run-off water on the surface of the ground. Rivers, canals, lakes, seas, oceans etc. are the reservoirs of this surface water. Ninety seven percent (97%) of the total amount of water remains on the ground surface and the rest three percent (3%) is present in the other elements of the earth.

The oceans (mean depth : 3.8 km and covering 71% of the earth's surface) hold 97% of all the earth's water. 75% of the total fresh water is locked up in glaciers and ice-sheets, while almost all the remainder is ground water; the atmosphere has a mere 0.035%. The circulation of water from ocean to atmosphere back to land and ocean, is known as the Hydrological Cycle. By heat from the sun water is evaporated from the surface of the land and ocean. In vapour form this water is carried in the atmosphere, later it is precipitated as rain or snow. The precipitated water, not taken in by the soil, runs off the surface and enters directly into the network or surface channels. Some water which infiltrates into the ground surface moves only down to a short depth as ground water to reappear as stream-flow. Some infiltrated water may be stored as ground water.

This exchange of water involved in the various stages of the hydrological cycle is :

Evaporation → Moisture transport → Condensation → Precipitation → Run off

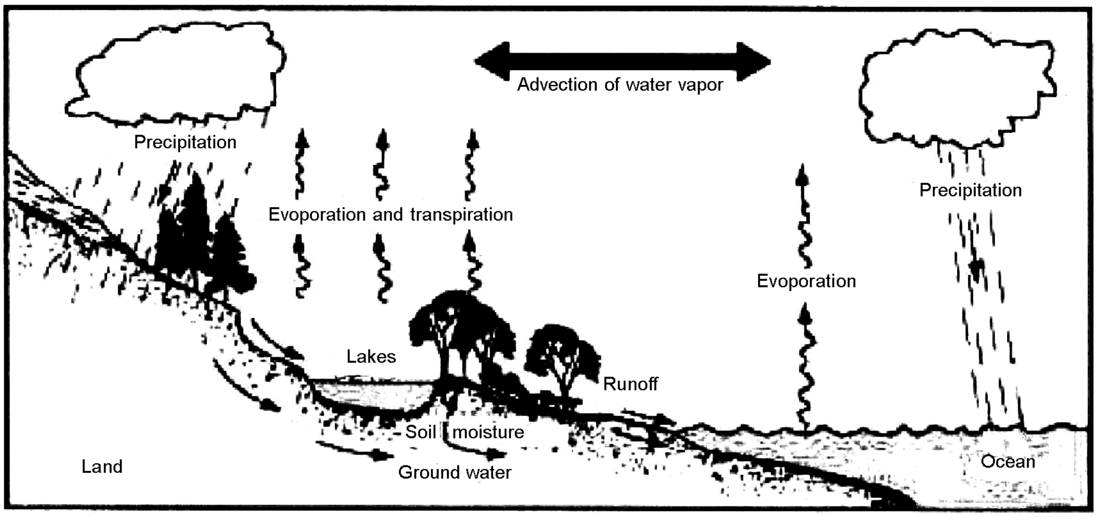

Fig. 3 : Hydrological cycle showing major stores and flow

The seasonal variation in global detention is matched by an inverse pattern of storage in the oceans. In October the seas are estimated to hold 7.5×10^{18} cm^3 more water than in March, although this is equivalent only to a sea-level change of 1 – 2 cm.

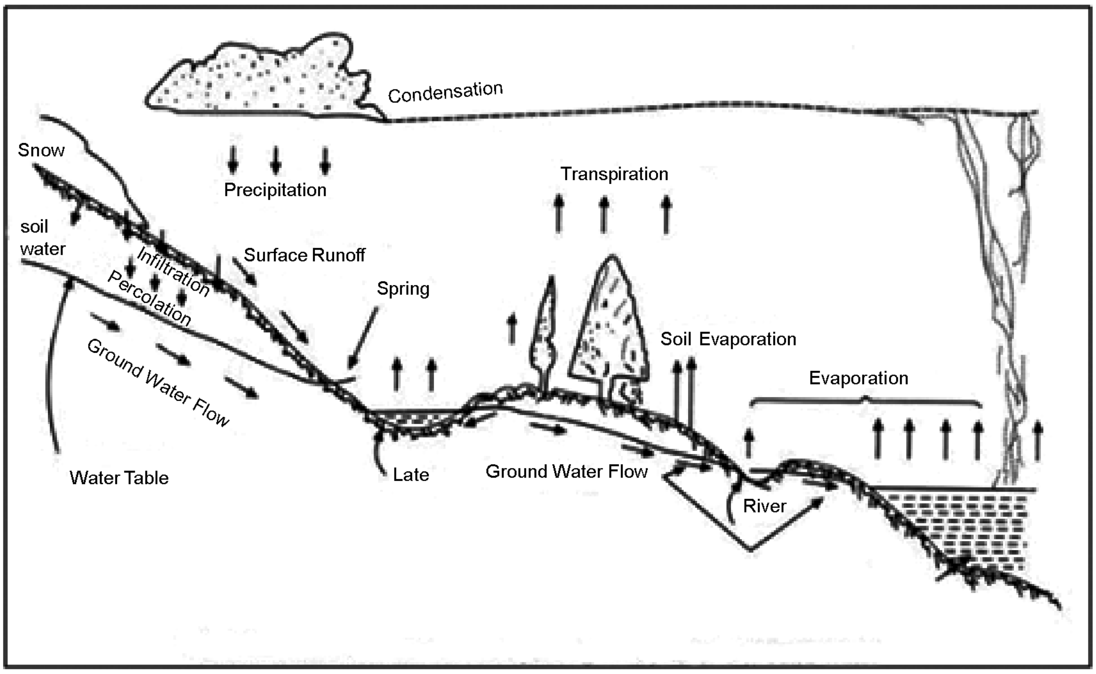

Fig. 4 : Main features of the hydrological cycle and ground water

Ground water is a stable component of the hydrological cycle. Most ground water represents precipitation which has percolated through the soil layers into the zone of saturation where all interstices are water-filled. Water of this origin is termed meteoric water. Minor sources of water are located in the earth's crust; they are connate water, representing water trapped during the formation of sedimentary rocks.

Global Water Balance :

The Global Water Balance as proposed by Budyko *et. al.* of Soviet Union is given in the tables below :

Table 1 : Water balance of the oceans (cm/year)

Oceans	Precipitation	Runoff from the adjacent lands	Evaporation	Water exchange
Pacific Ocean	121	6	114	13
Atlantic Ocean	78	20	104	– 6
Indian Ocean	108	7	131	– 30
Arctic Ocean	24	23	12	35

Table 2 : Water balance of the continents (cm/year)

Continents	Precipitation	Evaporation	Runoff
Asia	61	39	22
Africa	67	51	16
North America	67	40	27
South America	135	86	49
Europe	60	36	24
Australia	47	41	6

Table 3 : Global water balance (cm/year)

Areas	Precipitation	Evaporation	Runoff
Oceans	112	125	– 13
Continents	72	41	31
Entire Earth	100	100	0

1.6 Importance of Hydrological Cycle : Its physical and biological role

Hydrological cycle is performed in two main ways : (1) Physical role and (2) Biological role.

1. Physical Role :

Discharge and recharge of waters : A formidable amount of water through rivers and canals or through the evaporation on the ground surface and through carbon synthesis is emitted.

(i) Most of waters return to the seas in the form of surface water and the rest gets evaporated and driven by air returns to the ocean. This process is known as 'Discharge'. If this discharge of water had happened only on one way, the waters of canals and rivers, along with the ground water, would have dried up. As a result, the plant world would have been extinct and the land would have turned into a desert, and the vast expanse of the land would have been inundated with the waters of the sea. But in reality it never happens. The waters of the seas evaporate and rise up and pushed towards the land driven by the wind. Then through condensation, fall in the form of drops to the ground. With this the rivers and other troughs become full of water and the ground water increases. This is called recharge. If there were no chance of evaporation, the land would have been flooded gradually. But, as the ratio of discharge and the recharge is almost proportional, there is hardly any possibility of inundation or the aridity of the land. Thus, the discharge and the recharge through mutual exchange of waters maintain the balance of the material world.

(ii) ***Transfer of water in between places in land*** : May the amount of evaporation be less or more in some places on the surface of the land, the water vapour is transferred by the wind. It may happen that where there is more evaporation, the precipitation is less and where there is less evaporation, the precipitation is more. The importance of Hydrological Cycle on the earth is that if there is no arrival of water-vapours from the seas, there will be no rain. Again because of the dry climate of the low river beds on account of their long journey, and want of sufficient rainfall, the deficit of waters is compensated by rainfall, snow-fall and ground water. Thus with the transfer of water and water-vapour, the role of Hydrological Cycle is efficiently come into action.

(iii) ***Role of Hydrological Cycle in landscape evolution*** : The Hydrological cycle plays the principal role in the changes that take place in the world. Rivers are responsible for causing the change of the ground surface. The surface of the land is influenced by ground water and the role of Hydrological cycle is very important in this as well as in the change of the underground for if there were no recharge, there would have been no ground water.

2. Biological Role

The Biological role in the Hydrological Cycle in preserving the material world is very important. This may happen in many ways :

(i) ***Water-supply to the living world :*** The other name of water is life as life condition first appeared in the water (in the seas, over 80 crores years ago). For want of water physical world is affected and so life is not possible without water. The ground water (tube wells and wells) and the sweet water of the rivers and lakes are the sources of drinking water

(ii) ***Growth of Plant Kingdom :*** No growth or birth of plants is possible without water. The excessive amount of water creates wood-land in the moist areas. Even in dry climate, beside the river-beds or where there is the existence of ground water in the neighbourhood oasis is created. Plants are the refuge of the animal world. Plants inhale the water-vapours through carbon synthesis and add water vapour to the atmosphere and rain takes place.

(iii) ***Cultivation :*** By Hydrological process, the soil gets wet, irrigation works flourish and as a result crops grow in normal process.

(iv) ***Maintaining Aquatic Eco-system :*** It is possible to maintain aquatic ecosystem on the land on account of the supply of water in the hydrological cycle. Fishes, snakes, frogs, crocodiles, and other aquatic animals and water-plants like marshes, grasses, water lotuses etc. constitute aquatic eco-system.

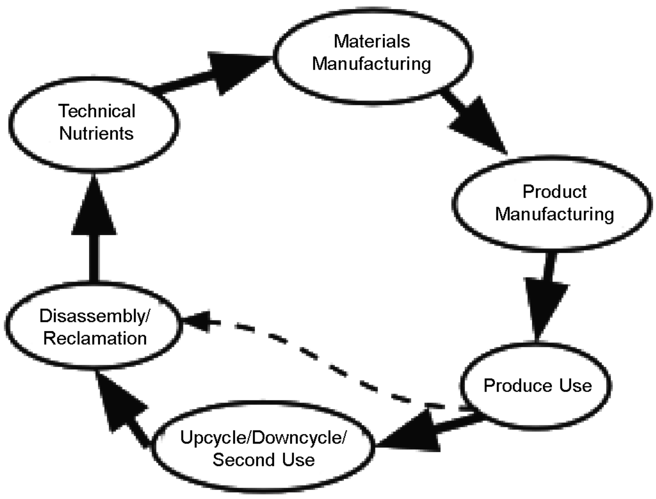

Fig. 5 : Bilogical cycle

(v) ***Growth of civilisation and conservation :*** No animal or plant can live without water. Because of the convenience offered by water in the river beds, the civilization of mankind centring round cultivation has become possible in the past. In recent times, the techniques of cultivation has been modernised, industries and technology have developed. As long as the advantage of hydrological cycle is available, human civilization will continue to progress. It is presumed that interruption in the Hydrological cycle and advent of another ice-age, a large area of the world will be engulfed by the ice sheets and glaciers. Most of the rivers will remain frozen. Evaporation in the seas will be reduced on account of the decrease of temperature. The water collected within the rock strata or in the dust will become frozen and, as a result, the flow of ground water will be seriously hampered. The discharge and recharge of water will be obstructed. The last ice-age (Pleistocene) appeared on the earth about 26 lakhs of years ago and terminated at about 18,000 years ago. With the reappearance of another ice age both animals and plants on land and water will become extinct on account of excessive cold condition on the land surface and in the atmosphere. Crops will not grow for the want of water and helpful temperature condition in the atmosphere. Human civilization will be at stake for want of food. Only those vegetables, crops animals who can sustain millions of years by adjusting to this adverse condition, will be able to carry on the flow of life up to the next warmer age, when the Hydrological Cycle will reappear.

1.7 Implication of global water

Water is a very important natural wealth that sustains life. Pure and less salty water is commonly used.

Human use of water : Water is principally used in two cases : (1) it is used as a medium carrying, and (2) it is used in the system of transfer from one state of existence to another. Moreover, uses of water take place directly or indirectly. As for example :

(i) in domestic use, water is amply used in cooking and washing clothes etc.,

(ii) Water is used plentifully in agricultural works. Agriculture depends principally on climate. Where there is the scarcity of water, the deficit is compensated by some other artificial process,

(iii) Water used in Industry : Industrial places need a plenty of water. The instruments and Tools used in industry need a lot of water for cooling. Moreover, the dwellings erected centring round the industry need water plentifully for their use,

(iv) Hydel Power : The most principal use of water can be seen in its production of electricity. It is gradually increasing in most of the developing countries;

(v) Water is used as the medium of conduction or transport;

(vi) The recreational use of water deserves special mention. In many places in the world pleasure-trip in a boat and water-sports are rampant. Water is used as a dwelling place of fishes;

(vii) Water as a wild life habitat. Not only man, but also for other animals need water to eke out their living. The pastures on which water is plentifully available can make wild animals drink water in plenty.

1.8 Summary and Conclusion

Water is life and hydrology is the study of water. No animal or plant can live without water. Moreover, Water as a wild life habitat. Not only man, but also for other animals need water to eke out their living. The study of this science is very much essential to mange this unique resource scientifically and as in recent times the techniques of cultivation has been modernised, industries and technology have developed, we need to learn the importance of water in every aspect of life. As long as the advantage of hydrological cycle is available, human civilization will continue to progress.

1.9 Key words

System approach, Hydrological Cycle, physical and biological role

1.10 Model Questions

Short Answer type :

1. What is a system approach in hydrology ?
2. What are the physical role of Hydrological Cycle ?
3. State the biological role of Hydrological Cycle.
4. What are the implications of water ?

Long Answer type :

1. Give on account about the Global Hydrological Cycle.
2. Describe the conponents of a Hydrological Cycle.
3. Discuss the physical and biological role of a Hydrological Cycle.
4. Discuss the system approach and the core concept of Hydrological studies.
5. Enumerate the Global Hydrological Cycle and discuss its physical and biological roles.

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Unit - 2 ❑ Run off : Controlling Factors and Run off Cycle

Structure

2.1 Introduction

This unit is going to discuss theconcept of runoff. We know that the discharge of water over the surface of the ground is known as surface runoff. The water flow over the ground surface until it reaches more permeable soil, or continue down slope as threads of water which may gradully merge until a defined channel is the runoff. Runoff cycle is the interaction between precipitation and surface runoff varies according to time and geographical environment. The are several factors that control the runoff. In this unit all these will be discussed thoroughly.

2.2 Objectives

- To know the concept Runoff.
- To know the factors controlling Runoff.
- To know about surface runoff.
- To know the Runoff cycle.

2.3 Run off

Water which cannot infiltrate may flow over the ground surface until it reaches more permeable soil, where it can infiltrate, or continue down slope as threads of water which may gradul1y merge until a defined channel is reached or formed. This is known as ***run off*** or ***surface run off***.

2.4 Factors affecting surface run off

Discharge of water over the surface of the ground is known as surface run off. Surface run off as a normal system of hydrology, exercise control over the basin hydrological cycle. The important factors influencing surface run off are lithology, structure slope, sunshine, rainfall, snowfall, snow-melt water, forest and evapo-transpiration.

(1) ***Lithology and surface run off* :** Characteristics of the lithological setting has a significant control upon the surface run off. Rocks may be of various types: hard or soil, pervious or impervious, porous or nonporous. Upon hard and impervious rock (granite, basalt) Floors surface flow becomes maximum under the given amount of water discharge, whereas upon porous rocks (sandstone, shale) a part of water enter in to the pore spaces reducing the rate of surface run off. Again upon pervious and soluble rocks (limestone) discharged water rapidly enters into the cavities through dolins or sinkholes thereby almost suspending the surface run off.

(2) ***Structure and surface run off* :** Geological structures also have a certain impact upon the surface run off. Upon horizontally bedded homogeneous rock structure surface run off is greater than that upon vertically inclined rock structure.

(3) ***Slope and surface run off* :** Velocity of surface run off increases with the increase in slope gradient run off is possible upon the slope as low as 1° and can be catastrophic upon slope gradient exceeding 20° provided the volume of water excessive.

(4) ***Sunshine and run off* :** Rate of evaporation is a decisive factor controlling run off Normally under strong sunshine the rate of evaporation is high and velocity of run off is checked considerably. In the tropics evaporation under strong sunshine is great hence in the humid tropical areas very high degree of surface run off is observed. On the other hand in the higher latitudes the intensity of sunshine is reduced rate of run off also comes down.

(5) ***Rainfall and surface run off*** **:** The supply of water received through rainfall primarily decides the rate and strength of surface run off. Thus the regions of high annual rainfall exhibits the highest the highest rate of surface run off.

(6) ***Snowfall and surface run off*** **:** Snowfall often inhibits both seepage and surface run off as the accumulated snow stand as a barrier to the discharge of water overland. Hence the humid regions under cold climate have a large degree of seasonal variation in surface run off. During cold season of the year when snow fall occurs run off becomes markedly restricted.

(7) ***Snow melt and surface run off*** **:** In cold climate regions where seasonal snow melting occurs a large degree of variation hi surface run off is exhibited. Excessive amount of snow may be accumulated during winter and on the following spring as the snow starts melting rapidly supply of water enhance surface run off particularly upon the sloping grounds.

(8) ***Forest and surface run off*** **:** Natural vegetation has a certain influence upon the run off. It is usually found in detailed studies that interception losses are greater beneath evergreen than beneath deciduous trees. Plants consequently have a major effect upon the supply of water to the soil and upon total run off into streams during short duration storms, but once the vegetation surfaces are saturated interception gets limited and the influence on runoff is greatly reduced.

(9) ***Evapo-transpiration and run off*** **:** The rate of evapo-transpiration decisively controls surface run off. Under dry climatic condition where the rate of evapo-transpiration is exceedingly high the possibility of surface run off is reduced accordingly.

2.5 Run off Cycle

When rain water falls on the ground surface, may it be saturated or impervious ground, it begins to flow overland downhill. During a heavy rain it can be noticed that small rivulets of water flowing downhill. Water will flow along channels as it moves into larger creeks, streams, and rivers. This assumption gives a graphic example of how surface run off enters a small creek. The run off in this case is flowing over the bare ground surface and is depositing sediment into the river. The runoff entering this creek is beginning its journey back to the ocean.

As with all aspects of the water cycle, the interaction between precipitation and surface run off varies according to time and geographical environment. Surface runoff is affected by meteorological factors, geology and topography of the land. Only about a third of the precipitation that falls over land runs off into streams and rivers and is returned to the oceans. The other two-thirds get evaporated, transpired or infiltrates to form groundwater. Surface run off can also be diverted by humans for their own uses.

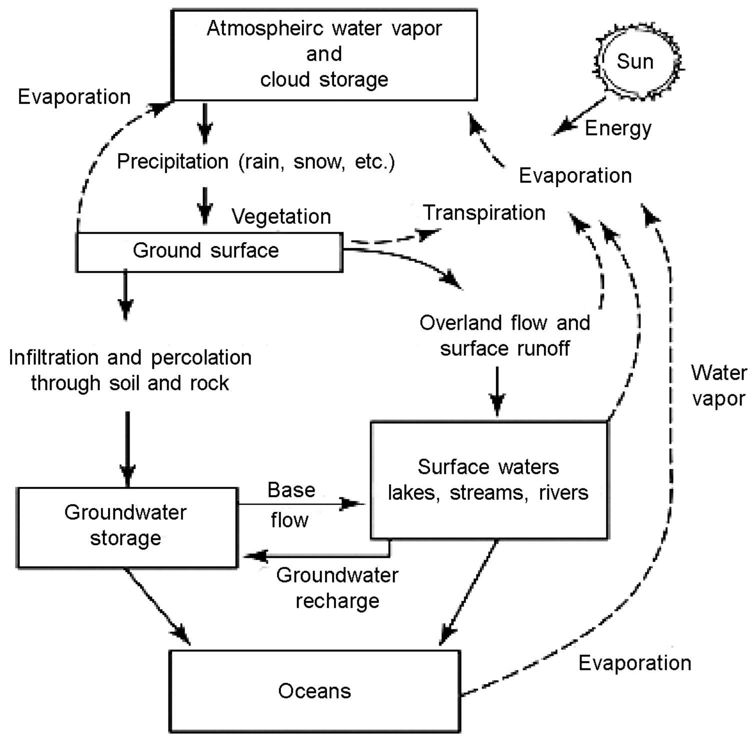

Fig. 6 : Scheme diagram of the natural hydrological cycle. The constant circulation of water is powered by energy from the sun and by gravity

2.6 Summary and Conclusion

The runoff cycle is important to maintain the global hydrological balances. The factors controlling the runoff are also able to control the infiltration which have a strog impact on ground water recharge and discharge. Therefore knowledge of this unit enrich the learners about hydrological cycle.

2.7 Key words

Runoff, surface runoff, Runoff cycle

2.8 Model Questions

Short Answer type :

1. What is Runoff cycle ?
2. What is Runoff ?

Long Answer type :

1. Under what conditions runoff takes place ? Examine the process of Runoff Cycle.
2. Explain the heat budget of the earth.

2.9 References

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Unit - 3 ❑ Infiltration and Evapo-Transpiration

Structure

3.1 Introduction

The study of infiltration and evapo-transpiration are very crucial in hydrology and the learners are came to know its various matter from this unit. Infiltration is very significant in ground ater recharge. It is the process by which water on the ground surface enters the soil. There are several factors that controls the infiltration. Evapo-transpiration is the sum total of evaporation and plant transpiration from the land and ocean surfaces to the atmosphere.

3.2 Objectives

- To know the nature of temperature distribution pattern of the atmosphere.
- To know the horinzontal distribution of temperature in the atmosphere.
- To know the vertical distribution of temperature in the atmosphere.
- To know the inversion of temperature in the atmosphere.

3.3 Infiltration

Infiltration is the process by which water on the ground surface enters the soil. The infiltration capacity is defined as the maximum rate of infiltration. It is most often measured in meters per day but can also be measured in other units of distance over time if necessary. The infiltration capacity decreases as the soil moisture content of soils surface layers increases. If the precipitation rate exceeds the infiltration rate, run off will usually occur unless there is some physical barrier.

Infiltration is caused by multiple factors including; gravity, capillary forces, adsorption and osmosis. Many soil characteristics can also play a role in determining the rate at which infiltration occurs.

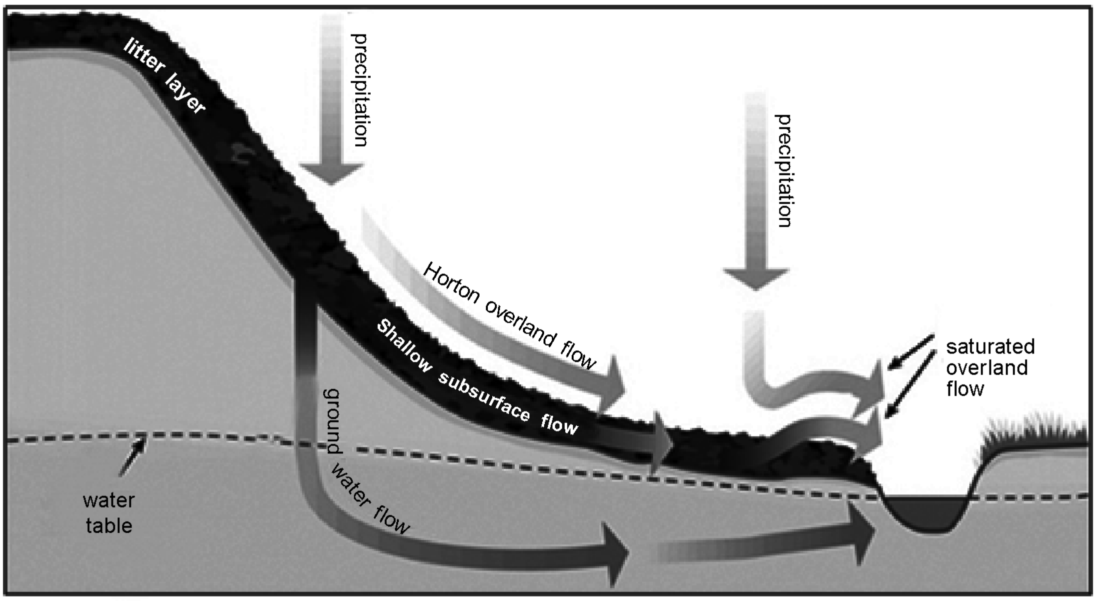

Fig. 7 : Infiltration

3.4 Controlling factors for infiltration

The factors controlling infiltration are : (1) Precipitation, (2) Soil characteristics, (3) Soil moisture content, (4) Organic materials, (5) Land cover and (6) Ground slope.

(1) ***Precipitation :***

Precipitation can create impact on infiltration in a number of ways. Rainfall leads to rapid infiltration rates than any other precipitation process, such as snow or sleet. In terms of amount, greater amounts of precipitation cause greater infiltration until the ground becomes fully saturated. Duration of rainfall also creates impact on the infiltration capacity as well. At the time when precipitation starts the infiltration occurs rapidly as the soil is unsaturated, but with the progress of time infiltration rate slows as the soil becomes more saturated. This relationship between rainfall and infiltration capacity also determines how much run off will occur. When rainfall occurs at a rate faster than the infiltration capacity runoff occurs.

(2) ***Soil characteristics :***

Porosity is critical for determining the infiltration capacity of the soil. Soils with smaller pore spaces, such as clay, have lower infiltration capacity and rates than soils having large pore size, such as sands. Exception can happen to this rule when clay is present in dry conditions. In such case the soil can develop large cracks which lead to greater capacity of infiltration. Soil compaction also creates impacts on infiltration capacity. Compaction of soils results in decrease in porosity within the soils, which in turn decreases infiltration capacity.

(3) ***Soil moisture content :***

Soil, which is already saturated, has no more capacity to absorb more water, therefore infiltration capacity is reached and the rate cannot increase beyond this point. This causes much more surface run off. When soil is partially saturated infiltration can occur at a moderate rate and completely unsaturated soils have the highest infiltration capacity.

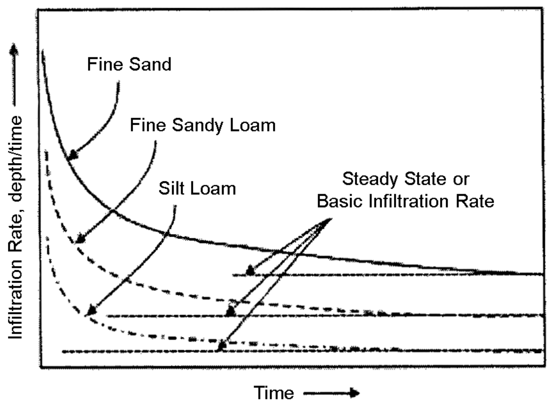

Fig. 8 : Soil moisture content

(4) ***Organic materials in soils :***

Organic materials present in the soil (including plants and animals) often increase the infiltration capacity. Vegetation contains roots inserted into the soil creating cracks and fissures in it allow more rapid infiltration and increased capacity. Vegetation can also reduce surface compaction of the soil which in turn allows increased infiltration. Without the presence of vegetation infiltration rates can be very low, leading to excessive run off and increased erosion.

(5) ***Land cover :***

If land has impermeable surfaces, such as pavement, infiltration cannot occur as the water cannot infiltrate through the impermeable surface layer. This relationship also leads to increased run off. Areas of impermeable cover often have storm drains which drain directly into water bodies. So no infiltration occurs.

Vegetative cover of the land also creates impacts on the infiltration capacity. Vegetative cover can lead to more interception of precipitation, which can decrease intensity leading to less run off, and more interception. Abundance of vegetation also leads to higher levels of evapo-transpiration decreasing the infiltration rate. Debris from vegetation such as leaf cover can also decrease infiltration rate by protecting the soils from intense precipitation events.

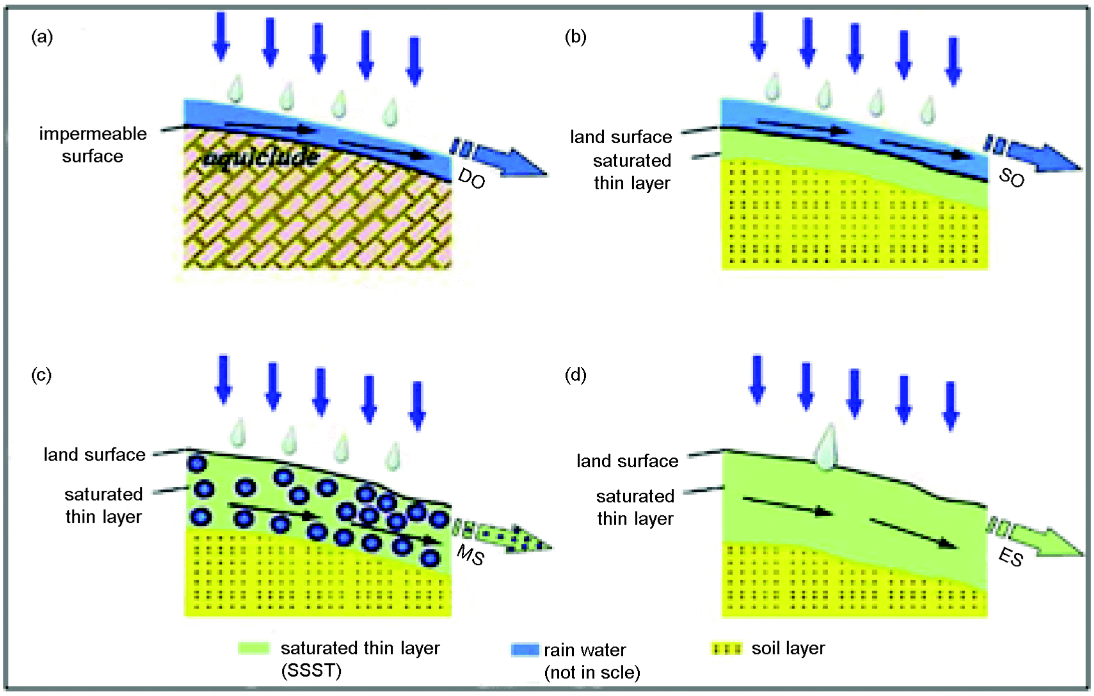

Fig. 9 : Land cover and infiltration

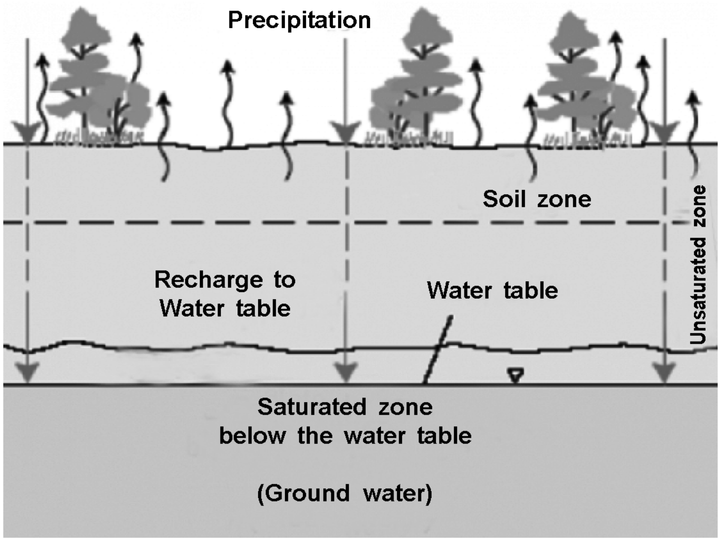

Fig. 10 : Infiltration and ground water recharge

(6) ***Slope :***

On the higher gradient of slope run off occurs more readily leading to lower infiltration rates.

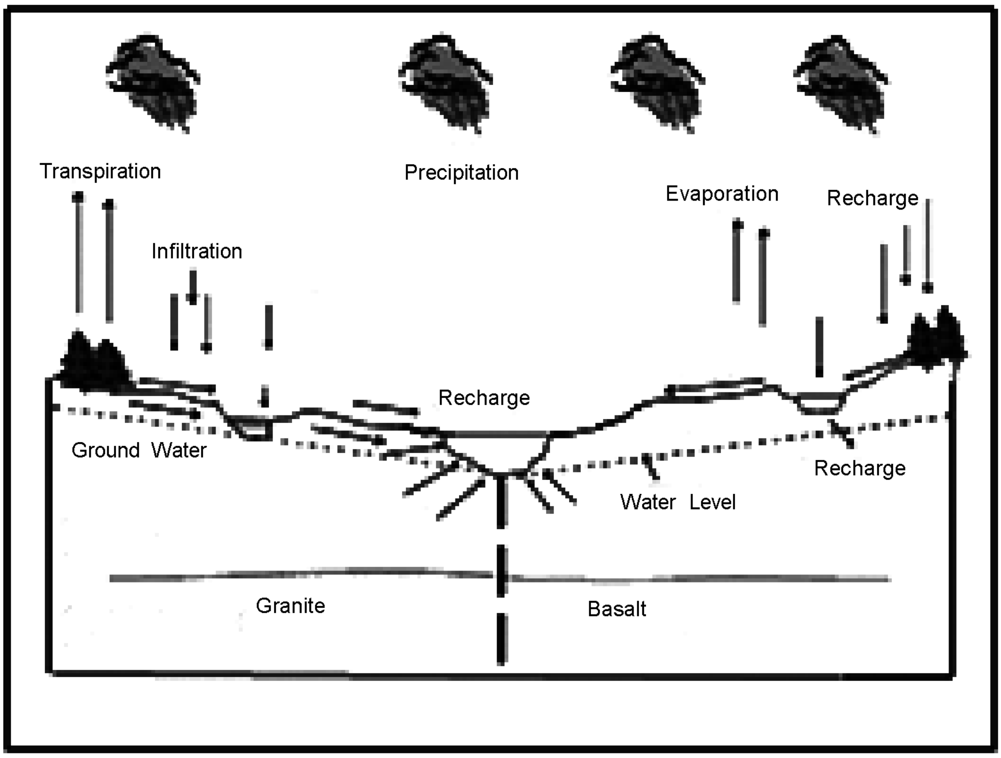

Fig. 11 : Slope and infiltration

3.5 Evapo-transpiration

Evapo-transpiration (ET) is the sum total of evaporation and plant transpiration from the land and ocean surfaces to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

It is an important part of the water cycle. An element, such as a tree, that contributes to evapo-transpiration can be called an evapo-transpitator.

