STUDY ON VARIATIONS OF MAJOR INDEX PROPERTIES OF RECENT SEDIMENTS ALONG THE COURSE OF THE RIVER GANGA FROM RISHIKESH,UTTARAKHAND TO DIAMOND HARBOUR,WEST BENGAL, INDIA

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By

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that **Sri Mukul Roy (Exam Roll No. MGEO194001)** has worked under my guidance on the topic **'Study on Variation of Major Index Properties of Recent Sediment along the Course of the River Ganga, from Rishikesh, Uttarakhand to Diamond Harbour, West Bengal, India'**, in the Department of Geological Sciences. He has completed his work with due sincerity, which is being submitted herewith as a thesis towards the partial fulfillment of his **M.Sc. Degree Examination in Applied Geology (2019)** of **Jadavpur University.**

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ABSTRACT

Recent sediment is considered as a thin crustal membrane, produced by a series of prolonged and complex natural processes. From the pre-historic time human inhabitation and subsequent civilization were mostly constricted along the river valley due to the fertility of alluvial sediment. In recent days, unplanned urbanization along the river course not only degrading its ecological health but also enhancing the threat of disaster like bank failure and recurring flood. Thus categorization of mechanical index properties of basin sediment is essential prior to plan a civil construction**.** In the Indian subcontinent the River Ganga constitute one of the important river systems responsible for the deposition of huge sedimentation and contributed a significant fertile land mass. In the present investigation an attempt has been made to study the variations of major index properties of recent soil along the course of the River Ganges from its foot hill flow to the down-stream end at the Bay of Bengal. Samples were collected from eleven locations, following the river flow. Detail analyses of the obtained results related to index properties were made to bring out a correlation between the soils geotechnical properties and related coefficients with the distance and over all conditions of its deposition.

Keywords: Alluvial Sediment, Index Properties, River Ganga, Correlation, Geotechnical Properties

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Chapter 1

Introduction

1. Introduction

Index properties of soil refer to those properties of a soil that indicate the type and conditions of the soil. Categorization of major index properties of soil is the first and foremost responsibilities of an engineer to start a civil construction project. Index properties of soil have a close and define relation with the formation history of the soil mass and vary substantially with the characteristics of source materials, duration of transportation, nature of the transporting agent, depositional environment and its stress history.

The river Ganga has significant economic, environmental and cultural value in India. Rising in the Himalayas and flowing in to the Bay of Bengal, the river traverses a course of more than 2,500 km through the plains of north and eastern India. The Ganga basin – which also extends into parts of Nepal, China and Bangladesh – accounts for 26 percent of India's landmass, 30 per cent of its water resources and more than 40 percent of its population. The Ganga also serves as one of India‘s holiest rivers whose cultural and spiritual significance transcends the boundaries of the basin.

The Ganga rises in the Garhwal Himalaya as the Bhagirathi. The ice cave of Gaumukh at the snout of the Gangotri glacier, at 3,892 metres above sea level, is recognized as the traditional source of the Ganga. The river cuts through the Himalayas until another head stream, the Alaknanda, joins at Devprayag. It is below this confluence that the united stream of Bhagirathi and Alaknanda becomes known as the River Ganga.

Ganga basin is the largest river basin in India in terms of catchment area, constituting 26% of the country's land mass (8,61,404 Sq. km) and supporting about 43% of its population (448.3 million as per 2001 census). The basin lies between East longitudes 73°30and 89° 0 and North latitudes of 22°30 and 31°30, covering an area of 1,086,000 sq km, extending over India, Nepal and Bangladesh. About 79% area of Ganga basin is in India. The basin covers 11 states viz., Uttarakhand, U.P., M.P., Rajasthan, Haryana, Himachal Pradesh, Chhattisgarh, Jharkhand, Bihar, West Bengal and Delhi.

Despite its importance, extreme pollution pressures pose a great threat to the biodiversity and environmental sustainability of the Ganga, with detrimental effects on both the quantity and quality of its flows. Due to increasing population in the basin and poor management of urbanization and industrial growth, river water quality and hydraulic parameters of the flow has significantly deteriorated, particularly in dry seasons. Tremendous pressure of civilization from the historical time significantly changes its soil characteristics imposing continuous anthropogenic activities.

The Ganga basin is characterized by a wide variety of soils. The soils of the high Himalayas in the north are subject to continued erosion and the Gangetic trough provides a huge receptacle into which thousands of meters of thick sediment layers are deposited to form a wide valley plain. The plateau on the south has a mantle of residual soils of varying thickness arising due to the weathering of the ancient rocks of the peninsular shield. Ten classes of soils have developed in the Ganga basin under different Iithological, climatic and pedogenetic conditions.

In the present study an attempt has been made to study the major index properties of soil collected from the different locations along the course of the river Ganga to get an apprehensive understanding and overall idea about the types of the soil and the changes and variations of major index properties along it courses as function of its transportation distance, flow conditions, depositional environment and stress history. For the investigation soil samples were collected from the ten (10) locations covering the entire course of the river, starting from Rishikesh, and then followed the location of Haridwar, Saharanpur, Allahabad, Varanasi, Patna, Raghunathgunj, Shibpur, Gadiara and lastly Diamond Harbour.

From all the location undisturbed soil samples were collected just from the bank of the river following the standard process (explained in Chapter – 3). The major index properties studied are grain size analysis, coefficient of uniformity, coefficient of curvature; dry density and optimum moisture content of the soil, liquid limit, plastic limit and plasticity index for cohesive soil (i.e. $d_{50} \approx$ or $< 75\mu$). All the experimental tests were conducted in the 'Geotechnical Laboratory' of Jadavpur University, Kolkata, West Bengal, following the standard experimental procedures.

Chapter 2

The River Ganga And its Soil Characteristics

2. The River Ganga and its Soil Characteristics

2.1 The River

India is drained by more than 12 major river systems (basins) with a catchment area of more than 2,500,000 Sq.km. These river systems are grouped into four broad categories: the Himalayan rivers, the Peninsular rivers, the Coastal rivers and the Inland rivers. In addition to the Ganga, the Himalayan river system includes the Indus and Brahmaputra river basins.

The Ganga River (about 2,525 km long) is fed by runoff from a vast land area bounded by the snow peaks of the Himalaya in the north and the peninsular highlands and the Vindhya Range in the south. The basin encompasses an area of more than a million square kilometers (1,186,000 Sq.km.) spread over four countries: India, Nepal, Bangladesh and China. With 861,404 Sq.km. within India itself, the Ganga basin is the largest river basin in India and covers approximately 25 percent of India's total geographical area. Fig 2.1 represents the geographical location of the basin and its spread in the Indian subcontinent.

The Ganga rises in the Garhwal Himalaya (30º55′ N, 79º7′E) as the Bhagirathi. The ice cave of Gaumukh at the snout of the Gangotri glacier, at 3,892 metres above sea level, is recognized as the traditional source of the Ganga. The river cuts through the Himalayas until another head stream, the Alaknanda, joins at Devprayag. It is below this confluence that the united stream of Bhagirathi and Alaknanda becomes known as the River Ganga.

At Haridwar, where the Ganga opens to the Gangetic Plains, a barrage diverts a large quantity of its waters into the Upper Ganga Canal, to provide water for irrigation. At Bijnore, another barrage diverts water into the Madhya Ganga Canal but only during monsoon months.

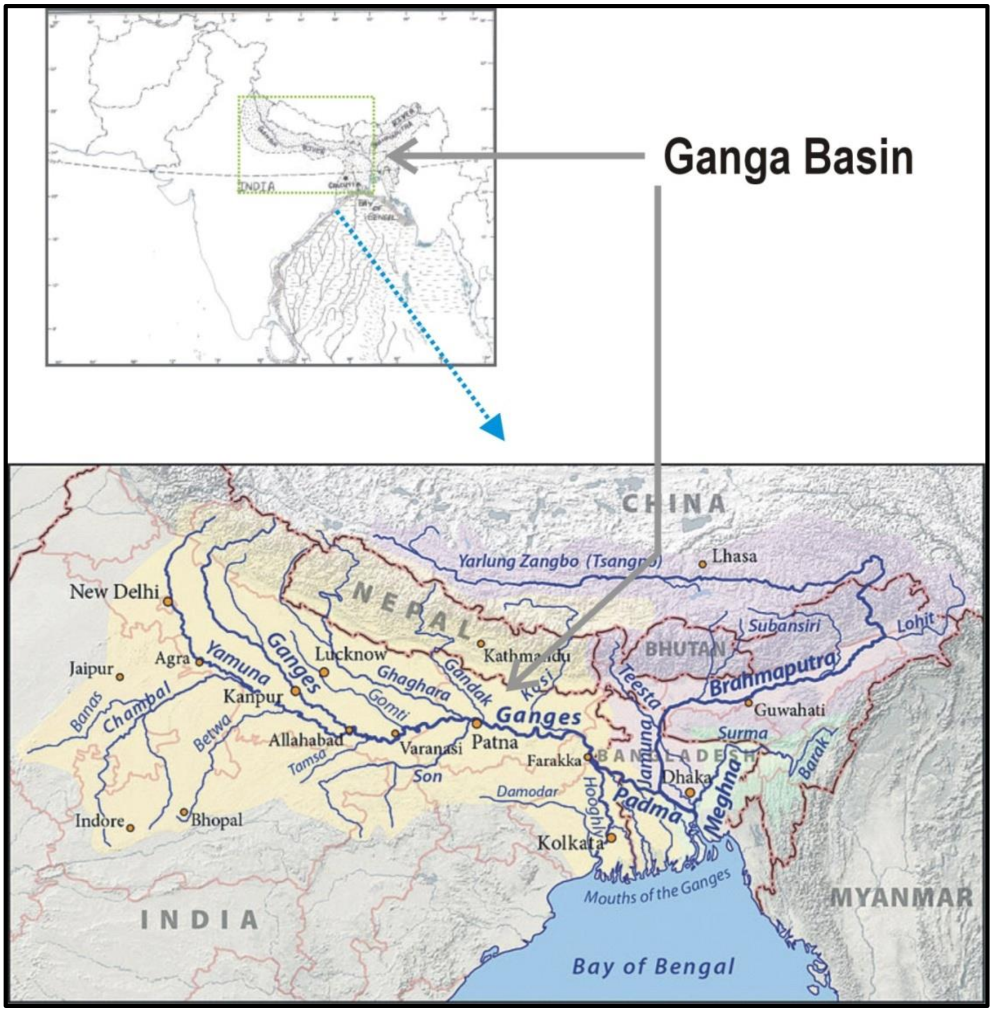


Fig 2.1 Geographical location of the Ganga Basin

The Ganga does not receive any major tributary until the Ramganga joins at Kannauj adding some 17.79 billion cum/annum of water. At Allahabad (1020 km from the source), the Ganga is joined on the right by the River Yamuna, which actually contributes more water (57.24 billion cum/annum) than the main river itself, augmenting the flow volume of the Ganga significantly.

After Allahabad, the Ganga begins to receive several major tributaries at more frequent intervals, namely, the Tons, Son, Gomati, Ghaghara, Gandak, BurhiGandak and Kosi. After Rajmahal, the Ganga eventually reaches the head of its delta at Farakka, in the state of Jharkhand, having increased its flow volume at each confluence. In addition to flow volume, water quality and sediment load also fluctuate depending on the composition of the contributing stream.

Below Farakka, the Ganga bifurcates into the Padma and the original channel of the Ganga, known as the Bhagirathi. Therefore, the Bhagirathi is treated as the main Ganga for all purposes in West Bengal. The Padma, carrying the majority of Ganga's flow, eventually turns southeastwards into Bangladesh, while the Bhagirathi (Ganga) winds southwards down the deltaic plain of West Bengal and ultimately empties into the Bay of Bengal under the name of Hugli. Nearly halfway between Farakka and SagarIsland, the hydraulic character of the Bhagirathi (Ganga) suddenly changes upon its entry into the tidal zone of the Gangetic delta. The speed and direction of water in the estuarine streams and creeks are in continual flux due to the ebb and flow of the tides. Line diagram of the Ganga with major tributaries is shown in Figure 2.2.

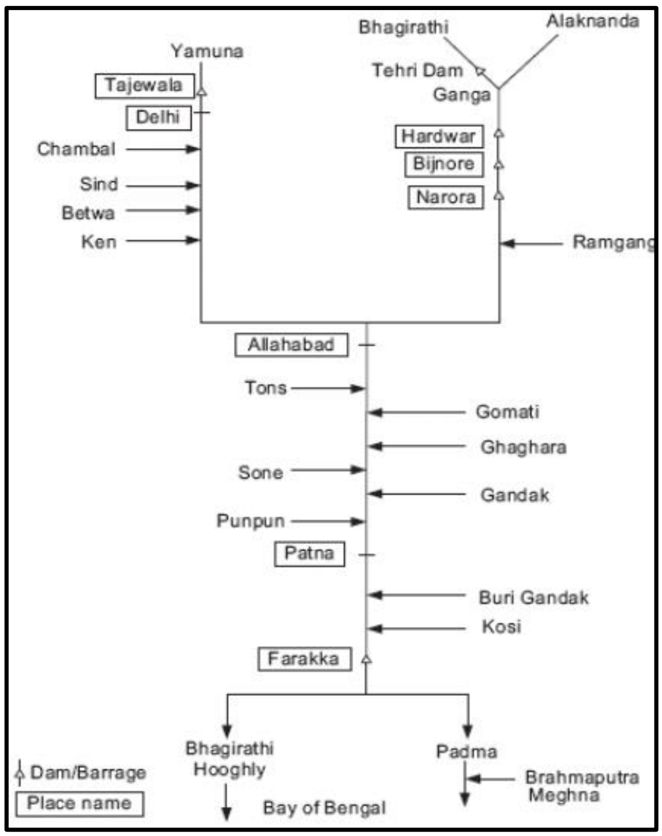


Figure 2.2 Line diagram of the Ganga with major tributarie

2.2 Stream Flow Characteristics

Due to their high gradient and a tremendous velocity, Himalayan rivers including the Ganga have a strong erosive power. The geological fact that the Himalayan rivers run through poorly consolidated sedimentary rocks affected by folds and faults results in high rates of erosion and silt deposition. Landslide debris further adds to the silt load.