Potential evapo-transpiration (PET) is a representation of the environmental demand for evapo-transpiration and it represents the evapo-transpiration rate of a short green crop (grass), providing the complete cover on the ground, of uniform height and with adequate water status in the soil profile. It is the reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. Actual evapo-transpiration is said to equal potential evapo-transpiration when there is sufficient water.

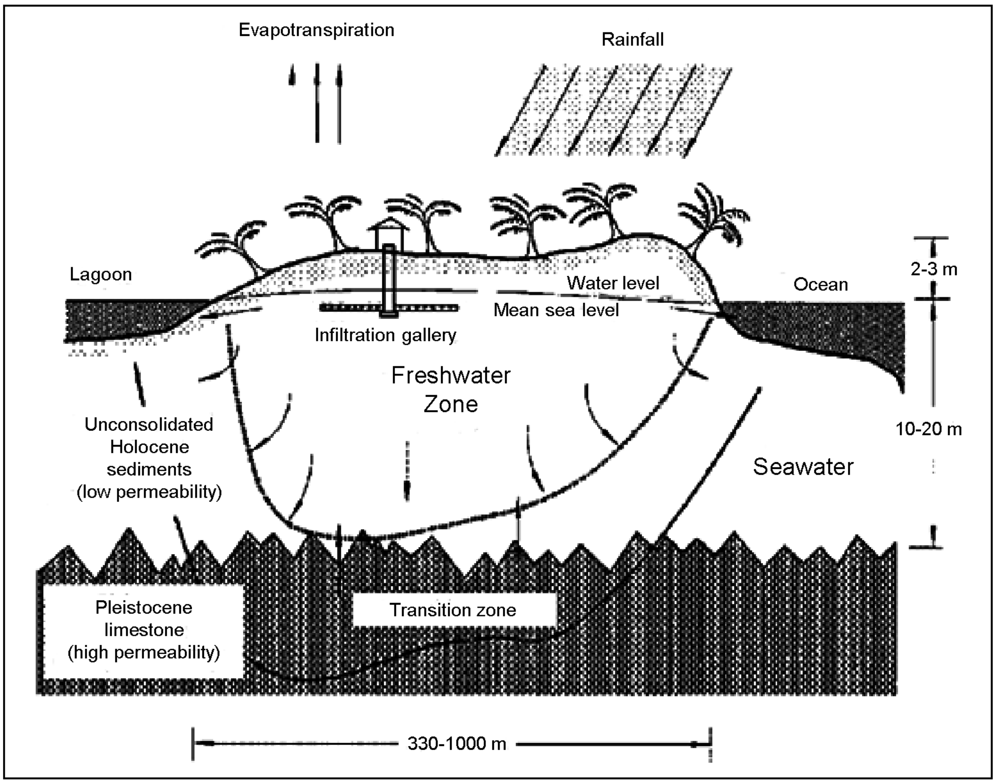

Fig. 12 : Evapo-transpiration

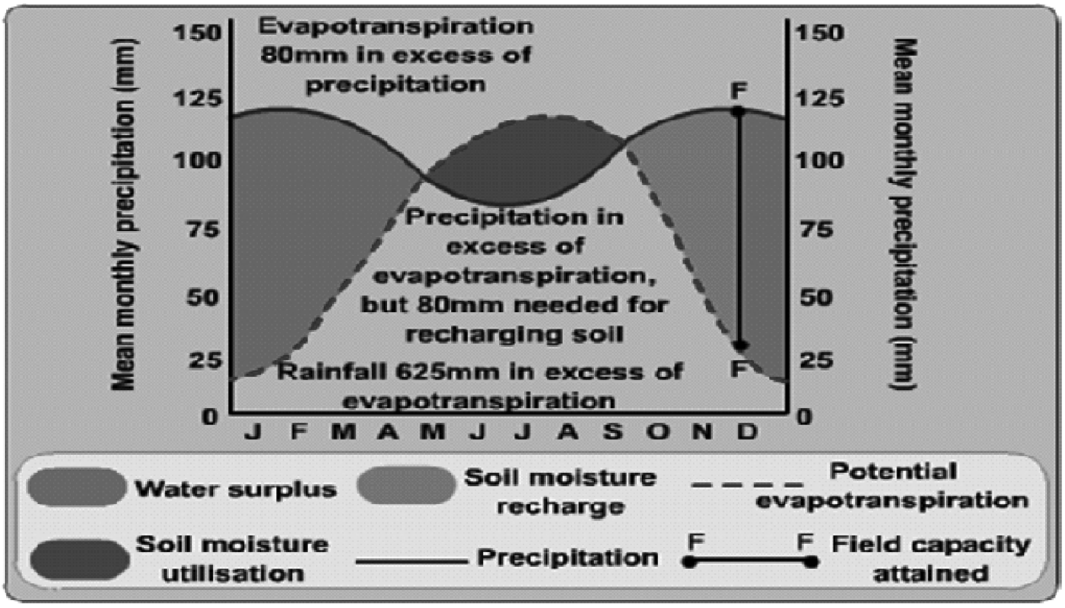

Fig. 13 : Potential Evapo-transpiration

3.6 Summary and Conclusion

The study of infiltration and evapo-transpiration and related various issues like, infiltration capacity, porosity, permeability, ground water, potential evapo-transpiration helps the learners to understand and correlate the runoff, hydrological cycle and ground water recharge and discharge pattern.

3.7 Key words

Infiltration and evapo-transpiration, infiltration capacity, porosity, permeability, ground water, potential evapo-transpiration

3.8 Model Questions

Short Answer type :

1. What is Infiltration ?
2. What is infiltration capacity ?
3. What is potential evapo-transpiration ?

Long Answer type :

1. Describe the factors controlling infiltration.
2. State the factors that controls potential evapo-transpiration.

3.9 References

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Unit - 4 ❑ Drainage Basin as a Hydrological Unit

Structure

4.1 Introduction

The study of drainage basin is very much important to a leaners of geography. The research, on physical geography, especially the geomorphology, which frequently attract the learner is very much related to drainage. The drainage basin is also known as catchment, catchment area, catchment basin, drainage area, river basin, water basin and watershed. The drainage basin is considered as a hydrologcal unit. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from the adjacent basins by a drainage divide.

4.2 Objectives

- To know the concept of drainage basin.
- To know the drainage basin as a hydrological unit.
- To know the importance of drainage basin.
- To know the factors related to drainage basin.

4.3 Drainage Basin

Drainage basins are the principal hydrologic unit considered in fluvial geomorphology. A drainage basin is the source for water and sediment that moves through the river or drainage system and reshapes the channel. In other words, a drainage basin is an extent or area of land where water from rain and melting snow or ice drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea or ocean. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from the adjacent basins by a drainage divide.

The drainage basin acts as a funnel by collecting all the water from within the area covered by the basin (drainage network system) and channeling it into a waterway. Each drainage basin is separated topographically from the adjacent basins by a geographical barrier such as a ridge line, hill or mountain range, which is known as a water parting.

Other terms used to describe a drainage basin are catchment, *catchment area, catchment basin, drainage area, river basin, water basin and watershed.* In the technical sense, a watershed refers to a divide that separates one drainage area from the other.

4.4 Drainage Basin as a Hydrological Unit

In a closed drainage basin, the water converges to a single point inside the basin, known as a sink, which may be a permanent lake, a dry lake or a point where surface water is disappear underground.

The drainage basin acts as a funnel by collecting all the water from within the area of the basin and channeling it to a single point. Each drainage basin is separated topographically from the adjacent basins by a perimeter, the drainage divide, making up a succession of higher geographical features forming a barrier.

Drainage basins are similar but not identical to hydrologic units, which are drainage areas delineated to nest into a multi-level hierarchical drainage system. Hydrologic units are actually defined to allow multiple inlets, outlets, or sinks. In its strict sense, all drainage basins are hydrologic units but not all hydrologic units are drainage basins.

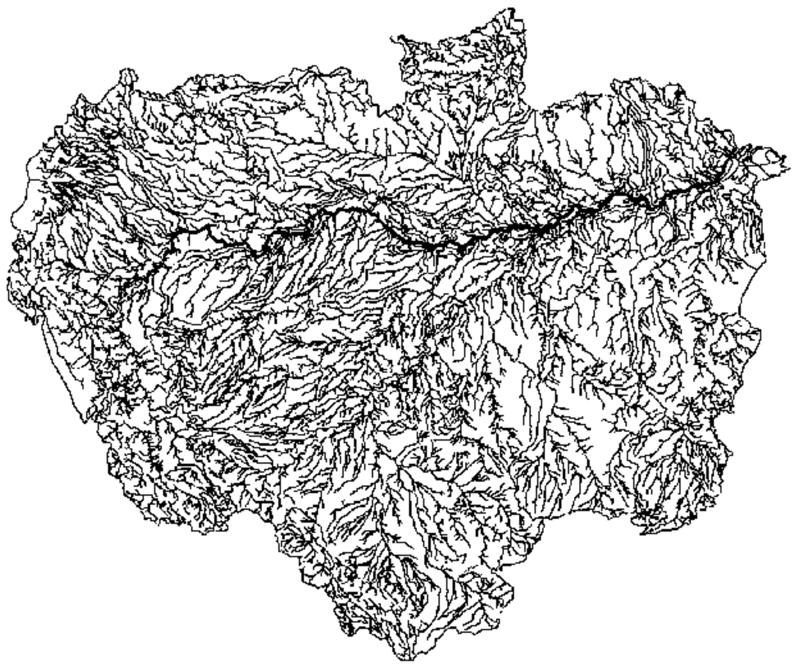

Fig. 14 : Drainage Basin as a Hydrological unit

4.5 Importance of drainage basins as Hydrological Unit

(a) Geopolitical boundaries :

Drainage basins are historically important for determining territorial boundaries, particularly in regions where trade by water has been important. Bioregional political organization today includes agreements of states or other political entities in a particular drainage basin to manage the bodies of water into which it drains.

(b) Hydrology :

In hydrology the drainage basin is a logical unit of focus for studying the movement or discharge of water within the hydrological cycle, because the majority of water that discharges from the basin outlet originated as precipitation received on the basin. A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network. Measurement of the water discharge from a basin may be made by a stream gauge located at the basin's outlet.

Isochrone maps can be used to show the time taken for run off water within a drainage basin to reach a, reservoir, lake or outlet, assuming constant and uniform effective rainfall.

(c) Geomorphology :

A drainage basin is the source for water and sediment that comes down from higher elevation through the river system to lower elevations as they continue to reshape the channel forms.

(d) Ecology :

Drainage basins are important in ecology as well. As water flows over the ground and along rivers, it normally picks up nutrients, sediment as well as pollutants. They are transported towards the outlet of the basin with the water, and can affect the ecological processes along the way as well as in the water source.

Modern use of artificial fertilizers, containing nitrogen, phosphorus, and potassium, affect the mouths of drainage basins. The minerals are carried down by the drainage basin to the mouth, and accumulate there, disturbing the natural mineral balance. This process is called eutrophication where plant growth is accelerated by the additional material.

(e) Resource management :

Since drainage basins are coherent entities in a hydro-logical sense, it is common to manage water resources on the basis of individual basins. In USA governmental entities that perform this function are called watershed districts. In New Zealand, they are known as catchment boards. In North America, this function is referred to as watershed management.

When a river basin crosses at least one political border, either a border within a nation or an international boundary, it is identified as a *trans-boundary river*. Management of shared drainage basins is also seen as a way to build lasting peaceful relationships among the countries.

(f) Catchment factors :

The catchment is the most significant factor determining the amount or possibility of flooding. The catchment factors are: topography, shape, size, soil type and land use. Catchment topography and shape determine the time taken for rain to reach the river, while catchment size, soil type, and development determine the amount of water to reach the river.

(g) Topography :

In general topography plays a decisive role in how rapid run off will reach a river. Rain, falling upon steep mountainous areas, reaches the primary river in the drainage basin quicker than flat or slightly sloping areas.

(h) Shape :

Shape of the basin contributes to the momentum with which the run off reaches a river. A long thin catchment will take longer to drain than a circular-shaped catchment.

(i) Size :

Size of the basin helps to determine the amount of water reaching the river, as the larger the catchment the greater is the potential for flooding. It is also determined on the basis of length and width of the drainage basin.

(j) Soil type :

Soil type also helps determine how much water reaches the river. Sandy soils are very free-draining, and rainfall on this soil is likely to be absorbed by the ground. On the other hand soils of clayey type can be almost impermeable and therefore rainfall on clay soils will run off and contribute to flood volumes. After prolonged rainfall even free-draining soils can become saturated. This suggests that any further rainfall will reach the river readily rather than being absorbed by the ground. If the surface material is impermeable the precipitation will create greater surface run-off which will lead to higher risk of flooding; if the ground is permeable, the precipitation will infiltrate the soil readily.

(k) Land use :

Land use can also contribute to the volume of water reaching the river, in a similar way to clay soils. For example, rainfall on concrete roofs, pavements, and roads will be collected by rivers with almost no absorption into the groundwater.

4.6 Summary and Conclusion

The study of drainage basin is found very significant to the leaners as it helps in understanding many aspects of surface hydrology and concepts related to river basin, water basin and watershed. This will build up the knowledge base which is required for the works on river basin management or watershed management.

4.7 Key words

Drainage basin, factors controlling drainage basin, hydrological unit

4.8 Model Questions

Short answer type :

1. What is a drainage basin?

Long answer type :

1. Write about the factors related to drainage basin.

4.9 References

- Dingman, S.L. 2015. Physical Hydrology, 3rd ed, Macmillan Publishing Co.
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Unit - 5 ❑ Principles of Rainwater Harvesting and Watershed Management

Structure

5.1 Introduction

This unit is going to discuss the rainwater harvesting and watershed management. Rainwater harvesting is considered one of the simplest and oldest methods of self supply of water for households usually financed by the user himself. The concept of watershed is very much related to catchment, catchment area, catchment basin, drainage area, river basin. It is known fact that the watershed is a natural hydrological entity that covers a specific aerial expanse of land surface from which the runoff generated from rainfall flows to a defined drainage channel, stream or river. The contiguity of watersheds to be treated is necessary for consolidation the measures of treatment.

5.2 Objectives

- To know the concept of rainwater harvesting.
- To know the nature and status of rainwater harvesting.
- To know the concept of watershed.

- To know about the integrated watershed management.
- To know the concept of micro-watershed and its management.

5.3 Rainwater Harvesting

Systems : There are several types of systems to harvest rainwater, ranging from very simple home systems to complex industrial systems. The rate at which water can be collected from either system is dependent on the plan area of the system, its efficiency, and the intensity of rainfall (i.e., annual precipitation mm per annum × square meter of catchment area = litres per annum yield). Storage tanks should be covered to prevent mosquito breeding and to reduce evaporation losses, contamination and algal growth.

A subsurface dike is built in an aquifer to obstruct the natural flow of groundwater, thereby raising the groundwater level and increasing the amount of water stored in the aquifer. The subsurface dike at Krishi Vigyan Kendra, Kannaur under Kerala Agricultural University with the support of ICAR, has become an effective method for ground water conservation by means of rain water harvesting technologies. The subsurface dike has been demonstrated to be a feasible method for conserving and exploiting the groundwater resources of the Kerala state of India. The dike is now the largest rainwater harvesting system in that region.

Fig. 15 : Rainwater harvesting method

5.4 Status of Rainwater harvesting

(a) ***Ancient period***

Rainwater harvesting has been used since biblical times. It was done in ancient Palestine, Greece and Rome. Around 3rd Century BC., farming communities in Baluchistan and Kutch used it for irrigation. In Ancient Tamil Nadu, India, Rainwater harvesting were done by Chola Kings. In the Indus Valley Civilisation, Elephanta Caves and Kanheri Caves in Mumbai rainwater harvesting alone was used to supply in their water requirements.

(b) ***Present Status in India***

- In Tamil Nadu rainwater harvesting was made compulsory for every building to avoid ground water depletion. It proved successful within five years and every other states took it as a role model. Since the implementation, Chennai saw 50 per cent rise in water level in five years and the water quality significantly improved.
- In Rajasthan rainwater harvesting has traditionally been practiced by the people of the Thar Desert area in its western part. There are many ancient water harvesting systems in Rajasthan, which have now been revived.
- Rainwater harvesting has also started in Kerala state.

5.5 Check Dams

A Check Dam is a small dam, which can be either temporary or permanent, built across a minor channel, swale, bioswale, or drainage ditch. Similar to drop structures in purpose, they reduce erosion and gullying in the channel and allow sediments and pollutants to settle. They also lower the speed of water flow during storm events. Check dams can be built with logs, stone, or sandbags. Of these, the former two are usually permanent or semi-permanent; and the sandbag check dam is usually for temporary purposes. Also, there are check dams that are constructed with rockfill or wooden boards. These dams are usually used only in small, open channels that drain 10 acres (0.040 km^2) or less; and usually do not exceed 2 feet (0.61 m) high.

Many check dams tend to form stream pools. Under low-flow circumstances, water infiltrates into the ground, evaporates, or seeps through or under the dam. Under high flow (flood) conditions, water flows over or through the structure. Coarse and medium-grained sediment from runoff tends to be deposited behind check dams, while finer grains are usually allowed through. Extra nutrients, phosphorus, nitrogen, heavy metals and floating garbage are also trapped or eliminated by the presence of check dams, increasing their effectiveness as water quality control measures. In nearly all instances, erosion control blankets, which are biodegradable open-weave blankets, are used in conjunction with check dams. These blankets help enforce vegetation growth on the slopes, shorelines and ditch bottoms.

5.6 Integrated Watershed Management

(a) Introduction :

A Drainage basin (also known as a Watershed) is the extent or an area of land where surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea or ocean. In a closed drainage basin the water converges to a single point inside the basin, known as a sink, which may be a permanent lake, dry lake or a point where surface water is disappear underground. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from the adjacent basins by a drainage divide which can be a ridge, hill or mountain.

Other terms used to describe a drainage basin are catchment, catchment area, catchment basin, drainage area, river basin and watershed. In U.K. and Australia, a watershed refers to a divide that separates one drainage area from another drainage area, while in North America it identifies the drainage basin or catchment area itself. Drainage basins drain into other drainage basins in a higherarchical pattern with smaller smaller sub-drainage basins combining into larger drainage basins.

Drainage basins are similar but not identical to hydrologic units, which are drainage areas delineated so as to nest into a multi-level hierarchical drainage system. Hydrologic units allow multiple inlets, outlets, or sinks. In a strict sense, all drainage basins are hydrologic units but not all hydrologic units are drainage basins.

(b) Delineation Principle of Drainage Basin or Watershed :

Drainage basin area is delineated according to the guidelines given below :

Drainage area (in hectares)	Unit
>1,00,000	Catchment area
40,000-1,00,000	Sub catchment area
4000-40,000	Water shed area
2000-4000	Sub water shed area
400-2000	Mini water shed area
<400	Micro water shed area

(c) Objectives of watershed management :

The following objectives have been laid down for drainage basin or watershed management.

- Reduction of run-off from its catchment to reduce peak flow into river system.
- Prevention of soil loss from the catchment to reduce the silt load in the channel flow.
- Improvement of land capability region in the catchment
- Promotion of land use to much capability.
- Promotion of multidisciplinary approach to tackle soil and water conservation problems in the affected catchment.
- People's involvement in the management and catchment.
- Up gradation of skills in the planning of execution of watershed development programme.

(d) Selection and delineation of watershed :

For the purpose of technical assessments of the condition of the different watersheds in terms of soil erosion, surveys have been conducted from by *All India Soil and Land use Survey Organization (AISLSO)*. After conducting reconnaissance survey priority for classification of the different water sheds, in terms of the needs for soil and moisture conservation, a report has been published by the authority. Here documents are taken as the primary guide lines for national planning and scheduling soil conservation and watershed management activities in a catchment. This consists of a number of sub-watersheds, many of which are in need for treatment. The basic principle followed in this regard is :

- Very high and high priority water sheds-first quality for treatment in that order.
- Contiguity of water sheds to be treated is necessary for consolidation the measures of treatment, the annual work programme are drawn up in this view.

(e) Priorities for Drainage Basin or Watershed Management :

Watershed management plans have been taken up scheduling all the treatments required ensuring proper and safe land use management plans being prepared with a project approach and is termed as watershed project report.

Treatment measure for soil and moisture conservation and afforastation by different project implementing agencies are planned in a synchronized manner.

Priority is given to vegetative measures like afforestation, growing of grasses and shrubs agro-forestry, horticulture and planting fuel fodder and fruit trees species with the special emphasis on retaining bio-diversity. Extensive structures are discouraged; protection of plantation is on target mainly through public co-operation.

For securing public involvement in the watershed management programme discussions are in progress with beneficiaries of the project to involve then in planning and implementation, which can ensure best land use according to land capability. In order to watershed productive on a sustainable basis fodder, grass legumes, shrubs and trees for fruit varieties are generally grown. The programme is also targeted to make cost effective.

The main implementing agencies are Forest and Agriculture Department; but the Departments Animal Resource Development and the Department of Fisheries should also be involved.

(f) Why should we apply the principles of the IRBM :

Integrated drainage basin approach in river basin management is based on the fact that the soil and river channel within a basin can form a unity. During the last decades general river ecology has pointed out that the biotic networks in a river ecosystem are strongly dependent on the organic matter produced in the soil ecosystems of the drainage basin. Most of the rivers in the world have been characterized as heterotrophic in terms of their energy balance. On the other hand, the river systems are also characterized by continuous material transport from the drainage basin into the river channel, and finally to the sea. This process has multiple impacts on the river biota. Knowledge of river systems at this general level should increase the general motivation to approach river basins as entities.

5.7 Micro-watershed Planning

(a) Micro watershed :

It has already been stated that the watershed is a natural hydrological entity that covers a specific aerial expanse of land surface from which the run off generated from rainfall flows to a defined drainage channel, stream or river at any particular point. Based on the size, the hydrological unit is termed as water resource region, basin, catchment, sub-catchment, watershed, sub-watershed and micro-watershed respectively. The smallest hydrologic unit in the hierarchal system is termed as Micro Watershed having size of less than 400 ha. (15km^2). Under regional planning and management the micro watersheds are the most workable units.

(b) Micro-watershed development and planning in India :

In India micro-watershed development is considered as one of the best programs in rural development, both in terms of immediate and long-term effects. It improves the quality of life of villagers through increased productivity of the land, availability of water - surface and ground, an increase in the vegetation cover, improving cattle health resulting in higher milk production, and improving the overall environmental system by tree plantation. If implemented in appropriate manner and with the participation of people in the society this programme can transform the entire village.

India's water availability in the future is predicted to be bleak if proper steps are not taken to deal with the management of the available water resources. The report titled : Watershed development in India – An approach evolving through experience by the World Bank points out that according to recent estimates, the rising demand for water along with further increase in population and economic growth can result in about half the demand for water in the country being unmet by 2030.

Besides scarcity, problems related to poor quality of the available water resources may make the situation even worse. Hence, solutions are needed considering both the supply and demand side, and for both ground and surface water.

(c) Implementing watershed management practices in India :

The report shows that implementing good watershed management practices and approaches can go a long way and help India potentially better manage and augment its water resources.

The report analyses the experiences and lessons learnt from three World Bank supported watershed development projects in the Indian states of Karnataka, Himachal Pradesh and Uttarakhand with the aim to :

- Understand the feasibility and applicability of watershed management practices in other parts of the country and
- Develop guidelines or models for the development and execution of new watershed development programmes in the country.

(d) Watershed development in India : Present status

Watershed development is not a new concept in India. History shows that the people of India have adapted by either living along river banks or by harvesting, storing, and managing rainfall, run off and stream flows in the past as well. Most of India's water management has been at the community level, relying upon diverse, imaginative and effective methods for harvesting rainwater in tanks and small underground storage structures.

Government of India has also adopted programs based on traditional water management approaches, which focus on micro-watersheds as the basis for planning and intervention since the late 1980s. The Guidelines for Watershed Development Projects became operational in 1995, and there has been a massive country-wide increase in the number and financing for community-based projects for micro-watershed development since then.

These projects are based on rainfall and run off harvesting schemes that involve rehabilitating, building small check dams and tanks, and groundwater recharge structures.

However, it has been realised that these programs have been more about rural development than about watersheds and water resources management. It has been felt that the programs should focus more on water resources objectives.

5.8 Summary and Conclusion

The study of rainwater harvesting and watershed management is found very significant to the leaners as it helps in understanding many aspects of surface hydrology and concepts related to river basin, water basin and watershed. This will build up the knowledge base of the learners, which is required for the study and reserches on water management and watershed management.

5.9 Key words

Rainwater harvesting, watershed management, micro-watershed

5.10 Model Questions

Short answer type :

1. What is a rainwater harvesting?
2. What is watershed?
3. What is micro-watershed?

Long answer type :

1. Write about the nature and status of rainwater harvesting.
2. State about the integrated watershed management.

5.11 References

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Unit - 6 ❑ Groundwater : Occurrence and Storgage; Factors Controlling Recharge, Discharge and Movement

Structure

6.1 Introduction

This unit is going to discuss the concept of groundwater hydrology. We frequently and widely use the ground water in our day to day life diversely. Thus, this study is very much essential to a leaners of geography. The research on physical geography, especially the hydrology is very much related to groundwater. This unit contains the concept of groundwater occurance, storage, recharge, discharge, movement.

6.2 Objectives

- To know the concept of groundwater.
- To know the process and sources of groundwater occurance.
- To know the storage of groundwater and its importance.
- To know about the groundwater recharge and discharge.

- To know the factors related to groundwater recharge.
- To know the process and pattern of groundwater movement.

6.3 Groundwater : Occurrence and Storage

(a) Groundwater occurrence :

It is the water existing beneath the earth's surface in the pore spaces of the soil-regolith and in the fractures of rock layers. A unit of rock or an unconsolidated deposit, when it can yield a usable quantity of water, is called an ***aquifer***. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water it is called the ***water table***. Ground water is recharged from the supply received from the surface. It may discharge from the surface naturally at springs and seeps, and can also form oases or wetlands. Groundwater is also often withdrawn for agricultural, domestic and industrial purposes by constructing and operating extraction wells.

It is a certain fact that much of the earth's subsurface contains some water, which may be mixed with other fluids in some cases. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is often used for supplies to the public.

(b) Groundwater storage :

Groundwater storage is the difference between recharge and discharge of water over time, ranging from days to thousands of years. Changes to both groundwater and surface-water levels may alter the interaction between groundwater and surface water and the interaction between natural and societal water supply and demand. Groundwater storage can be affected by the intrinsic properties of the aquifer (storage capacity, transmission capacity, and aquifer geometry) controlled by its size and type. An aquifer receiving recharge from extensive catchment areas is insensitive to short-term climatic variability, while shallow unconfined aquifers are more reactive to smaller-scale climate variability. Deeper aquifers react only with delay to large-scale climate change. Shallow groundwater systems are more responsive to smaller-scale climate variability. Groundwater storage is also influenced by climate change depending upon whether groundwater is renewable or not or comprises a fossil resource. Groundwater storage will be more sensitive to climate if it is renewable. Groundwater resources are divided into four categories.

1. Confined aquifers with upper impermeable layers where recharge occurs only from precipitation where the water-bearing layers outcrop at land surface.

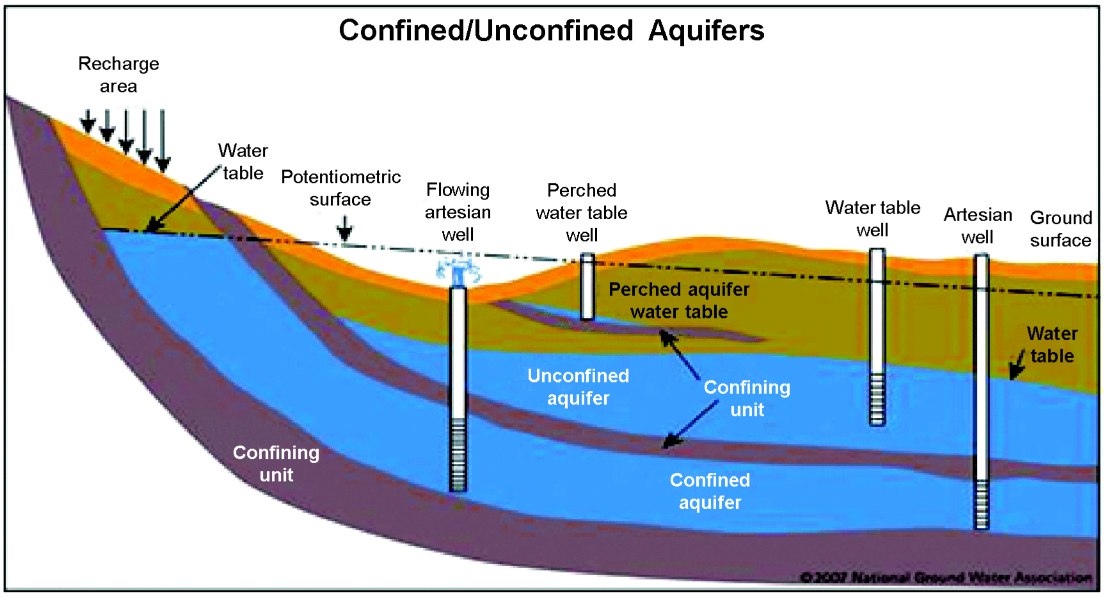

Fig. 16 : Aquifers

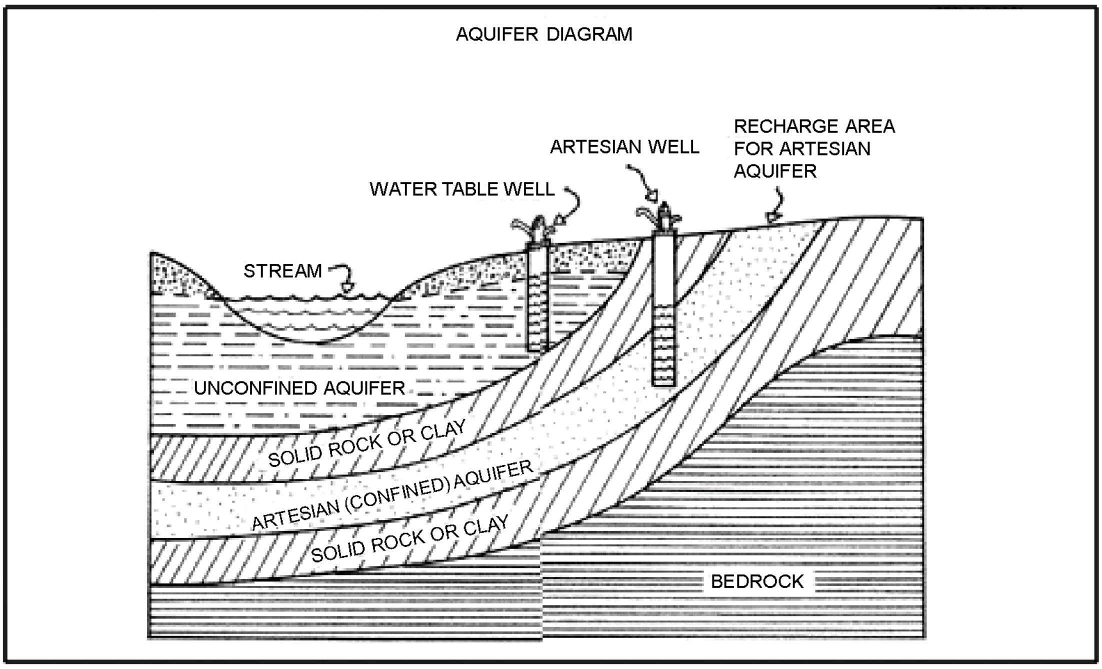

Fig. 17 : Aquifer and Artesian well

2. Unconfined (phreatic) aquifers in wet regions where rainfall is high and evapo-transpiration is low. These aquifers are highly renewable because precipitation exceeds evapo-transpiration throughout the year. Nonrenewable groundwater is vulnerable to the indirect effects of increased abstraction by humanbeings to meet current water requirements and future water demand under a changing climate.

3. Unconfined aquifers in arid and semiarid environments that are likely to have shifting annual balances between precipitation and evapo-transpiration. It is a fact that recharge may be less to these aquifers, resulting in less groundwater availability but an increase in demand from growing population and less reliable surface-water resources.