Rainfall, subsurface flows and snow melt from galciers are the main sources of water in river Ganga. More than 60 percent of the water flowing into the Ganga basin comes from the Himalayan streams joining the Ganga from the north. The Peninsular streams combine to contribute only 40 percent of the water, despite the fact that the catchment area of the Peninsular streams extends well over 60 percent of the entire Ganga basin.

The mountainous section stretches from the river's source to Rishikesh. This section has an average bed slope of 1 in 67 and a mean flow rate of 850 cubic metres per second at Rishikesh. The subsequent upper plain section extends from Rishikesh downstream until Allahabad at a slope of 1 in 4,100 and a mean flow rate ranging between 850 and 1,720 cum per second before its confluence with the Yamuna. The third, middle plain section stretches from Allahabad to Farakka, with a slope of 1 in 13,800 and an increase in the mean flow rate to 10,200 cum per second at Azamabad. Following this part lies the upper deltaic non-tidal plain section, with a slope of 1 in 23,000 and a much reduced mean flow rate of 1,300 cum per second near Nabadwip. The final segment is the lower deltaic tidal plain section, with a slope of 1 in 24,000 and varying flows due to influence of the tides.

The large volume and high flow of the Ganga in the middle plain section (1,005 km) between Allahabad and Farakka render this stretch relatively less vulnerable to pollution, compared to the sections on the upstream of Allahabad and downstream of Farakka. However, upstream of Allahabad the mean annual flow is less than 1,700 cum per second and, as a result, the upper plain course of the Ganga is liable to be polluted to some extent if adequate precautionary measures are not taken this fact is especially true during the lean months. This same increased susceptibility to pollution also occurs downstream of Farakka, where the mean annual stream flow again falls off drastically to a level of 1,300 cum per second at Nabadwip. Further down, especially in the estuarine section near the outfall, the up and down movement of the water periodically causes temporary suspension of the water current, as the tide shifts from ebb to flow and vise versa. As a result of this stagnation, removal of pollutants in the tidal section can expected to be slow and difficult.

(*Source: Status paper on river Ganga, NRCD, MoEF, 2009)*

2.3 Soil Characteristics

The Ganga basin is characterized by a wide variety of soils. The soils of the high Himalayas in the north are subject to continued erosion and the Gangetic trough provides a huge receptacle into which thousands of metres of thick sediment layers are deposited to form a wide valley plain. The plateau on the south has a mantle of residual soils of varying thickness arising due to the weathering of the ancient rocks of the peninsular shield. Ten classes of soils have developed in the Ganga basin under different Iithological, climatic and pedogenetic conditions. Some of the soils within the Ganga basin are highly susceptible to erosion. Such soils need adequate conservation measures and appropriate land management interventions, with an eye towards preserving the soil resource and keeping the turbidity levels of the surface water within tolerable limits. Among the soil types within Ganga basin, the alluvial soil covers more than 52 percent of the basin. The alluvial deposits of the basin not only cover the great Gangetic trough, but also extend over a sizable portion of the peninsular foreland in the form of a layer less than 3 metres thick. The entire alluvial formation is endowed with rich soil nutrients. The alluvial deposits of the Ganga and its tributaries, coming down the Himalaya and the peninsular foreland, have yielded annual harvests of crops for the past thousands of years with little significant deterioration. Besides paddy, this tract produces a wide variety of crops including wheat, jowar, bajra, small millets, pulses of different kinds, maize, cotton, jute and many other food and commercial crops.

If managed properly, the alluvial soils are highly fertile soils, capable of producing the highest possible yields of crops to feed the millions. However, these soils are sensitive to change and prone to rapid degradation and pollution. In certain parts of the basin, the soils are already showing signs of salinity (as in Haryana), alkalinity (as in western U.P.), calcareousness (as in north Bihar) and acidity (as in West Bengal) due to overuse, long occupation and continued application of inputs like excessive irrigation water and toxic agro-chemicals of various types. The land degradation status within Ganga basin is given in subsequent sections.

(*Source: Status paper on river Ganga, NRCD, MoEF, 2009*)

Chapter 3

Index Properties of Recent Sediment

3. Index Properties of Recent Sediment

3.1 General

Index properties of soil refer to those properties of a soil that indicate the type and conditions of the recent sediments. Categorization of major index properties of recent sediments is the first and foremost responsibilities of an engineer to start a civil construction project. Index properties of recent sediment have a close and define relation with the formation history of the soil mass and vary substantially with the characteristics of source materials, duration of transportation, nature of the transporting agent, depositional environment and its stress history.

Recent sediment index properties are used extensively by engineers to discriminate between the different kinds of soil within a broad category, e.g. clay will exhibit a wide range of engineering properties depending upon its composition. Classification tests to determine index properties will provide the engineer with valuable information when the results are compared against empirical data relative to the index properties determined. Precise discussion on major index properties is given below, which are taken into consideration and examined in the present investigation.

3.2 Particle Size Distribution

In soil mechanics, it is virtually always useful to quantify the size of the grains in a type of recent sediment. Since a given soil will often be made up of grains of many different sizes, sizes are measured in terms of grain size distributions.

The percentage of various sizes of particle in a given dry recent sediment sample is found by particle size analysis or mechanical analysis. By mechanical analysis is meant the separation of a soil into its different size fractions. The mechanical analysis is performed in two stages: **(i)** Sieve Analysis, **(ii)** Sedimentation Analysis

The first stage is meant for coarse grained recent sediments only, while the second stage is performed for fine- grained recent sediments.

3.3 Water Content

The water content (*W*c) also called the moister content and is defined as the ratio of weight of water to the weight of solids in a given mass of soil. The water content is generally expressed as a percentage.

3.4 Specific Gravity

Specific gravity is defined as the ratio of the weight of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at that temperature, both weights being taken in air. In other words, it is the ratio of the unit weight of recent sediment solids to that of water. The Indian Standard specifies 27°C as the standard temperature for reporting the specific gravity.

3.5 Density of Recent sediment: The density of soil is defined as the mass of the recent sediment per unit volume.

- **Bulk density (ρ):** The bulk density or moist density is the total mass M of the recent sediment per unit of its total volume. It is expressed in terms of g/cm^3 or kg/m^3.
- **Dry density (ρ_d):** The dry density is the mass of the mass of solids per unit of total volume (prior to drying) of the recent sediment mass.
- **Density of solids (ρ_s):** The density of recent sediment solids is the mass of recent sediment solids per unit of volume of solids.
- **Saturated density (ρ_{sat}):** When the recent sediment mass is saturated, its bulk density is called saturated density. Thus, saturated density is the ratio of the total recent sediment mass of saturated sample to its total volume.
- **Submerged density (ρ'):** The submerged density is the submerged mass of recent sedimentper unit of total volume of the recent sediment mass.

3.6 Consistency of Fine Grained Recent sediments

By consistency is meant the relative ease with recent sediment can be deformed. This term is mostly used for fine grained recent sediments for which the consistency is related to a large extent to water content. Consistency denotes degree of firmness of the recent sediment which may be termed as soft, stiff or hard. The Swedish agriculturist Atterberg divided the entire range from liquid to solid state into four stages:

(i)the liquid state, **(ii)** the plastic state, **(iii)** the semi-solid state and **(iv)** the solid state

3.6.1 Liquid Limit (W_L)

Liquid limit is the water content corresponding to the arbitrary limit between liquid and plastic state of consistency of a recent sediment. It is defined as the minimum water content at which the recent sediment is still in the liquid state, but has a small shearing strength against flowing which can be measured by standard available means. With reference to the standard liquid limit device, it is defined as the minimum water content at which a part of recent sediment cut by groove of standard dimensions will flow together for a distance of 12 mm under an impact of 25 blows in the device.

3.6.2 Plastic Limit (W_P)

The water content corresponding to an arbitrary limit between the plastic and the semisolid state of consistency of a soil; water content at which a soil will just begin to crumble when rolled into a thread approximately 1/8 inches in diameter. The minimum amount of water in terms of percentage that will make the soil plastic.

3.6.3 Shrinkage Limit (W_s)

Shrinkage limit is defined as the maximum water content at which a reduction in water content at which a reduction in water content will not cause a decrease in the volume of a recent sediment mass. It is lowest water content at which a recent sediment can still be completely saturated.

3.6.4 Consistency Index (I_c)

The consistency index or the relative consistency is defined as the ratio of the liquid limit minus the natural water content to the plasticity index of recent sediment.

Consistency index is useful in the study of the field behavior of saturated fine grained recent sediments. Thus, if the consistency index of recent sediment is equal to unity, it is at the plastic limit. Similarly, recent sediment with consistency index equal to zero is at its liquid limit.

3.6.5 Liquidity Index (I_L)

The liquidity index or water-plasticity ratio is the ratio, expressed as a percentage, of the natural water content of recent sediment minus its plastic limit, to its plasticity index.

3.6.6 Plasticity Index (I_p)

The range of consistency within which recent sediment exhibits plastic properties is called plastic range and is called plastic range and is indicated by plasticity index. The plasticity index is defined as the numerical difference between the liquid limit and the plastic limit of recent sediment.

Chapter 4

Methodology

4. Methodology

4.1 General

For the present investigation soils samples were collected from the bank of the river Ganga. The locations from where the soil samples were collected are as follows:

1. Rishikesh
2. Haridwar
3. Saharanpur
4. Allahabad
5. Varanasi
6. Patna
7. Raghunathgunj
8. Shibpur
9. Gadiara
10. Diamond Harbour

All these locations are the old major townships located at the bank of the river and soils in these locations are being exploited from the historic time. Fig. 4.1 reveals the geographical position of the sampled locations along the course of the river.

Index properties those are studied for the samples collected are as follows:

1. Grain size analysis and related coefficients
    a. Modified Proctor compaction test to determine,
    b. Maximum dry density of the soil.
2. Optimum moisture content of the soil (OMC).
3. Liquid limit; Plastic limit and Plasticity index of the soil for the fine grained soil.

4.2 Collection of Soil Samples

Along the course of the river Ganga the samples for the present study were collected from the locations as mentioned above so that it covers the entire flow of the river starting from the foothills of the Himalaya (Rishikesh – location 1) to the location near to its estuaries (Diamond Harbour – location 10). Table 4.1 has been presented to reveal the distances of the sampled locations from the entry of the river Ganga to the plains i.e. Rishikesh. All the locations of sampling were chosen in such a manner to study the variations of soil index properties with the flow distance and transportation history of the deposited soil.

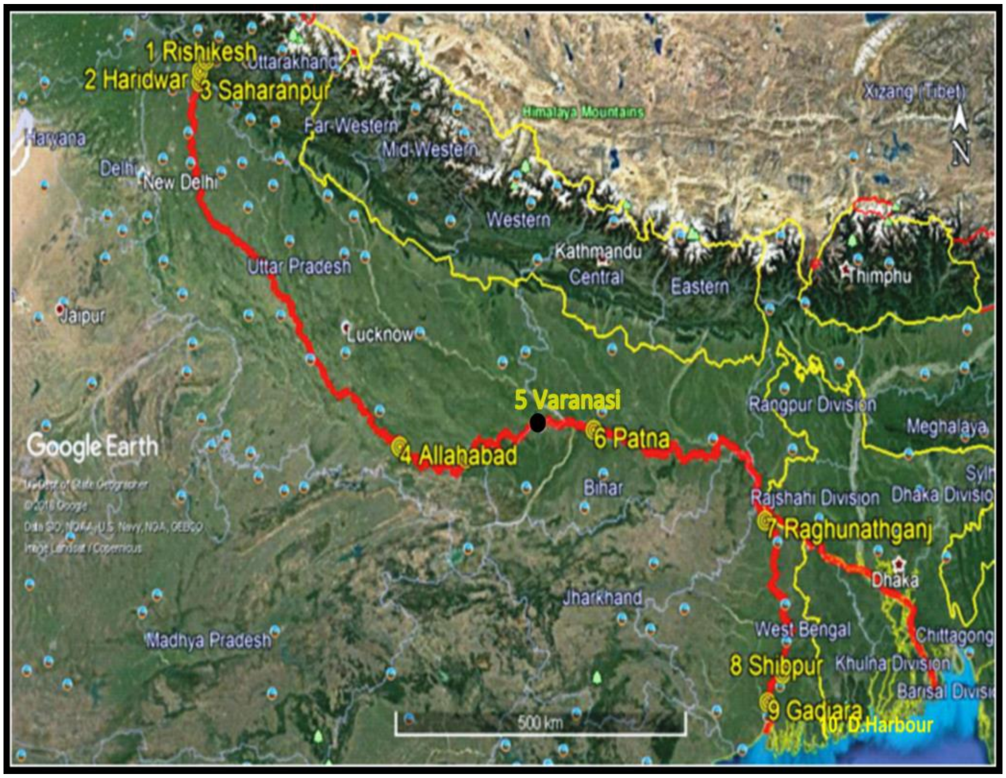


Fig 4.1 Geographical position of the sampled locations along the course of the River Ganga, 1- Rishikesh, 2- Haridwar, 3- Saharanpur, 4- Allahabad, 5- Varanasi, 6- Patna, 7- Raghunathgunj, 8- Shibpur, 9- Gadiara, 10- Diamond Harbour

In all the locations soil samples were collected manually in the month of August and September 2018. For the collection normal digging tool were used. From a particular the soil sample collected from the six points (06) covering a spatial area of 0.5 Km^2. The length of the area was 1km covering a longitudinal distance located in between 0.25 to 0.50 km from the bank flow of the river.

Table 4.1 Distances of the sampled locations from the entry of the river Ganga to the plains i.e. from Rishikesh

Sr. No.	Location	Distance along course from Rishikesh (km)
1	Rishikesh	0
2	Haridwar	25
3	Saharanpur	95
4	Allahabad	820
5	Varanasi	950
6	Patna	1190
7	Raghunathgunj	1550
8	Shibpur	1835
9	Gadiara	2050
10	Diamond Harbour	2500

Source :' Status Paper on River Ganga'. Directorate-Ministry of Environment and Forests,Government of India,August, 2009

For all the sampling points the sample were taken from a depth of around 0.5m from the surface by means of a digging tool. Around 2 kg of soil were collected from the each point and then all the collected sample were put in separate poly bags and marked accordingly. So for individual location around 12 kg of the soil samples were collected and taken for laboratory experimentation. Photographs presented in Fig.4.2 (a-b) reveals the collection of sample form the location of Shibpur and Diamond Harbour.

In laboratory the all the six samples bags were open and samples were initially dried in sunlight for 7 days then the dry nodules (specially for fine grained cohesive samples from Patna and downward locations) were crushed by the rubber hammer blow to make those as fine as possible. There after all the samples collected from a particular location mixed thoroughly by hand for approximately one hour to make that as homogenous as possible.

Fig. 4.2 Collection of samples from the bank of the river Ganga from different locations – (a) Shibpur, (b) Diamond Harbour

Finally 2 kg of sample was taken out from that naturally dried soil for experimental analysis and placed into the oven for 24 hours. Fig. 4.3 shows the photograph of the total ten (10) finally prepared samples with the nomenclatures as taken for the laboratory study.

Fig. 4.3 Finally prepared samples from ten (10) locations

4.3 Experimentation to Study the Index Properties

Index properties those are studied in the Geotechnical Laboratory of College of Engineering Roorkee, includes the grain size analysis by standard sieve analysis; Proctor compaction test following the standard method of modified Proctor compaction test and determination of liquid limit and plastic limit and plasticity index for the fine grained soil sample ($d_{50} <\approx 75\mu$). From the results of the mentioned analysis the soils were categorized according to the ISCS standard and an analysis has been made to relate the properties with the distance of transportation of the soil.

4.3.1 Grain size analysis

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

The main significance of this analysis is that the distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

The equipment used for this experiments include Balance, Automated Sieve shaker Set of sieves, Cleaning brush, Mixer (blender).

The steps those are followed in the Sieve Analysis of the soil samples comprise of the followings:

a. Noting down the weight of each sieve, as well as the bottom pan used in the analysis.

b. Record the weight of the given dry soil sample.

c. Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (i.e. finest one was placed at the bottom). Place the pan below the finest sieve. Carefully pour the soil sample into the top sieve and place the cap over it.

d. Place the sieve stack in the mechanical shaker and shake for 10 minutes.

e. Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

In the present sieve analysis a set of 7 sieves of size 4750μ, 2360μ, 1180μ, 600μ, 300μ, 150μ, 75μ were used.

4.3.2 Standard Proctor compaction test

The main objective of the standard Proctor compaction test is to determinethe optimum water content and the maximum dry density that can be achieved with a certain compaction effort. The relationship between the moisture content and the density of the soil will be obtained in this process. Compaction is the process of increasing the bulk density of the soil or aggregate by driving out the air. For a given soil, for a given amount of compaction effort, the density obtained depends on the moisture content.

The method followed in this experiment is based on the standard 'Proctor Compaction Test'. Soil is compacted in a mould in three layers by dropping a 2.50 kg rammer a distance of 300 mm. Dry densities achieved by mixing soil with different water contents were determined to obtain the maximum dry density and the corresponding optimum moisture content (OMC). Apparatus those are used in the test are:

- Moulds - The mould of diameter 105 mm with a height of 115 mm and therefore have been of a volume 995.78 cm^3 were used in the test.
- A metal rammer having a 50 mm diameter circular face and weighing 2.50 kg was used to compact the soil sample placed within the mould. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to 300mm.
- Balances - A digital balance with a capacity of 20 kg, readable and accurate (accuracy

level ± 0.01 gm) was used to weight the soil sample with mould. A fine balance readable and accurate to ± 0.01 gm was also used to determine the water content (W_c) of the soil samples.

- Sieves - 4.75 mm sieve.
- Miscellaneous tools such as mixing pan, spoon, trowel, spatula etc.
- A large metal tray (600 mm X 500 mm and 80 mm deep).
- Thermostatically controlled oven to provide temperature 105º -110 º*C*.
- Cans to take samples for moisture content determination.

The steps those are followed to perform the standard 'Proctor Compaction Test' are include the followings:

a. Obtain approximately 3 kg of air-dried soil in the mixing pan, break all the lumps so that it passes the sieve of 4.75 mm.
b. Add suitable amount of water.
c. Determine the weight of the empty mould without the base plate and the collar ($M1$) to the nearest 1gm.
d. Fix the collar and the base plate.
e. Compact the moist soil in to the mould in three layers of approximately equal mass.
f. Each layer should be compacted by 25 blows. Blows must be distributed uniformly over the surface of each layer so that the rammer always falls freely. The amount of soil must be sufficient to fill the mould, leaving not more than 6mm to be struck off when the extension is removed.
g. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil leaving to the mould.
h. Obtain the weight of mould with the moist soil ($M2$) after removing the base plate.
i. Extrude the sample and break it to collect the sample for water content determination preferably at least two specimens one near the top and other near the bottom.
j. Weigh an empty moisture can ($M3$)and weigh again with the moist soil obtained from the extruded sample($M4$).
k. Keep this can in the oven for water content determination.
l. Repeat step'd' to 'i'. During this process weight $M2$increases for some time with the increase in moisture and decreases thereafter. Conduct at least two trials after the weight starts to reduce.
m. After 24 hours get the weight of oven dried sample ($M5$).

Computation of moisture content and thereby obtaining the maximum dry density of the soil with optimum moisture content includes the following steps:

The bulk density, ρin $kg/m^3$of each compacted specimen shall be computed from the equation $\rho = \frac{M2 - M1}{V}$

where,

*M*1 is the mass of the mould and base(in kg).M2is the mass of mould, base and soil (in kg)and *V* is the volume of the mould in m^3.

Moisture content is obtained from the equation

$$Wc = \frac{M4 - M5}{M5 - M3}$$

Where *Wc*is the moisture content of the soil in fraction.

$$\rho_d = \frac{\rho}{(1 + Wc)}$$

The dry densities ρ_d asobtained in a series of determination processes for a particular sample is then plotted against the corresponding moisture content *Wc*. A smooth curve shall be drawn through the plotted points and the position of the maximum on this curve shall be determined. The maximum dry density (ρ_d) of the soil and the corresponding water content i.e. OMC then obtained from the curve.

4.3.3 Determination of Liquid Limit and Plastic Limit of the Soil

'Liquid limit' of a fine grained soil determines the boundary between the liquid and plastic states of the soil where as the '**Plastic limit' denotes t**he boundary between the plastic and semi-solid states and '**Shrinkage limit' is t**he boundary between the semi-solid and solid states.

The Liquid Limit, also known as the water content at which soil changes from the liquid state to a plastic state or it is the minimum moisture content at which a soil flows upon application of very small shear force.The Plastic Limit, also known as the lower plastic limit, is the water content at which a soil changes from the plastic state to a semisolid state.

Plastic Limit (*W*p) - the water content, in percent, of a soil at the boundary between the plastic and semi-solid states.

Plasticity Index (I_P) -The range of water content over which a soil behaves plastically.

The steps those are followed to determine the liquid limit of the soil samples are as follows:

a. Place a portion of the prepared sample in the cup of the liquid limit device at the point where the cup rests on the base and spread it so that it is 10mm deep at its deepest point. Form a horizontal surface over the soil. Take care to eliminate air bubbles from the soil specimen. Keep the unused portion of the specimen in the storage container.

b. Form a groove in the soil by drawing the grooving tool, beveled edge forward, through the soil from the top of the cup to the bottom of the cup. When forming the groove, hold the tip of the grooving tool against the surface of the cup and keep the tool perpendicular to the surface of the cup.

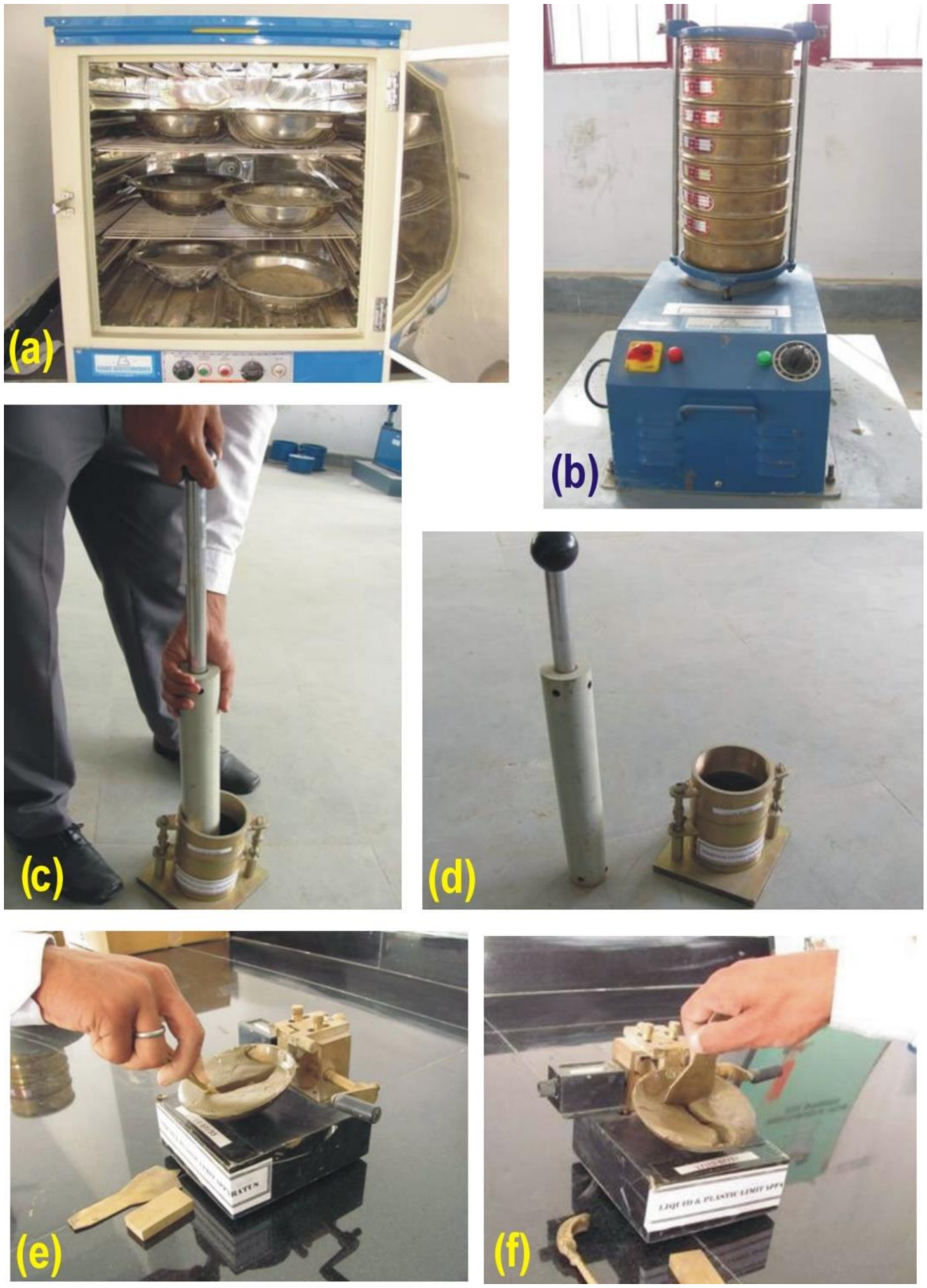
c. Lift and drop the cup at a rate of 2 drops per second. Continue cranking until the two halves of the soil specimen meet each other at the bottom of the groove. The two halves must meet along a distance of 13mm (1/2 in).

d. Record the number of drops required to close the groove.

e. Remove a slice of soil and determine its water content*W*c.

f. Repeat steps ‘a’ through ‘e’ with a sample of soil at slightly higher or lower water content. Whether water should be added or removed depends on the number of blows required to close the grove in the previous sample.

g. Now all the determined water contents (*W*c) are plotted in a semi logarithmic graph paper against respective numbers of blows to determine the *W*c for 25 blows. That water content represents the liquid limit of the soil sample.