4. Coastal aquifers are vulnerable to rising sea levels and salt-water intrusion.

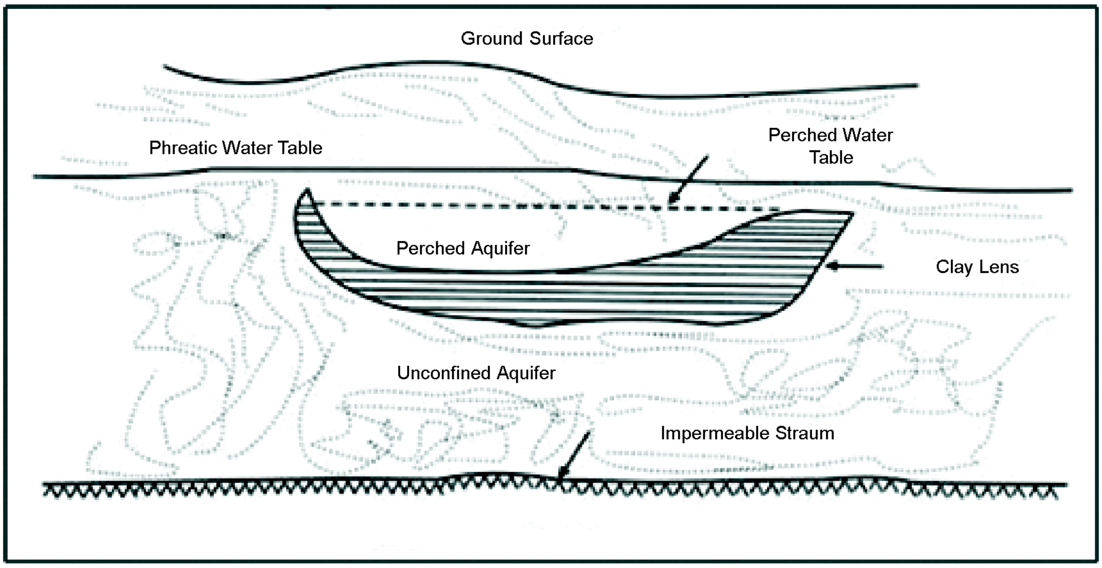

Fig. 18 : Unconfined and perched aquifers

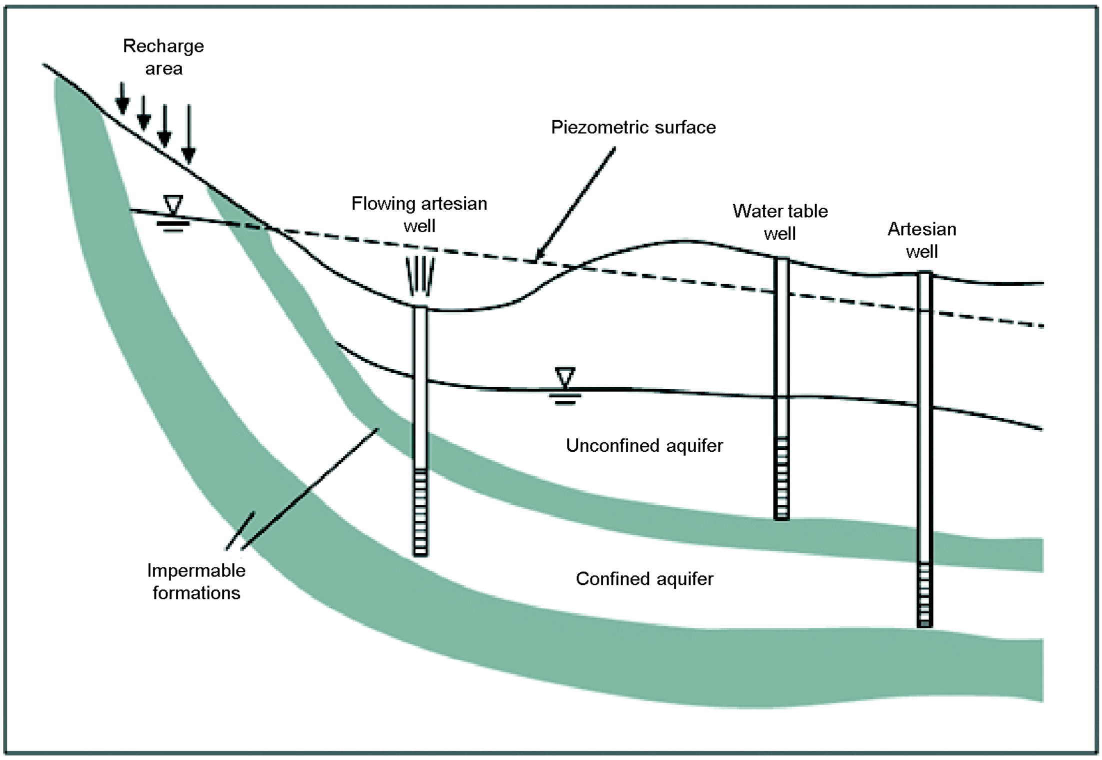

Fig. 19 : Aquifers and Piezometric surface

6.4 Factors controlling Groundwater Recharge

Groundwater recharge is a hydrological process through which water moves downward from the ground surface. Recharge is the basic method through which water enters into an aquifer. This process usually occurs in the zone under the ground which is known as the vadose zone (below plant roots) and is often expressed as a flux to the water table surface. Groundwater recharge also means the process through which water moves away from the water table farther into the saturated zone. Recharge occurs both naturally through the water cycle as well as through anthropogenic processes (i.e., artificial groundwater recharge), where rainwater is routed to the subsurface.

Groundwater gets recharged naturally by rain and snow-melt and to an extent, by surface water (rivers and lakes). Recharge may be retarded to a certain extent by human activities including paving, development, or logging. These activities can result in deterioration of topsoil resulting in reduced water infiltration, enhanced surface runoff and reduction in recharge. Utilization of groundwater, especially for irrigation purpose, may also subside the water table. Groundwater recharge is an important process for sustainable groundwater management, as because the volume-rate abstracted from an aquifer in the long term, should be less than or equal to the volume-rate recharged.

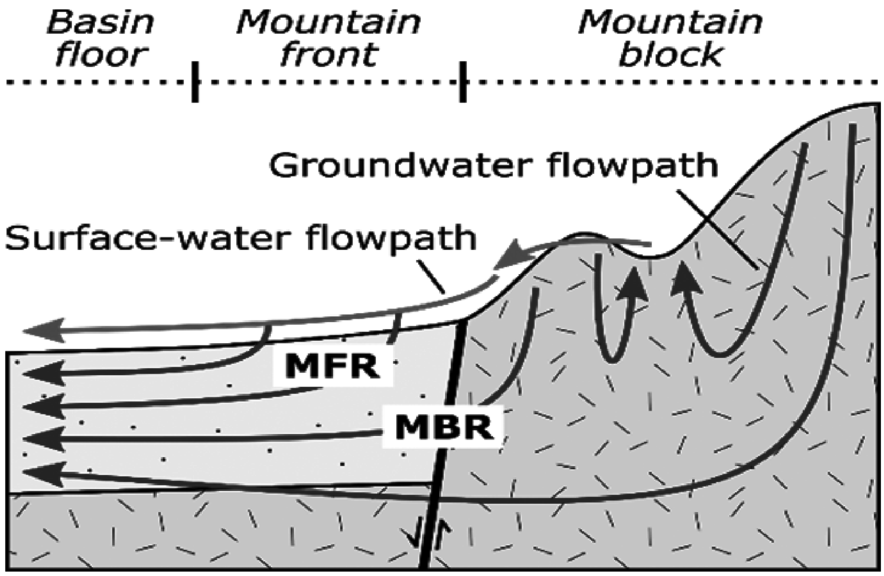

Fig. 20 : Groundwatr recharge system

Recharge can help reduction of the excess salts that accumulate in the root zone to deeper soil layers, or into the groundwater system. Tree roots increase saturation of water into ground water reducing water runoff. Widespread flooding can temporarily increase riverbed permeability by moving clay soils downstream, and this increases aquifer recharge.

In the present day artificial groundwater recharge becomes increasingly important in India, where over drawing of groundwater by farmers has led to underground water resources depleted. In 2007, on the recommendations of the International Water Management Institute the Govt. of India allocated Rs.1,800 crore (in 2018) to fund dug-well recharge projects in 100 districts within seven states where water stored in hard-rock aquifers had already been over-exploited.

6.5 Factors Controlling Groundwater Discharge

Groundwater discharge is the movement of groundwater from the subsurface to the surface. Natural discharge occurs into lakes, streams and springs and the human discharge, is generally referred to as pumping. The natural discharge is controlled by the topography and geology, with groundwater discharging in topographically low areas containing higher permeability sandstone layers or gravels. There are various processes which natural discharge of groundwater takes place. The first is along the stream when the channel bed is located at the water table. The groundwater discharges into the stream to provide base flow during hot summer months. This type of discharge is generally continuous along the length of the channel bed as long as it is at the water table.

Groundwater also gets discharged through springs, whereby groundwater moves laterally through permeable sandstone and emerges at an outcrop. Spring discharge can also occur through the overlying gravels before entering the stream. Water is able to move through the gravels due to their high permeability, allowing water to flow through easily.

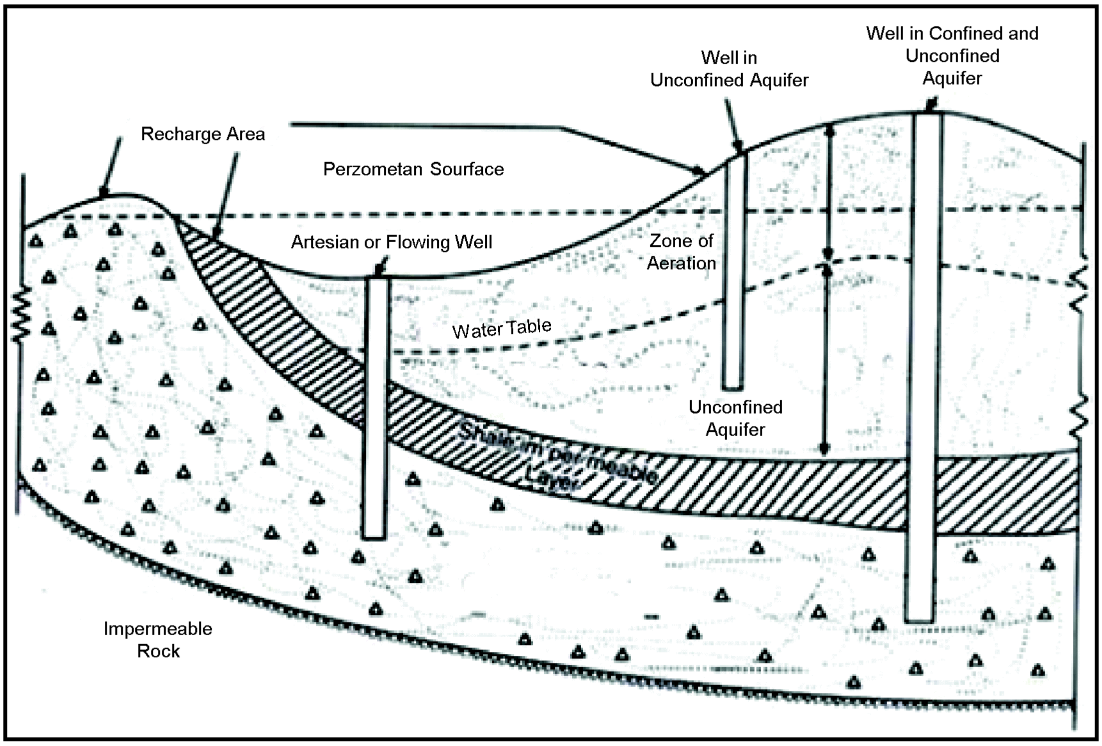

Fig. 21 : Groundwater terminology model

Human impact on groundwater discharge

Human impact on groundwater discharge has also become remarkable in the present day. This occurs when water is pumped out for residential, commercial or industrial uses. Groundwater extraction for human use can have significant impact on groundwater resources. With the water pumped from a well it causes a 'drawdown' of the aquifer water level near the well. If there is a surface water body being fed by the aquifer being pumped, the lowering of the water level can cause the stream levels to decline creating impact on the aquatic ecosystem.

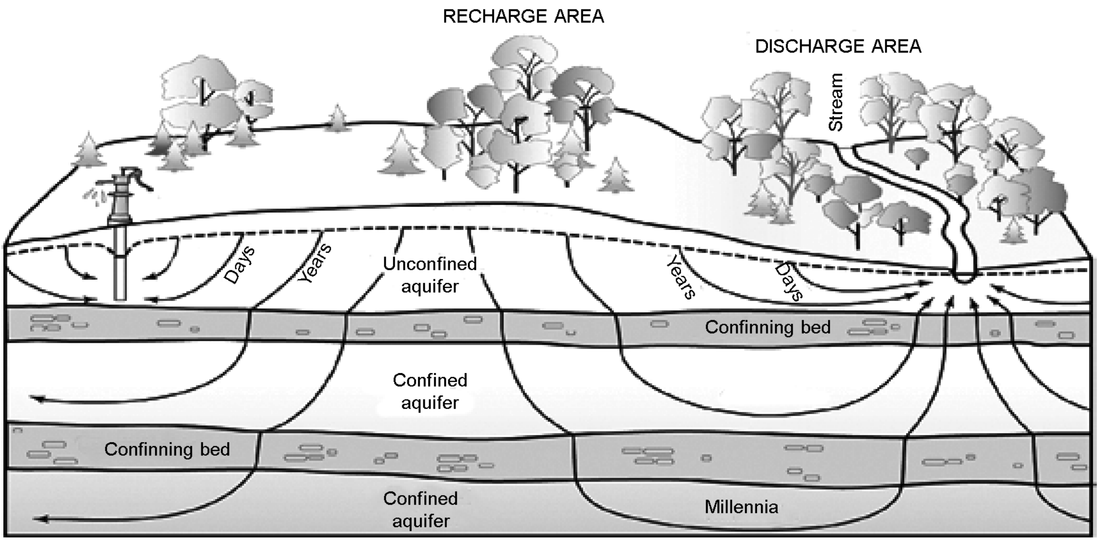

Fig. 22 : Groundwater recharge and discharge

6.6 Factors Controlling Groundwater Movement

Groundwater is stored in and moves slowly through the layers of soil, sand and rocks called aquifers. The rate of groundwater movement depends on the permeability of the soil or rocks and how well the spaces are connected, as well as the hydraulic head (water pressure).

In hydrogeology groundwater flow is defined as the part of stream flow infiltrated into the ground. It has entered the phreatic zone, and has been discharged into a stream channel or springs and seepage water. The rate of groundwater flow depends on the permeability (the size of the spaces in the soil or rocks and how well the spaces are connected) and the hydraulic head (water pressure).

6.7 Summary and Conclusion

The study of ground water is found very significant to the leaners as it helps in understanding many aspects of sub-surface hydrology and concepts related to grundwater hydrology. We all know that the groundwater is cheaper and more convenient and less vulnerable to pollution than surface water. Therefore, it is often used for supplies to the public for various purposes, but it is utmost necessity in the present day to save the ground water. The knowledge base gained in this unit will build up a broader sense about ground water, which is required for the works on ground water dynamics and ground water management.

6.8 Key words

Groundwater, sources of groundwater, storage of groundwater, groundwater recharge and discharge, groundwater movement

6.9 Model Questions

Short answer type :

1. What is ground water ?
2. What is aquifer ?
3. What are the sources of ground water ?

Long answer type :

1. Write about the factors controlling groundwater recharge and discharge.
2. Explain the groundwater movement.
3. Give an account for the occurrence and storage system for ground water.

6.10 References

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Summary and Conclusions of Module 1

The study of Hydrology involves the measurement of the quantities and rates of movement of water at all times and at every stage of its course. It concerns the development of accurate and acceptable methods of making these measurements of diverse kinds, and with the accumulation and compilation of the great mass of quantitative data. The global hydrological cycle involves the continuous circulation of water in the Earth-atmosphere system. Of the many processes involved in the water cycle, the most important are evaporation, transpiration, condensation, precipitation, and runoff. This cycle is performed in two main ways : (1) Physical role and (2) Biological role.

The water which cannot infiltrate may flow over the ground surface until it reaches more permeable soil, where it can infiltrate, or continue down slope as threads of water which gradully may merge until a defined channel is reached or formed - process known as runoff. Lithology, structure, ground slope, sunshine, rainfall and snowfall, forest cover and evapo-transpiration are the factors which affect surface runoff. Runoff cycle is a decisive factor for the global water budget. Infiltration is the process by which water on the ground surface enters the soil and it is caused by multiple factors including; gravity, capillary forces, adsorption and osmosis. Factors controlling infiltration are: precipitation, soil characteristics, soil moisture content, organic materials, land cover and ground slope. Evapo-transpiration is the sum total of evaporation and plant transpiration from the land and ocean surfaces to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception and water bodies. Drainage basins are the principal hydrologic unit considered in fluvial geomorphology. Drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels and it acts as a funnel by collecting all the water from within the area covered by the basin. Drainage basins are similar but not identical to hydrologic units, which are drainage areas delineated to nest into a multi-level hierarchical drainage system. Rainwater harvesting an effective scientific process of water management is the collection and storage of rainwater for reuse on-site. Among several methods of rainwater harvest there are very simple home systems as well as complex industrial systems. For wise use of water watershed management, using scientific techniques, are now given priority by the planning authorities. The main objectives of watershed management are prevention of soil loss from the catchment to reduce the silt load in the channel flow and reduction of run-off from its catchment. In India micro-watershed development is considered as one of the best programs in rural development. Ground water is the water existing beneath the earth's surface in the pore spaces of the soil-regolith and in the fractures of rock layers. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Its recharge is a hydrological process through which water moves downward from the ground surface. Natural discharge occurs into lakes, streams and springs and the human discharge, is generally referred to as pumping.

Key Words of Module 1

Hydrology, sustainability, subterranean, evaporation, quantitative data, interstices, atmospheric water, precipitation, hydrological cycle, interception, condensation, absorption, evapo-transpiration, infiltration, soil-water, capillary action, meteoric water, eco-system, hydel power, surface runoff, porosity, unsaturated,, impermeable, vegetative cover, perimeter, consolidation

Further Readings of Module 1

- Principles of Hydrology – R. C. Ward and M. Robinson
- Hydrology – O.E. Meinzer
- Water, Earth and Man – R. Chorley
- The Basin Hydrological Cycle – R. J. Moore (in Water, Earth and Man – R. Chorley)
- Fluvial Processes in Geomorphology – L.B. Leopold, M.G. Wolman and J. P. Miller
- Reddy, P. Jaya Rami (2007). A textbook of hydrology. Laxmi Publ. New Delhi

Model Questions of Module 1

1. Discuss the system approach and the core concept of Hydrological studies.
2. Enumerate the Global Hydrological Cycle and discuss its physical and biological roles.
3. What is Runoff ? Under what conditions runoff takes place ? Examine the process of Runoff Cycle.
4. What is infiltration. Describe the mechanism and controlling factors of infiltration.
5. Make a discussion on the process of evapo-transpiration
6. Discuss how a drainage basin is delineated. Justify the points on which a Drainage Basin is considered as a Hydrological Unit.
7. Make a discussion on the importance of drainage basins as Hydrological unit.
8. What is rainwater harvesting and why its increasingly becoming indispensible in the present day.
9. Write an account on the Integrated River Basin Management. What is a Micro-watershed ?
10. Account for the occurrence and storage system for ground water.
11. Give a systematic account of the factors controlling Recharge, Discharge and Movement.

Module 2

Oceanography

Introduction

An ocean is a body of water that composes much of our planet's hydrosphere. On the earth, an ocean is one of the major conventional divisions. Oceanography deals with the study of hydrological and physical characteristics of the oceans covering 71% of the earth's surface. A thorough discussion has been made here on the major relief features of the ocean floor : characteristics and origin according to plate tectonics. The environmental conditions of the ocean have been discussed in terms of water mass as well as their physical and chemical properties. The controlling conditions of ocean temperature and salinity, their distribution and determinants have been discussed in detail. Formation, evolution, their classification and possible threats have been examined. The wide range of marine resources has been identified and the causes and consequences of global sea level rise have been discussed in detail.

Objectives

- to have a comprehensive idea of oceanography.
- to gather knowledge about the relief freatures of oecan floor.
- to study the processes of air-sea interaction and oceanic circulation.
- to gather knowledge about ocean temperature and salinity, their determinates and distribution.

  to study about coral reef formation and depletion.
- to assume the oceanic resource.
- to assess the facts relating to the sea level change.

Unit - 1 ❑ Major Relief Features of the Ocean Floor : Characteristics and Origin According to Plate Tectonics

Structure

1.1 Introduction

Oceanography is an very significant branch of physical geography, that is studied in under-graduate and post-graduate course of geography discipline. Oceanography deals with the study of hydrological and physical characteristics of the oceans covering 71% of the earth's surface. In broad sense, oceanography relates to all the waters of the ocean. This unit is going to introduce the formation of ocean topography in the ight of plate techtonic and various topographic features are also discussed into it.

1.2 Objectives

- To know the process of formation of oceanic bottom topography.
- To know the major relief features of ocean floor.
- To know the salient features of ocean floor.

1.3 Major Relief Features : Characteristics and Origin

The ocean floor or abyssal plain is an underwater plain on the deep ocean floor; usually occur at depths between 3,000 metres (9,800 ft) and 6,000 metres (20,000 ft) below the sea water surface. Lying generally between the foot of a continental rise and a mid-oceanic ridge, abyssal plains cover more than 50% of the earth's surface. They are among the flattest and least explored regions on the earth. Abyssal plains are key geologic elements of ocean basins. In addition to these elements, active oceanic basins (those that are associated with a moving Plate Tectonic boundary) also typically include an ocean trench and a subduction zone.

Until the late 1940s abyssal plains were not recognized as distinct physiographic features of the sea floor and, until very recently, very few systematic studies have been done on this. They are not preserved in the sedimentary record because they tend to be under the subduction process. Formation of the abyssal plain is the final result of spreading of the seafloor (plate tectonics) and melting of the lower oceanic crust. Molten magma rises from above the asthenosphere (layer of the upper mantle) and as this basaltic material come out to the surface at mid-ocean ridges it forms new oceanic crust. Abyssal plains result from the covering of an originally uneven surface of oceanic crust by fine-grained sediments, mainly clay and silt. Much of this sediment is deposited by the turbidity currents that have been channeled from the continental margins along the submarine canyons down into deeper water. The remainder of the sediment is incorporates chiefly of pelagic sediments. Metallic nodules are common in some areas of the plains, with varying concentrations of metals, including manganese, iron, nickel, cobalt and copper.

Abyssal plains, with their vast expanse, are believed to be a major storehouse of biodiversity. The abyss also causes significant influence upon ocean carbon cycling, dissolution of calcium carbonate and atmospheric carbon (CO_2) concentrations over timescales of 100–1000 years. It has been explored that the structure and function of abyssal ecosystems are strongly influenced by the rate of flux of food to the seafloor and the composition of the material that settles. Climate change, fishing practices and ocean fertilisation are expected to have a significant effect on patterns of primary production in the euphotic zone. This will undoubtedly create impact the flux of organic material to the abyss in a similar manner and thus have a great effect on the structure, function and diversity of abyssal ecosystems.

1.4 Formation

Oceanic crust, which forms the bedrock of abyssal plains, is continuously being created at mid-ocean ridges alongside the divergent plate boundary by a process known as decompression melting. Plume-related decompression melting of solid mantle is responsible for creating ocean islands like the Hawaiian Islands, as well as the ocean crust at mid-oceanic ridges. Decompression melting occurs when the upper mantle is partially melted into magma as it moves upwards through the mid-ocean ridges. This upwelling magma then cools and solidifies by conduction and convection of heat to form new oceanic crust. Accretion occurs as mantle is added to the growing edges of a tectonic plates, usually associated with seafloor spreading. The age of oceanic crust is therefore a function of distance from the mid-oceanic ridge. Thus the youngest oceanic crust is at the mid-oceanic ridges, and it becomes progressively older, cooler and denser as it migrates outwards from the mid-ocean ridges as part of the process called mantle convection.

Geo-tectonic studies have explored the fact that the lithosphere, which rides atop the asthenosphere, is divided into a number of tectonic plates that are continuously being created and consumed at their opposite plate boundaries. Oceanic crust and tectonic plates are continuously formed and move apart at mid-ocean ridges. Consumption or destruction of the oceanic lithosphere occurs at oceanic trenches (a type of convergent boundary, also known as a destructive plate boundary) by a process of subduction. Oceanic trenches are found at places where the oceanic lithospheric bodies of two different plates meet, and the denser (older) slab begins to descend into the mantle. At the consumption edge of the plate (the oceanic trench), the oceanic lithosphere has thermally contracted to become denser, and it sinks in the process of subduction. The subduction process consumes older oceanic lithosphere, so oceanic crust is believed to be more than 200 million years old. The overall process of repeated cycles of creation and destruction of oceanic crust is known as the 'Supercontinent cycle', a term first proposed by Tuzo Wilson, the Canadian geophysicist and geologist in 1965.

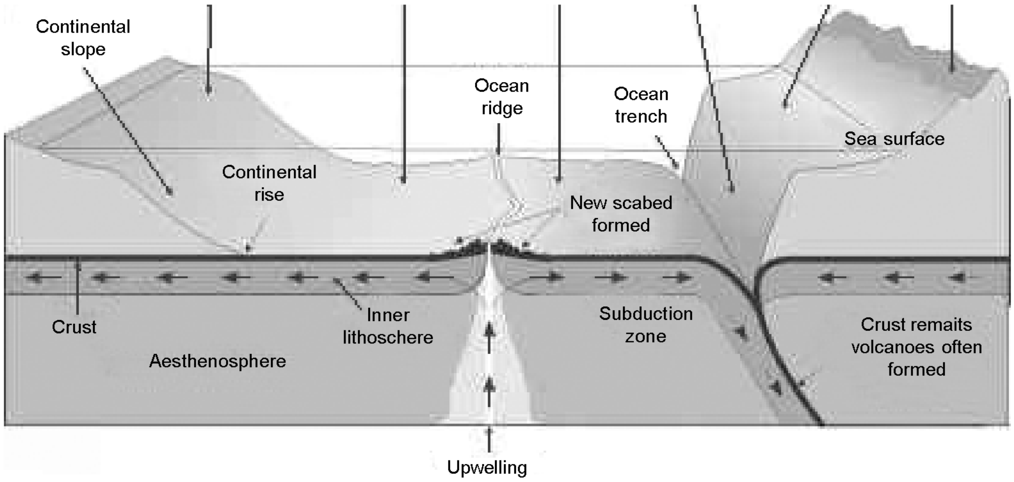

Fig. 23 : Formation of condinental slope and rise

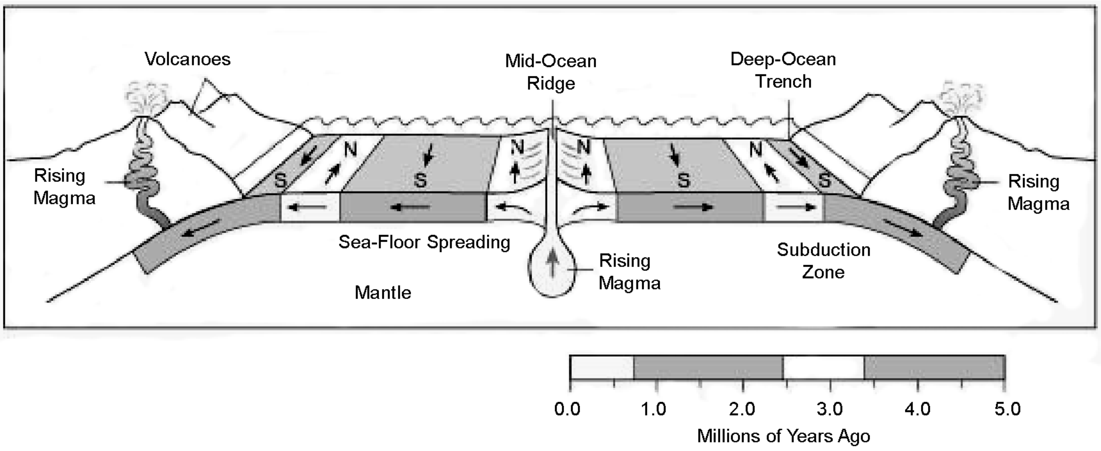

Fig. 24 : Formation of Mid-oceanic ridge

It is also believed that the oceanic crust closest to the mid-oceanic ridges, is mostly basalt at shallow levels and has a rugged topography. The roughness of this topography results from the function of the rate at which the mid-ocean ridge is spreading. Magnitudes of spreading rates vary significantly. Typical values for rapid-spreading ridges are greater than 100 mm/yr, while slow-spreading ridges are typically less than 20 mm/yr. Studies have shown that the slower the spreading rate, the rougher the new oceanic crust becomes, and vice versa. It is assumed that this phenomenon is the result of faulting at the mid-ocean ridge when the new oceanic crust was formed. These faults pervading the oceanic crust, along with their bounding abyssal hills, are the most common tectonic and topographic features on

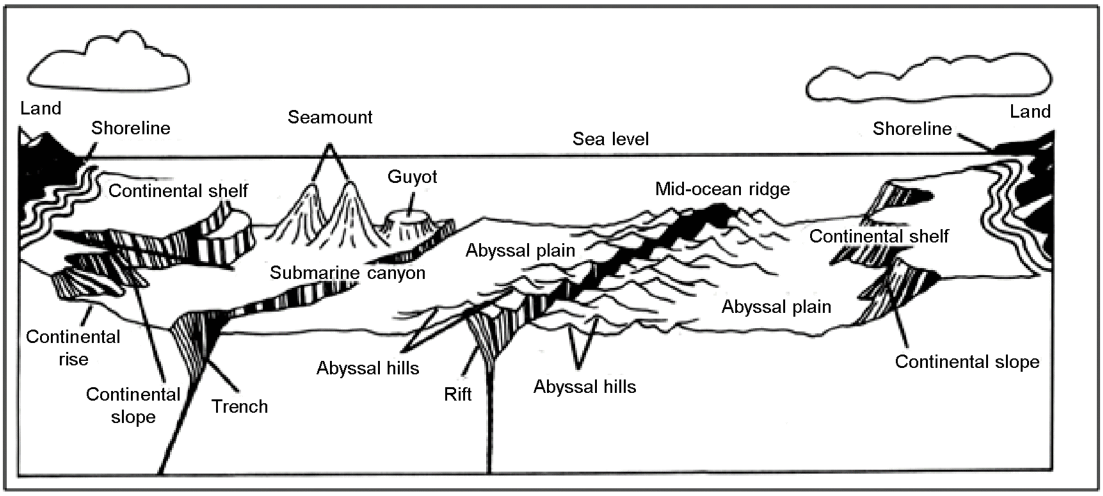

Fig. 25 : Formation of submarine canyon, guyot, seamount, trench

the earth's surface. The process of seafloor spreading helps to explain the concept of continental drift which is the basic concept behind the theory of Plate Tectonics.

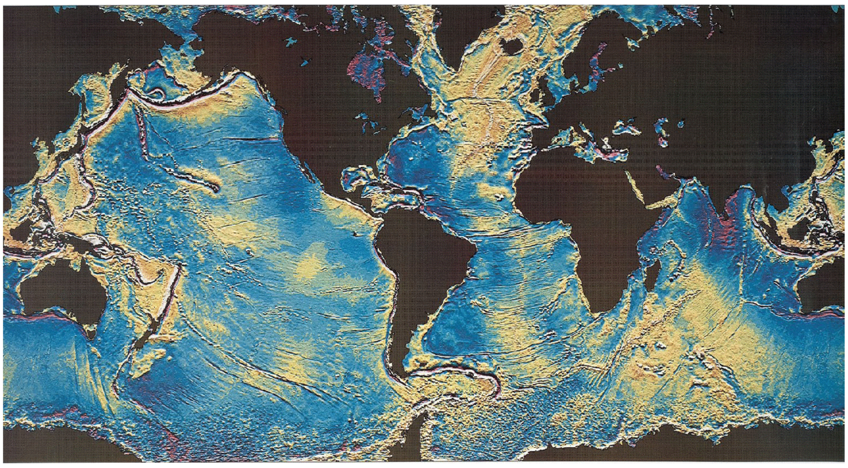

Fig. 26 : Condition of the sea floor (Abyssal Plain)

The flat appearance of mature abyssal plains results from the blanketing of this originally uneven surface of oceanic crust by fine-grained sediments, mainly clay and silt. Much of this sediment is deposited from turbidity currents that have been channeled from the continental margins along submarine canyons down into deeper water. The remainder of the sediment comprises chiefly dust (clay particles) blown out to sea from land, and the remains of small marine plants and animals which sink from the upper layer of the ocean, known as pelagic sediments. The total sediment deposition rate in remote areas is estimated at two to three centimeters per thousand years. Sediment-covered abyssal plains are less common in the Pacific Ocean than in other major ocean basins because sediments from turbidity currents are trapped in oceanic trenches that border the Pacific Ocean.

1.5 Plate Tectonics and the ocean floor

It has now been established that the shape of the ocean floor and its boundary is largely the result of a process called plate tectonics. The outer rocky layer of the earth comprises about a dozen large sections called tectonic plates which are arranged like a sperical jig-saw puzzle floating on top of the earth's hot layer pf mantle. Convection currents in the molten mantle drive the plates to slowly move about the earth a few centimetres per year. Many ocean floor features are the result of the interactions that occur at the edge of the plates. The continuously moving plates may converge, diverge or transform relative to each other. With convergence of plates one plate may get subdued under the other causing earthquakes, volcanic eruptions or creating deep ocean trenches such as Mariana Trench. Where plates diverge from each other molten magma flows upward between the plates forming mid-ocean ridges, underwater volcanoes and new ocean floor crust. The Mid-Atlantic Ridge is an example of this type of plate boundary. Transform boundaries are formed when two plates, adjacent to each other, slide past one another and cause earthquakes.

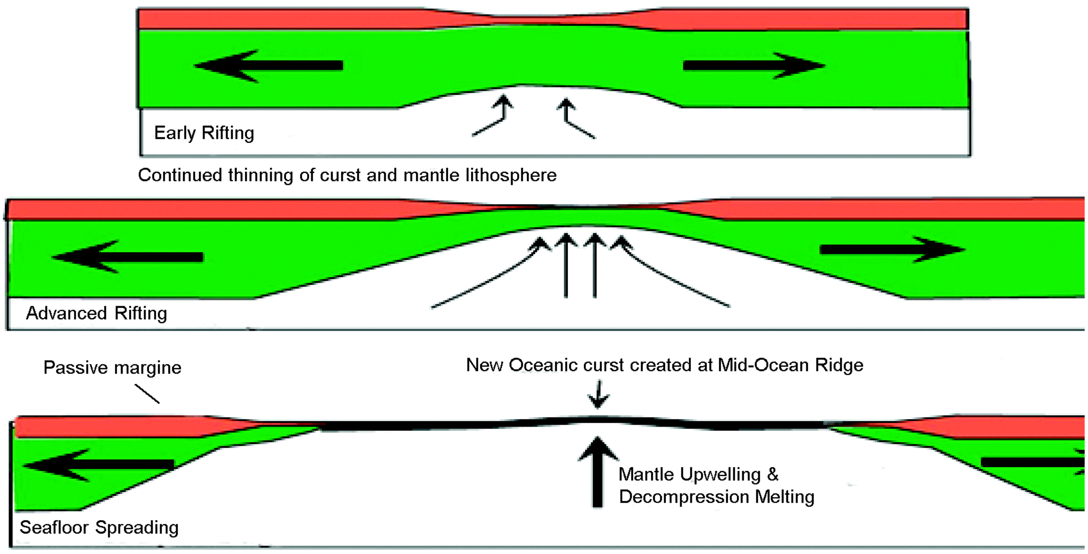

Fig. 27 : Plate movement and formation of oceanic crust

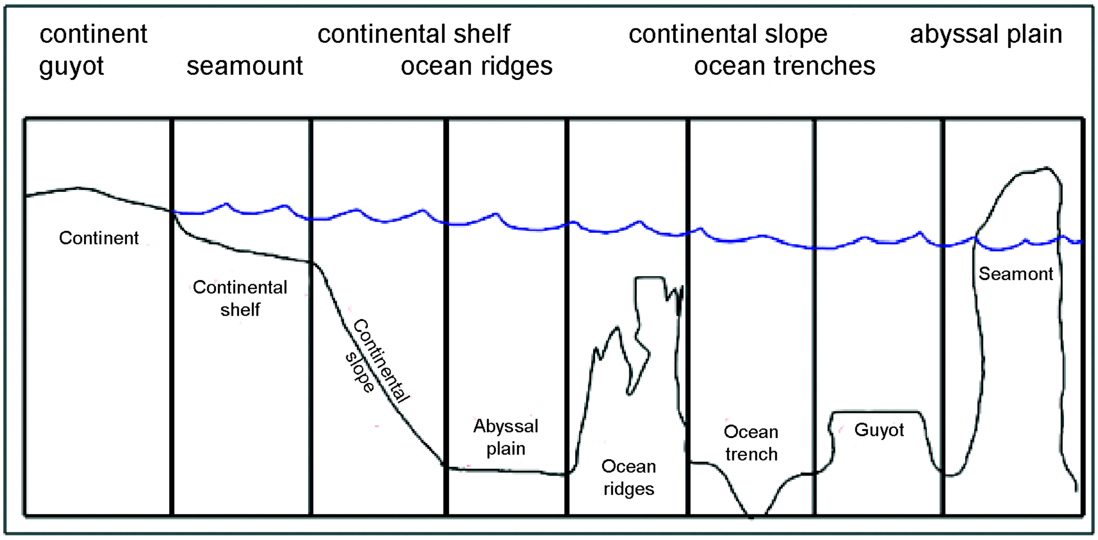

Fig. 28 : Ocean floor features

1.6 Summary and Conclusion

The study of oceanic bottom topography is found very significant to the leaners as it helps in understanding many aspects of oceanography that are discussed in the subsequent units. Moreover, how the plate techtonics can shape the bottom topography of the ocean, starting from the continental shelf, continental slope up to the continental rise and a mid-oceanic ridge, abyssal plains, which all are jointly cover more than 50% of the earth's surface.