Figs. 4.4 (a – f) Photographs of different tests performed in the laboratory – a. Dried soil in the oven, b. Sieving of sample by automated sieve shaker, (c) Compaction of soil during Proctor test, (d) Proctor mould and rammer used during test, (e) putting the wet soil sample in the apparatus during liquid limit test, (f) Grooving the sample by tool during liquid limit test

The steps followed to determine thePlastic limit of the soil samples are as follows:

a. From the 20gm sample select a 1.5 to 2 gm specimen for testing.

b. Roll the test specimen between the palm or fingers on the ground glass plate to from a thread of uniform diameter.

c. Continue rolling the thread until it reaches a uniform diameter of 3 mm.

d. When the thread becomes a diameter of 3 mm reform it into a ball.

e. Knead the soil for a few minutes to reduce its water content slightly.

f. Repeat steps 2 to 5 until the thread crumbles when it reaches a uniform diameter of 3 mm.

g. When the soil reaches the point where it will crumble, and when the thread is a uniform diameter of3 mm, it is at its plastic limit. Determine the water content of the soil.

Figs. 4.4 (a – f) represents the photographs of different analyses and tests performed in the laboratory as depicted above.

Chapter 5

Result and Discussions

5. Results And Discussion

In the present study mostly all the major index/mechanical properties of the recent sediments collected from the bank of river Ganga where analyzed in details. The major parameters which are taken into account for the detail investigation of the collected sediments are the Grain Size, Proctor Compaction Test to carry out the optimum moisture content of the particular sediments and from where the clay content of the sediments increase where we perform Liquid & Plastic Limit Test to create an overall idea of the present states on the mechanical properties of the sediments along the bank of the river Ganga which is historically inhabiting place for the Indian subcontinents and anthropologically intervention was also through some extent study during the time of the collection of the sediments with in laboratory. Two major category of the parameter are taken out by means of majorly Sieve Analysis and testing some other chemical parameters following some standard procedure within the geotechnical laboratory. So, In this portion we are serially come three major attributes of the recent sediments has been discussed as follows.

5.1 Grain size Analysis

5.2 Proctor Compaction Test

5.3 Liquid Limit & Plastic Limit Test

5.1 Grain Size Analysis

5.1.1 General

Grain-size distribution or the percentage of various sizes of recent sediment grains present in a given dry recent sediment sample is an important soil grain property. Grain size analysis of coarse grained soil is carried out by the sieve analysis, where for fine rained soil by hydrometer analysis method. In general as most of the soil contain both coarse and fine grained constituents both the analysis is usually carried out. In the present investigation as from initial sieve analysis it was found that proportion of fine fragment i.e. <10μ is almost nil for all the samples only sieve analysis results has been presented and taken into consideration for analysis.

5.1.2 Sieve Analysis

Sieve analysis was carried out for all the collected samples from different locations. Nomenclature of the samples made according to the serial geographical position of the locations along the course of the river Ganga, i.e. 'Sample No. 1' refers to the soil of Rishikesh and accordingly 'Sample No. 10' refers to the soil of Diamond Harbour. At the start all the samples were initially dried at sunlight and then after breaking up the lump (specially for the sample from Patna and Diamond Harbour) by rubber hammer all the samples were put in oven. All the samples were oven dried for more than 24 hours at a temp of 110º Celsius. Thereafter sieve analysis was carried out 2 kg of individual sample of all the seven locations. Detailed procedure of the sieve analysis has been presented in the Chapter – 2. It is to be mentioned here that for individual analysis shaking was done for two times serially for 20 minutes each.

5.1.3 Grain size distribution curves

Obtained results of individual analysis was plotted in graph (with the log10 ordinate) to get the grain size distribution curve of the tested soil. 'Grapher- 4' software has been used to draw the grain size distribution curves in all the cases. From all the curves d_{50}, d_{10}, d_{30} and d_{60} value were obtained to calculate the 'Coefficient of Curvature' and 'Coefficient of Uniformity' of the sample analyzed to get an overall understanding on the grain size characteristics of the soils. Grain size distribution curves of all the samples i.e. sample no.1 to sample no.10 are presented serially in the Figs 5.1.1 to 5.1.10 In all the presented graphs corresponding value of all the measured and calculated parameters are provided in a tabular format below the graph. The obtained numerical weigh fractions of individual grain sizes ranges is presented in Table 5.1. Fig 5.1.11 reveals the grain size distribution curves of all the ten samples of different locations collectively to have a comparative idea on the soil grain size characteristics of the locations as it differs with the distance of transportation in fluvial environment. Though irrespective of the distance several other factors also have a significant influence on the variation of grain size distributions of the soils collected. Specially the local discharge and corresponding velocity of the flow, slope of the river bed, proportions of bed load and suspended load, characteristics of incoming flows of connecting rivers, streams, rivulets etc also are the major affecting factors of the grain size and grain shape if the soil.

Content of biological fragments also plays a significant role in the transportation history of the soil. In our investigation, mainly the distance of transportation taken as a main variables for the variations in grain size of the sediment along the bank of the River Ganga.

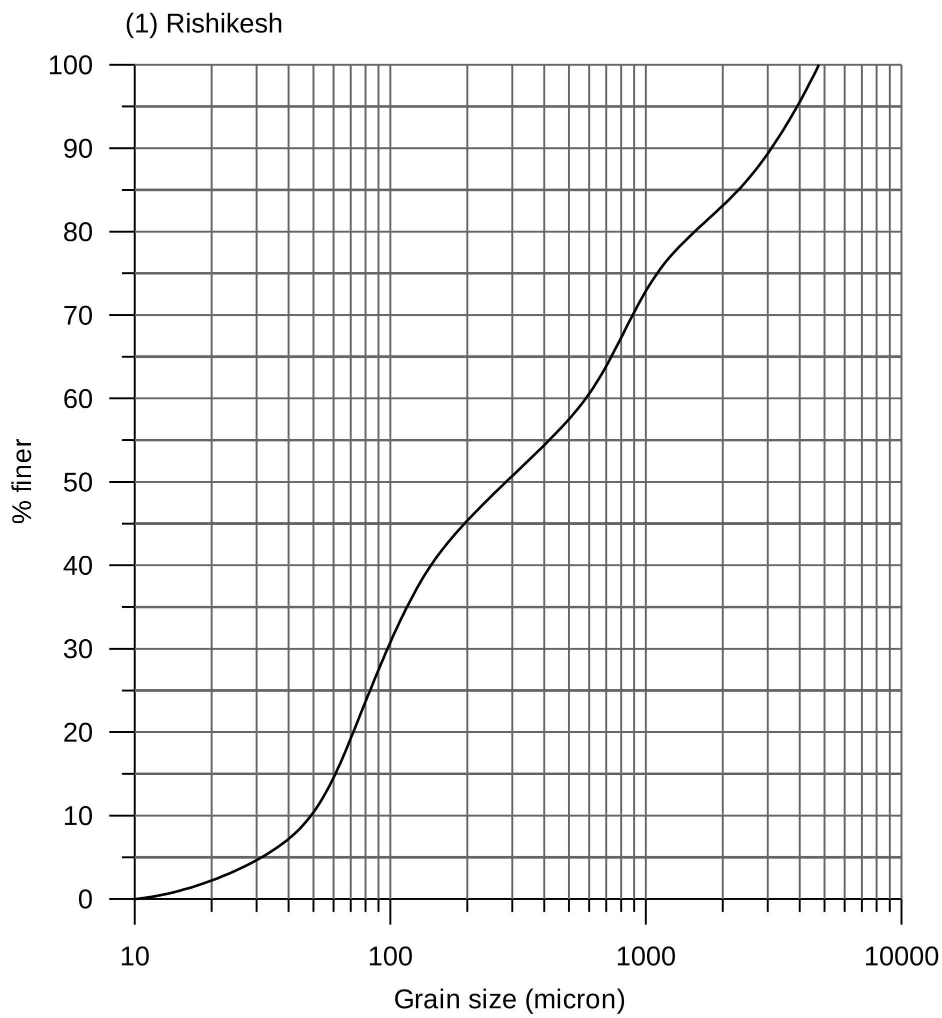


Fig. 5.1.1 Grain size distribution curve of the soil sample from Rishikesh (sample no. – 1)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L1	**Rishikesh**	0	50	96	290	590	11.80	0.31

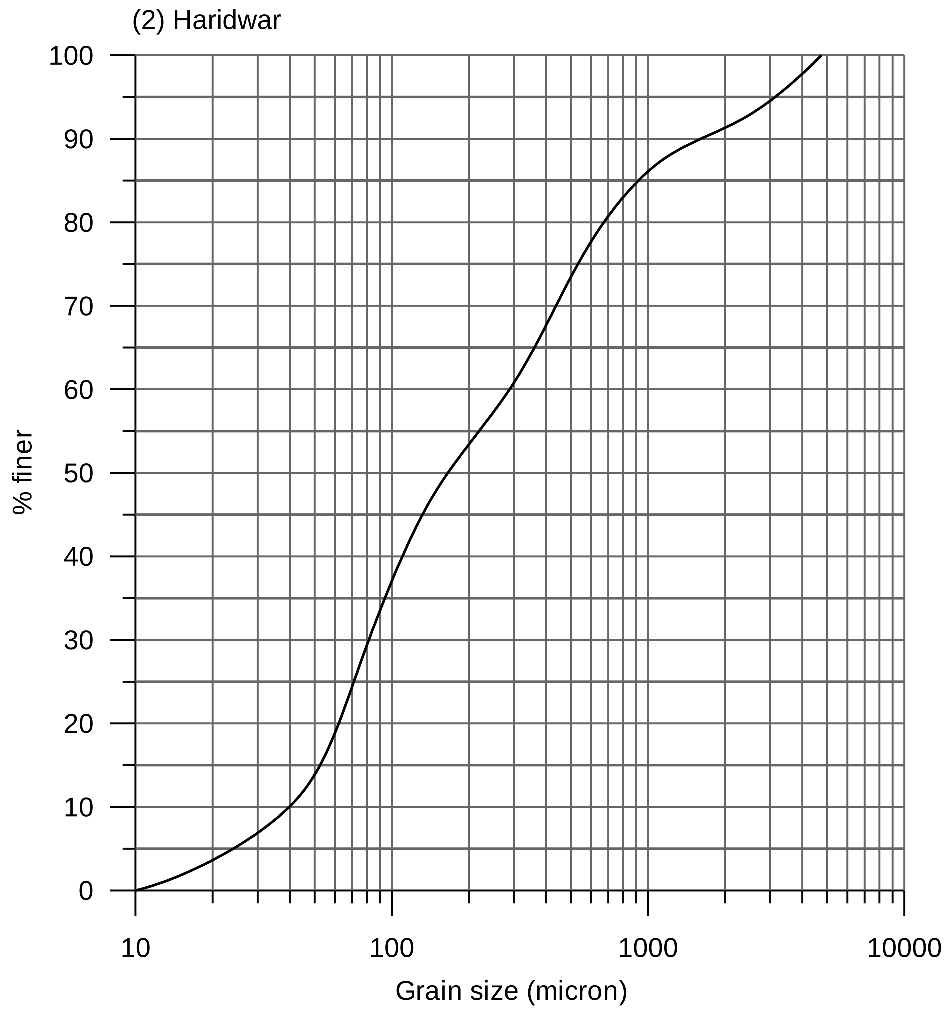


Fig. 5.1.2 Grain size distribution curve of the soil sample from Haridwar (sample no. –2)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L2	**Haridwar**	30	40	80	180	290	7.25	0.55

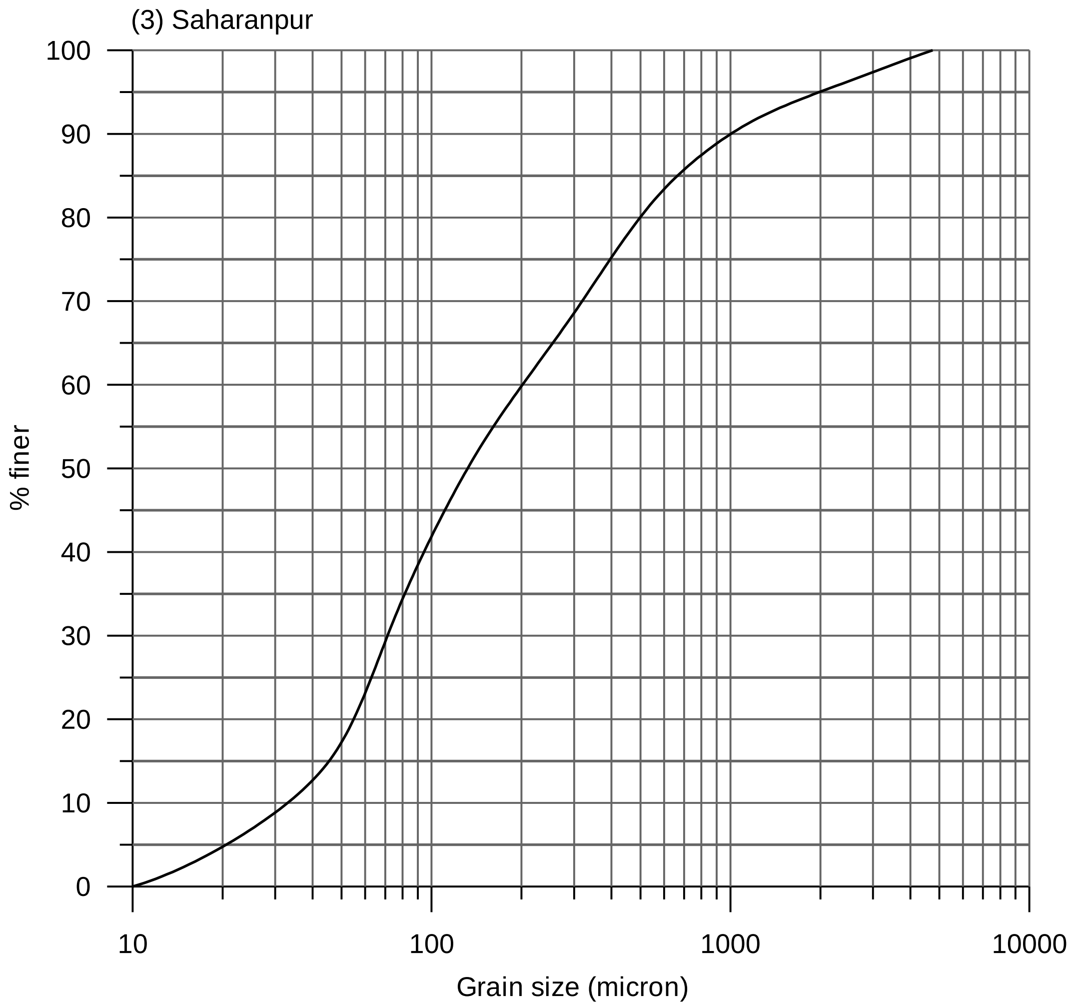


Fig. 5.1.3 Grain size distribution curve of the soil sample from Saharanpur (sample no. – 3)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L3	**Saharanpur**	95	32	71	140	200	6.25	0.79

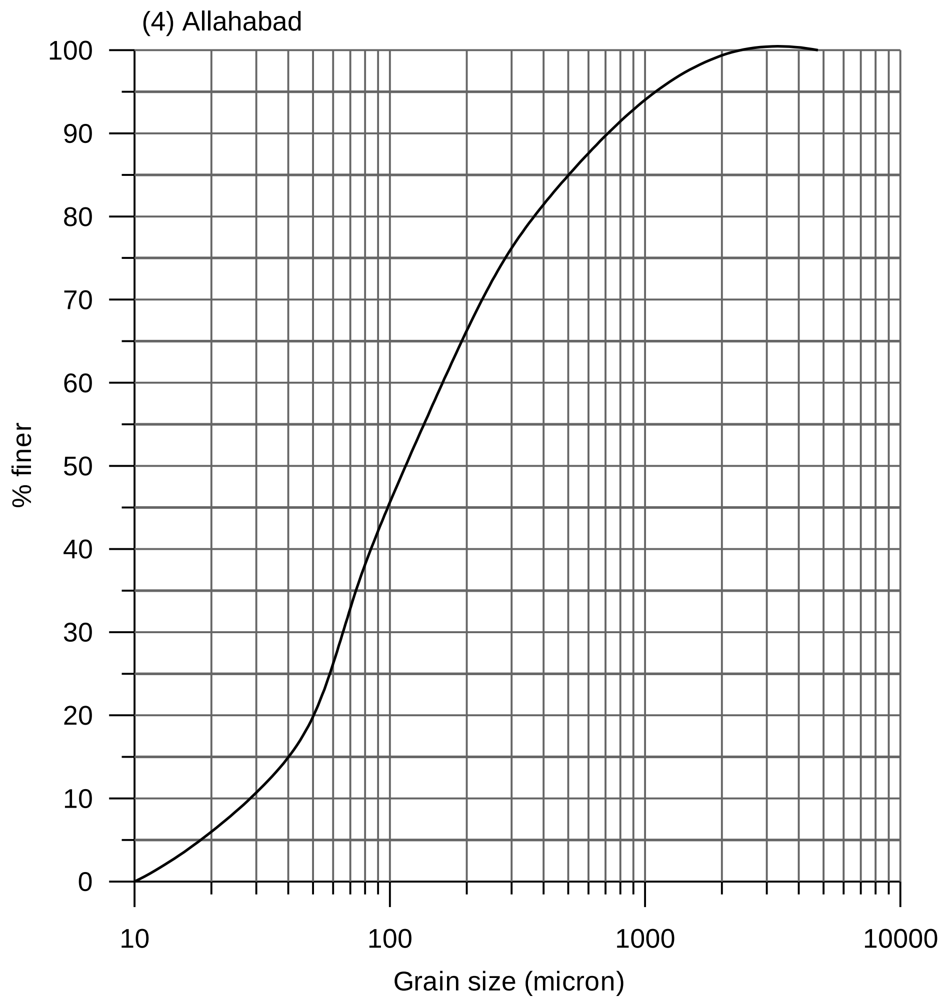


Fig. 5.1.4 Grain size distribution curve of the soil sample from Allahabad (sample no. – 4)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L4	**Allahabad**	743	29	66	120	170	5.86	0.88

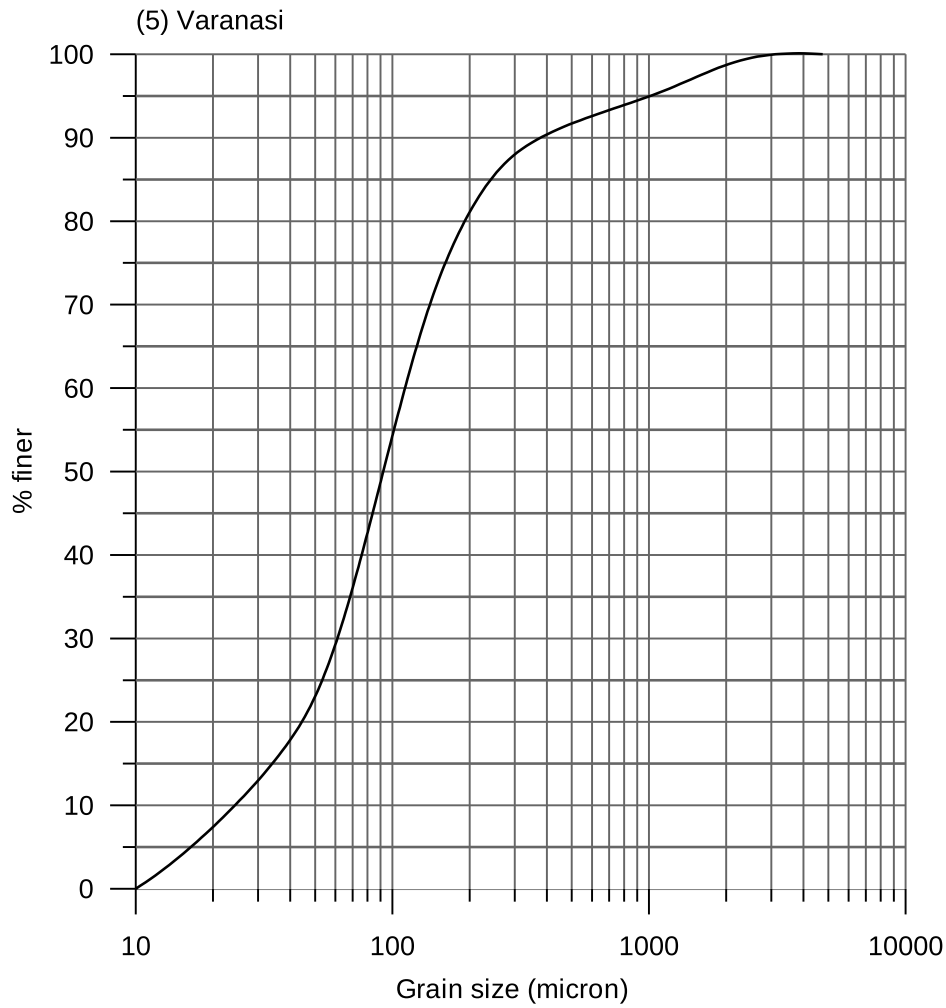


Fig. 5.1.5 Grain size distribution curve of the soil sample from Varanasi (sample no. –5)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L5	**Varanasi**	908	25	60	92	120	4.8	1.2

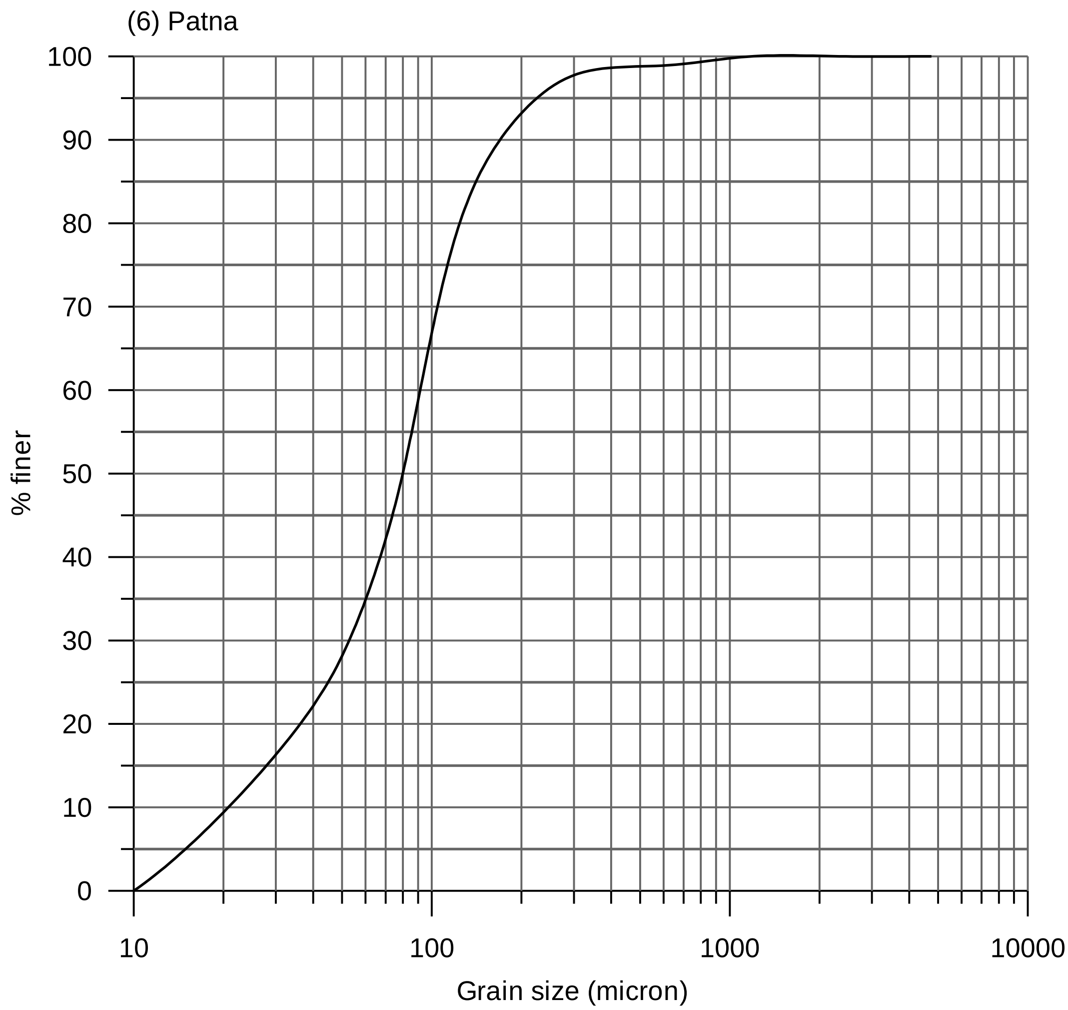


Fig. 5.1.6 Grain size distribution curve of the soil sample from Patna(sample no. –6)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L6	**Patna**	1188	21	53	80	90	4.29	1.49