1.7 Key words

Continental shelf, continental slope,continental rise, mid-oceanic ridge, abyssal plains, plate techtonics

1.8 Model Questions

Short answer type :

1. What is continental shelf ?
2. What is continental slope ?
3. What is abyssal plains ?

Long answer type :

1. Discuss the role of plate techtonics in the formation of various bottom topography of the ocean.
2. Explain the major relief features of the ocean floor.

1.9 References

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Unit - 2 ❑ Water Mass : Physical and Chemical Properties of Ocean Water

Structure

2.1 Introduction

This unit is going to discuss the concept of water mass and the physical and chemical properties of ocean water. This study is very much important to a leaners of geography because this prior knowledge is required before reading the other relevant concept of ocean water and ocean resources. The research on related to the discussed matter in oceanography is become interesting and attaractive to the learners in their future.

2.2 Objectives

- To know the water mass.
- To know the types of water mass.

- To know the physical properties of ocean water.
- To know the chemical properties of ocean water.
- To learn about T-S diagram.

2.3 Water Mass of the Oceans

Water mass is a body of ocean water with a certain range of temperature and salinity, and a particular density resulting from these two parameters. Water masses are formed as the result of climatic effects in specific regions. The vast majority of water masses are formed at the surface of the oceans in middle and high latitudes as a result of climatic effects. Cold, highly dense surface water sinks until it reaches a level having the same constant density, where it spreads out horizontally. The manner in which it spreads out depends upon its density in relation to the density of the surrounding water. This pattern is maintained for nearly all water masses, except those of low latitudes—in particular, the equatorial water masses of the Indian and Pacific Oceans. These water masses are formed by the mixing of subsurface waters. Water masses are generally distinguished by their location in the Worlds' oceans, and their vertical position. So there are surface water masses, intermediate water masses and deep water masses. Surface water masses set their T-S (Temperature-Salinity) properties at the ocean surface when comes in contact with the atmosphere. These properties are conserved during their subsurface movement. It is thus quite natural to identify water masses from observations using their T-S properties. Because of their subsurface journey, water masses are at the core of mass, heat, oxygen, nutrient and freshwater transports and redistribution; both at local and global scales.

Water Masses

Water masses may be classified as :

Depth Basis

1. Surface	→ (a) upper	→	< 300	m
	→ (b) Lower	→	300-800	,,
2. Intermediate		→	800-2000	,,
3. Deep		→	2000-4000	,,
4. Bottom		→	> 4000	,,

Controlling Factors Basis :

1. Latitude of regions
2. Degree of Isoline
3. Types of Curren

Indian Ocean

Indian Ocean	**T (°C)**	**S (‰)**
1. Indian Central	6-15	34.5 - 35.4
2. Indian Equatorial	4-16	34.8 - 35.2
3. Indian deep & Antarctic cum polar	5-2	34.7 - 34.7
4. Antaretic Interregion	2-6	3.4.4 - 34.7
5. Red sea	9	35.5

North Atlantic	**T (°C)**	**S (‰)**
2. Sub Arctic	3°C - 5°C	34.7 - 34.9‰
3. North Atlantic Central	4°C - 17°C	35.1 - 36.2‰
4. North Deep	3°C - 4°C	34.9 - 35.0‰
5. North Bottom	1°C - 3°C	34.8 - 34.9‰
6. Mediterranean	6°C - 10°C	35.3 - 36.4‰

South Atlantic	**T (°C)**	**S (‰)**
7. South Atlantic Central (Intermediate)	5 - 16	34.3 - 35.6‰
8. Antarctic	3°C - 5°C	34.1 - 34.2‰
9. Sub Antarctic	3°C - 9°C	33.8 - 34.5‰
10. Atlantic Circumpolar	0.5°C - 2.5°C	34.7 - 34.8‰
11. South Atlantic deep and bottom	0°C - 2°C	34.5 - 34.6‰
12. South bottom	–0.4°C	34.65

Pacific Ocean

North Pacific	T (°C)	S (‰)
1. North Pacific sub Arctic	2°C - 10°C	33.5 - 34.4
2. Pacific Equatrial	6°C - 16°C	34.5 - 35.2
3. Eastern North Pacific Central	10°C - 16°C	34.0 - 34.6
4. N. W. Pacific	7°C - 16°C	34.1 - 34.6
5. Arctic Intermediates	6°C - 10°C	34.0 - 34.1
6. Pacific Deep + Bottom	(–)1°C-(–)3°C	34.6 - 34.7
South Pacific	**T (°C)**	**S (‰)**
7. S. E. Pecific	9°C - 16°C	34.5 - 35.1
8. SW Pacific	7°C - 16°C	34.5 - 35.5
9. Antare intermediate	4°C - 7°C	34.3 - 34.5
10. Sub Antarctic Pacific	3°C - 7°C	34.1 - 34.6
11. Pacific deep & Antarctic circumpolar	(–)1°C-(–)3°C	34.6 - 34.7

2.4 Physical and Chemical properties of Ocean Water

The most important property of seawater is its high salinity. It makes the water of the oceans different from the lakes and rivers of fresh water. Greater than 96% of seawater is made up mainly of liquid in which chloride (Cl^-) and sodium (Na^+) are the dominant dissolved chemicals.

By weight, chloride (Cl^-) and sodium (Na^+) together comprise more than 85.65 percent of all dissolved substances in seawater. When these two ions bond chemically into a solid, they form halite and give seawater its most distinctive property – its salinity. The six most abundant ions, namely chloride (Cl^-), sodium (Na^+), sulfate ($SO_4{}^{2-}$), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+) make up more than 99% of all of seawater's solutes. The addition of five more solutes are bicarbonate (HCO^{3-}), bromide (Br^-), boric acid (H_3BO_3), strontium (Sr^{2+}) and fluoride (F^-). Altogether they make up 99.9%.

While surface temperatures of the sea have been measured from space for over 3 decades, the technology to measure sea surface salinity from space has only recently come into process. Salinity in the ocean is defined as the grams of salt per 1000 grams of water. Salinity varies due to evaporation and precipitation over the ocean as well as addition of water by river runoff and ice melt. Along with temperature, it is a major factor in contributing to changes in density of seawater and thereby ocean water circulation. Even minor changes in the salinity of the oceans can have impacts on the climate. The Aquarius mission, launched on June 10, 2011, is the first mission with the primary goal of measuring sea surface salinity (SSS) from space. Data from Aquarius will play an important role in understanding climate change and the global hydrological cycle.

Sea surface density, a driving force in ocean circulation and a function of temperature and salinity can be measured every month on a global scale. As the oceans have 1100 times the heat capacity of the atmosphere, the ocean circulation becomes critical for understanding the transfer of heat over the earth and thus understanding the pattern of climate change.

2.5 Variations in the Physical Properties of Ocean Water

Studies on ocean environment in recent years have provided a good deal of information about variations in the fundamental properties of ocean water, i.e., variation of temperature, salinity, and density in the surface as well as at depths. These three important parameters of ocean water have been reviewed here.

(a) Variation of Temperature

Since the amount of solar energy reaching the earth's surface is maximum at the equator and decreases to the higher latitudes, ocean surface temperatures are found highest in the tropics and decrease towards the north and south poles. As a consequence isotherms generally trend in an east-west direction, parallel to lines of latitude. With the variation of Insolation (incoming solar radiation) with the seasons, the sea surface temperatures change accordingly. The intense sunlight in the tropics and subtropics produces a temperature higher than 25°C, which shifts from north to south with the seasons. In comparison, the polar seas are very cold; in some places even below 0°C. Seasonal shifts of isotherms are minor in the ocean around Antarctica, but are marked in the North Pacific and North Atlantic Oceans. Ocean currents, flowing around the periphery of each ocean, affect the distribution of sea surface temperature. For example, the equatorial bands of warm water (>25°C) in the tropical Atlantic and Pacific Oceans are much broader at their western extremities than at their eastern margins. This distortion is produced by currents that send warm water toward the poles along the western coasts of oceans and cold water towards the equator along their eastern margins.

Investigations on the water temperature conditions with depth reveal that the oceans in the middle and lower latitudes have a layered thermal structure. A layer of warm water, several hundred to a thousand meters thick, floats over colder, denser water that fills up the rest of the basin. The two water masses (warm and cold) are separated from each other by a layer of water that has a sharp temperature gradient, called the thermocline. In the mid-latitudes, there occurs a seasonal variation in the depth of the *thermocline*, which varies between 40 to 100m during the summer months. The daily (diurnal) thermoclines occur at very shallow water depths (less than 12m).

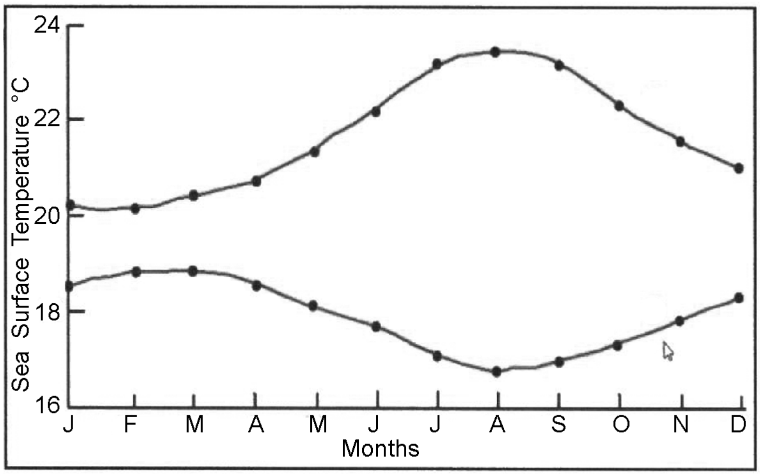

Fig. 29 : Monthly variation of sea surface temperature for (A) northern hemiespheric ocean and (B) for southern hemispheric oceans

Unlike the surface water, where temperature changes by the hour, day, and the season, water below the permanent thermocline maintains a low, stable temperature over time, averaging less than 4°C for most of the oceans. Thus, the most voluminous waters in the tropical oceans are cold, and not the warm waters of the thin surface layer above the thermocline. In the oceans of temperate and tropical regions, the thermocline is a permanent hydrographic feature, and lies at a depth ranging from 200 to 1000 m. Ocean water freezes only when temperature drops below 1.9°C.

The monthly sea surface temperature values in the northern hemispheric oceans always remain higher than those in the southern hemispheric oceans. This is due to the occurrence of large areas of cold water in high latitudes of the southern hemisphere. The maximum sea surface temperature difference of 6.6°C between the two hemispheric oceans is found during the month of August and the minimum difference of 1.4°C is observed in the month of February.

(b) Variation of Salinity

Variation in the salinity of surface waters also shows a latitudinal dependence. The highest salinity of surface waters is found between 20 to 30 degrees north and south latitude and decrease toward the equator and the poles. Salinity variations are caused by addition or removal of water. Processes that remove water include evaporation and the formation of ice. Precipitation (rain, snow, and sleet), river runoff, and melting ice add water, diluting the salinity of seawater and reducing its density. Since these processes are largely dependent on climate, and climate varies with latitude, the salinity of surface seawater varies directly with latitude

It can be seen that maximum sea surface salinity occurs in the subtropics and minimum near the equator and the Polar Regions. In order to estimate the salinity for any latitude, the total amount of evaporation for one year is subtracted from the total precipitation for the same year. If the result is a positive value, then evaporation has exceeded precipitation, and salinity in this region will be higher than normal. A negative value denotes the converse, that is, precipitation exceeds evaporation, and salinity here is lower than normal. The rate of evaporation depends strongly, though not exclusively, on temperature and, hence, varies directly with latitude, being very low in the polar and sub-polar regions, rising in the middle latitudes, and being highest in the subtropics and tropics. By contrast, rainfall maxima occur in the tropics and temperate latitudes, and minima in the subtropics and high latitudes. Therefore, during the course of a year, there is a net exc ess of precipitation over evaporation in the tropics and temperate latitudes, and an excess of evaporation over precipitation between 20 and 35 degrees latitude, where, not surprisingly, most of the major land deserts occur.

At the equator, evaporation rates are high, but rainfall is even greater, leading to the lower surface salinity in these waters. In mid-latitudes, rainfall rates surpass evaporation rates to an even greater degree than they do in the tropics, which reduces salinity to less than 34‰. Surface salinity in the polar seas ?uctuates with seasons as ice forms and melts. The water of the coasts and continental shelves is diluted by the freshwater of rivers. A case in point is the Amazon River, which injects more than 5 ß 10^{11} cubic meters of freshwater into the western South Atlantic Ocean each year, greatly lowering the salinity.

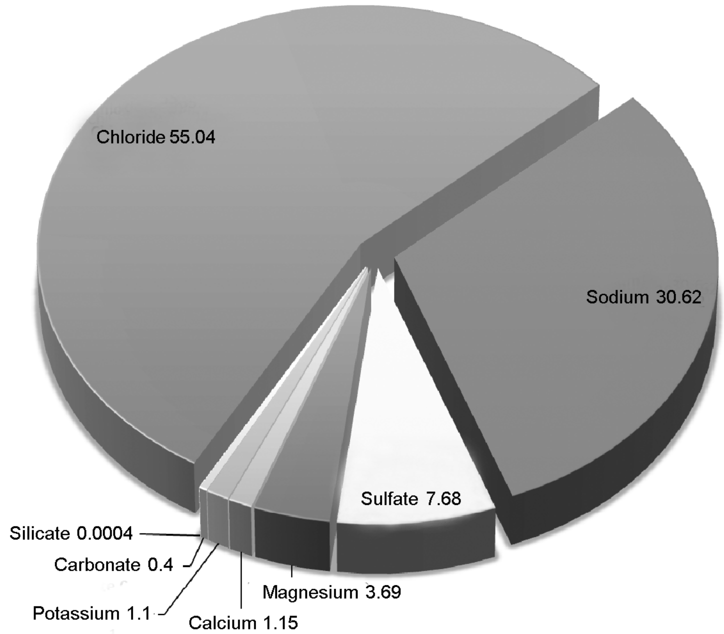

Fig. 30 : Oceanic salinity composition

With temperature, sharp salinity gradients characterize the water column of the oceans. These gradients are termed *haloclines* and represent boundary zones between distinct water masses of different densities. A north-south longitudinal profile of salinity in the western Atlantic Ocean shows a well-d eveloped layering of water masses. Water stratification (layering) is evident between 40°N and 40°S latitudes, where a lens of high-salinity (35‰) surface water is separated from less saline water below by a sharp halocline. Also, two tongues of water with salinities of less than 34.74‰ extend northward from the Antarctic region: one at about a 1,000-meter depth, the other along the deep-sea bottom. These tongues indicate that their water originated at the sea surface in the south polar seas and are separated from each other by a water mass that flowed southward out of the North Atlantic Ocean. A remarkable matter is the uniform salinity of about 34.9‰ in the North Atlantic water below a depth of 2 kilometers. This condition shows that once water sinks, it is no longer in contact with the atmosphere, where precipitation and evaporation alter the salinity. Hence, the salinity of deep water remains unchanged over time; although very slow mixing processes not well understood do eventually change the salinity of water masses.

(c) Variation of Density

Density of seawater depends very much on the temperature, salinity, and pressure conditions. Because of the fact that water is essentially incompressible, pressure affects density only in the deepest parts of the ocean. It can, however, be observed that, if water were absolutely incompressible, sea level would be 50m higher than its present state.

Water density controls the vertical structure of the water column, with denser water underlying the less dense water. The density of water increases with decreasing temperature and increasing salinity, thus implying that cold, saline water is denser than warm freshwater. It is however, possible that waters with higher salinity and higher temperature may overlie waters with lower salinity and lower temperature, If vertical gradients of water temperature (called *thermoclines*) and salinity (*haloclines*) exist in the ocean, then it is reasonable to accept that density, which is dependent on these two factors, will show a similar gradient (*pycnocline*). Density strati?cation of the ocean imposes a three-layered structure on the water column. These are: a surface layer, a pycnocline layer, and a deep layer.

Surface Layer : This layer is ~100m thick, 2% of ocean volume and with least density because of higher temperature. Since it is in contact with the atmosphere, its water is affected by weather and climate, which cause diurnal, seasonal, and annual ?uctuations of salinity and temperature. Light penetrates to the bottom of this zone, which allows plant photosynthesis to occur wherever nutrient levels are adequate. In the Polar Regions, cooling of this layer produces dense water which sinks readily. This sinking process prevents the formation of a pycnocline in the oceans of the high latitudes.

Pycnocline Layer : this forms the boundary zone between the surface-water and deep-water layers. Its sharp density gradient is referred to as the thermocline by many oceanographers because there is a dominant control of temperature over density. This corresponds to permanent thermocline in low latitudes, because of strong and persistent heating of the water by the tropical sun. In mid-latitudes this layer weakens and coincides with the halocline, which is produced by the abundant rainfall that dilutes the salinity of the water in the surface layer.

Deep Layer : This layer assumes temperature less than 4°C and constitutes ~80% of the total volume of the oceans. This originates in the high latitudes, where it is cooled while in contact with the frigid polar atmosphere. This cold polar water sinks to the ocean bottom because of high density, and ?ows gradually towards the equator, forcing surface waters into oceanic depths.

(d) Variation of Pressure

Along with salinity and temperature, pressure at different depths in the oceans is another important parameter influencing the physical characteristics of sea water. Pressure is measured in atmospheres. An atmosphere is defined as the pressure exerted per square cm by a column of mercury 76cm high. In the CGS system pressure is reckoned as dyne/cm^2, and 1 atmosphere is equal to 1.0133 ß 10^6 dyne/cm^2. 10^6 dyne/cm^2 is equal to 1 bar, which is approximately equal to 1 atmosphere. Pressure within the oceans increases with increasing depth. In fact, for every 10 meters of water depth, there is an increase of 1 atmosphere (≈1 bar) in pressure. In other words, the hydrostatic pressure in the sea increases by 1 decibar at approximately each meter of depth. Pressure at a depth of 2000 m is over 200 bars. In considering pressures in the ocean, the atmospheric pressure is always neglected and the pressure at the surface of the ocean is taken as zero. As the pressure is essentially a function of depth and the numerical value in decibars is equal to the depth in metres, the range in pressure is taken as zero (0) at the surface of the ocean to more than 10,000 decibars in the deepest part of the ocean. In order to descend to greater ocean depths, scientists and explorers must use specially designed equipment like remotely operated vehicles and manned submersibles that can operate under extreme pressures.

(e) Variation in Colour

Clear ocean water appears deep blue. Since more than three fourths of the earth's surface is under oceanic waters, the earth appears as a blue planet as seen from the space. The reason the ocean is blue is due to the absorption and scattering of light. Sea water absorbs all but the shortest wavelengths of the visible spectrum, viz., the blue and violet. When sunlight falls on the ocean, much of it penetrates through its surface and gets absorbed. Only a small portion, the blue and violet wavelengths, are scattered in a manner similar to the scattering in the atmosphere, imparting to the oceans a blue colour. In shallow waters however, as for instance in coastal regions, some of the light is reflected by the sea bottom and/or suspended sediments which are contributed by rivers or are agitated into suspension by wave action.

Suspended particles of sediment or other substances like phytoplankton (algae) bring about an increase in the scattering of light of different wavelengths. In coastal areas, runoff from the rivers, agitation of sand and silt from the bottom by tides, waves and storms and a number of other substances can change the colour of the near-shore waters. The most important light-absorbing substance in the oceans is chlorophyll, which phytoplankton use to produce carbon by photosynthesis. Due to this green pigment, phytoplankton preferentially absorbs the red and blue portions of the spectrum, but reflect the green. So over regions with high concentrations of phytoplankton, the oceans will appear in shades ranging from blue-green to green, depending upon the type and density of the phytoplankton population.

2.6 Variations in Chemical Properties of Ocean water

It has been found that many characteristics of ocean water are similar to those of fresh water. In marine chemistry the solvent properties of water are of primary interest. The solubility of substances, especially ionic compounds, is much higher in water than in other solvents. This high solubility results from the atomic structure of the water molecule with the hydrogen atoms tightly bound to oxygen and separated by a 105o angle, giving the water molecule a dipolar charge balance. Because of their dipolar configuration, water molecules tend to interact strongly with each other, as well as with other solute molecules. This property makes water a near-universal solvent and makes the ocean a chemical soup containing almost all elements in solution in some amount.

Seawater is a complex mixture of 96.5% water, ~3.5% salts, and smaller amounts of other substances, including dissolved organic materials such as carbohydrates and amino acids, organic-rich particulates and gases like nitrogen, oxygen, argon and carbon dioxide. It constitutes a rich source of various commercially important chemical elements. The six most abundant ions that make up 99% of all sea salts are chloride (Cl^-), sodium (Na^+), sulfate (SO_2^{4-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+). Apart from these, inorganic carbon, boron, bromide, strontium and fluoride are the other major dissolved substances. Minor chemical constituents in sea water are inorganic phosphorous and nitrogen. Salinities in the open ocean have been observed to range from about 34 to 37 parts per thousand, which may also be expressed as 34 to 37 practical salinity units psu (a measure of salinity based on seawater conductivity). In certain parts of the world, common salt (NaCl) is still obtained by evaporating seawater. It is also a rich source of magnesium and bromine.

The chemical composition of sea water is influenced by a wide variety of chemical transport mechanisms. Rivers add dissolved chemicals to the oceanic margins. Wind-borne particulates are carried to mid-ocean regions thousands of km from their continental source areas. Hydrothermal solutions circulating through crustal materials beneath the seafloor add both dissolved and particulate materials to the deep ocean. Much of the dissolved constituents of seawater are extracted by organisms in the upper ocean and converted to solids, which eventually settle to oceanic depths. Particulates in transit to the seafloor, as well as materials on and within the seafloor, undergo chemical exchange with surrounding solutions. Through these local and regional chemical input and removal mechanisms, each element in the oceans tends to exhibit spatial and temporal concentration variations. Physical mixing in the oceans on account of thermohaline and wind-driven circulation, tends to homogenize the chemical composition of seawater. The opposing influences of physical mixing and of biogeochemical input and removal mechanisms result in a substantial variety of chemical distributions in the oceans. The chemical constituents of seawater can be reckoned in three major categories – major ions, trace elements and dissolved gases.

(a) Major Ions

The major ions in seawater makes a significant contribution to measured salinity. This definition is generally taken to mean elements present in concentrations greater than 1 part per million (ppm) in oceanic water. The chemical and physicochemical properties of seawater can be attributed to the 13 major ions that make up over 99.90% of the material dissolved in seawater. These ions are listed in Table 1 below. These major ions exist primarily as free ions, but small amounts form ion pairs due to the electrostatic interaction between the highly charged ions in solution. Ion pairing becomes significant for sulfate ions, which can form ion pairs with magnesium, calcium, and strontium. Only half of the sulfate in seawater exists as a free ion.

Table–1 The major ions of seawater

Ion	g/kg at S = 35	% as free ion	% by wt of total major constituents
Na^+	10.78	99	30.68
Mg^{2+}	1.283	87	3.65
Ca^{2+}	0.4119	91	1.17
K^+	0.399	99	1.13
Sr^{2+}	0.0079	90	0.02
Cl^-	19.344	100	55.03
SO_4^{2-}	2.711	50	7.71
HCO3–	0.1 135	67	0.32
Br^-	0.0672	100	0.19
$B(OH)^3$	0.0203	–	0.06
CO_3^{2-}	0.0116	–	0.03
$B(OH)_4^-$	0.0066	10	0.02
F–	0.0012	100	0.01
			100.00

The primary source of major ions to the ocean is riverine input. Once these ions enter the ocean, their existence time becomes very long compared to the mixing time for the oceans. The total salt content (or salinity) of a seawater sample may change with depth or location in the ocean, due to precipitation, evaporation or mixing. However, the ratio of the major ions varies only slightly in the open ocean. This concept, known as constancy of composition, or Marcet's principle, results from the fact that the oceans are well mixed in relation to the major constituents.

(b) Trace Elements

Those elements found in seawater are considered trace elements. The dissolved gases and some nutrient elements are undeniably trace species. Important trace elements in seawater are listed in Table–2 below. Trace elements exhibit an enormous range of chemical reactions and enter widely into the biochemical and geochemical cycles of the ocean. The concentrations and residence times have large variations both geographically and with depth. Like the major ions, riverine input is the primary source of trace elements to the ocean, accounting for over 90% of the total. Other significant inputs come from ice transport (mainly from Antarctica) and atmospheric dust. Removal of trace elements from the ocean results from a combination of adsorption onto particulate material, biological uptake, and perhaps precipitation of a few elements. Such processes result in short residence times for trace elements and make their concentrations low in seawater.

Table-2 Important trace elements in seawater. Broecker, W. S. and T. H. Peng (1982).

Lithium	Tin	Cesium	Scandium
Rubidium	Copper	Cerium	Lead
Iodine	Arsenic	Yttrium	Mercury
Barium	Uranium	Silver	Gallium
Indium	Nickel	Lanthanum	Bismuth
Zinc	Vanadium	Cadmium	Niobium
Iron	Manganese	Tungsten	Thallium
Aluminum	Titanium	Germanium	Gold
Molybdenum	Antimony	Chromium	Praseodymium
Selenium	Cobalt	Thorium	

(c) Dissolved Gases

Sea water also contains various dissolved atmospheric gases, mainly nitrogen, oxygen, argon, and carbon dioxide. Virtually all atmospheric gases are found dissolved in sea water. Unlike the major sea water components the primary source for dissolved gases in seawater are not rivers but the atmosphere.

(d) Temperature

Cold water holds more gas than warm water, a features which have been noticed with bottles of fizzy drink, which are basically carbon dioxide in water. A warm fizzy drink cannot hold its gas, so as soon as a bottle is opened the carbon dioxide leaves the water in a big spray of bubbles.

(e) Salinity

Sea water with low salinity holds more gas than high salinity water.

(f) Pressure

Deep water, which has a high pressure, holds more gas than shallow water. Dissolved oxygen and carbon dioxide are vital for marine life. Marine plants use dissolved carbon dioxide, sunlight and water to make carbohydrates through the process of photosynthesis. This process releases oxygen into the water. All marine organisms use oxygen for respiration, which releases energy from carbohydrates and has carbon dioxide and water as byproducts. Marine animals with gills, such as fish, use these organs to extract oxygen from the seawater. The seawater exchanges dissolved gases with the atmosphere to keep a balance between the ocean and the atmosphere. This exchange is helped by the mixing of the surface by wind and waves.

2.7 T-S Diagram

In oceanography temperature-salinity diagrams, sometimes called T-S diagrams, are used to identify water masses. In a T-S diagram, rather than plotting each water property as a separate 'profile,' with pressure or depth as the vertical coordinate, potential temperature (on the vertical axis) is plotted versus salinity (on the horizontal axis).

As long as it remains isolated from the surface, where heat or fresh water can be gained or lost, and in the absence of mixing with other water masses, a water

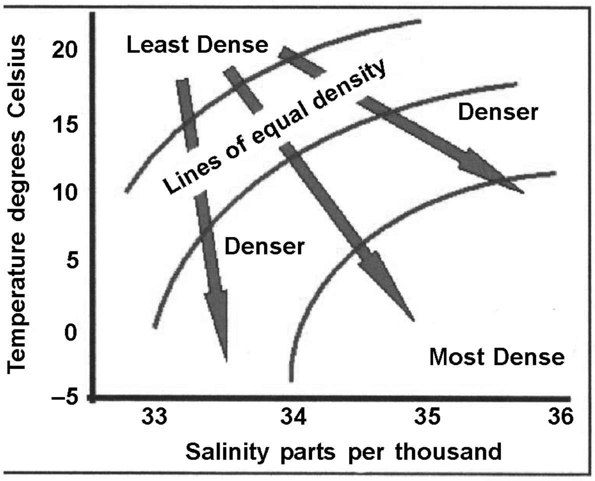

Fig. 31 : Format of a T-S Diagram

parcel's potential temperature and salinity are conserved. Deep water masses thus retain their T-S characteristics for long periods of time, and can be identified readily on a T-S plot.

2.8 Summary and Conclusion

The studies of ocean environment in recent years have provided a good deal of information about the properties of ocean water temperature, salinity, density in the surface as well as at depths. The water masses are formed at the surface of the oceans in middle and high latitudes as a result of climatic effects. There are surface water masses, intermediate water masses and deep water masses. The most important properties of seawater are salinity and temperatures and the relationship of these two are often expressed by the T-S diagram. These concepts are thoroughly discussed in this unit and the learners are came to know these broadly.

2.9 Key words

Water mass, physical properties of ocean water, chemical properties of ocean water, T-S diagram

2.10 Model Questions

Short answer type :

1. What is water mass ?
2. Classsify water mass.
3. State the characteristics of water mass.
4. What is T-S diagram ?

Long answer type :

1. Classify water masses and account for their features.
2. Explain the physical and chemical properties of ocean water.

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Unit - 3 ❑ Ocean Temperature and Salinity : Distribution and determinants

Structure

3.1 Introduction

The most important properties of seawater are salinity and temperature and the determinants and distribution of these two are discussed in this unit. Therefore, the learners are came to know the temperature and salinity of Pacific, Atlantic and Indian oceans. The properties of these two are varied latitudinally and depth wise, which can effect the surrounding environment. Moreover, the density of seawater depends very much on the temperature, salinity, and pressure conditions, which also explain in this unit.

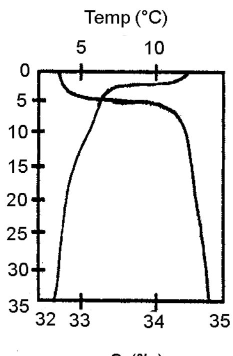
3.2 Objectives

- To know the factors controlling salinity.
- To know the distribution of salinity.
- To know the factors controlling temperature.
- To know the distribution of temperature.
- To know about density of seawater.

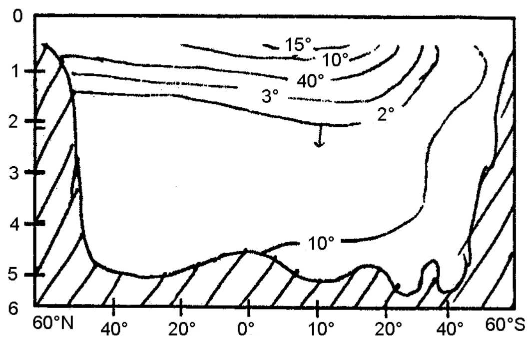
3.3 Temperature of the Ocean Water

The temperature of the sea water is measured in degrees centigrade to an accuracy of + 0.020°C, oceanic temperature ranges between –2°C and +30°C; at the lower limit ice forms. The potential temperature of sea water is defined as the temperature that it would have if it were raised adiabatically to the surface. The freezing-point of sea water depends on the salinity, ranging from –0.5°C at a salinity of 10‰ to just below –2°C at a salinity of about 36‰.

The distribution of temperature in the surface layers of the ocean reflects the general distribution of heat supply from the sun received from the sun the value of heat received from the sun sis greratest at the equator and decreases towards the poles, but not at the same rate. Thus a surplus of heat occurs between the equator and 30° latitude and a net defit from there to the poles.



—A Themocline
—A Halocline



• Temperature in Pacific

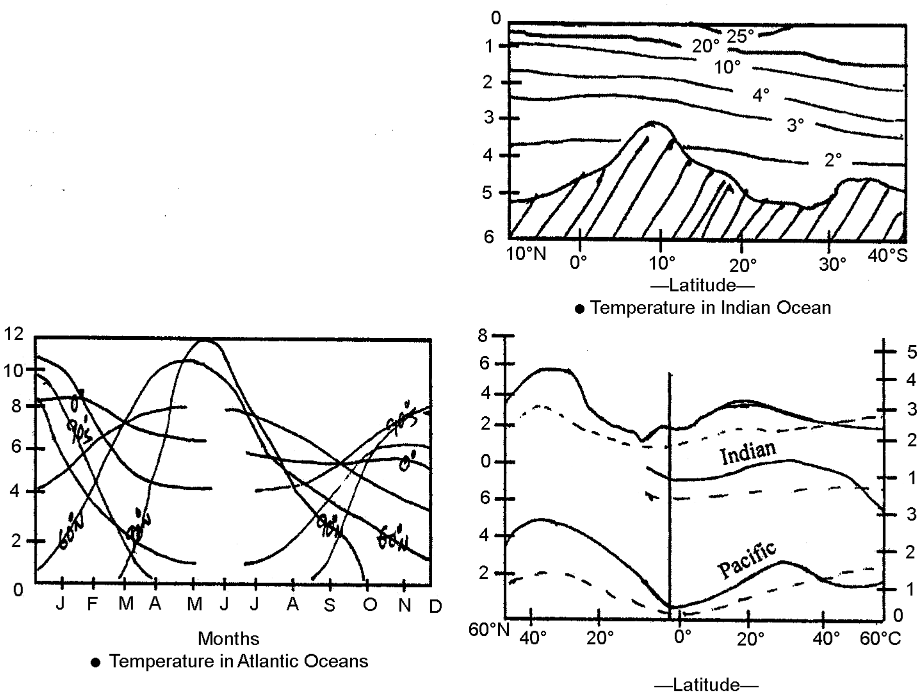


Fig. 32 : Temperature in different Ocean

3.4 Heat Budget of the Oceans

All the supply of radiation energy received from the sun is balanced by equally large losses energy. The important factors are :

1. The radiation energy received from the sun.
2. The interchange of sensible heat with the atmosphere.
3. Evaporation from the sunface of the sea or the condensation of atmosphere water vapour. All the may tabalatide as follows :

Table for Heat Budget of the Oceans

Heat Sources	Heat Losses
1. Absorption of Solar Radiation (Qs) 2. Convection of Sensible heat from atmosphere to the sea	1. Radiation from the sea surface (Qb) 2. Convection of sensible heat from sea to atmosphere (Qa)

Heat Sources	Heat Losses
3. Conduction of heat through the sea from the interior of the earth. 4. Conversion of Kinetic energy into heat. 5. Heat produced by bio-chemical processes 6. Condensation of water vapour on the sea surface 7. Radioactive disintegration in the sea water.	3. Evaporation from the sea surface (Qe)

The heat budget equation of the oceans is given below :

$Q_s - Q_b - Q_h - Q_e = 0$

Where Q_s = heat received by the ocean surface;

Q_b = back radiation from sea surface;

Q_h = convection on sensible heat to the atmosphere;

Q_e = the heat of evaporation

The temperature of the surface waters (the mixed layer) varies mainly with latitude. The polar seas (high latitude) can be as cold as –2 degrees Celsius while the Persian Gulf (low latitude) can be as warm as 36 degrees Celsius. The average temperature of the ocean surface waters is about 17 degrees Celsius.