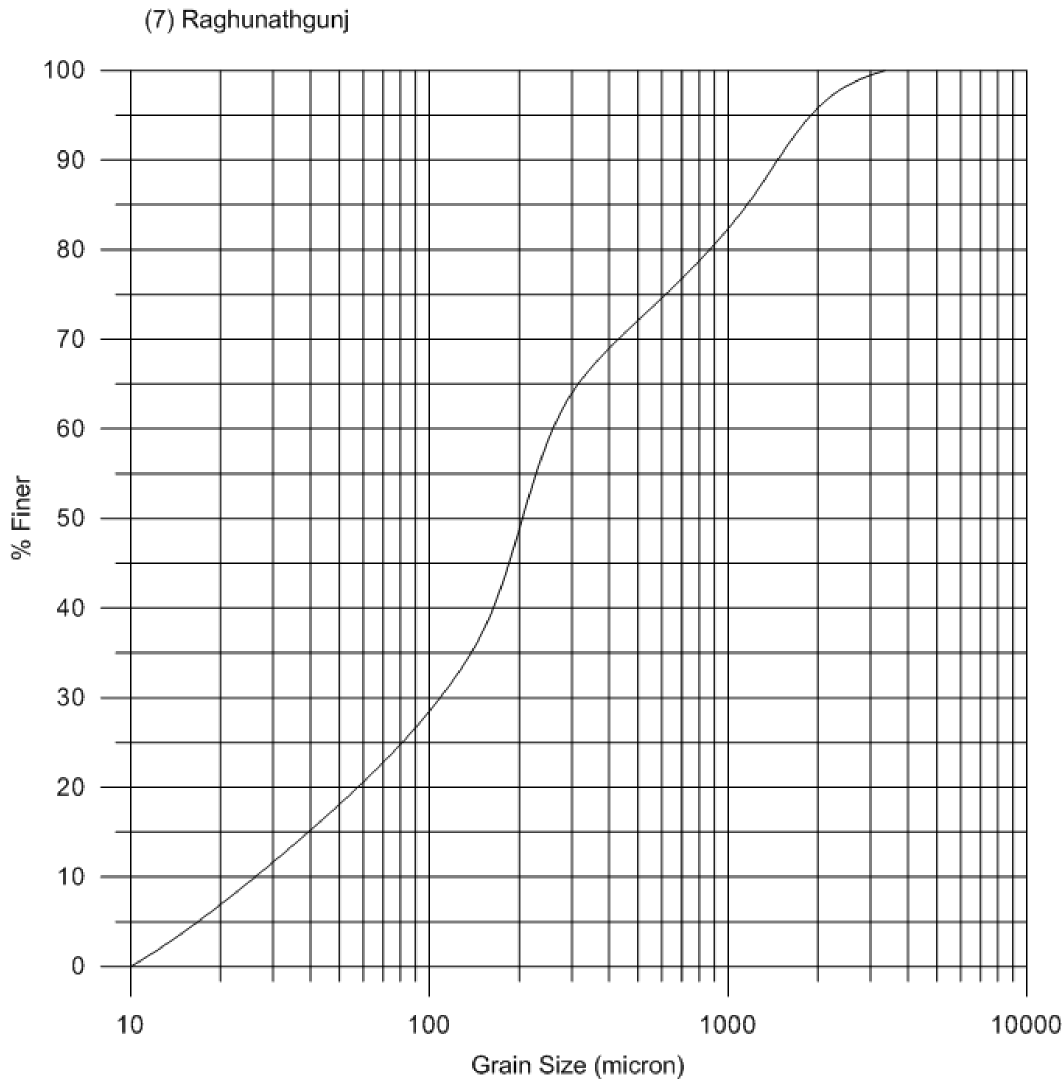


Fig. 5.1.7 Grain size distribution curve of the soil sample from Raghunathgunj (sample no. –7)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L7	**Raghunathgunj**	1550	27	115	205	265	9.8	1.85

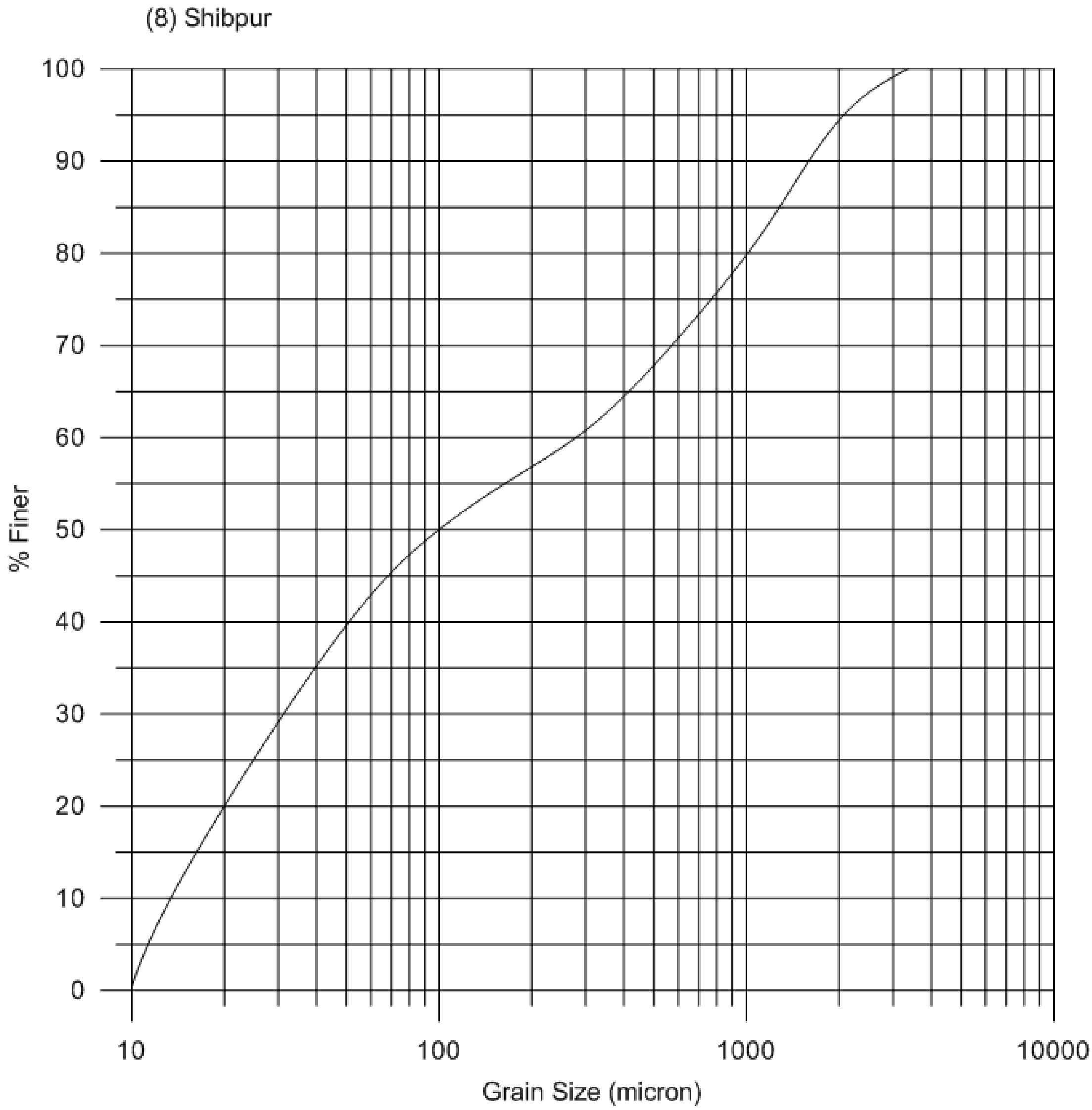


Fig. 5.1.8 Grain size distribution curve of the soil sample from Shibpur(sample no. –8)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L8	**Shibpur**	1835	14	31	100	280	20	0.25

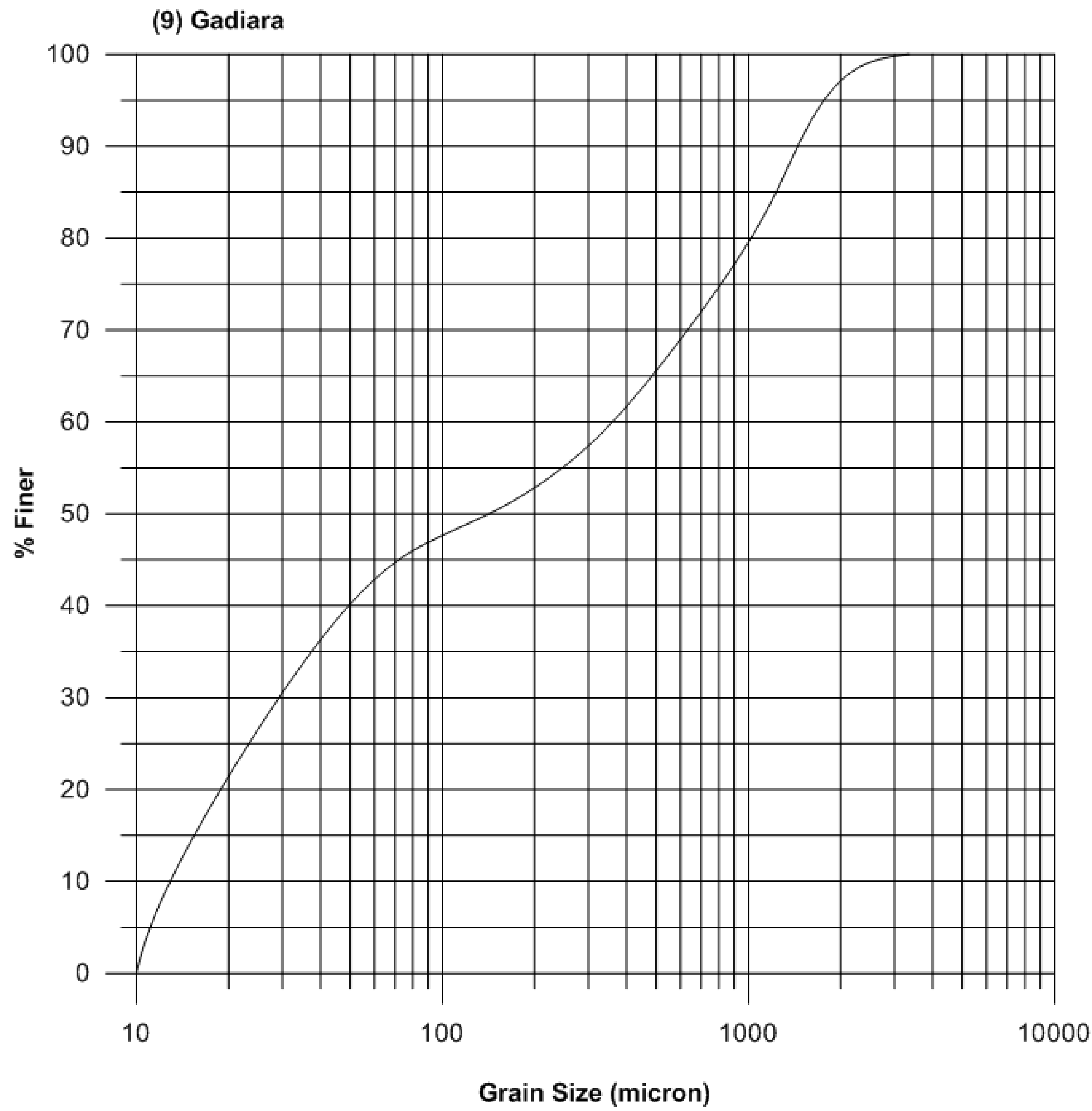


Fig. 5.1.9 Grain size distribution curve of the soil sample from Gadiara(sample no. –9)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L9	**Gadiara**	2050	13	29	150	360	27.69	0.179

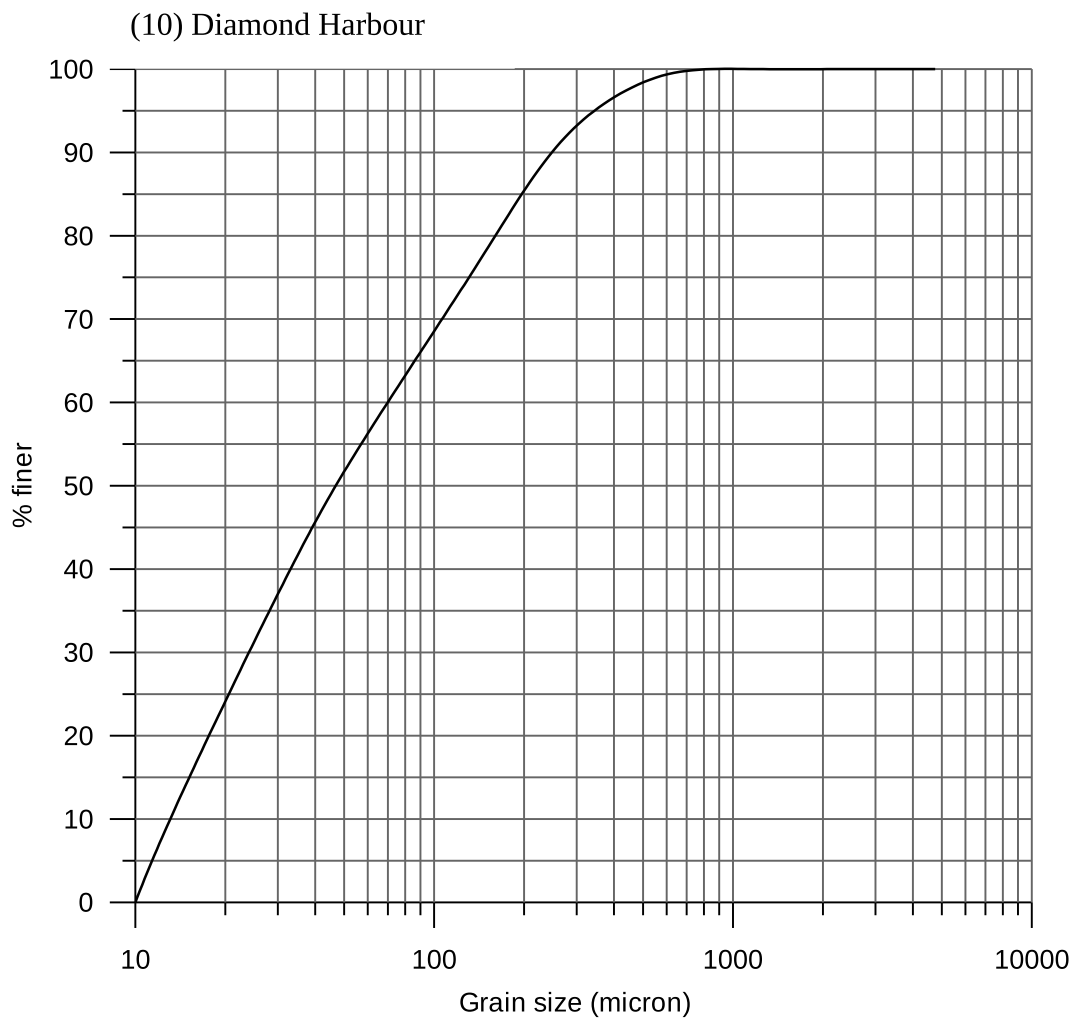


Fig. 5.1.10 Grain size distribution curve of the soil sample from Diamond Harbour (sample no. –10)

Sr. No.	Location	Distance along course from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
L10	**Diamond Harbour**	2500	14	25	48	70	5.00	0.64

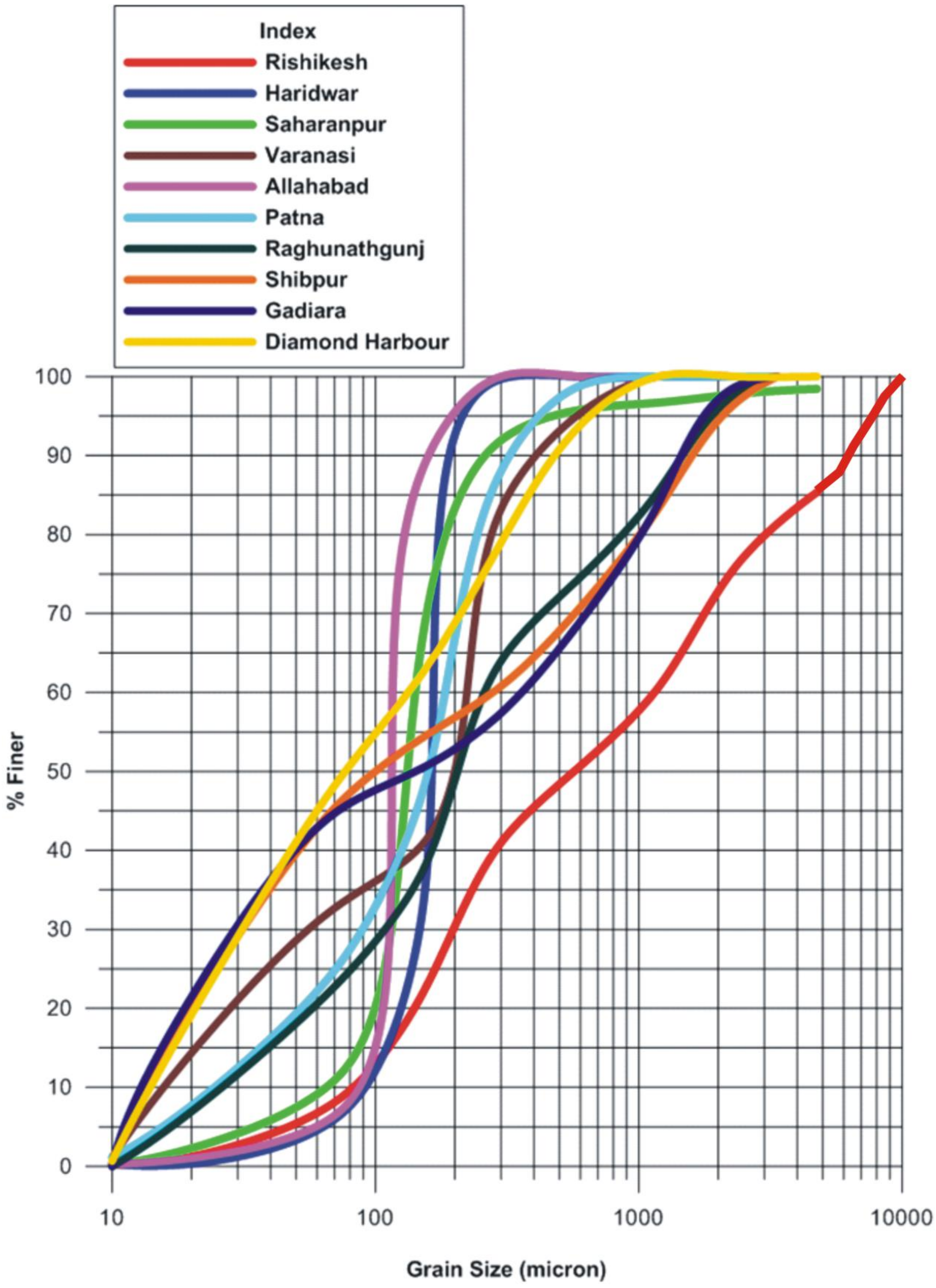


Fig. 5.1.11 Comparison of grain size distribution curves of the samples collected from all the locations

Table 5.1.1 Important size fragments and coefficients of the soil samples collected

Sr. No.	Location	Distance from Rishikesh (km)	d_{10} (micron)	d_{30} (micron)	d_{50} (micron)	d_{60} (micron)	C_u	C_c
1	**Rishikesh**	0	50	96	290	590	11.80	0.31
2	**Haridwar**	25	40	80	180	290	7.25	0.55
3	**Saharanpur**	95	32	71	140	200	6.25	0.79
4	**Allahabad**	820	29	66	120	170	5.86	0.88
5	**Varanasi**	950	25	60	92	120	4.80	1.20
6	**Patna**	1190	21	53	80	90	4.29	1.49
7	**Raghunathgunj**	1550	27	115	205	265	9.8	1.85
8	**Shibpur**	1835	14	31	100	280	20	0.24
9	**Gadiara**	2050	13	29	150	360	27.69	0.17
10	**Diamond Harbour**	2500	14	25	48	70	5.00	0.64

5.1.4 Discussion on results of grain size analysis

It is quite clear from the obtained curves of grain size analysis of all the ten samples that size of the constituting grain of the soil reduce with the distance of deposition and have a strong influence on its transportation history. Sample nos. 1 to 5 i.e sample of Rishikesh, Haridwar, Saharanpur, Allahabad and Varanasi are mainly sand ranging from medium to fine where as soil of Patna is near to silt and downward locations are a admixture of fine silt and clayey particles. Fig. 5.1.12 shows the graph, that reveals a comparison of d_{50} of the soil samples of the different location against the distance transported by the sediment, where the distance of

Rishikesh taken as zero (0) and distance mention in the ordinate is the distance of the sampled location from Rishikesh.

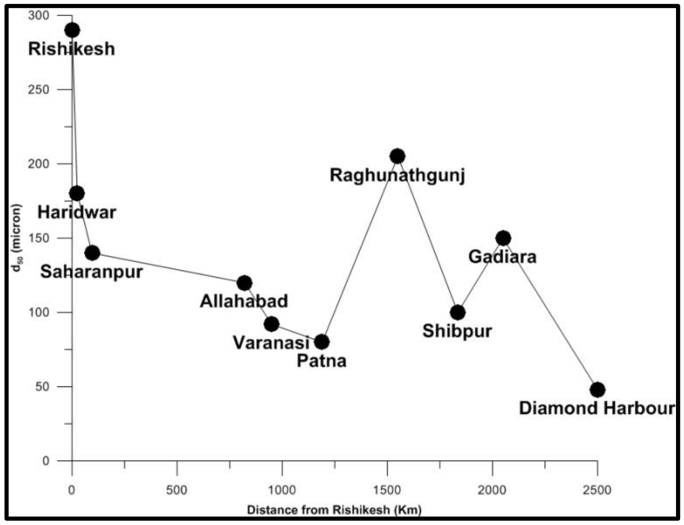


Fig 5.1.12 Variations of 'd_{50}' of the soil samples with the distances of transport

From the fig. 5.1.12 it is interesting to note that the reduction of d_{50} is sharply steady from Rishikesh to Haridwar and then up to Saharanpur, after that the gradient of decrement of d_{50} is quite lessen up to Patna. 'd_{50}' of the soil of Diamond Harbour is less than that of Patna but the reduction gradient is extremely low. It reveals a clear resemblance of grain size variation of soil with the flow energy of the fluvial environment. As the river slope is comparatively much steeper in first three locations the d_{50} decrease sharply from Rishikesh to Haridwar and then at Saharanpur. From Saharanpur to Allahabad it shows a sudden decrease of flow energy as revealed by the comparatively less decrement in grain size, which resemblance clearly with the almost flat topography of the region of the Gangetic plane attributed by almost no altitude difference. But in case of Varanasi the average grain size reduced in a much rapid manner compare its reduction gradient from Saharanpur to Allahabad. The joining of 'Yamuna' to the Ganga may be one of the influencing factors to increase of the flow energy and reduction of d_{50} quite rapidly for the soil at the bank of Varanasi. From Varanasi to Patna change of d_{50} is smooth and gradual and for the soil of Patna d_{50} is 80μ which is almost silty in nature. Soil of Kolkata is fine silt ranging towards clay. Significant amount of cohesiveness was there in the soil samples collected from the river bank of Patna and down stream locations. For the sediment of Raghunathgunj a radical increase was noted, which is quite abnormal in accordance with the overall trend of distribution pattern. But here it is to be mention that effect of Farakka Barrage & frequent shift of flow direction of the River Ganga in past few years cause an overall increase of the turbulence of the fluvial flow. Subsequent operation of Farakka Barrage water probably the most relevant cause for the frequent fluctuation of flow energy and resultant this kind of anomaly. Similar rise of the trend is also noted at Gadiara where overall d_{50} decrease but still higher d_{50} than that of sediments collected from (Location-8) Shibpur. As gadiara is the location where confluence of Damodor, Rupnarayan & Hoogly occur, that obviously make a change in the overall flow condition of the river and resultant to the high energy dissipation and d_{50} is noted at Gadiara is 360µ. The last location Diamond Harbour reveals the expected normal trend of grain size distribution.

Determination of liquid limit (W_L) and plastic limit (W_P) and plasticity index (I_P) for those samples was carried out for classification on 'Indian Standard'. Fig 5.1.13 presents the graphs which show the comparison of C_C and C_U of the soils of different location as varied with the distance (i.e from Rishikesh). Except the fine grained soil of Raghunathgunj, Gadiara, Diamond Harbour both the parameters are showing a significant influence of transportation distance. C_C is increase with the distance , whereas C_U shows the opposite relationship from Rishikesh to patna. For both the coefficient change is quite sharp up to Saharanpur then the slope of the gradient become much gentle.After Patna there is increase in C_U and decrease in C_C upto Gadiara. This is because of Presence of Farakka Barrage at Malda and at Gadiara which is confluence of Hoogly, Damodor river. This also shows a similar pattern with that of the grain size.

On the basis of the above grain size parameter (as presented in the Table 5.1.1) and pattern of grain size distributions curves sample no. 1 to sample no. 5 are classified broadly in the category of 'Sand' according to the 'Indian Standard Soil Classification System'. Detail sample wise class with its nomenclature is provided in the Table 5.1.2.

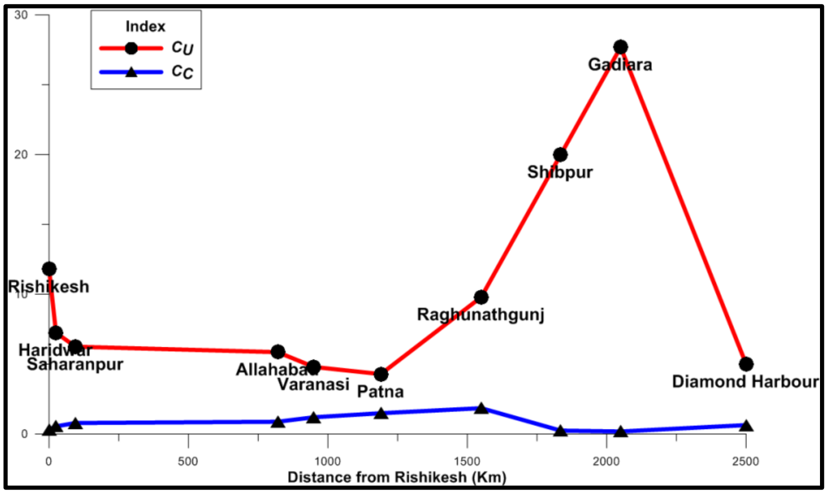


Fig. 5.1.13 Comparison of C_C as and C_U of the soils of different location with the distance

Table 5.1.2 Classification of coarse grained soil sample according to 'ISSCS'

Sample No.	Sample Location	Soil Type	Nomenclature
S-1	Rishikesh	Coarse Sand , Well graded	SW
S-2	Haridwar	Medium Sand, Well graded	SW
S-3	Saharanpur	Fine Sand, Poor graded	SP
S-4	Allahabad	Fine Sand, Well graded	SW
S-5	Varanasi	Fine Sand, Well graded	SW

5.1.5 Concluding Summary

From the grain size analysis of the soil samples of different locations it is quite clear that there is a significant decrease in over all grain size of the soil along the course of the river Ganga. At its entry to the plains from Rishikesh to Saharanpur , there is a rapid decrease of the soil grain size compare to the rest of the portion of the river. After Allahabad a comparatively fare decrease is recorded, which probably a reflection of a significant increase of discharge to the joining of 'Yamuna' and accordingly may be the velocity of the flow. Though having a considerable size difference, soils up to Varanasi fall in the class of 'Sand' as per the 'Indian Standard Soil Classification System'. Soil samples from the bank of Patna and downward locations are of the class of 'Silt' with an appreciable amount of cohesiveness. C_U and C_C of the soils also show a decreasing and increasing trend respectively with its distance of deposition from the source up to Patna. From Patna to Gadiara the trends for both the coefficients is just opposite to the previous trends. This is because of Presence of Farakka Barrage at Malda and at Gadiara which is confluence of Hoogly, Damodor river. After Gadiara C_U decrease upto 5 at Diamond Harbour. Fineness of the soil sample may be a probable cause for this change.