There is a boundary between surface waters of the ocean and deeper layers that are not mixed. The boundary usually begins around 100-400 meters and extends several hundred of meters downward fromthere. This boundary extends several hundred of meters downward from there. This boundary region, where there is a rapid decrease of temperature, is called the thermocline. 9‰ of the total volume of ocean is found below the thermocline in the deep ocean.

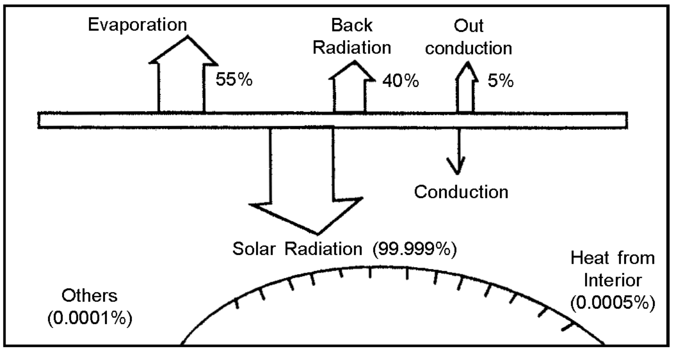


Fig. 33 : Heat budget of the Oceans

The density of ocean water continuously increases with decreasing temperature until the water freezes. Ocean water, with an average salinity of 35‰ freezes at – 1.94 degrees Celsius.

3.5 Salinity of the Ocean Water

3.5.1 Introduction

Salinity is defined as the ratio between the weight of the dissolved material and the sample of sea water expressed in parts per 10 million (ppm).

The amount of chlorine is normally used to determine the salinity, and its ratio to that of the other chemicals is constant, the total salinity can be obtained. It is expressed as parts per thousand by weight, g./kg. or usually ‰. In the open ocean the salinity normally varies between 33‰ and 37‰ it can reach values below the level where much fresh water enfers from large rivers, or exceed in areas where the influx from the land in negligible and where the surface evaporation is considerable, as for example, in the Red Sea, where it exceeds 40‰.

3.5.2 Controlling factors of Salinity :

The major controlling factors of salinity are describes as follows :

(a) Evaporation : The process of evaporation on the sea water is responsible for the concentration of salts which in turn increases the salinity of the oceans. According to Wust, the total evaporation from the ocean amounts to 331,000 KM^3 per year. This may be excessive in regions of higher temperature, strong steady winds and less rainy days. In fact, the process of evaporation in the sea water increases the boiling point and decreases the vapour tensions slighty and the ratio between the temperature and the humidity gradients of the air is small or nearly constant throught the year in low latitudes, but greater in the middle latitudes. Thus due to excessive evaporation and higher temperature, humidity ratio in the lower middle latitudes near Tropic of Cancer and Tropic of Capricorn in lower and salinity is higher. On the contrary, salinity is relatively low in equatotial regions due to evaporation and high relative humidities. He salient features of evaporation as a controlling factors are the following :

(i) The evaporation varies from the eastern to the western parts of the ocean and also from one season to another.

(ii) Evaporation increases with strong winds like trade winds and westerlies and also when the sea water is warmer than the air.

(b) Precipitation : It is another factor controlling the salinity of the oceans. In equatorial regions, in spite of high temperature, the salinity is less because these are the zones of heavy rainfall which reduces salinity. Again in the polar and sub-polar regions there is an excessive amount of precipitation in the form of snow and when the melt water subsequently reaches the sea, it adds fresh water and hence reduces salinity.

(c) River water : The amount of salinity of sea water also varies due to the influex of fresh water by the rivers. Hence near the mouths of rivers Amazon, Congo, Niger, Ganges and St. Lawrence comparatively lower salinity is recorded. Such effect is also noticed along the coasts in the enclosed seas such as Baltic Sea, the Gulf of Bothnia and also in the Black Sea where the rivers like Danube, Dneister and Dneiper pour fresh water in to the sea. On the other hand the salinity is appreciably higher in the Mediterranean Sea where the influx of fresh water is comparatively less than the amount of evaporation.

(d) Atmosphere Pressure and Wind Direction : Salinity changes slightly due to winds resulting from difference in atmospheric pressure. For instance, Winds from high pressure area over the North Sea move towards the low pressure area over the Baltic, thereby raising the amount of salinity of the Baltic sea to a slight extent. Similarly, the strong winds blowing throughout the year carry much of the warm and saline water from the western shores of the land in lower middle latitudes and from the eastern shores of the land in the lower middle latitudes and from the eastern shores in the higher latitudes resulting in the variation of salinity distribution of sea water.

(e) Movement of sea water : Tidal currents, cold and warm currents and drifts are also considered as controlling factors of salinity since the latitudinal movements of sea water and mixing of water affect the salinity of oceans.

(f) Periodic variations of salinity : The difference between Precipitation and evaporation is also responsible for the periodic variation of salinity. Bohnecke has computed the oceanic water budget and observed that salinity is higher in spring than in Fall.

3.5.3 Composition of Salinity :

The salinity in the oceans is generally between 33‰ and 37‰. In the region of high rainfall on dilution by large rivers the surface salinity may be considerably less and in certain semicircular areas, such as Gulf of Bothnia, it may be less than by 5‰. On the other hand in isolated seas in intermediate latitudes where evaparalion is excessive as in the Red sea, salinity may reach 40‰ or higher. As the range in the open ocean in rather samll, it is sometimes convinent to be the salinity of 35‰ as an average of all the ocean.

The normal chemical content of sea water with a total salinity of 35‰ is as follows :

1.	Chloride	19.353 (in gm/kg.)
2.	Sodium	10.760
3.	Sulphate	2.712
4.	Magnesium	1.234
5.	Calcium	0.413
6.	Potassium	0.387
7.	Bi-Carbonate	0.142
8.	Bromide	0.067
9.	Strontium	0.008
10.	Boron	0.004
11.	Fluoride	0.001

Name	Symbol	Percentage
1. Chloride	Cl–	55.07
2. Sodium	Na+	30.62
3. Sulphate	SO_4^{-2}	7.72
4. Magnesium	Mg^{2+}	5.68
5. Calcium	Ca^{2+}	1.17
6. Potassium	K^+	110
		99.36

These six salts constitute 99% of ocean water and the remaining 1% are Trace Elements.

3.5.4 Variation in the Distribution of Salinity

The salinity varies between 33 ppm to 37 ppm. The characteristress of variation of surface salinity may be presented as :

1. The higher of region rainfall or dilution by large river, the surface salinity may be considerably low in certain semi enclosed areas such as Gulf of Bothnia, Deat sea, below 5 ppm.
2. In isolated areas (seas) in the Intermediate latitude where evaporation where is excessive such as Red sea salinity may reach 40 ppm and more.
3. As the rain in the open ocean is rather small its salinity is low. Salinity 35 ppm as an average for all oceans.

3.5.4.1 Horizontal Distribution of Surface Salinity

In all oceans the surface salinity varies with latitude in a similar manner. It is at a minimum near the equator, reaches at a maximum in about 20° N and 20° S and again decreases towards high latitudes.

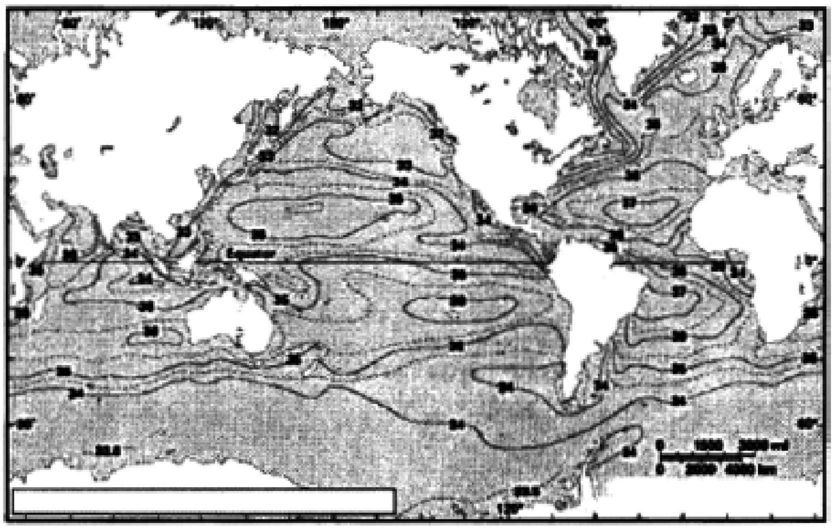


Fig. 34 : Distribution of Salinity

Table-3 Surface Salinity

	Northern Hemisphere				Southern Hemisphere			
Latitude	**S(‰)**	**E (cm/yr)**	**P (cm/yr)**	**E-P**	**S(‰)**	**E (cm/yr)**	**P (cm/yr)**	**E-P**
0°	35.08	119	102	17	35.08	119	102	17
10°	34.72	129	127	2	35.34	130	96	34
20°	34.44	133	65	68	35.69	134	70	64
30°	35.66	120	65	55	34.62	111	64	47
40°	34.54	94	93	1	34.79	81	84	–3
50°					33.99	43	84	–41

S–Salinity, E–Evaporation and P–Precipitation

On the basis of these values, Wiist has shown that for each ocean the elevation of the surface salinity form a standard value is directly proportional. In the following diagram, surface salinity are plotte for all the oceans and the difference of E-P, as function of latitudes and the corresponding values of salinity and the difference. E-P are plotted against each other in the scatter diagram. The value fall nearly on a straight line leading to the empirical relationship. S = 34.60 + 0.0175 (E-P)

1. Decrease of salinity by precipitation.
2. Increase of salinity by evaporation.
3. Change of salinity by the process of mixing.

3.5.4.2 Vertical Distribution of Salinity

Salinity in the ocean decreases or increases towards the bottom according to the nature of the water mass. Although the salinity generally decreases at depth, the role cold or warm water mass is significant in bringing about drastic changes in the vertical distribution of temperature. For example, at the southern boundary of the Atlantic, surface salinity is 33‰ increasing to 34.5‰ at 365.8 m and still deeper at 1097.3 m it reaches up to 34.75‰. Again, at 20° S the surface salinity of 37‰ decreases up to 35‰ at the bottom. At the equatorial region of Indian Ocean, the surface salinity of 34‰ increases with the depth to 35‰ due to greater mixture of fresh water at the surface.

Generally it can be said that in high latitude salinity increases with depth due to dense water found at the bottom, whereas in the middle latitudes, salinity increases with depth up to 365.8 m and then decreases with increasing depth of the oceans.

3.5.5 Temperature - Salinity Relationship

Temperature and Salinity are represented in a scatter diagram called **T-S Diagram.**

The characteristics of water masses by T-S diagram are represented :

1. Temperature is a function of salinity.
2. Practical significance of TS curve.
3. T-S curve and mixing of water masses.

(a) Temperature is a function of salinity

Temperature + salinity vary with depth. An investigation of these corelating features based mainly on a graphical of the variation of these quantities with depth. Assuming salinity as a function of Temperature or plotting Salinity against T in a system of coordinates (say in Katesian (Co-Ordinates System) S as 'x' and T as 'y'. The Plotting for each depth are not distributed at random over the diagram but fall on a definite more or less smooth curve called T-S curve/T-S Diagram. For open ocean with uniform oceanographic, spatial, climatic as well as undistrubed flow continued. The T-S relationship is quite characteristic. A given temperature correspends to a given salinity regardless of the depth. Any given water mass is characterised by a definite T-S diagram. If this water mass is then oceanographic facts in homogeneous it are constant and it can be represented on a TS diagram by a single plot.

Beneath the top layer with distrubance however continued in the ocean are quasi standard or T-S curves can thus be constructed different oceanic region and conclusion can be drawn about the origin and a spreading of water mass for the development of the value at a parts of station from these of the standard curve.

(b) Practical Significance of T-S curve

The practical significance was first plotted out by Helland & Hausen (1918), and then it has become important in oceangraphic summarised as follows.

1. T-S curve offers advance in the scientific preparation of the oceanographic data.
2. Used to detect errors. If the value for a depth at an oceanographic station does not fall on a simple curve and usually smooth curve it can be confidently assumed that there is an observational error or a fault is the computation. The T-S curve is thus a reliable criteria of the accuracy and homogeneity of a set of data for any oceanographic station. The curve for neighboring station are similar, all values can be checked and corrected immidiately.
3. In this way its pass by interpolation of oceanographic value to fill up many of the gaps in the observational matter for different oceanographic station.

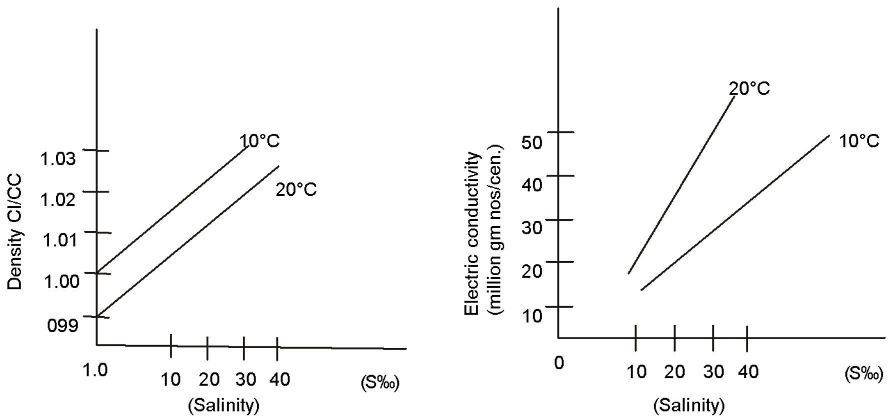
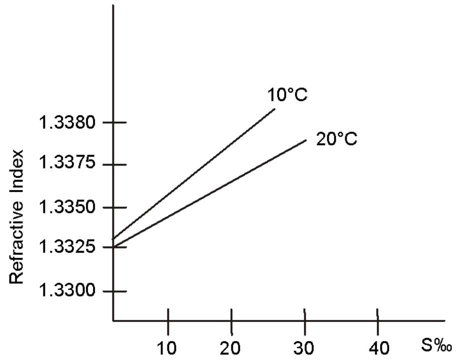


Fig. 35



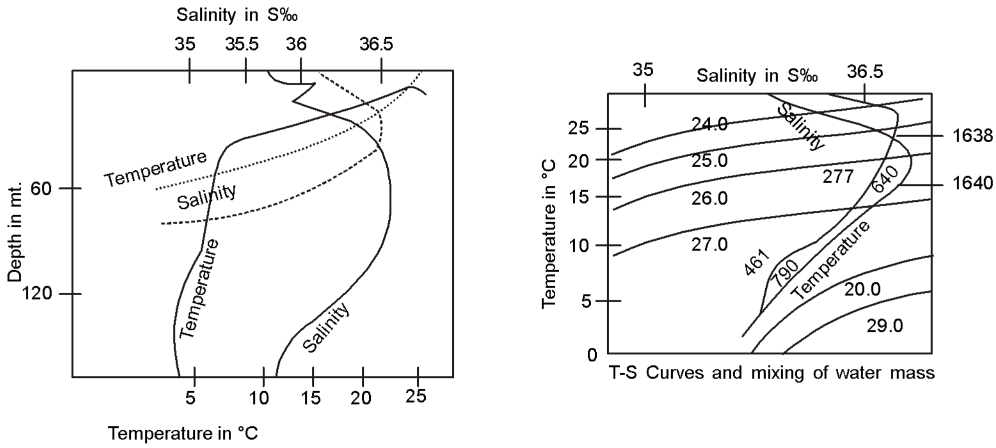


Fig. 36 : T-S Curve

(c) T-S Curve and Mixing of water masses

If two homogeneous water masses are mixed in a given proportion, the mixture will have a definite T-S curve. Each of these water masses is characterised by two plots say $w_1 + w_2$ with T and S represented for each as $t_1s_1 + t_2s_2$ are mixed is the ratio of $m_1 : m_2$ and the resulting water mass is bigger.

$$T = \frac{m_1t_1 + m_2t_2}{m_1 + m_2} \qquad S = \frac{m_1s_1 + m_2s_2}{m_1 + m_1}$$

$$T_0 = \frac{\sum Tm}{m} \qquad S_0 = \frac{\sum Sm}{m}$$

3.6 Summary and Conclusion

The study of the two most important properties of seawater, i.e. salinity and temperature; and the the determinants and distribution of these two are found very significant to the leaners. It helps in understand behavioural aspects, the thermo-haline properties of ocean water, the significance of T-S diagram that are discussed in the other units of oceanography.

3.7 Key words

Oceanic salinity, oceanic temperature, factors controlling salinity, factors controlling temperature

3.8 Model Questions

Short answer type :

1. What is oceanic salinity ?
2. What is oceanic temperature ?

Long answer type :

1. State the factors controlling oceanic salinity and temperature.
2. Discuss the distribution of oceanic salinity and temperature of the major oceans of the earth.

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Unit - 4 ❑ Air-Sea Interactions, Ocean Circulation, Wave and Tide

Structure

4.1 Introduction

This unit is going to discuss the concept of air-sea interaction, oceanic circulation, wave and tide. It also explains the El Nino, which is a warm phase of a larger phenomenon called the El Nino-Southern Oscillation (ENSO); while La Nina is the cool phase of ENSO phenomena, that describes the unusual cooling of the region's surface waters. Besides, tides and waves are natural phenomenon formed on the related to water bodies. These studies are very much important to a leaners of geography because this prior knowledge is required before reading the other relevant concept of ocean water and development of coral reef. The oceanic research are occupaying a large part these discussed concepts of oceanography.

4.2 Objectives

- To know the air-sea interaction.

- To know the oceanic circulation.
- To know the the concept of wave.
- To know the types and process of tide.
- To lern about El Nino, La Nina, ENSO phenomena.

4.3 Air-Sea Interactions

Air-sea interaction through gas (atmospheric) exchange is a physio-chemical process, primarily controlled by the air-sea difference in gas concentrations and the exchange coefficient, which determines how quickly a molecule of gas can move across the ocean-atmosphere boundary. It takes about one year to equilibrate CO_2 in the surface ocean with atmospheric CO_2. So it is not unusual to observe large air-sea differences in CO_2 concentrations. Most of the differences are caused by variability in the oceans due to biology and ocean circulation. The oceans contain a very large reservoir of carbon that can be exchanged with the atmosphere because the CO_2 reacts with water to form carbonic acid and its dissociation products. As atmospheric CO_2 increases, the interaction with the surface ocean will change the chemistry of the seawater resulting in ocean acidification.

Evidence suggests that the past and current ocean uptake of anthropogenic (human-derived) CO_2 is primarily a physical response to rising atmospheric CO2 concentrations. Whenever the partial pressure of a gas is increased in the atmosphere over a body of water, the gas will diffuse into that water until the partial pressures across the air-water interface are equilibrated. However, because the global carbon cycle is intimately embedded in the physical climate system there exist several feedback loops between the two systems. For example, increasing CO_2 modifies the climate which in turn impacts ocean circulation and therefore ocean CO_2 uptake. Changes in marine ecosystems resulting from rising CO_2 and/or changing climate can also result in changes in air-sea CO_2 exchange. These feedbacks can change the role of the oceans in taking up atmospheric CO_2 making it very difficult to predict how the ocean carbon cycle will operate in the future.

The study of air-sea interactions shows how the atmosphere and ocean affect each other through the exchange of heat, momentum, and water across the air-sea interface. In natural process the atmosphere receives heat from the ocean, thus affecting the atmospheric circulation and surface winds, which in turn generate ocean currents and the large scale ocean circulation. The spatial range of interactions extends from local heat fluxes to surface wave generation, formation of hurricanes, Arctic sea ice melt, and the nearly global scale of El Nino. Understanding how this tightly joined system works is critical to our knowledge of climate and how it might change in the future.

4.4 El Nino Condition

El Nino is a climatic phenomenon occurring when a vast pool of water in the eastern tropical Pacific Ocean becomes unusually warm. Under usual conditions, the warm water and the rains it drives are in the western Pacific. Thus it is a climate pattern that describes the unusual warming of surface waters in the eastern tropical Pacific Ocean. El Nino can be called a warm phase of a larger phenomenon called the El Nino-Southern Oscillation (ENSO). La Nina, the cool phase of ENSO, is a pattern that describes the unusual cooling of the region's surface waters. El Niño and La Niña are considered the ocean part of ENSO, while the Southern Oscillation is its atmospheric changes. El Niño has an impact on ocean temperatures, the speed and strength of ocean currents, the health of coastal fisheries, and local weather from Australia to South America and beyond. Its events occur irregularly at two- to seven-year intervals.

El Nino and La Nina

(a) Introduction :

El Nino and La Nina are considered a significant weather phenomena or events, which observed mainly in Peru and Chile coasts of South America. In this portion, one can understand what an El Nino and La Nina is, how it occurs, what are the effects, how these become an important phenomenon particularly for the countries near to the Pacific Ocean, how these affect the weather of India.

(b) Concept of El Nino :

El Nino is a subsurface warm current flow from north to south between 3°S to 36° S latitudes near the Peru and Chile coasts of South America. The term 'El Nino' comes from the Spanish word meaning 'the little boy'. It has also termed as 'The Christ Child'.

(c) Features of El Nino :

- El Nino was first recognized by Peruvian fishermen off the coast of Peru as the appearance of unusually warm water.
- The Spanish immigrants called it El Nino, meaning "the little boy" in Spanish.
- El Nino soon came to describe irregular and intense climate changes rather than just the warming of coastal surface waters.
- The El Nino event is not a regular cycle, they are not predictable and occur irregularly at two to seven-year intervals.
- The climatologists determined that El Nino occurs simultaneously with the Southern Oscillation. The Southern Oscillation is a change in air pressure over the tropical Pacific Ocean.
- When coastal waters become warmer in the eastern tropical Pacific (El Nino), the atmospheric pressure above the ocean decreases.
- Climatologists define these linked phenomena as El Nino-Southern Oscillation (ENSO).

(d) How does El Nino and La Nina Occur?

El Nino can be understood as a natural phenomenon wherein the ocean temperatures rise especially in parts of the Pacific ocean. It is the nomenclature which is referred to for a periodic development along the coast of Peru. This development is a temporary replacement of the cold current along the coast of Peru. El Nino is a Spanish word. The term El Nino basically means 'the child'. This is due to the fact that this current starts to flow around Christmas and hence the name referring to baby Christ.

Another natural phenomenon, similar to El Nino is La Nina, which is also in news these days. The term La Nina literally means 'little girl'. It is termed as opposite to the phenomenon of El Nino as it results in the 'cooling' of the ocean water in parts of the Pacific ocean. Both of them also result in changes in atmospheric conditions along with oceanic changes.

(e) El Nino Southern Oscillation (ENSO)

It is called El Nino Southern Oscillation. In normal times, when the tropical south Pacific ocean experiences high pressure, alternatively the tropical Indian ocean experiences low pressure conditions. However, these pressure conditions are sometimes reversed, and results in low pressure in the Pacific and alternatively high pressure in the Indian ocean. This is the periodic change in pressure conditions which is referred to as the Southern Oscillation. These changes in the pressure conditions being developed in the Pacific and Indian oceans are connected with the phenomenon of El Nino. This connected phenomenon is referred to as the El Nino Southern Oscillations or the ENSO.

(f) Impact of El Nino :

- In order to understand the concept of El Nino, it's important to be familiar with non-El Nino conditions in the Pacific Ocean. Normally, strong trade winds blow westward across the tropical Pacific, the region of the Pacific Ocean located between the Tropic of Cancer and the Tropic of Capricorn.
- **Impact on Ocean :** El Nino also impacts ocean temperatures, the speed and strength of ocean currents, the health of coastal fisheries, and local weather from Australia to South America and beyond.
- **Increased Rainfall :** Convection above warmer surface waters brings increased precipitation. Rainfall increases drastically in South America, contributing to coastal flooding and erosion.
- **Diseases caused by Floods and Droughts :** Diseases thrive in communities devastated by natural hazards such as flood or drought. El Nino-related flooding is associated with increases in cholera, dengue, and malaria in some parts of the world, while drought can lead to wildfires that create respiratory problems.
- **Positive impact :** It can sometimes have a positive impact too, for example, El Nino reduces the instances of hurricanes in the Atlantic.
- **In South America :** As El Nino brings rain to South America, it brings droughts to Indonesia and Australia. These droughts threaten the region's water supplies, as reservoirs dry and rivers carry less water. Agriculture, which depends on water for irrigation, is also threatened.
- **In Western Pacific :** These winds push warm surface water towards the western Pacific, where it borders Asia and Australia. Due to the warm trade

winds, the sea surface is normally about 0.5 meter higher and 4-5° F warmer in Indonesia than Ecuador. The westward movement of warmer waters causes cooler waters to rise up towards the surface on the coasts of Ecuador, Peru, and Chile. This process is known as upwelling. Upwelling elevates cold, nutrient-rich water to the euphotic zone, the upper layer of the ocean.

(g) Specific Effects of El Nino :

- El Nino results in the rise of sea surface temperatures
- It also weakens the trade winds of the affected region
- In India, Australia, it can bring about drought conditions. This affects the crop productivity largely.
- It has been also observed certain times, that El Nino may not bring drought but cause heavy rainfall. In both the cases, it causes heavy damage. In some other countries it may result in a complete reversal, i.e., excessive rainfall.
- The coast of Peru in South America has a higher pressure than the region near northern Australia and South East Asia, which was completely changed during El Nino time.
- The Indian Ocean is warmer than the adjoining oceans and so, has relatively lower pressure. Hence, moisture-laden winds move from near the western Pacific to the Indian Ocean. But the pressure distribution of Indian subcontinents is changed by the effect of El Nino.
- The pressure on the landmass of India is lower than on the Indian Ocean, and so, the moisture-laden winds move further from the ocean to the lands. If this normal pressure distribution is affected for some reason, the monsoons are affected by the El Nino.

(h) Mitigation of El Nino Effects :

- Keeping a check on the sea surface temperatures
- Maintaining sufficient buffer stocks of food grains and ensuring their smooth supply
- Ensuring relevant support to the farmer community including economic help
- Alternative ways to be promoted such as the practice of sustainable agriculture

(i) Previous El Nino Events :

- El Nino events of **1982-83 and 1997-98** were the **most intense** of the 20^{th} century.
- During the **1982-83** event, sea surface temperatures in the eastern tropical Pacific were 9-18° F above normal.
- The El Nino event of **1997-98** was the first El Nino event to be **scientifically monitored from beginning to end**.
- The 1997-98 event produced drought conditions in Indonesia, Malaysia, and the Philippines. Peru and California experienced very heavy rains and severe flooding.
- The Midwest experienced record-breaking warm temperatures during a period known as **"the year without a winter."**

La Nina

(a) Introduction :

La Nina means The Little Girl in Spanish. It is also sometimes called El Viejo, anti-El Nino, or simply "a cold event." La Nina events represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific. It is indicated by sea-surface temperature decreased by more than 0.9°F for at least five successive three-month seasons.

(b) Features of La Nina :

- La Nina event is observed when the water temperature in the Eastern Pacific gets comparatively colder than normal, as a consequence of which, there is a strong high pressure over the eastern equatorial Pacific.
- La Nina is caused by a build-up of cooler-than-normal waters in the tropical Pacific, the area of the Pacific Ocean between the Tropic of Cancer and the Tropic of Capricorn.
- La Nina is characterized by lower-than-normal air pressure over the western Pacific. These low-pressure zones contribute to increased rainfall.
- La Nina events are also associated with rainier-than-normal conditions over south-eastern Africa and northern Brazil.

- However, strong La Nina events are associated with catastrophic floods in northern Australia.
- La Nina is also characterized by higher-than-normal pressure over the central and eastern Pacific.
- This results in decreased cloud production and rainfall in that region.
- Drier-than-normal conditions are observed along the west coast of tropical South America, the Gulf Coast of the United States, and the pampas region of southern South America.

(c) Impact of La Nina :

- **Europe :** In Europe, El Nino reduces the number of autumnal hurricanes.

  La Nina tends to lead to milder winters in Northern Europe (especially UK) and colder winters in southern/western Europe leading to snow in the Mediterranean region.
- **North America :** It is continental North America where most of these conditions are felt. The wider effects include :
  - ✓ Stronger winds along the equatorial region, especially in the Pacific.
  - ✓ Favourable conditions for hurricanes in the Caribbean and central Atlantic area.
  - ✓ Greater instances of tornados in various states of the US.
- **South America :** La Nina causes drought in the South American countries of Peru and Ecuador. It usually has a positive impact on the fishing industry of western South America.
- **Western Pacific :** In the western Pacific, La Nina increases the potential for landfall in those areas most vulnerable to their effects, and especially into continental Asia and China.
  - ✓ It also leads to heavy floods in Australia.
  - ✓ There are increased temperatures in Western Pacific, Indian Ocean and off the Somalian coast.

(d) Previous La Nina Events :

- The 2010 La Nina event correlates with one of the worst floods in the history of Queensland, Australia.
- More than 10,000 people were forced to evacuate, and damage from the disaster was estimated at more than $2 billion.

(e) ENSO and India :

- **El Nino :** Strong El Nino events contribute to weaker monsoons and even droughts in India Southeast Asia.
- **La Nina :** The cold air occupies a larger part of India than the El Nino cold air.
- In the 'La Nina year', rainfall associated with the summer monsoon in Southeast Asia tends to be greater than normal, especially in northwest India and Bangladesh.
- This generally benefits the Indian economy, which depends on the monsoon for agriculture and industry.
- It usually brings in colder than normal winters in India.
- La Nina influences the Indian subcontinent by piping in cold air from Siberia and South China, which interacts with the tropical heating to produce a north-south low-pressure system.
- The cold air of La Nina associated with this north-south trough tends to extend much further south into India.
- This is remarkably different from the more northwest-southeast blast of cold air associated with El Nino.
- The pressure pattern going north-south means lesser impact of western disturbances.
- The cold temperature can go down as far as Tamil Nadu, but may not affect the North East that much.

(f) El Nino and La Nina : Comparisons

- **El Nino** and **La Nina** are complex weather patterns resulting from variations in ocean temperatures in the Equatorial Pacific Region. They are opposite phases of what is known as the **El Nino-Southern Oscillation (ENSO)** cycle. The ENSO cycle describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific.
- El Nino and La Nina episodes typically last nine to 12 months, but some prolonged events may last for years.
- El Nino is a climate pattern that describes the unusual warming of surface waters in the eastern tropical Pacific Ocean.

- It is the "warm phase" of a larger phenomenon called the El Nino-Southern Oscillation (ENSO). It occurs more frequently than La Nina.
- La Nina, the "cool phase" of ENSO, is a pattern that describes the unusual cooling of the tropical eastern Pacific.
- La Nina events may last between one and three years, unlike El Nino, which usually lasts no more than a year.
- Both phenomena tend to peak during the Northern Hemisphere winter.

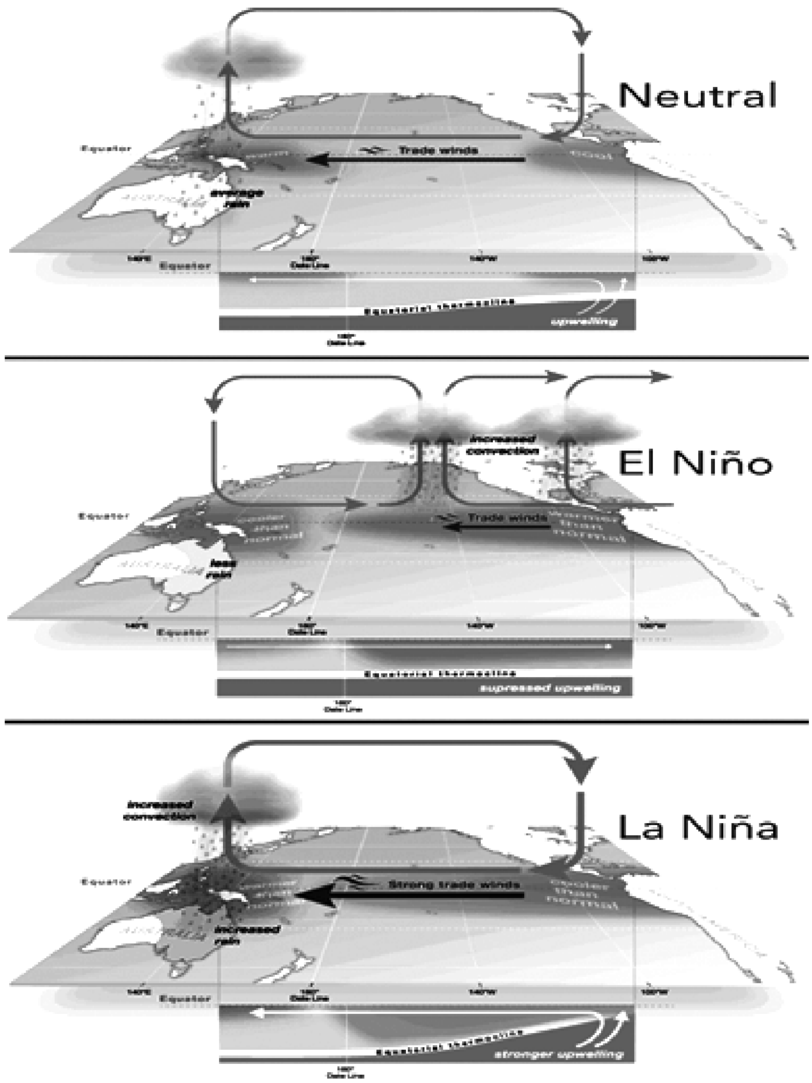

Fig. 37

(g) Monitoring El Nino and La Nina :

- Scientists, governments, and non-governmental organizations (NGOs) collect data about El Nino using a number of technologies such as scientific buoys.
  - A buoy is a type of an object that floats in water and is used in the middle of the seas as locators or as warning points for the ships. They are generally bright (fluorescent) in colour.
  - These buoys measure ocean and air temperatures, currents, winds, and humidity.
  - The buoys transmit data daily to researchers and forecasters around the world enabling the scientists to more accurately predict El Nino and visualize its development and impact around the globe.
  - The **Oceanic Nino Index (ONI)** is used to measure deviations from normal sea surface temperatures. The intensity of El Nino events varies from weak temperature increases (about 4-5° F) with only moderate local effects on weather and climate to very strong increases (14-18° F) associated with worldwide climatic changes.

(h) Oceanic Nino Index (ONI)

- **The Oceanic Niño Index (ONI)** is a measure of the departure from normal sea surface temperature in the east-central Pacific Ocean, is the standard means by which each El Nino episode is determined, gauged and forecast.

4.5 Ocean Circulation

Ocean circulation is the large scale movement of waters through the oceans. Winds drive surface circulation, and the cooling and sinking of waters in the Polar Regions drive deep circulation.

Surface circulation carries the warm part of the upper waters pole ward from the tropics. Heat is disbursed along the way from the waters to the atmosphere. At the poles, the water is further cooled during winter season, and sinks to the deep ocean. This is observed distinctly in the North Atlantic zone and along Antarctica. Deep ocean water gradually returns to the surface nearly everywhere in the ocean. Once at the surface it is carried back to the tropics, and the cycle is generated again. The more active the cycle, the more heat is transferred, and the warmer the climate.

Due to the rotation of the earth, currents are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This effect is known as the "Coriolis force." The deflection leads to highs and lows of sea level directly proportional to the speed of the currents at the ocean surface. The changes in sea level due to currents are the ocean topography that is observed by TOPEX/Poseidon.

(Launched in 1992, TOPEX/Poseidon is a joint venture between CNES and NASA that measured ocean surface topography to an accuracy of 4.2 cm, enabled scientists to forecast 1997-98 El Nino and improved understanding of ocean circulation and its effect on global climate)

Observations of ocean topography and knowledge of the Coriolis force permit scientists to map ocean currents using data from the satellite. Every ten days TOPEX/Poseidon produces maps of the currents everywhere in the ocean.

Variations in the ocean's circulation can lead to variations in heat transport and to variations in weather patterns. One important variation in the circulation is the change in the equatorial circulation known as El Niño which occurs with an irregular period of two to five years. The most recent El Niños have been observed with unprecedented accuracy by TOPEX/Poseidon.

4.6 Wave

Tides and Waves are natural phenomenon formed on the related to water bodies. Tides are the rise and fall of huge amounts of water. The cause of such rise and fall is the different interaction of gravitational forces exerted between the moons, the earth and, to some degree, the sun. By contrast, waves are simply the effects of powerful winds raging on oceanic surfaces and even on some other bodies of water like lakes, the cause for the rise and fall of water is probably the single most important difference that the two have.

(a) Wave : Characteristics and Generation

Waves are among the most familiar features in the ocean. All waves work similarly, so although we are talking about ocean waves here, the same information would apply to any other waves you might discuss in science classes.

Ocean waves transport energy over vast distances, although the water itself does not move, except up and down. This may surprise you, but if you think about it, once you are past the breakers on your raft, you pretty much just bob up and down. This orbital motion is explained in the figure below :

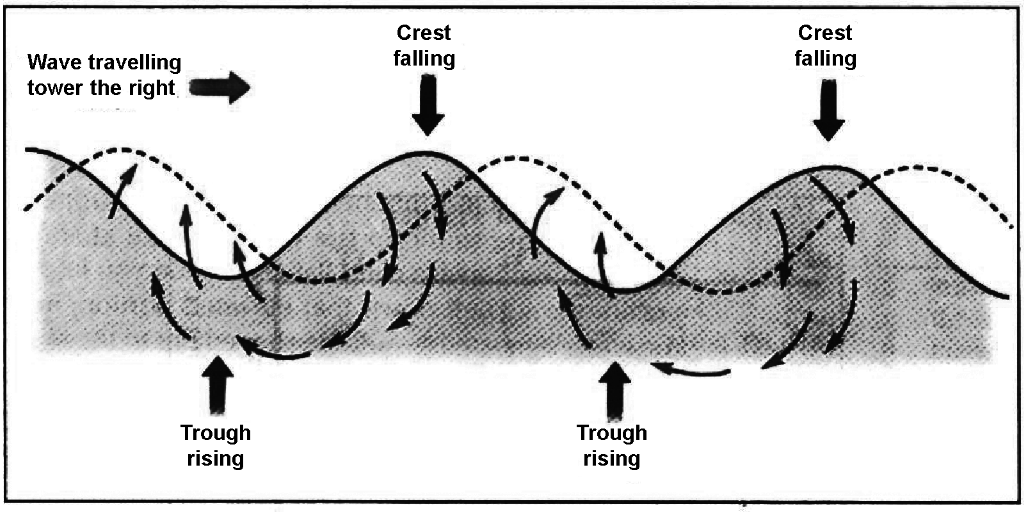

Fig. 38 : Rise and fall of waves

(b) Identification of dimension of waves

Crest - the very top of the wave

Trough - the hollow between two crests

Wave height - the vertical distance between the top of one wave crest and the bottom of the next trough

Wave length - the horizontal distance between any one point on one wave and the corresponding point on the next.

Wave steepness - the ratio of height to length

Amplitude - the maximum vertical displacement of the sea surface from still water level (half the wave height)

Period - the time it takes for one complete wavelength to pass a stationary point

Wave speed - the velocity with which waves travel

Deep water waves - waves that are in water that is deeper than half their wavelength

Shallow water waves - waves that are in water that is shallower than 1/20 their wavelength (the important difference on these last two is whether or not the sea floor influences the motion of the wave).

(c) Gravity wave generation

The degree of energy transfers from the atmosphere from the atmosphere to the ocean surface, and thus the degree of wave development depends upon three factors : (i) wind speed, (ii) wind duration and (iii) the distance (or fetch) over which the wind blows. Numerous wave-forecasting methods have been devised to predict wind wave characteristics from meteorological data. Waves formed in a storm area form a steep, short-lived and confused crests and troughs. However, as the waves move out of the area of generation they become sorted by wave period, with highest period waves moving most rapidly. This sorting process also narrows the wave spectrum, yielding swell waves of more regular wave heights, length and period. Such swell waves may travel over huge ocean distances with little energy loss before making landfall.

(d) Swash, backwash and the beach profile

Water movement and sediment transport under breakers of different types and subsequent breaker type-specific processes in the swash/backwash zone in part translate into changes in the beach profile. Long-period surging waves, characterised by a short burst of high onshore velocities at time of breaking, induce well-spaced, discrete swash packets on the beach, which in a simple and symmetrical pattern, decelerate, reverse and return as backwash before the arrival of the next wave. It can be seen how surging waves, particularly where percolation of swash volumes is high, as on beaches composed of coarse sediments, might be associated with build-up of the beach profile, whereas the high volumes of water on the beach and in the backwash under spilling wave conditions might be conductive to the combining of material from the beach and the flattening of the beach profile. Large tidal ranges have several effects on beaches as they retard the rate at which sediment transport and morphological changes occur, increase the importance of shoaling wave processes thus reducing beach gradients, inhibit bar formation, affect rip current flows at different states of the tide, and encourage the dominance of shore-parallel currents seaward of the lower intertidal zone.

(e) Properties of Waves

The source of energy for coastal erosion and sediment transport is wave action: A wave possesses potential energy as a result of its position above the wave trough, and kinetic energy caused by the motion of the water within the wave. This wave energy is generated by the frictional effect of winds moving over the ocean surface.

The higher the wind speed and the longer the fetch, or distance of open water across which the wind blows and waves travel, the larger the waves and the more energy they therefore possess. It is important to realize that moving waves do not move the water itself forward, but rather the waves impart a circular motion to the individual molecules of water. If you have ever gone fishing in a boat on the ocean or a large lake you will have experienced this phenomenon. As a moving wave passes beneath you, the boat rises and falls but does not move any distance across the water body.

Waves posses several measurable characteristics, including length and height. Wavelength is defined as the horizontal distance from wave crest to wave crest, while wave height is the vertical difference between the wave's trough and crest. The time taken for successive crests to pass a point is called the wave period and remains almost constant despite other changes in the wave. The length of a wave (L) is equal to the product of the wave period (P) and the velocity of the wave (V) :

$$L = V \times P$$

Long open-ocean waves or swells travel faster than short, locally generated sea waves. They also have longer wave periods and this is how they are distinguished from the short sea waves on reaching the coast. Long swells which have traveled hundreds of kilometres may have wave periods of up to 20 seconds. Smaller sea waves have wave periods of 5 to 8 seconds.

Where ocean depths are greater than the length of the waves, the wave motion does not extend to the ocean floor and therefore remains unaffected by the floor. As the ocean depth falls below half the wavelength, the wave motion becomes increasingly affected by the bottom. As the depth of water decreases the wave height increases rapidly and the wavelength decreases rapidly. Thus, the wave becomes more and more peaked as it approaches the shore, finally curling over as a breaker and breaking on the shore As the wave breaks, its potential energy is converted into kinetic energy, providing a large amount of energy for the wave to do work along the shoreline. If you have ever watched waves breaking on a shore you may have observed that the waves appear to climb out of the water and also catch up to one another.

4.7 Tide and Tidal Force

The alternating advance and retreat of seawater along a coastline is called a tide. High tide is when water advances to its furthest extent onto the shoreline. Low tide is when it recedes to its furthest extent. Some freshwater rivers and lakes can have tides, too. A high tide that is significantly higher than normal is called a king tide. It often accompanies a new moon and when the moon is closest to the Earth.

The moon's gravitational pull on the Earth and the Earth's rotational force are the two main factors that cause high and low tides. The side of the Earth closest to the Moon experiences the Moon's pull the strongest, and this causes the seas to rise, creating high tides. On the side facing away from the Moon, the rotational force of the Earth is stronger than the Moon's gravitational pull. The rotational force causes water to pile up as the water tries to resist that force, so high tides form on this side, too. Elsewhere on the Earth, the ocean recedes, producing low tides. The gravitational attraction of the Sun also plays a small role in the formation of tides. Tides move around the Earth as bulges in the ocean.

Most shorelines experience two high and two low tides within a twenty-four-hour period, though some areas have just one of each. A coastline's physical features, such as a wide sandy beach or a rocky cove, along with the depth of the water just offshore, affect the height of the tides.

Tides affect marine ecosystems by influencing the kinds of plants and animals that thrive in what is known as the intertidal zone - the area between high and low tide. Because the area is alternately covered and uncovered by the ocean throughout the day, plants and animals must be able to survive both underwater and out in the air and sunlight. They must also be able to withstand crashing waves.

For example, plants and animals that can anchor themselves to the rocks along a shoreline can survive the lashing from waves and the less violent movement of the changing tides. On sandy beaches, survival means being able to swim in shallow water or burrow under the sand as the waves arrive and depart overhead. Sand crabs not only burrow to survive, they actually follow the tides to maintain just the right depth in the wet sand.

Along many shorelines, tides form tide pools. These small pools of water are often left behind among the rocks at low tide. They can include a diverse population of tiny plants and animals that may serve as food for larger species.

The rise in sea levels will affect tides and their impacts, not just on marine ecosystems but on coastal areas that are home to millions of people and animals. The more that is known about how tides work and how they shape our coastlines, scientists say, the better prepared we will be for future changes in the oceans.

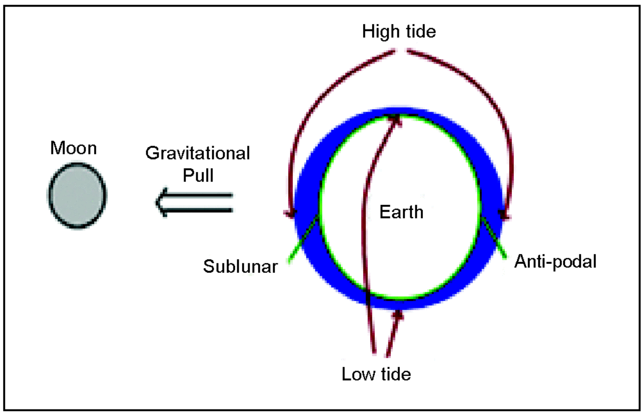

Fig. 39 : High tide and Low tide

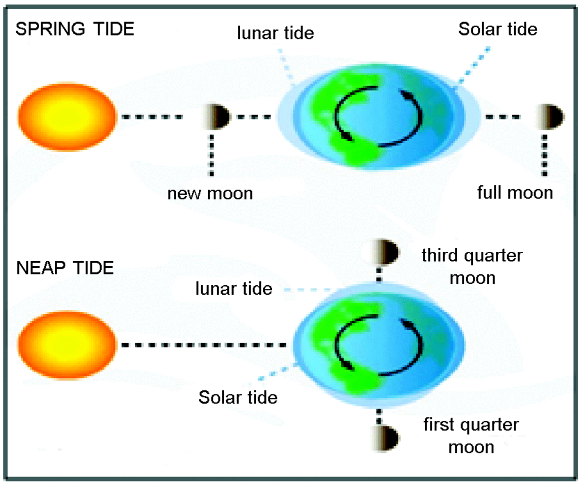

Fig. 40 : Spring tide and Neap tide

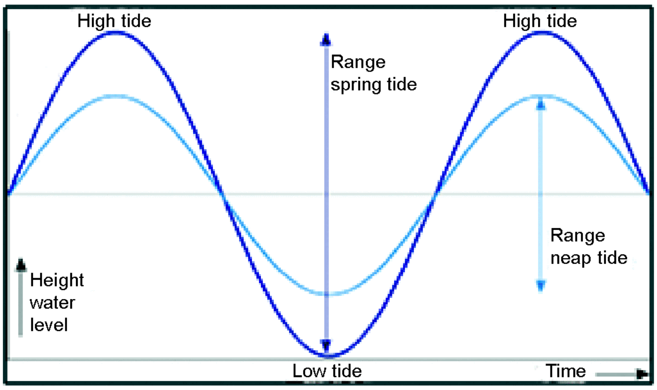

Fig. 41 : Tidal range

4.8 Summary and Conclusion

The topic discussed in this unit are very much important as it covers a large portion of oceanic knowledge. All these features effect the climatic features of any region largely apart from the coastal region. Ocean circulation is the large scale movement of waters through the oceans and it was connected with the air-sea interaction.

4.9 Key words

Air-sea interaction, oceanic circulation, wave, tide, El Nino, La Nina, ENSO phenomena

4.10 Model Questions

Short answer type :

1. What is El Nino?
2. What is La Nina?
3. What is ENSO phenomena?
4. What are types of tide?
5. What is wave?

Long answer type :

1. Differentiate El Nino from La Nina. Discuss about the ENSO phenomena.
2. Briefly explain the air-sea interaction.
3. What is oceanic circulation? Discuss the factors controlling oceanic circulation.

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Unit - 5 ❑ Coral Reefs : Formation, Classification and Threats

Structure

5.1 Introduction

The formation, classification of coral reef is discussed in this unit. The learners will come to know about coral reef which are very important part of ocean. The favourable conditions for the formation of coral reef, the theories related to the formation are thoroughly explained in this unit as most of the coral reefs seen today were formed after the last glacial period. Moreover, coral reefs render ecosystem services to tourism, fisheries and shoreline maintenance. As, by character coral reefs are fragile ecosystems, partly because they are very sensitive to water temperature; therefore, the global climate change is the greatest threat to coral reef ecosystems around the world. The other factors responsible for the coral bleaching are also discussed here.

5.2 Objectives

- To know about the coral reef.
- To know the formation of coral reef.
- To know the theories related to the formation of coral reef.
- To know the of types coral reef.
- To know the factors of coral bleaching.

5.3 Coral Reefs

Coral Reefs are diverse underwater ecosystems held together by calcium carbonate structures secreted by corals. These are built by colonies of tiny animals found in marine waters that contain few nutrients. Most coral reefs are built from stony corals, which in turn consist of polyps that cluster in groups. The polyps belong to a group of animals known as Cnidaria, which also includes sea anemones and jellyfish. Unlike sea anemones, corals secrete hard carbonate, which support and protect the coral polyps. Most reefs grow best in warm, shallow, clear, sunny and agitated waters.

Shallow coral reefs form some of the most diverse ecosystems on the earth which are often called 'rainforests of the sea', They occupy less than 0.1% of the world's ocean surface supporting about 25% of all marine species, including fish, mollusks, worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians. Coral reefs flourish even though they are surrounded by ocean waters that provide some amount of nutrients. Although they are most commonly found at shallow depths in tropical waters, cold water corals also exist on smaller scales in some areas.

Coral reefs render ecosystem services to tourism, fisheries and shoreline maintenance. By character coral reefs are fragile ecosystems, partly because they are very sensitive to water temperature. They are under threat from climate change, oceanic acidification, blast fishing, cyanide fishing sunscreen use, overuse of reef resources, and harmful land-use practices, including urban and agricultural runoff and water pollution, which can be harmful for reefs by encouraging excess algal growth.

An atoll, sometimes called a coral atoll, is a ring-shaped coral reef that encircles a lagoon partially or completely. The coral of the atoll often sits atop the rim of an extinct seamount or volcano, which has eroded or subsided partially beneath the water. The lagoon forms over the volcanic crater or caldera, while the higher rim remains above water or at shallow depths that permits the coral to grow and form the reefs.

5.4 History of formation

Most of the coral reefs seen today were formed after the last glacial period when melting ice caused the sea level to rise and flood the continental shelves. This shows that most modern coral reefs are less than 10,000 years old. As communities established themselves on the shelves, the reefs grew upwards, keeping pace with rising sea levels. Reefs that rose too slowly could become drowned reefs. They are

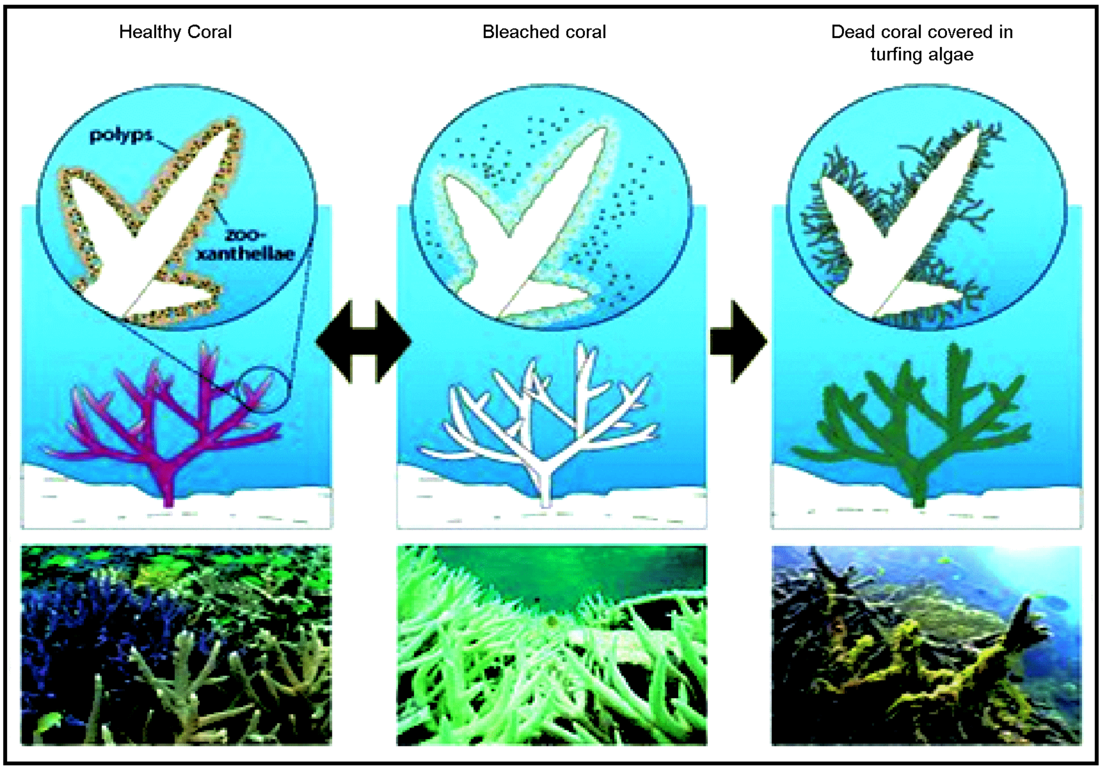


Fig. 42 : Corals

covered by so much water that there was insufficient light. Coral reefs are found in the deep sea away from the atolls, continental shelves and around oceanic islands. The majority of these islands are volcanic in origin. There are a few exceptions which are of tectonic origin where plate movements have elevated the deep ocean floor on the surface.

5.5 Types of Coral Reefs

Coral reefs are organically structures produced by living organisms. In most reefs the predominant organisms are colonial cnidarians that secrete an exoskeleton of calcium carbonate. The accumulation of this skeletal material, broken and piled by wave action and bioeroders, produces massive calcareous formations that make ideal habitats for living corals and a great variety of other animal and plant life. Coral reefs can take a variety of forms, defined in following :

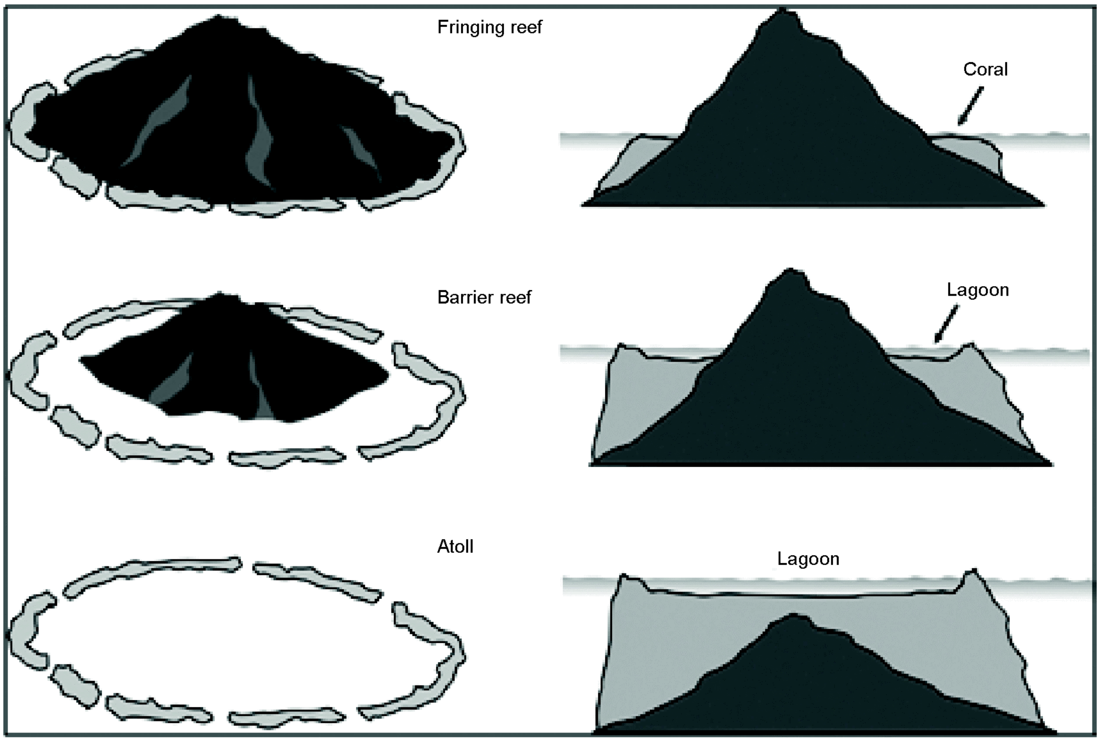


Fig. 43 : Coral reefs

- **Fringing reef :** a reef that is directly attached to a shore or borders it with an intervening shallow channel or lagoon.
- **Barrier reef :** a reef separated from a mainland or island shore by a deep lagoon (see Great Barrier Reef).
- **Patch reef :** an isolated, often circular reef, usually within a lagoon or embayment.
- **Apron reef :** a short reef resembling a fringing reef, but more sloped; extending out and downward from a point or peninsular shore.
- **Bank reef :** a linear or semi-circular shaped-outline, larger than a patch reef.
- **Ribbon reef :** a long, narrow, somewhat winding reef, usually associated with an atoll lagoon.
- **Atoll reef :** a more or less circular or continuous barrier reef extending all the way around a lagoon without a central island.
- **Table reef :** an isolated reef, approaching an atoll type, but without a lagoon.

The most common type of reef is the fringing reef. This type of reef grows seaward directly from the shore area of the mainland. They form borders along the shoreline and surrounding islands. When a fringing reef continues to grow upward from a volcanic island, sunk entirely below sea level, an atoll is formed. Atolls are usually circular in shape, with an open lagoon in the center.

Barrier reefs are similar to fringing reefs in that they also border a shoreline; for example the Great Barrier Reef close to the east Australian coast. However, instead of growing directly out from the shore, they can be separated from land by an expanse of water. This creates a lagoon.

Coral reefs are important because they bring in billions of dollars to the economy of some countries through tourism, protect coastal homes from storms, support promising medical treatments and provide a home for millions of aquatic species.

Coral Reef Conservation Programme of NOAA (National Oceanic and Atmospheric Administration) works to protect coral reefs through research, education, and preservation programmes. Many reefs, such as the Virgin Islands Coral Reef National Monument, are housed in NOAA's system of marine protected areas.

Genetic Classification of Coral Reef

Major Types
- (A) Fringing Reefs
- (B) Barrier Reefs
- (C) Atolls

Minor Types
- (A) Faros
- (B) Table Reefs or Coral Banks
- (C) Patch reefs, Krolls or Pinades

5.6 Factors of formation of Coral Reefs and Atolls

The factors of formation of coral reefs and atolls are :

1. Depth of water
2. Temperature of water
3. Condition of water
4. Circulation of water
5. Salinity of water
6. Bottom condition
7. Level of water
8. Action of wave.

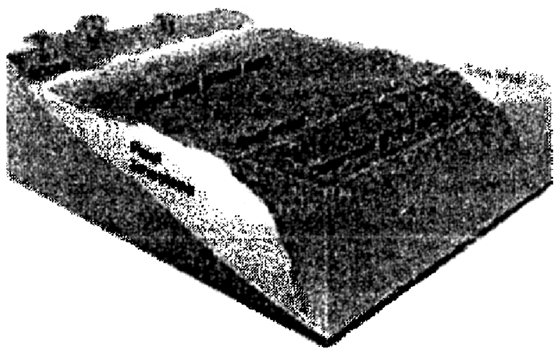
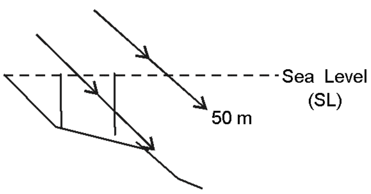


Fig. 44

(1) Coral growth is restricted to the areas of shallow waters, so that the organisms can bare sufficient light and oxiganeted water that help photosynthes is of plants and symbiotic living of the organism. Corals are found upto an average depth of 50m.



(2) All of the water temperature of 18°–20°C can be tolerated by coral. Coral

grow more abundantly at temperature between 20°–30°C and the must ideal temperature for the growth of coral. The upper limit is 35°C, so it ranges between 20°C–35°C.

(3) A long amount of silt is detremental not only because of its interference with light penetration but also because of sediment on the organism and thereby obstrecting their growth.

(4) Active circulation water are also essential for the growth of corals. Corals are sedentary organism and depend upon the depth of waves for the supply of their food, plantion and organism.

(5) Reef corals are also dependent on the proper salinity condition of 27-40 ppm (parts per million) lack of sufficient salinity also may for the absence of reef parts to the opposite of the mount of the large river as in the Bay of Bengal.

(6) Reef building corals prefer a faundation and do not thrive on muddy bottom.

(7) Another factor which is essential both for regorous growth and survival of coral colonies is that they will be covered with water except at extremely low tides.

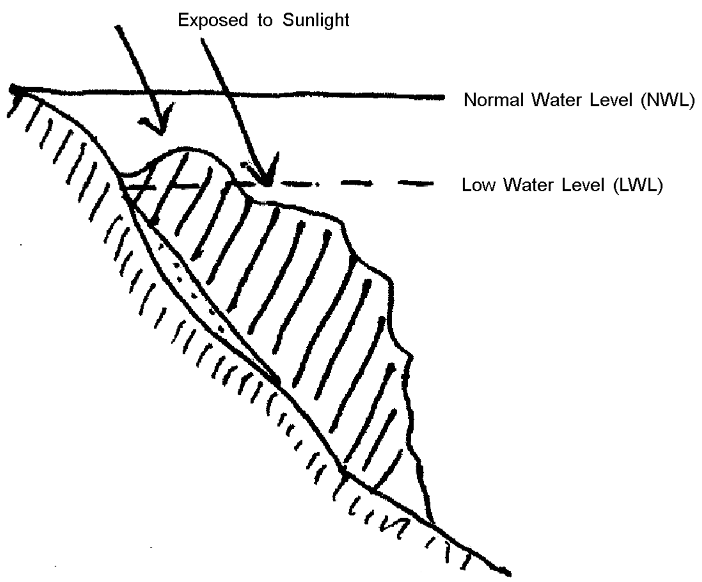


Fig. 45 : Coral formation

(8) The action of the wave has a quite impact in saving the coral feef. In calm water they may develop branches like stag horn.

5.7 Theories of Origion of Coral Reef

Most difficulty arises regarding origin of lagoons behind the barriar reefs and atolls. However, theories explaning origin of reef and may by classified into three groups :

(1) Anticedent platform theory

(2) Glacial centrol theory

(3) Subsidence theory

Introduction :

There are various theories that have been put forth to explain the mode of origin of coral reefs, taking into account the fluctuation of the Pleistocene sea level and the stability of the land concerned. The latter fact analyses three conditions—a subsiding island, a stationary island and an emerging land with reefs along them. Out of the three types of reefs, fringing reef is perhaps the most simple and easiest to explain. Corals in the past established themselves along suitable submarine structures, within 30 fathoms (around 50 metres) of depth. Upward growth, however, ceased when the reef reached the low tide level because coral polyps cannot stand a long exposure to atmosphere, but the outward growth towards the sea continued. The material eroded by waves was consequently deposited on its surface. The origin of the other two reefs, the barrier and the atoll, is not so easy to explain. Hence, there are different views on their origin :

1. Darwin's Subsidence Theory :

This theory was put forth by Charles Darwin in 1837 and modified in 1842, during his voyage on the Beagle when it became clear to him that coral polyps could grow only in shallow waters. Darwin assumes that along a suitable platform, coral polyps flocked together and grew upward towards a low water level. The resulting reef, in this stable condition, would be a fringing reef. But, at the same time, Darwin assumes, the sea floor and the projecting land in coral seas started submerging, and the living corals found themselves in deeper waters. Hence, an urge to grow upward and outward would be balanced by the subsidence of the land. As a result of this, Darwin postulated that the fringing reef, barrier reefs and atolls are only three stages in the evolutionary growth of a reef (Fig. 46). As the land subsides, the fringing reef would grow upwards and outwards, resulting in the formation of a shallow lagoon. Further subsidence would convert it into a barrier reef with wide and comparatively deeper lagoon. The width of the reef is increased due to the rapid outward growth of the reef and deposition of coral debris along it. The last stage of submergence (comparable to thousands of feet) results in partial or complete disappearance of the land and the existence of a coral ring enclosing a lagoon.

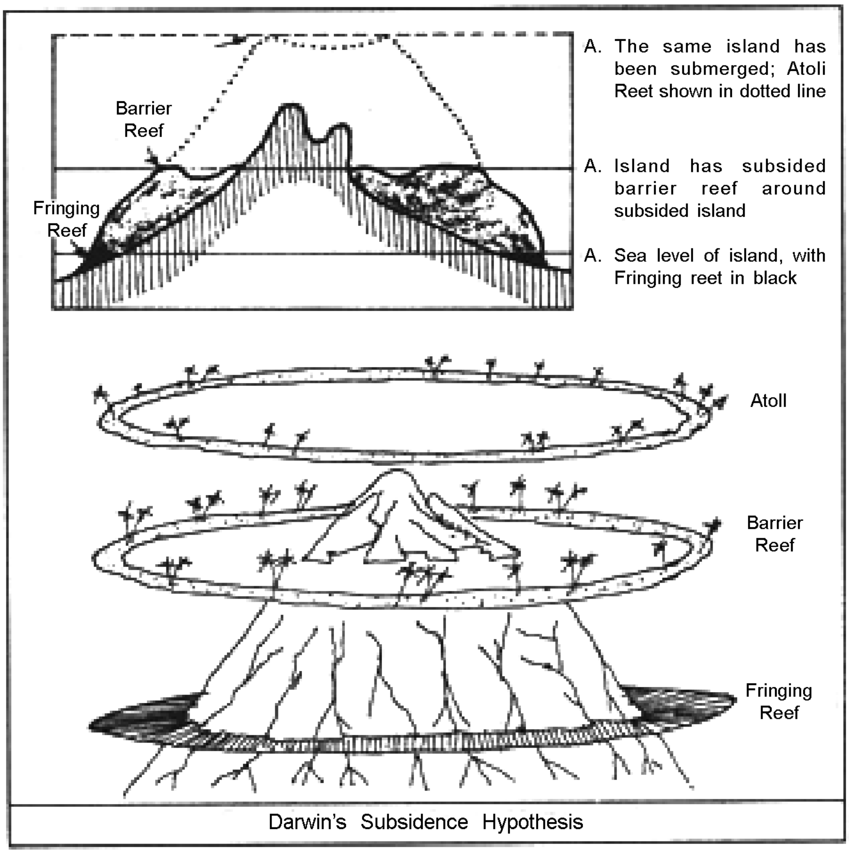


Fig. 46 Graphic presentation of Darwin's Subsidence Hypothesis

In spite of continued subsidence, Darwin maintains that the shallowness of the lagoon would be due to the deposition of the sediment from the nearby subsiding land. Hence, the lagoon always remains flat and shallow. The theory, though simple in its presentation, implies that the barrier reef and atoll can occur only in the areas of submergence, and the great amount of vertical thickness of coral material is primarily due to the subsidence of land and consequent upward growth of coral polyps.

Evidence in Support of the Theory :

There is much evidence of subsidence in coral areas. For example, submerged valleys in the east coast of Indonesia and the coastal areas of Queensland can be considered. Here the sediment produced by the erosion of coral reefs would have filled the lagoons and caused the death of corals. The material produced by erosion gets continuously accumulated at the subsiding lagoon bottom. That is why the lagoons are shallow. During an experimental boring, done to a depth of 340 m in the island atoll of Funafuti, dead corals were discovered at these depths. Only subsidence can explain existence of corals at this depth because, generally, corals cannot grow below 100 metres. Also, these dead corals showed the evidence of their having got 'dolomitised' which is possible only in shallow waters. All this evidence goes to prove the subsidence theory.

Evidence against the Subsidence Theory :

Many scien¬tists, like Agassiz and Semper, have argued that the corals have developed in places where there is no evidence of subsidence. Timor is one such area. Similarly, lagoons, with depths of 40m to 45m and many kilometres wide, cannot be explained on the basis of subsidence. Moreover, the question arises as to why there is uniform subsidence in the tropical and sub-tropical areas and not so in other areas. Kuenon has described some areas where the fringing and barrier reefs are found close to each other. This is not possible if the subsidence has been a continuous process. Finally, if it is supposed that the coral islands are a product of subsidence, we will have to assume the existence of a vast area in the Pacific Ocean which has submerged, leaving behind corals as islands. There is no evidence of the existence of such a vast land area in Pacific Ocean which existed in the ancient times.

2. Daly's Glacial Control Theory :

Daly observed that the reefs were very narrow and there were marks of glaciations while he studying the coral reefs of Hawaii. It appeared to him that there should be a close relationship between the growth of reefs and temperature. According to Daly's hypothesis, in the last glacial period, an ice sheet had developed due to the fall in temperature. This caused a withdrawal of water, equal to the weight of the ice sheet. This withdrawal lowered the sea level by 125-150 m. The corals which existed prior to the ice age had to face this fall in temperature dining this age and they were also exposed to air when the sea level fell. As a result, the corals were killed and the coral reefs and atolls were planed down by sea erosion to the falling level of sea in that period. When the ice age ended, the temperature started rising and the ice sheet melted. The water returned to the sea, which started rising. Due to the rise in temperature and sea level, corals again started growing over the platforms which were lowered due to marine erosion.

As the sea level rose, the coral colonies also rose. The coral colonies developed more on the circumference of the platforms because food and other facilities were better available there than anywhere else. Hence, the shape of coral reefs took the form of the edges of submerged platforms, A long coral reef developed on the continental shelf situated on the coast of eastern Australia. Coral reefs and atolls developed on submerged plateau tops. After the ice age, the surface of platforms was not affected by any endogenetic forces and the crust of the earth remained stationary.

Evidence in Support of Daly's Hypothesis :

The experimental borings done on the Funafuti atoll provide evidence in support of Daly's hypothesis. Also, in the ice age, all the platforms were cut down to the sea level by marine erosion. Hence, the depth of these platforms and that of lagoons with barrier reefs and coral atolls were almost equal. Moreover, study shows that the depths of the platforms and of lagoons are equal at all places. The greatest merit of this hypothesis is that it needs no subsidence of the crust, as is the case with Darwin's hypothesis. Finally, the sea waves and currents could have easily cut down the islands and converted them into low platforms.

Evidence against Daly's Hypothesis :

There are some platforms which are so long and broad that their formation cannot be considered as the work of marine erosion alone. One such platform is the Nazareth Platform—350 km long and 100 km wide. It is about 600 m high everywhere. Also, Daly could not explain the existence s of coral colonies at depths of 100 metres. He had to admit local subsidence to be able to explain coral colonies in some deeper areas. Daly had also calculated that the fall of sea level during the ice age was around 80 metres. It appears that this calculation is not correct. In fact, the fall of sea level can be correctly measured by the angle of walls of submerged V-shaped valleys. If calculation is done on this basis, the sea level should have fallen by more than 80m. Finally, Daly had stated that the temperature was lowered during the ice age. It must have caused the death of corals, but there is no evidence of this phenomenon. It appears from the above discussion that the hypotheses of Darwin and Daly are not contradictory but complementary. Both together throw a lot of light on the phenomenon.

3. Davis' Application of Physiography to the Problem of Origin of Coral Reefs :

Davis gave his explanation in order to revive and re-establish the old idea of submergence as applied to the coral reef problem. He attempted to give concrete physiographic evidences to explain various problems hitherto unsolved in 1928. To begin with, Davis reasserted the validity of submergence. He stressed that the indented and embayed coastlines found in the coral seas demonstrate the submergence of the land. According to him, the flatness does not denote the true bottom of the lagoon, but is only due to the deposition of debris. Similarly, the shallowness of the lagoon illustrates the subsidence of the land.

Davis has also taken into consideration the facts of changing sea level. According to him, lowered sea level on subsiding islands would also create cliffs and spurs, but most of them would be protected by reefs along the shores from wave attack, hence cliffs would not be seen. Further, subsidence would also drown such cliffs if they were formed. Thus, this theory advocates the old idea of subsidence with renewed application of physiography. It is also comprehensive in its application as it includes the changes of the sea -level as well as the tectonic changes of the landmass (Fig. 47).

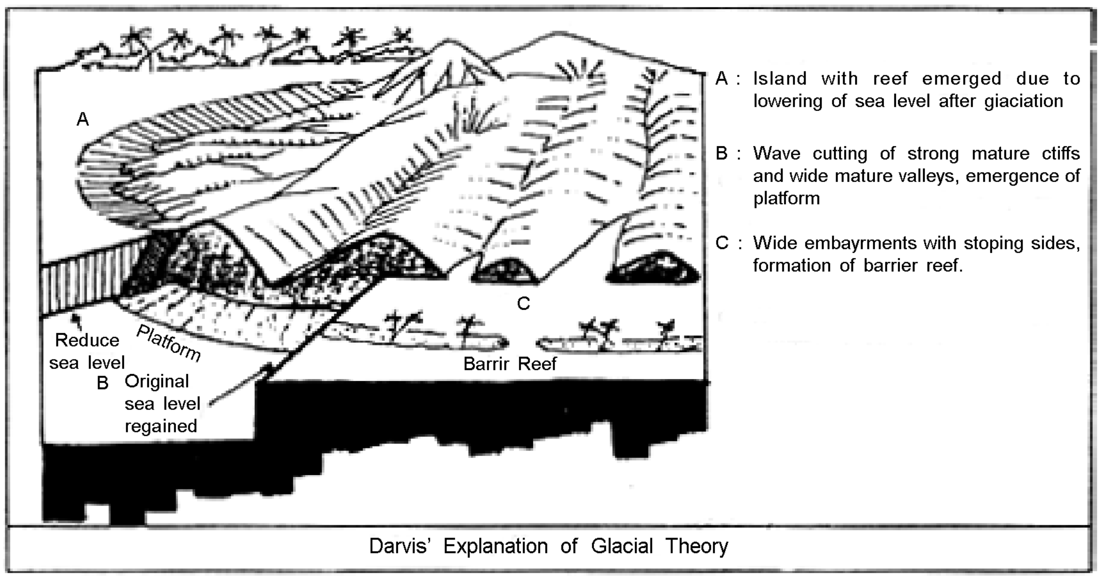


Fig. 47 A Graphic presentation of Davis' explanation of Glacial Theory

In spite of the above evidence, one fact is left unexplained, viz. the assumed equal depth of the lagoons. The flat floor of the lagoon and its shallow depths may be attributed to the sedimentation, but this in no case proves that the original bottom of the lagoon, concealed beneath, may not be showing different depths.

5.8 Threats to Coral Reefs

Global climate change is the greatest threat to coral reef ecosystems around the world. Scientific evidence indicates that the warming is taking place in earth's atmosphere and in the ocean water and that these changes are primarily due to greenhouse gases derived from the anthopogenic activities.

With the rise of temperature, mass coral bleaching events and infectious disease outbreaks are becoming more frequent. In addition carbon dioxide absorbed into the ocean from the atmosphere has already begun to reduce calcification rates in reef-building process and deterioration of reef-associated organisms by altering seawater chemistry through decreases in pH. This process is called ocean acidification.

Climate change continues to affect coral reef ecosystems, through sea level rise, changes to the frequency and intensity of tropical storms, and altered ocean circulation patterns. Understandably when combined, all of these impacts dramatically alter ecosystem function, as well as the goods and services coral reef ecosystems provide to people around the globe.

5.9 Summary and Conclusion

We all know that coral reef is very important as they occupy less than 0.1% of the world's ocean surface, but supporting about 25% of all marine species. This coral reefs flourish even though they are surrounded by ocean waters that provide some amount of nutrients. These are found in the deep sea away from the atolls, continental shelves and around oceanic islands. Therefore, various knowledge related to coral reef are discussed throughly here and thus this unit becomes very interesting to the learners.

5.10 Key words

Coral reef, types of coral reefs, formation of coral reefs, theories of coral reefs, coral bleaching

5.11 Model Questions

Short answer type :

1. What is coral reefs ?
2. What is coral bleaching ?

Long answer type :

1. What are the favourable conditions of formation of coral reefs ?
2. Discuss the theories of coral reefs.
3. State the factors factors responsible for coral bleaching.

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Unit - 6 ❑ Marine Resources : Classification and Sustainable Utilization

Structure

6.1 Introduction

This unit is going to discuss the concept of marine environment, marine ecosystem, marine resource and the sustainable uses of the marine resources. We know that the marine ecosystem is large enough, and there are many subfields; many marine species are economically important to humans, including a wide variety of fish. Various marine resources are frequently and widely used by the human and man exploits marine resources in diverse ways, which need to controlled and managed for the sustainable development. Therefore, the concepts discussed here are able to develop keen interest to the learning and probably this helps in spreading awareness and consciousness, helps in developing a strategy to ensure the sustainable use of living marine resources.

6.2 Objectives

- To know the concept of marine environment.
- To know the features of marine ecosystem.
- To know the classification of marine resources.

6.3 Marine Biological Environment

Marine biological environment comprises a wide variety of biological resources. Thus Marine biology is the scientific study of living organisms in the ocean or other marine or brackish bodies of water.

It has been found that many phyla, families and genera have some species that live in the sea. Marine biology classifies species based on the environment rather than on taxonomy. Marine biology differs from marine ecology as the latter is focused on how organisms interact with each other and environment and biology is the study of the animal itself.

Through scientific studies it has been explored that marine life is a vast resource, providing food, medicine and raw materials, in addition to helping to support recreation and tourism all over the world. At the basic level marine life helps determine the very nature of our planet. Marine organisms contribute significantly to the oxygen cycle, and are involved in the regulation of the climate of the earth. Shorelines are partially shaped and protected by marine life, and some marine organisms, like corals even help create new land.

Marine biology covers a great deal, from the microscopic, including most zooplankton and phytoplankton to the large cetaceans (whales), which reach up to a reported 50 meters in length.

The habitats studied include everything from the tiny layers of surface water in which organisms and abiotic items may be trapped in surface tension between the ocean and atmosphere, down to the depths of the abyssal trenches, which are often 10,000 meters or more beneath the surface of the ocean. It studies habitats such as coral reefs, kelp, forests, tidepools, muddy, sandy and rocky bottoms, and the open ocean (pelagic) zone, where solid objects are rare and the surface of the water forms the only visible boundary.

A vast amount of all life on earth exists in the oceans. It is still unknown exactly how large the proportion is there. While the oceans comprise about 71% of the earth's surface, due to their depth they encompass about 300 times the habitable volume of the terrestrial habitats on the earth.

Many species are economically important to humans, including a wide variety of fish. It is also understood that the well-being of the marine organisms and other organisms are linked in very fundamental ways. The cycles include those of matter (such as the carbon cycle) and of air (such as earth's respiration, and movement of energy through ecosystems including the ocean). Large areas beneath the ocean surface still remain unexplored.

6.4 Marine Ecosystem

The marine ecosystem is large enough, and there are many subfields of marine biology. Most involve studying specializations of particular animal groups. Other subfields study the physical effects of continual inundation in sea water and the ocean in general, adaptation to a salty environment, and the effects of changing various oceanic properties on marine life. A subfield of marine biology studies the relationships between oceans and life condition in the ocean, and global warming, as well as other environmental issues.

(a) Introduction :

Marine ecosystems make up the largest aquatic system in the world covering more then 70 percent of the planet. Marine ecosystems are considered to be the habitats that complete the larges system from the shores to the dark sea floor. The marine ecosystem includes: marshes, tidal zones, estuaries, the mangrove forest, lagoons, sea grass beds, the sea floor, and the coral reefs. Just like every other ecosystem in the world, the aquatic ecosystems rely on each other for maintaining a balanced marine ecosystem. The marine ecosystems are important to the world, because without them, the marine life would not have and protection from predators, which could eventually make the marine life go extinct.

(b) Concept :

Marine ecosystems can be defined as the interaction of plants, animals, and the marine environment. By "marine," we mean of, or produced by, the sea or ocean. The term encompasses the salty waters of the Earth, and is also known simply as a salt water ecosystem. As over 70% of Earth's surface is covered in water, and 97% of that water is salt water, marine ecosystems are the largest types of ecosystems on the planet. The marine ecosystem refers to the oceans and seas and other salt water environments as a whole; however, it can be divided into smaller, distinct ecosystems upon closer inspection. There are various types of marine ecosystems, including salt marshes, estuaries, the ocean floor, the broad ocean, the inter-tidal zones, coral reefs, lagoons, and mangroves. In accordance with, but not necessarily because of, their large size and wide range, marine ecosystems are also easily the most diverse of all the ecosystems on the planet. Coral reefs alone are home to over 25% of all marine life, despite occupying less than 1% of the ocean floor. Like all ecosystems, marine ecosystems are finely balanced and highly complex. There are many different parts that make up an ecosystem, and each part plays a role in maintaining balance within the system. Organisms depend on, and are highly influenced by, the physiochemical environmental conditions in their ecosystem.

(c) Classification :

Marine ecosystems are aquatic ecosystems whose waters possess a high salt content. Out of all of the types of ecosystems on the planet, marine ecosystems are the most prevalent. They teem with life, providing nearly half of the Earth's oxygen and a home for a wide array of species. Scientists generally classify marine ecosystems into six main categories :

1. Open Marine Ecosystems

The first thing many people think of upon hearing the term "marine ecosystem" is the open ocean, which is indeed a major type of marine ecosystem. This category includes types of sea life that float or swim, such as algae, plankton, jellyfish and whales. Many creatures living in the open ocean inhabit the upper layer of the ocean where the sun's rays penetrate. This is known as the euphotic zone and extends to a depth of about 150 meters (500 feet).

2. Ocean Floor Ecosystems

Marine life not only exists in the open ocean waters, but on its floor as well. Species that live in this ecosystem include certain types of fish, crustaceans, clams, oysters, worms, urchins, seaweed and smaller organisms. In the shallow water, sunlight can penetrate to the bottom. However, at greater depths, sunlight cannot penetrate, and organisms inhabiting this deep water rely on the sinking of organic matter above for survival. Many such organisms are small and generate their own light to find or attract food sources.

3. Coral Reef Ecosystems

Coral reefs are a special subtype of seafloor ecosystem. Found only in warm tropical waters and at relatively shallow depths, coral reefs are among the most productive ecosystems on the planet. About one-quarter of marine species depend on coral reefs for food, shelter or both. While coral reefs are famous for attracting brightly colored exotic fish, a plethora of other species—snails, sponges and seahorses, to name a few—inhabit coral reefs. The reefs themselves are produced by simple animals that build external skeletons around themselves.

4. Estuary Ecosystems

The term "estuary" typically describes the shallow, sheltered area of a river mouth where freshwater intermingles with saltwater as it enters the sea, although the term can also refer to other areas with flowing brackish waters, such as lagoons or glades. The degree of salinity varies with the tides and the volume of outflow from the river. The organisms inhabiting estuaries are specially adapted to these distinct conditions; hence, the diversity of species tends to be lower than in the open ocean. However, species which generally inhabit neighboring ecosystems may occasionally be found in estuaries. Estuaries also serve an important function as nurseries for many types of fish and shrimp.

5. Saltwater Wetland Estuary Ecosystems

Found in coastal areas, saltwater wetlands may be considered a special type of estuary, as they also consist of a transition zone between land and sea. These wetlands can be divided into two categories : saltwater swamps and salt marshes. Swamps and marshes differ in that the former are dominated by trees while the latter are dominated by grasses or reeds. Fish, shellfish, amphibians, reptiles and birds may live in or seasonally migrate to wetlands. Additionally, wetlands serve as a protective barrier to inland ecosystems, as they provide a buffer from storm surges.

6. Mangrove Ecosystems

Some tropical and subtropical coastal areas are home to special types of saltwater swamps known as mangroves. Mangroves may be considered part of shoreline ecosystems or estuary ecosystems. Mangrove swamps are characterized by trees that tolerate a saline environment, whose roots systems extend above the water line to obtain oxygen, presenting a mazelike web. Mangroves host a wide diversity of life, including sponges, shrimp, crabs, jellyfish, fish, birds and even crocofiles.

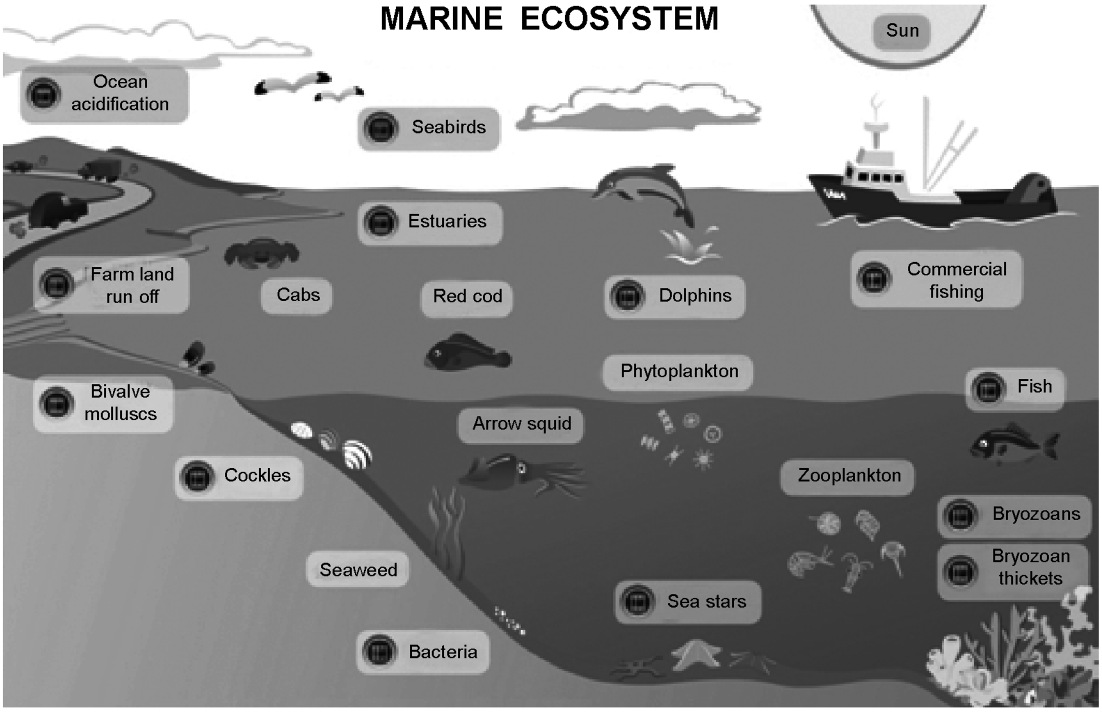

Fig. 48 Marine Ecosystem

(d) Zonation of Marine Ecosystem :

The major divisions of marine ecosystems are :

- **Pelagic zone** include neritic zone the productive coastal waters.- and oceanic zone deep waters of the open ocean Another division in the pelagic zone is related to light penetration. (see below)
- **The benthic zone** extends from the seashore to the deepest parts of the sea. The material that makes up the bottom is the substratum and the organisms living there are the benthos

Classification of Organisms by Environment

Horizontal : Neritic and Oceanic zones

Vertical :

- Epipelagic (top) is euphotic (good-light = enough for photosynthesis)

- Mesopelagic (middle) is disphotic (low-light = too weak for photosynthesis)
- Bathypelagic (deep) is aphotic (without-light)
- Abyssopelagic ("bottomless")
- Deep sea layers bathypelagic 1000-4000m and the abyssopelagic zone (below 4000m) have limited food supplies although bacteria have been found that can make their own food

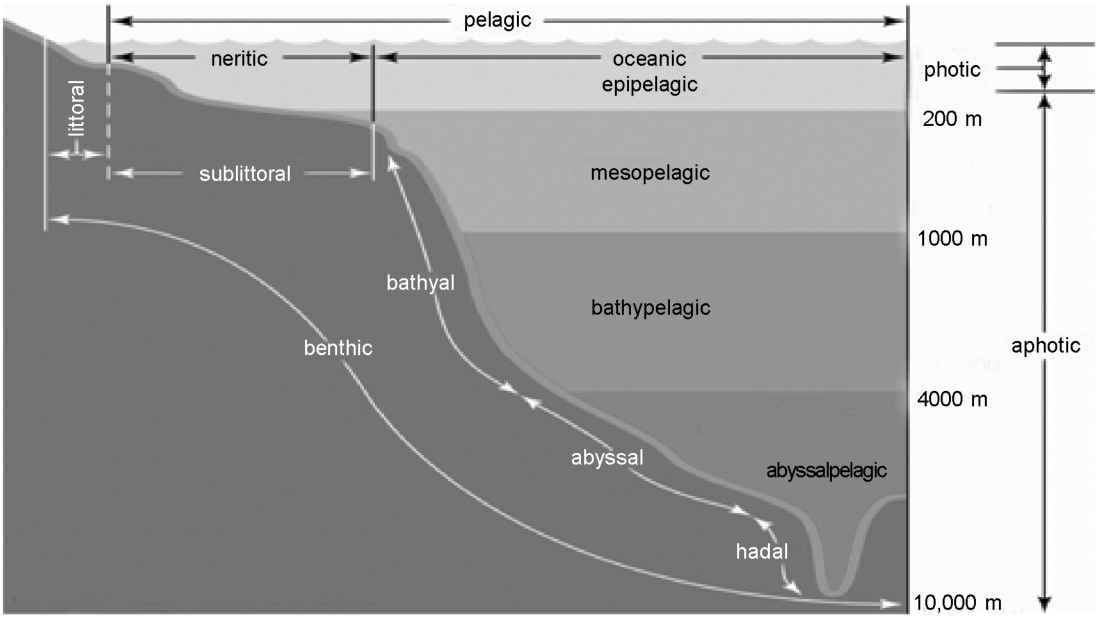

Fig. 49 Zonation of Marine Ecosystem

Classification of Organisms Based on Lifestyle

Plankton (floaters)

- Plankton are weak swimmers, and are known as drifters, unable to counteract currents. Made up of Phytoplankton (plant plankton) the primary producers in the pelagic region and Zooplankton (animals) which range from bacteria size to 15 m jellyfish.
- Diatoms (cooler water) and Dinoflagellates (warmer water are major types of phytoplankton
- Other algae include coccolithophores, silicoflagellates, blue-green algae and green algae (usually in coastal waters)

- Occupy the first two or three links in the marine food chains. Adaptations which keep them in upper sunlight layers include small size, structure, shape, decreased density due to oil droplets in cytoplasm. Zooplankton can be as numerous as 500,000 per gallon. The most common are Copepods who along with other zoo plankton have vertical migrations –moving up toward the surface to feed in the evening as light diminished as light, shadows, and pigment colors help them locate food – this assists phytoplankton with photosynthesis in daylight
- Holoplankton are permanent members of the zooplankton community and have evolved special adaptations as special appendages, droplets of oil and wax, ability to tread water, jell-like layer, and gas-filled float to remain adrift
- Meroplankton are temporary members of the zooplankton community because they are part of the plankton for only part of their life cycle usually larvae of sea urchins, sea stars, crustaceans, some marine worms, gastropods and most fish.
- A majority of the invertebrates and many vertebrates have a planktonic state as meroplankton. They use the water mass to feed and disperse their planktonic young to new habitats. The reproductive cycles often coincide with maximum concentrations of food and favourable; currents such as spring phytoplankton blooms that increase zooplankton coincide with migration patterns of whales, penguins, and seals

Nekton (swimmers)

- Nekton are active swimmers capable of counteracting currents eg. Fish, Squids, Reptiles, Birds, and Mammals. Planktivouous Nekton are animals that feed on plankton as baleen whales and some fish
- Herbivorous Nekton feed on large seaweeds and sea grasses as turtles and manatees
- Carnivorous Nekton are the dominant animals of the nekton and they migrate great distances for food
- Nekton animals use their ability to swim as their means of locomotion, to find food and to escape predators so they have many adaptations as fins, jets of water, strong flippers, flukes and flippers to swim through the water.

Many of the Nekton animals are the top of the trophic levels as carnivores or herbivores without natural predators except man

Benthos (bottom dwellers) – live on the bottom

- They resides primarily in or on the substrate and doesn't swim or drift for extended periods as an adult. They either burrow, crawl, walk, (motile) or are sessile-permanently affixed to the substrate or each other. Epiflora or epifauna live on the sea bottom while infauna live in the sea bottom where the substrate could be a source of food. Benthic plants are restricted to shallow waters because they need light for photosynthesis. Benthic animals occur everywhere from shallow depths to the deep sea. Divided by size :
  - Microbenthos (< 100 mm) includes bacteria & protests
  - Meiobenthos (100-500 mm) includes small metazoa and larger protists
  - Macrobenthos (> 500 mm) includes larger metazoa and megabenthos
  - Megabenthos (very large) large crustaceans, mollusks, etc.
- Divided by what they eat :
  - Herbivores-feeds on plant material
  - Carnivores/predators-feeds on other benthic organisms
  - Detritivores-feeds on dead plant and animal material
- Divided by how they eat :
  - Suspension feeders-eats using a mucus-covered appendage that catches particles in water column
  - Filter feeders-strain particles from the water column
  - Deposit feeders-ingest sediment and removing the nutrients
- Demersal organisms, usually fish and invertebrates, alternate between swimming and feeding near the bottom and resting on the bottom

Trophic (feeding) relationships

- Energy transfer is accomplished in a series of steps by groups of organisms known as autotrophs, heterotrophs, and decomposers. Each level on the pyramid represents a trophic level.

- AUTOTROPHS - absorb sunlight energy and transfer inorganic mineral nutrients into organic molecules. The autotrophs of the marine environment include algae and flowering plants and in the deep sea are chemosynthetic bacteria that harness inorganic chemical energy to build organic matter. Autotrophic nutrition supplies food molecules to organisms that can't absorb sunlight.
- HETEROTROPHS- Consumers that must rely on primary producers as a source of energy...heterotrophic nutrition. The energy stored in the organic molecules is passed to consumers in a series of steps of eating and being eaten and is known as a food chain. o Each step represents a trophic level and the complex food chains within a community interconnect and are known as a food web.
- DECOMPOSERS- The final trophic level that connects consumer to producer is that of the decomposers. They live on dead plant and animal material and the waste products excreted by living things. The nutritional activity of these replenish nutrients that are essential ingredients for primary production. The dead and partially decayed plant and animal tissue and organic wastes from the food chain are DETRITUS. This contains an enormous amount of energy and nutrients. Many filter/deposit feeding animals use detritus as food. Saprophytes decompose detritus completing the cycle

Food Chain

- Producer
- 1st order Consumer or Herbivore
- 2nd order Consumer or 1st order Carnivore
- 3rd order Consumer or 2nd order Carnivore
- 4th order Consumer or 3rd order Carnivore
- Decomposers – consume dead and decaying matter as bacteria (often not shown on food chains or food webs but essential to the ecosystem

Food Web – multiple food chains in an ecosystem

Ecological Pyramid

- Ecological pyramid - a graph representing trophic level numbers within an ecosystem.

- The primary producer level is at the base of the pyramid with the consumer levels above.
  - Numbers pyramid - compares the number of individuals in each trophic level. May be inverted due to size of individuals
  - Biomass pyramid - compares the total dry weight of the organisms in each trophic level.
  - Energy pyramid - compares the total amount of energy available in each trophic level. This energy is usually measured in kilocalories.

(e) Energy transfers in marine environments

- Primary producers usually outnumber consumers and at each succeeding step of the food chain the numbers decrease. The numerical relationship is called the numbers pyramid. The energy pyramid is the energy distribution at each trophic level as it passes from producers through the consumers. Some energy is lost as it passes to the next level because :
  - consumers don't usually consume the entire organism
  - energy is used to capture food
  - organisms used energy during their metabolism
  - energy is lost as heat
- Ecological Efficiency = efficiency of energy transfer between trophic levels: ~20% for herbivores; 10-15% for carnivores; 80-90% of energy is lost due to respiration
- Number of trophic levels will determine how much energy and food is available to top predators (whales, fish, birds). The number of trophic levels :
  - High in open ocean waters
  - Low in upwelling regions
- Phytoplankton size: If phytoplankton is small (pico-, nanoplankton), then more trophic
- levels (protozoa) because larger animals (copepods) are unable to graze such small food particles; upwelling regions – large phytoplankton

- Generally only 10% will pass on to the next level (10% Rule)
- Scavengers feed on dead plants and animals that they have NOT killed...crabs ripping chunks of flesh from fish on the beach are scavengers.
- Most scavengers consume detritus rather than flesh and deep sea animals can feed on both.

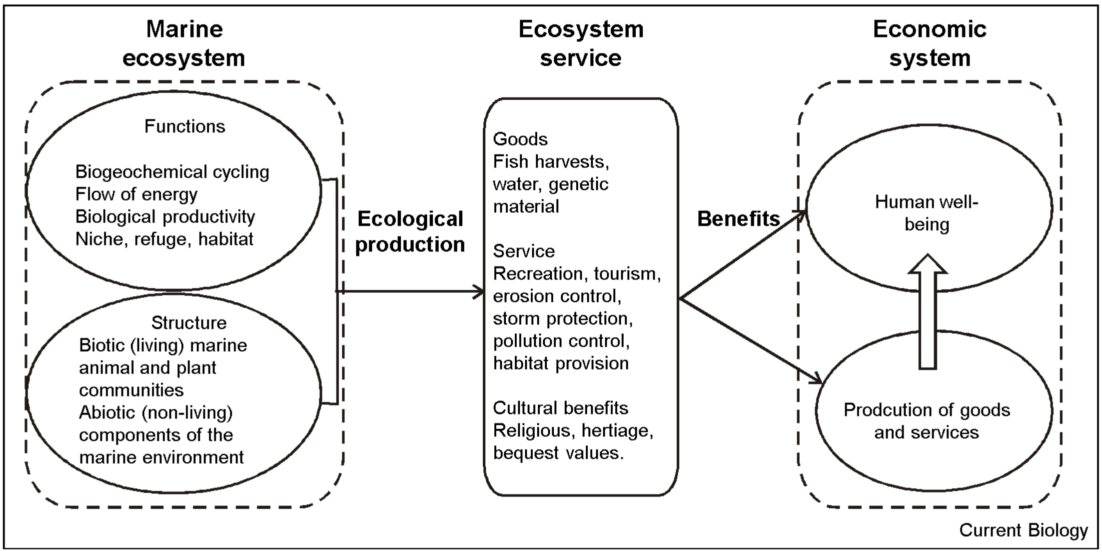

Fig. 50 Ecosystem service

(f) Recycling of Nutrients in Marine Environments

Recycling of nutrients is key to productivity in marine environments.

- Food Production occurs mainly through photosynthesis with some chemosynthesis in lower depth without light
- Primary productivity varies seasonally and geographically and is measured as carbon/m2/year
- The more vertical mixing that occurs in an area, the higher the primary productivity
- It decreases as depth increases due to less light for photosynthesis
- Accessory pigments in algae enables them to make the most of the light that gets to them
- Key nutrients are necessary along with energy to sustain life and allow

reproduction and growth of organisms. Important Nutrient Cycles include carbon, nitrogen, and phosphate cycles in addition to the water cycle.

(g) Imbalances in Marine Environments

- Nutrient over-enrichment : eutrophication such as Algal Blooms eg. the Red tide
- Ecosystem Alteration
- Climate Change and Sea Temperature Rise
- Acidification of the Oceans
- Pollution as pathogen contamination and toxic chemicals
- Alteration of freshwater inflow
- Loss and degradation of habitat
- Declines in fish and wildlife populations
- Introduction of invasive species
- Accidental spills as Oil Spills
- Pollution : Sources of water pollution may include point source pollution from a clearly identifiable location or nonpoint source pollution that comes from many different places. Sources of pollution usually fall into four main categories – industrial, residential, commercial, and environmental. Some types of pollution may include
    - *organic pollution* – decomposition of living organisms and their bi-products
    - *inorganic pollution* – dissolved and suspended solids as silt, salts, and minerals
    - *toxic pollution* – heavy medals and other chemical compounds that are lethal to organisms
    - *thermal pollution* – waste heat from industrial and power generation processes

(h) Threats to Marine Water Quality and Marine Environments

The threats that have impacted the marine ecosystems are pollution and overfishing. Pollution is impacting the marine ecosystems, because as more carbon dioxide is released into the air more of the ice caps are melting. Therefore, the rising of ocean levels and the decrease in salinity levels are causing problems for the marine life. If the salinity levels keep dropping the marine life that survive in salt water will not be able to survive in the fresh water rich waters. Pollution is killing marine animals not only in the salinity drop, but also they eat or get trapped in harmful garbage, marine life in the ocean die from swallowing or getting caught on trash everyday. Over one million sea birds are killed by pollution every year; three hundred dolphin and porpoise are killed by pollution, by either swallowing trash or getting tangled in trash and one hundred thousand marine mammals are killed by ingesting plastics and other pollution substance every year. Pollution is a major reason why marine ecosystems are being threatened. But, another threat to marine ecosystems are overfishing. Overfishing is a threat for marine ecosystems because a decrease in number of a species will effect the marine food web disrupting the whole ocean. If overfishing causes a specie to become extinct in the marine ecosystem then it will have one of the species in the ocean to become overpopulated. Once one specie becomes overpopulated then that organism dominates the ocean making other species to become endangered or extinct. The threats in the marine ecosystems can have an impact that the system will never repair itself, which will disrupt the world more then any other ecosystem would. There are numinous amount of reason why catch limits are being exceeded such as : miscount of population, by catch in a fishery, and fishing rates are higher than estimated. The key issues of threats are :

- Oil spills and their ecological disasters
- Marine dumping of wastes – plastic and other wastes
- Dredging Wastes
- Overfishing
- Ocean acidification
- Population displacement
- Mangrove Destruction
- Bycatch – marine wildlife unintentionally caught as sea turtles, porpoises, albatross, crabs, starfish & fish
- Whaling is still a problem though strides are being make
- Overfishing and Exploitation
- Climate Change

- Sea Temperature Rise
- Invasive Species
- Ocean Dead Zones

(i) Importance :

Marine ecosystems are an important part of the world, because the marine ecosystems give marine life such as : tiny plankton, fish, crustaceans, invertebrates, reptiles, marine mammals, sharks, and rays a place to live and survive. It also gives those marine animals a place to hunt. Many marine life have an important role in the world such as the tiny plankton because without them the world would build up with carbon dioxide, the plankton absorbs the carbon dioxide in the air and releases oxygen back into the air. Without marine ecosystems to protect the tiny plankton, more species would become extinct. The most important marine ecosystems for marine life are estuaries and coral reefs. These two marine ecosystems are important because the estuaries are breeding territories for many marine animals, because it is easy for young-lings to survive there, since there are no known predators that live in that region. Coral reefs are important for the marine life, because it provides a shelter for various amount of species. Coral reefs also are the most diverse ecosystem in the whole aquatic system. Without all the marine ecosystems, the marine food web and the whole ocean would be in danger of continuing in its current state.

6.5 Marine Resources for sustenance of the human generation in future

The world population is expected to be double in less than a century. UN figures suggest that 75% of these, with the highest rate of growth, will occupy a narrow strip some 60 km in width along the shores of the continents. In Southeast Asia, about 65% of all major cities are already located along the coasts. From near future a large proportion of the population will have to look for other alternative food sources than grown and available from the land areas. Thus the resources available from the oceans and seas will have to be depended on.

It has been found through scientific investigations that oceans are the vast reservoirs of biotic resources. Nearly 40,000 spe¬cies of molluscs, and 25,000 species of fishes are found in marine waters. Besides mineral resources, different types of vitamins and medicinal elements are also found. Generally, marine resources are divided into three categories e.g., biotic resources, abiotic (mineral and energy) resources and commercial resources (navi¬gation, aviation, trade and transport etc.).

The marine resources are unique in the sense that they are renewable as most of the organisms can be regenerated. Since time imme¬morial oceans have always been useful for human society and have attracted man in different ways. Man has been using oceans in a number of ways since long e.g., for transport, communication and trade, fishing, defense purposes, mineral extraction, recreation, medi¬cines, waste disposal etc.

Presently, the importance of oceans has increased many folds because of increased demand of food and minerals consequent upon ever-increasing world population. Consequently, man, besides traditional ways of exploitations of marine resources, has become capable of modernizing tradi¬tional methods through his skill and advanced science and technologies.

For example, the productivity and production of marine organisms (plants and animals) have been increased many fold through marine culture (mariculture), aquaculture, ocean ranching etc. There has begun a race for the exploitation of minerals associated with oceanic water, ocean deposits and ocean crusts, with the result the strategic importance of oceans has also increased accordingly.

6.6 Classification of Marine Resources

Based on above mentioned considerations marine resources can be divided into the following categories :

- **Food Resources :** Animal and Plant resources - Fishes, crabs, prawns, zoo planktons, phytoplanktons, sea grass)
- **Non-food Resources :** Corals, Zoo planktons
- **Mineral Resources :** Minerals of the continental shelf deposits, Minerals of the continental slope deposits, Minerals of the deep sea bottom deposits, Metallic minerals.
- **Fuel minerals :** Petroleum, Natural gas).
- **Construction materials :** Gravels, Sands etc.

Energy resources :

- **Conventional energy :** Petroleum. Natural Gas.

- **Non-conventional energy :** Tidal energy, Wave energy.

Oceans cover 70 percent of Earth's surface, host a vast variety of geological processes responsible for the formation and concentration of mineral resources, and are the ultimate repository of many materials eroded or dissolved from the land surface. Hence, oceans contain vast quantities of materials that presently serve as major resources for humans. Today, direct extraction of resources is limited to salt; magnesium; placer gold, tin, titanium, and diamonds; and fresh water.

Ancient ocean deposits of sediments and evaporites now located on land were originally deposited under marine conditions. These deposits are being exploited on a very large scale and in preference to modern marine resources because of the easier accessibility and lower cost of terrestrial

These mounds of sea salt were mined from deeply buried beds deposited when sea water evaporated in an ancient environment. The beds were preserved by being covered and then uplifted in a modern terrestrial setting. Mining accounts for most of the annual salt production, even though it also can be obtained by evaporating ocean water.

Resources. Yet the increasing population and the exhaustion of readily accessible terrestrial deposits undoubtedly will lead to broader exploitation of ancient deposits and increasing extraction directly from ocean water and **ocean basins.**

Major Resources of the Ocean

We regard ocean as food, renewable energy, resource, fossil fuel, minerals, chemical fertilzer, and medicines.

- **Food** - We have fishes, vegetation grown under weed.
- **Energy** - Wave energy and oceans thermal structure.
- **Fuel** - Found under strata, deposited in the form of oil and gas.
- **Minerals** - Diamond, sand, gravel, metalls etc.
- **Fertilizer** - Different chemical fertilizer.

Under UN, the law of sea countries say they have right to explore oceans. Right to claim Exclusive Economic Zone (EEZ) extending to 370 Km i.e. 200 nautical miles offshore. [NM = Distance on surface of earth measuring exaclly on inch at the centre of the earth.]

Food :

Fishes are caught not only for consumption but also to turn less edible to turn fish meal etc. Disposition of world fish production :

Years (% production)

Type	1981	1991	2001
Fresh	21.7	22.6	23.7
Freezing	23.8	25.0	26.5
Curing	12.8	10.9	5.0
Canning	14.5	12.9	10.6
Paultry Feed	27.2	28.6	30.2
Total	100.0	100.0	100.0

World Fish Catch (106 tonnes - mile metric tonnes)

Type	1985	1990	1995	2000
Marine	75.7	82.8	90.2	100.5
Inland	10.6	14.6	17.5	21.2
Total	86.3	97.4	107.7	121.7

Although fishing has traditionally been most important resource exploited by humans in such a increasing evidence, that these valuable resource are being destroyed by polluting coastal zone, breeding grounds, oveffishing capturing and destroying young fish, marin life and organism.

Example : Coast of sunderban, prawn culture.

World Producer	(fish production in %)
China	13.1
Japan	9.3
USSR/CIS	9.3
Peru	6.5
Chili	6.0
US	5.5
India	4.0
Total	54.4
Other countries	45.9

Sea weeds have long been recognised as a major food resource. India for pharmaceutical purpose extracted from sea weed and used as sterilizers and gels for food medicine as well as rubber, textile, ceramic production.

Energy :

Sunderbans, has only 15% electrified. Intermitten electric, oil and gas, like coal are finite, non renewable resources. Knowing that they will last forever, more effort is being put into alternative sources of energy to which renewable energy like solar, waves and wind etc. The ocean has been abundant in its wind, waves and tides, currents in thermal structure of the water masses.

Winds : Ocean wends are a source of energy for coastal community and small island. Sure in planning to utilize by windmill to generate electricity. US has installed a wind turbuine on Hawai coast. In India wind driven power is being utilised coastal areas particularly in W.B. coast and as in Fraiegunj and Sagar Island, and in Goa in Kerala, Gujrat and elsewhere.

Waves : The experiment on sea wave was conducted in France about 150 years back. In 1967 Japan generated power by using sea waves (37 yrs back). Ocean energy group of HT (Chennai) designed a device installed is Trivandrum for generating of electric sea waves. Prof. Salter of Edinburgh University and Mr. Biswas of Eastern Railway (India) invented different measures for extracting power from sea waves but in .experimental stage.

Tides and Currents : Kinetic energy can be obtained from flow of water (H_2O) due to the tide-motion. This energy can be converted to electricity in this method. Sea water during high tide is allowed to enter reservoir through such gates. As the water enters the reservoir rotates the turbine and generates electric. In the River Ranee estuary (France) 240 mil. watts of electric is produced. In India one to power project is established Kuchh with 900 megawatt capacity.

Thermal structure - Difference between temperature of sea and surface at lower levels can be utilise to harvess electricity. In this method low boiling liquid like Ammonia, Propane, Freon are heated by hot sea water near the sea. The vapors produced protect the turbine to the generator. This vapor are condenced into cool water in lower levels of sea water and reused by the method of producing electricity Ocean Thermal Energy Conservation systems (OTECS). It first came into .existence in Cuba, 1927. India with its 5000 km. wide shoreline has potential location both in East and West for developing OTECS.

Fossil Fuel

The world presently release heavily on the energy stared in fossil fuel as they are cheap and easy to extract. Coal found in beds near surface and gas can be reneased with little more effort than drilling holes in the ground. Due to both, the case of recover their rich energy content fossil fuel consumption has grown quickly so much so that these result will be adjusted within a short period.

World Reserves of Fossil Fuel

Fuel	Reserve	1991	Years left to be exhausted
Coal	15,000	90	170
Petroleum	3,500	127	28
Natural Gas	2,000	66	30
Uranium	5,800	17	47

World Energy Use :

Years

Fuel	1901	1951	1991
Coal	20	40	90
Petroleum	0	20	127
Natural gas	0	10	66
Hydro Electric	0	5	25
Nuclear Power	0	0	15
Wood	10	5	1

Oil was first produced from beneath the sea in 1894 off the Pacific coast of California. Production was costly and it was not until 1936 that operations began in Gulf of Mexico. By 1948 the first offshore platform out of right (in open ocean) of land had been completed off the coast of USA. At present oil is produced in substantial amount off California coast, Gulf of Mexico, North Sea, Black sea, Coast of Angola of Brazil, off S.E, Australia, E. Indies, Persian gulf and many other places.

Natural gas is also produced in huge amount offshore. The North Sea being a major source. According to UK Petroleun annual worldwide production of and natural gas reached 3.2 bill tonnes which about 40% beyond continental slopes. However the natural gas subject to constraints faced for oli extraction. It readily be trapped from deep ocean sediments. Its estimated that there are 3xlO'5 wait of clean not gas trapped in the deep oceans.

Minerals :

The raw material for building trade so they have been used for generation in different parts of the world for construction. About 25% of sand and gravel for in S.E. England comes from offshore. But of aggregrate world production is from Japan. Beaches around the world have been mined for many minerals including Nambia, gold off Alaska, Bromide off Oregon, Indonesia, Thailand, pure quarls is mexid from the beach in W. North Iceland. On tropical island fringed with coral reef white sands containing $CaCO_3$ are used for cement industry. Elsewhere in sea bed parts in deep sea floor (4000-5000 m deep) Fe, Manganese oxide minerals, are deposited in the size and shape of potato in shallow H_2O (< 2000m deep). Flanks of volcanic islands and sea minerals, MgO_2 are reach in cobalt. Its now established that hydrothermal activity and associated massive sulphide deposit rich in Cu and Zn are common along the crest of mid oceanic ridges. The ocean has been used as a source of salt for many 1000 yrs. fresh water is commercially extracted from oceans. The most common method of devoling it is distillation.

Principal Mineral Resources of the Oceans :

Resources presently extracted from the sea or areas that were formerly in the sea range from common construction materials to high-tech metals to water itself. Chemical analyses have demonstrated that sea water contains about 3.5 percent dissolved solids, with more than sixty chemical elements identified. The limitations on extraction of the dissolved elements as well as the extraction of solid mineral resources are nearly always economic, but may also be affected by geographic location (ownership and transport distance) and hampered by technological constraints (depth of ocean basins). The principal mineral resources presently being extracted and likely to be extracted in the near future are briefly considered here.

Salt :

Salt, or sodium chloride, occurs in sea water at a concentration of about 3 percent and hence constitutes more than 80 percent of the dissolved chemical elements in sea water. The quantity available in all the oceans is so enormous that it could supply all the human needs for hundreds, perhaps thousands, of years. Although salt is extracted directly from the oceans in many countries by evaporating the water arid leaving the residual salts, most of the nearly 200 million metric tons of salt produced annually is mined from large beds of salt These beds, now deeply buried, were left when waters from ancient oceans evaporated in shallow seas or marginal basins, leaving residual thick beds of salt; the beds were subsequently covered and protected from solution and destruction.

Potassium :

Like the sodium and chlorine of salt, potassium occurs in vast quantities in sea water, but its average concentration of about 1,300 parts per million (or 0.13 percent) is generally too low to permit direct economic extraction. Potassium salts, however, occur in many thick evaporite sequences along with common salt and is mined from these beds at rates of tens of millions of metric tons per year. The potassium salts were deposited when sea water had been evaporated down to about one-twentieth of its original volume.

Magnesium :

Magnesium, dissolved in sea water at a concentration of about 1,000 parts per million, is the only metal directly extracted from sea water. Presently, approximately 60 percent of the magnesium metal and many of the magnesium salts produced in the United States are extracted from sea water electrolytically. The re~rnaining portion of the magnesium metal and salts is extracted from ancient ocean deposits where the salts precipitated during evaporation or formed during diagenesis. The principal minerals mined for this purpose are magnesite ($MgCO_3$) and dolomite. ($CaMg[CO_3]_2$).

Sand and Gravel :

The ocean basins constitute the ultimate depositional site of sediments eroded from the land, and beaches represent the largest residual deposits of sand. Although beaches and near-shore sediments are locally extracted for use in construction, they are generally considered too valuable as recreational areas to permit removal for construction purposes. Nevertheless, older beach sand deposits are abundant on the continents, especially the coastal plains, where they are extensively mined for construction materials, glass manufacture, and preparation of silicon metal. Gravel deposits generally are more heterogeneous but occur in the same manner and are processed extensively for building materials.

Limestone and Gypsum :

Limestones (rocks composed of calcium carbonate) are forming extensively in the tropical to semitropical oceans of the world today as the result of precipitation by biological organisms ranging from mollusks to corals and plants. There is little exploitation of the modern limestones as they are forming in the oceans. However, the continents and tropical islands contain vast sequences of limestones that are extensively mined; these limestones commonly are interspersed with dolomites that formed through diagenetic alteration of limestone. Much of the limestone is used directly in cut or crushed form, but much is also calcined (cooked) to be converted into cement used for construction purposes. Gypsum (calcium sulfate hydrate) forms during evaporation of sea water and thus may occur with evaporite salts and/or with limestones. The gypsum deposits are mined and generally converted into plaster of paris and used for construction.

Manganese Nodules :

The deep ocean floor contains extremely large quantities of nodules ranging from centimeters to decimeters in diameter (that is, from less than an inch to several inches). Although commonly called manganese nodules, they generally contain more iron than manganese, but do constitute the largest known resource of manganese.

Despite the abundance and the wealth of metals contained in manganese nodules (iron, manganese, copper, cobalt, and nickel), no economic way has yet been developed to harvest these resources from the deep ocean floor. Consequently, these rich deposits remain as potential resources'for the future. Terrestrial deposits of manganese are still relied on to meet human needs.

Phosphorites :

Complex organic and inorganic processes constantly precipitate phosphate-rich crusts and granules in shallow marine environments. These are the analogs (comparative equivalents) of the onshore deposits being mined in several parts of the world, and represent future potential reserves if land-based deposits become exhausted.

Metal Deposits Associated with Volcanism and Seafloor Vents :

I Submarine investigations of oceanic rift zones have revealed that rich deposits of zinc and I copper, with associated lead, silver, and gold, are forming at the sites of hot hydrothermal emanations commonly called black smokers. These metal-rich deposits, ranging from chimneyto pancake-like, form where deeply circulating sea water has dissolved metals from the underlying rocks and issue out onto the cold seafloor along major fractures. The deposits forming today are not being mined because of their remote locations, but many analogous ancient deposits are being mined throughout the world.

Placer Gold, Tin, Titanium, and Diamonds :

Placer deposits are accumulations of resistant and insoluble minerals that have been eroded from their original locations of formation and deposited along river courses or at the ocean margins. The most important of these deposits contain gold, tin, titanium, and diamonds.

Today, much of the world's tin and many of the gem diamonds are recovered by dredging near-shore ocean sediments for minerals that were carried into the sea by rivers. Gold has been recovered in the. past from such deposits, most notably in Nome, Alaska. Large quantities of placer titanium minerals occur in beach and nearshore sediments, but mining today is confined generally to the beaches or onshore deposits because of the higher costs and environmental constraints of marine mining.

Water :

The world's oceans, with a total volume of more than 500 million cubic kilometers, hold more than 97 percent of all the water on Earth. However, the 3.5-percent salt content of this water makes it unusable for most human needs. The extraction of fresh water from ocean water has been carried out for many years, but provides only a very small portion of the water used, and remains quite expensive relative to land-based water resources. Technological advances, especially in **reverse osmosis,** continue to increase the efficiency of fresh-water extraction ; However, geographic limitations and dependency on world energy costs pose major barriers to large-scale extraction.

6.7 Sustainable use of Marine Resources

Developing a strategy to ensure the sustainable use of living marine resources and their environment is only one aspect of man's relationship with the biosphere addressed at the UN Conference on Environment and Development (Rio de Janeiro, June 1992). However, this aspect poses particular problems for international collaborative management that do not apply to most terrestrial environments, where the ownership of resources and their environment, and the corresponding responsibility for their management, have usually been long established. The urgent need now is how to establish the conditions for Sustainable Development of living marine resources within the existing framework of rights and responsibilities for different maritime areas and resources. The beginnings of a consensus on this issue effectively date from the United Nations Convention on the Law of the Sea in 1982 (United Nations, 1983), which is used by most of the signatory States as a basis for relevant national and international legislation and State practice. The Convention came formally into force in November 1994.

6.8 Summary and Conclusion

This unit discussed the marine environment, marine ecosystem, marine resource and the sustainable uses of the marine resources, which are very much imperative. There are various marine resources and most of which are unique in the sense that they are renewable as most of the organisms can be regenerated. The leaners will definitely get pleasure from the knowledge of this unit.

6.9 Key words

Marine environment, marine ecosystem, marine resources

6.10 Model Question

Short answer type :

1. State about the marine environment.
2. What Ooze?
3. Classify Ooze.

Long answer type :

1. Explain the structure and function of marine ecosystem.
2. Discuss classification of marine resources.

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Unit - 7 ❑ Sea Level Change : Types and Causes

Structure

7.1 Introduction

This unit is going to discuss the concept of sea level change, which is a global phenomena. The causes and consequences are discuss in it. Global sea level has been rising unusually over the past century, and the rate has increased in recent decades. With continued ocean and atmospheric warming, sea levels will likely rise for many centuries at rates higher than that of the current century. The constant threat of sea level rise cases menacing impact on the hundreds of millions of people living in coastal communities.

7.2 Objectives

- To know about sea level change.
- To know about the causes of sea level change.
- To learn about the consequences sea level change.

7.3 Sea Level Change (Rise and Fall)

Sea level change is a global phonon. Over the long Geological Time Periods the sea level changed several times at different extents in response to the Isostatic change of the earth's crust. With gradual deglaciation through the Quaternary period the sea level continues to rise.

Global sea level has been rising unusually over the past century, and the rate has increased in recent decades. It has been found that in 2014, global sea level was 6.6 cms above the 1993 average, the highest annual average in the satellite record (1993-present). Sea level continues to rise at a rate of about one-eighth of an inch per year.

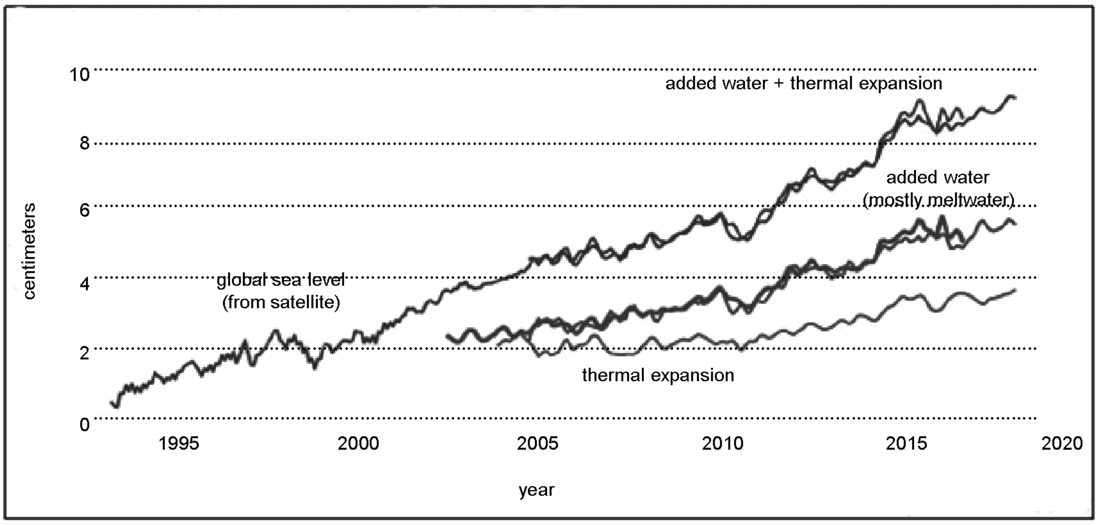

Fig. 51 : Sea level change

Higher sea levels mean that deadly and destructive storm surges push farther inland than they once did, which also means more frequent destructive flooding. Disruptive and flooding is estimated to be from 300 percent to 900 percent more frequent in many coastal areas than it was just 50 years ago.

7.4 Causes of Sea Level Rise

The two major causes of global sea level rise are (1) thermal expansion caused by warming of the ocean (since water expands as it warms) and (2) increased melting of continental ice (Antarctica, Greenland and mountains in the other continents). The oceans are absorbing more than 90 percent of the increased atmospheric heat associated with emissions from human activity.

With continued ocean and atmospheric warming, sea levels will likely rise for many centuries at rates higher than that of the current century. In the United States, almost 40% of the population lives in relatively high-population-density coastal areas, where sea level plays a role in flooding, shoreline erosion, and hazards from storms. Globally, eight of the world's 10 largest cities are near a coast, according to the U.N. Atlas of the Oceans.

Projecting future sea level has always been challenging, due to our imperfect understanding of many aspects of the climate system. As climate research leads to improved computer models, projections have consistently increased. For example, in 2007 the high end of Intergovernmental Panel on Climate Change (IPCC) projections through 2099 was less than 0.6m but in their 2014 report the high end was considered to be about 0.91m. A number of later studies have concluded that 2.0 to 2.7 metres rise this century is possible. The contributions to sea level rise since 1993, based on 2018 figures, divide into ocean thermal expansion (42%), melting of temperate glaciers (21%), Greenland (15%) and Antarctica (8%).

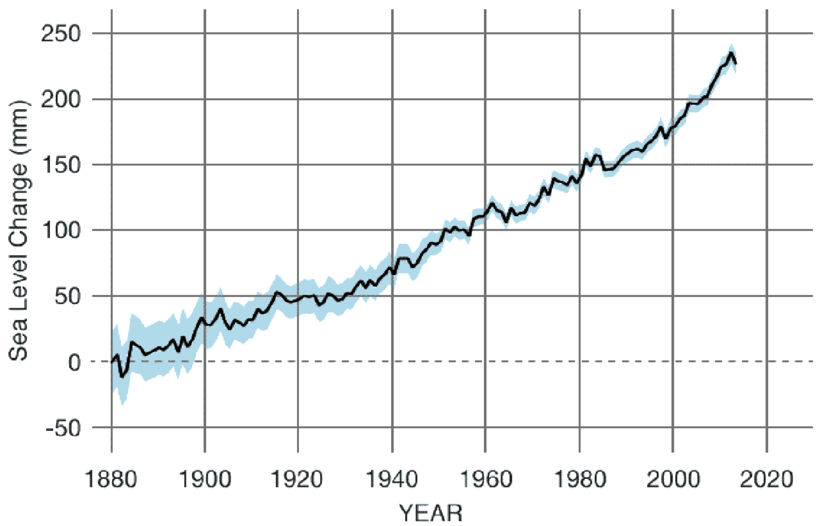

Fig. 52 : Sea level changes

7.5 Consequences of Sea-level Rise

The effects of sea level rise have already been felt, and the forecasts are quite grim. First, water is increasingly invading coastal areas, causing soil erosion and threatening farmland, housing or recreation areas with danger of inundation. The flooding of wetlands and pollution of aquifers also occur, affecting the flora and fauna of the areas around, causing loss of habitat for fish, birds, plants and many other species.

On the other hand, a higher sea level causes heavy rains and strong winds, unleashes severe storms and other serious atmospheric phenomena that can be a real threat to places that might be on its way.

On the social aspect, the constant threat of sea level rise cases menacing impact on the hundreds of millions of people living in coastal communities. If water continues to rise, they will be forced to abandon their homeland and move to the farther inland areas with the corresponding demographic problem. This is known as forced migration resulting from climate change.

Finally, low-lying islands would be swallowed by the oceans, leading to the disappearance of large land areas and even some countries.

7.6 Summary and Conclusion

The learners came to know about various aspects of sea level changes in this unit. We all know that the higher sea levels mean that deadly and destructive storm surges push farther inland. It also means more frequent destructive flooding and the disruptive and flooding is estimated to be from 300 percent to 900 percent more frequent in many coastal areas than it was just 50 years ago. Moreover, the higher sea level causes heavy rains and strong winds, unleashes severe storms and other serious atmospheric phenomena that can be a real threat to places that might be on its way. Thus, finally the knowledge of this unit will be helpful for higher studies and grow interest to study the recent stories and progress related to this.

7.7 Key words

Sea level change, causes of sea level change, consequences of sea level change

7.8 Model Questions

Short answer type :

1. What is sea level changes ?
2. What are the recent trend of sea level change ?

Long answer type :

1. Discuss the salient features of sea level change.
2. Explain the causes of sea level change.
3. Explain the consequences of sea level change.

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Summary and Conclusions of Module 2

The study of oceanography is a very import part in the discipline of Physical Geography. Ocean floor or abyssal plain covers the study on the physical part of the subject. This is an underwater plain on the deep ocean floor; which occurs at depths between 3,000 metres (9,800 ft) and 6,000 metres (20,000 ft) below the sea water surface covering more than 50% of the earth's surface. Abyssal plains, with their vast expanse, are believed to be a major storehouse of biodiversity. The abyss also causes significant influence upon ocean carbon cycling, dissolution of calcium carbonate and atmospheric carbon (CO_2) concentrations over timescales of 100–1000 years. According to the theory of Plate Tectonics oceanic crust, which forms the bedrock of abyssal plains, is continuously being created at mid-ocean ridges alongside the divergent plate boundary by a process known as decompression melting. Accretion occurs as mantle is added to the growing edges of a tectonic plate, usually associated with seafloor spreading. Oceanic crust and tectonic plates are continuously formed and move apart at mid-ocean ridges. Consumption or destruction of the oceanic lithosphere occurs at oceanic trenches (a type of convergent boundary, also known as a destructive plate boundary) by a process of subduction. Oceanic trenches are found at places where the oceanic lithospheric bodies of two different plates meet, and the denser (older) slab begins to descend into the mantle.

In the ocean water masses are formed as the result of climatic effects. The vast majority of water masses are formed at the surface of the oceans in middle and high latitudes as a result of climatic effects. Cold, highly dense surface water sinks until it reaches a level having the same constant density, where it spreads out horizontally. The manner in which it spreads out depends upon its density in relation to the density of the surrounding water. Surface water masses set their T-S (Temperature-Salinity) properties at the ocean surface when comes in contact with the atmosphere.

The most important property of seawater is its high salinity. It makes the water of the oceans different from the lakes and rivers of fresh water. Greater than 96% of seawater is made up mainly of liquid in which chloride (Cl^-) and sodium (Na^+) are the dominant dissolved chemicals. By weight, chloride (Cl^-) and sodium (Na^+)

together comprise more than 85.65 percent of all dissolved substances in seawater. When these two ions bond chemically into a solid, they form halite and give seawater its most distinctive property – its salinity.

Since the amount of solar energy reaching the earth's surface is maximum at the equator and decreases to the higher latitudes, ocean surface temperatures are found highest in the tropics and decrease towards the north and south poles. As a consequence isotherms generally trend in an east-west direction, parallel to lines of latitude. With the variation of Insolation (incoming solar radiation) with the seasons, the sea surface temperatures change accordingly. Ocean currents, flowing around the periphery of each ocean, affect the distribution of sea surface temperature. The two water masses (warm and cold) are separated from each other by a layer of water that has a sharp temperature gradient, called the thermocline.

The monthly sea surface temperature values in the northern hemispheric oceans always remain higher than those in the southern hemispheric oceans. At the equator, evaporation rates are high, but rainfall is even greater, leading to the lower surface salinity in these waters. Density of seawater depends very much on the temperature, salinity, and pressure conditions. Water density controls the vertical structure of the water column, with denser water underlying the less dense water. The density of water increases with decreasing temperature and increasing salinity, thus implying that cold, saline water is denser than warm freshwater. Along with salinity and temperature, pressure at different depths in the oceans is another important parameter influencing the physical characteristics of sea water.

Since more than three fourths of the earth's surface is under oceanic waters, the earth appears as a blue planet as seen from the space. The reason the ocean is blue is due to the absorption and scattering of light.

The solubility of substances, especially ionic compounds, is much higher in water than in other solvents. This high solubility results from the atomic structure of the water molecule with the hydrogen atoms tightly bound to oxygen and separated by a 105° angle, giving the water molecule a dipolar charge balance. The primary source of major ions to the ocean is riverine input. Once these ions enter the ocean, their existence time becomes very long compared to the mixing time for the oceans.

Sea water also contains various dissolved atmospheric gases, mainly nitrogen, oxygen, argon, and carbon dioxide. Virtually all atmospheric gases are found dissolved in sea water. Cold water holds more gas than warm water, Also deep water, which has a high pressure, holds more gas than shallow water. Dissolved oxygen and carbon dioxide are vital for marine life. Marine plants use dissolved carbon dioxide, sunlight and water to make carbohydrates through the process of photosynthesis. In oceanography temperature-salinity diagrams, sometimes called T-S diagrams, are used to identify water masses.

Air-sea interaction through gas (atmospheric) exchange is a physio-chemical process, primarily controlled by the air-sea difference in gas concentrations and the exchange coefficient, which determines how quickly a molecule of gas can move across the ocean-atmosphere boundary. It takes about one year to equilibrate CO_2 in the surface ocean with atmospheric CO_2. The study of air-sea interactions shows how the atmosphere and ocean affect each other through the exchange of heat, momentum, and water across the air-sea interface.

Ocean circulation is the large scale movement of waters through the oceans. Winds drive surface circulation, and the cooling and sinking of waters in the Polar Regions drive deep circulation. Variations in the ocean's circulation can lead to variations in heat transport and to variations in weather patterns.

Tides and Waves are natural phenomenon formed on the related to water bodies. Tides are the rise and fall of huge amounts of water. By contrast, waves are simply the effects of powerful winds raging on oceanic surfaces Ocean waves transport energy over vast distances, Water movement and sediment transport under breakers of different types and subsequent breaker type-specific processes in the swash/ backwash zone in part translate into changes in the beach profile.

The alternating advance and retreat of seawater along a coastline is called a tide. High tide is when water advances to its furthest extent onto the shoreline. Low tide is when it recedes to its furthest extent. Most shorelines experience two high and two low tides within a twenty-four-hour period, though some areas have just one of each.

Coral Reefs are built by colonies of tiny animals found in marine waters that contain few nutrients. Most coral reefs are built from stony corals, which in turn consist of polyps that cluster in groups. Shallow coral reefs form some of the most diverse ecosystems on the earth which are often called 'rainforests of the sea'. They render ecosystem services to tourism, fisheries and shoreline maintenance. By character coral reefs are fragile ecosystems, partly because they are very sensitive to water temperature. They are under threat from climate change, oceanic acidification, blast fishing, cyanide fishing sunscreen use, overuse of reef resources, and harmful land-use practices, including urban and agricultural runoff and water pollution, which can be harmful for reefs by encouraging excess algal growth.

Global sea level has been rising unusually over the past century, and the rate has increased in recent decades. Higher sea levels mean that deadly and destructive storm surges push farther inland than they once did, which also means more frequent destructive flooding. Disruptive and flooding is estimated to be from 300 percent to 900 percent more frequent in many coastal areas than it was just 50 years ago. With continued ocean and atmospheric warming, sea levels will likely rise for many centuries at rates higher than that of the current century.

Key Words of Module 2

Abyssal plain, Plate Tectonic, ecosystem, asthenosphere, lithosphere, pelagic sediments, ocean fertilisation, euphotic zone, decompression, seafloor spreading, mid-oceanic ridges, subduction zone, oceanic trench, Supercontinent cycle, pelagic sediments, turbidity, jig-saw puzzle, Transform, water mass, salinity, subsurface movement, evaporation, precipitation, Insolation, isotherms, thermocline, thermohaline, halocline, pycnocline, Precipitation, evaporation, incompressible, photosynthesis, hydrostatic pressure, phytoplankton, chlorophyll, configuration, phosphorous, particulate, organisms, biogeochemical, physicochemical, biochemical, geochemical, adsorption, respiration, byproducts, anthropogenic, El Niño, Coriolis force, gravitational force, orbital motion, Amplitude, swash,, backwash, Cnidaria, acidification, anthopogenic, mollases, Isostatic, deglaciation, migration

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Model Questions of Module 2

1. What are the major relief features of the ocean floor ? Describe the process of its formation.

2. Examine the characteristics and origin of the origin and evolution of the ocean floor according to the theory of Plate Tectonics.
3. Give an account of the component of water mass of the oceans and describe its physical and chemical properties.
4. What is T-S diagram ? Describe its utility.
5. Give an account of the temperature conditions of the oceans and the pattern of its latitudinal and longitudinal distribution over the oceans.
6. What are the determinants of temperature variations over the oceans ? Give a reasoned acccount.
7. What are the determinants of variations in the salinity in the ocean water ? Give a reasoned account.
8. What do you mean by air-sea interaction ? Describe the process through which air-sea interaction process takes place.
9. Elucidated the significance of El Nino condition in the atmosphere over the oceans.
10. Distinguish between wave and tide and describe the conditions under which they form.
11. Identify the properties of waves and account for the mechanisms of Swash, backwash.
12. Describe the ocean environmental conditions for the formation of coral reefs.
13. Discuss about the different threats of formations of coral. Why corals face degradation in the present day.
14. What are the components of Marine Ecosystem ? Account for the Marine Resources for sustenance of the human generation in future
15. Classify the marine resources according to their types examine the need and process for their sustainable use.
16. What is Sea-level change ? Describe reasons for global sea-level rise in the present day.

NOTES