5.2. Determination of Maximum Dry Densities and OMC

5.2.1 General

There are many situations in engineering practice when the soil itself is used as a construction material. In the construction of engineering structures such as highway embankments or earth dams, for example loose fills are required to be compacted to increase the soil density and improve their strength characteristics. Compaction is the most common and important method of soil improvement. The densification of soil by application of mechanical energy is known as compaction. For a particular soil sample compaction is a function of the factors which include (i) water content; (ii) compactive effort; (iii) type of the soil; (iv) method of compaction. In the present investigation 'standard Proctor test' were performed on the collected samples to determine its maximum dry density and optimum moisture content (OMC) to get an overall engineering understanding about the soils.

5.2.2 Proctor Compaction Test and Results

Out of the total samples collected from the seven locations Proctor test was performed accurately on the eight soil samples except of Varanasi and Diamond Harbour as sample quantity those were remained after the sieving were not sufficient to fill the mould of the test with collar. Detail experimental procedure is depicted in the Chapter 3. In all the cases water was added to the dry soil till the weight of the compacted soil start to decrease after initial increment. Graphs were obtained by plotting the dry densities against the respective water content and from the obtained curve the maximum dry density of the soil sample was determined. Water content of the soil at its maximum dry density is the OMC which vary considerably from sample to sample clearly refer to a prominent dissimilarity in physical and textural properties of soils along the course of the river. Table 5.2.1 has been presented to reveal the maximum dry density and related OMC of the soil samples as obtained from laboratory compaction test.

Table 5.2.1 Maximum dry densities and OMCs of the soil samples

Sample	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L1	Rishikesh	1.87	11.40
L2	Haridwar	1.57	17.20
L3	Saharanpur	1.65	14.90
L4	Allahabad	1.47	16.20
L5	Patna	1.70	18.00
L6	Raghunathgunj	1.87	12.5
L7	Shibpur	1.68	17.35
L8	Gadiara	1.65	16.99

Curves as obtained though graphical plots of the moisture content and related dry densities for individual test are presented in the Figs. 5.2.1 to Fig. 5.2.8 serially according to the downstream flow of the river starting from Rishikesh. In all the compaction tests at least four other wise more plots of dry densities were considered to obtain the final curve to get the vale of OMC of that particular soil and the maximum dry density. Here also 'Grapher – 8' software was used to draw the water content against dry density curves by fitting the 'spline smooth' fits between the plots.

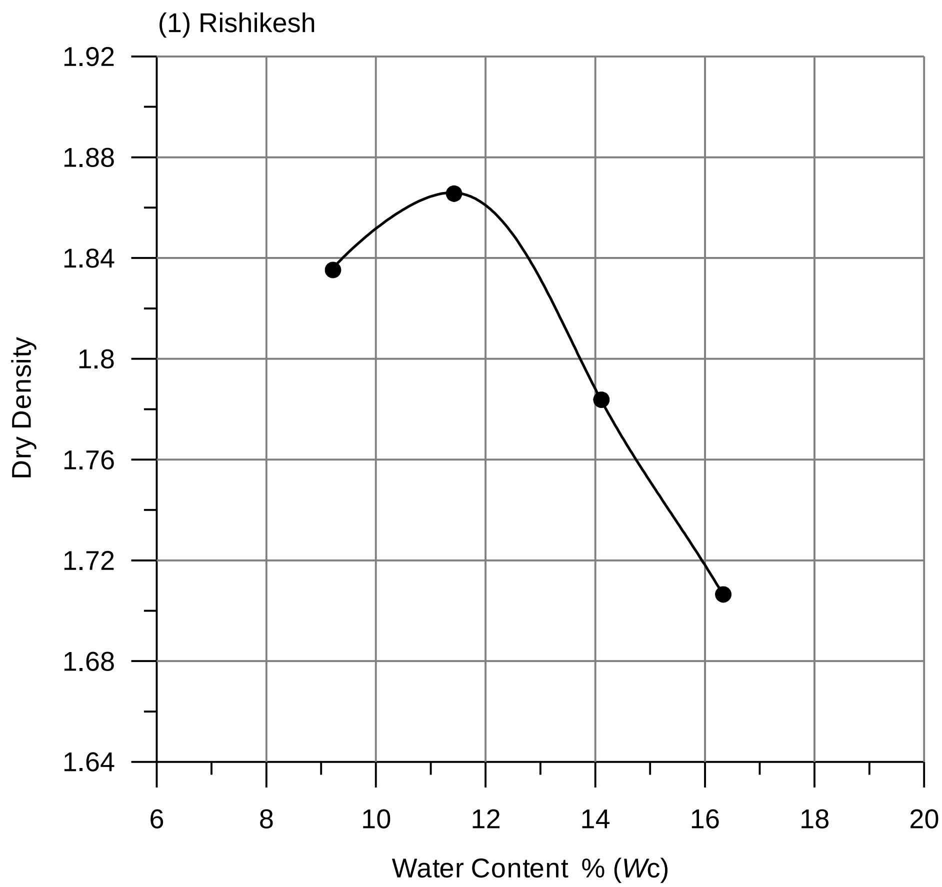


Fig. 5.2.1 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Rishikesh

Sample no.	Location	Max Dry Density (gm/cc)	OMC (%)
L1	Rishikesh	1.87	11.40

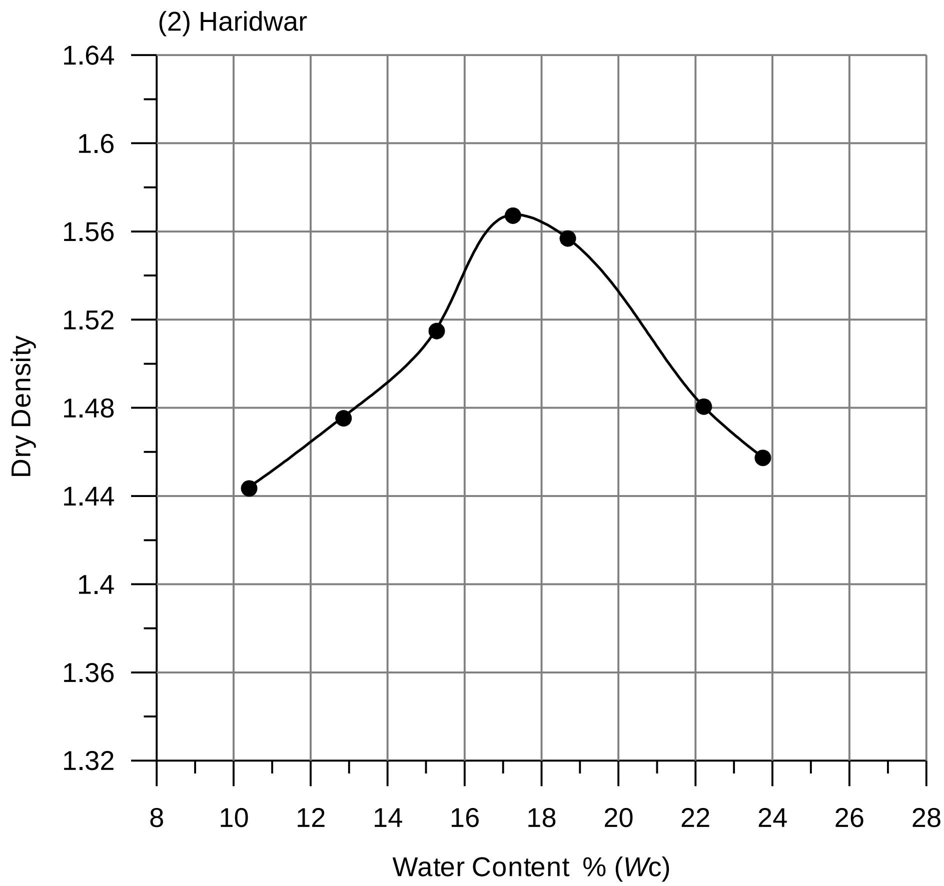


Fig. 5.2.2 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Haridwar

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L2	Haridwar	1.57	17.20

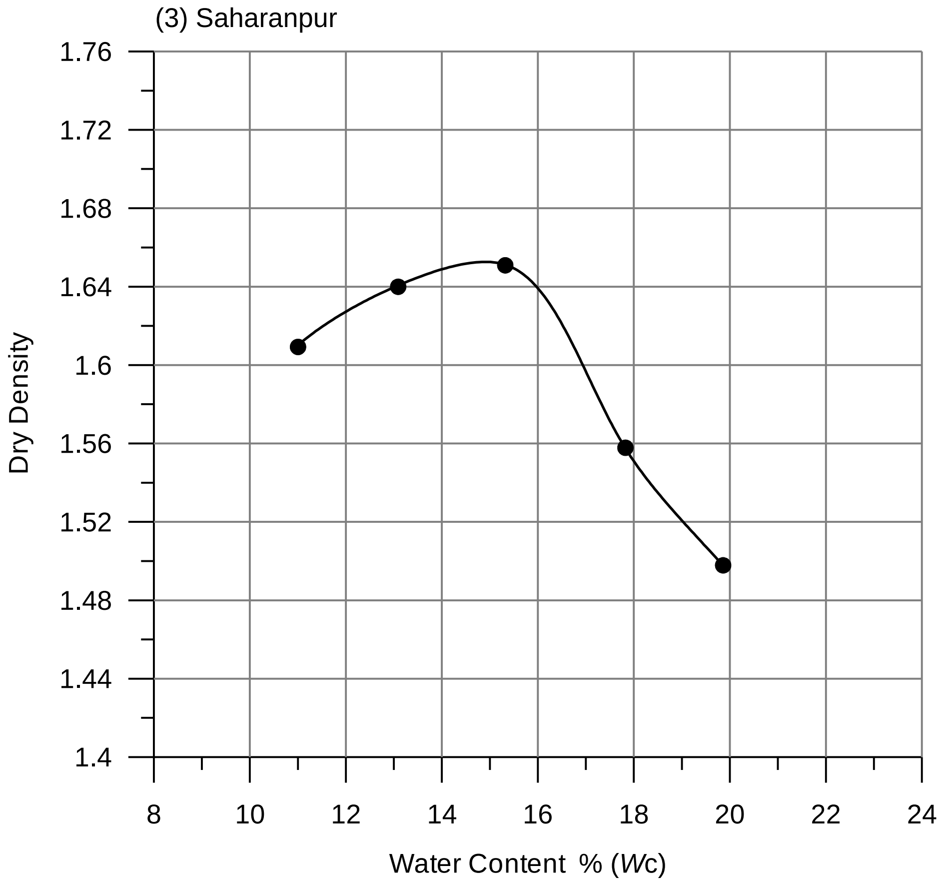


Fig. 5.2.3 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Saharanpur

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L3	Saharanpur	1.65	14.90

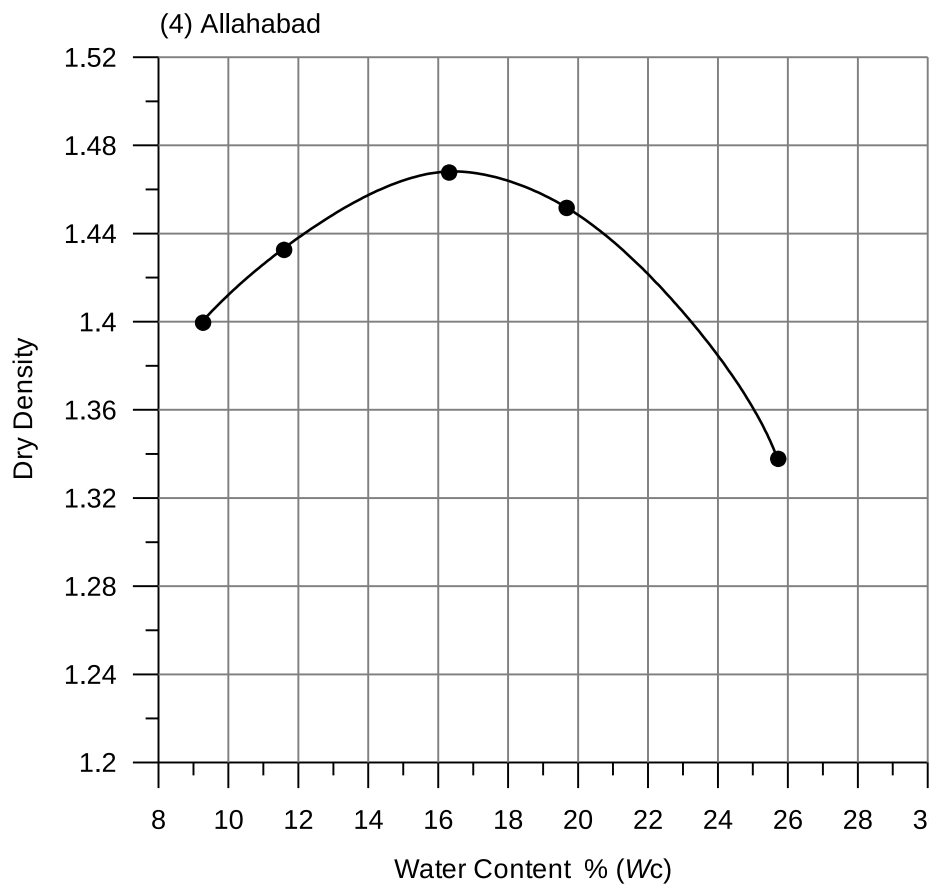


Fig. 5.2.4 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Allahabad

Sample no.	Location	Max Dry Density (gm/cc)	OMC (%)
L4	Allahabad	1.47	16.20

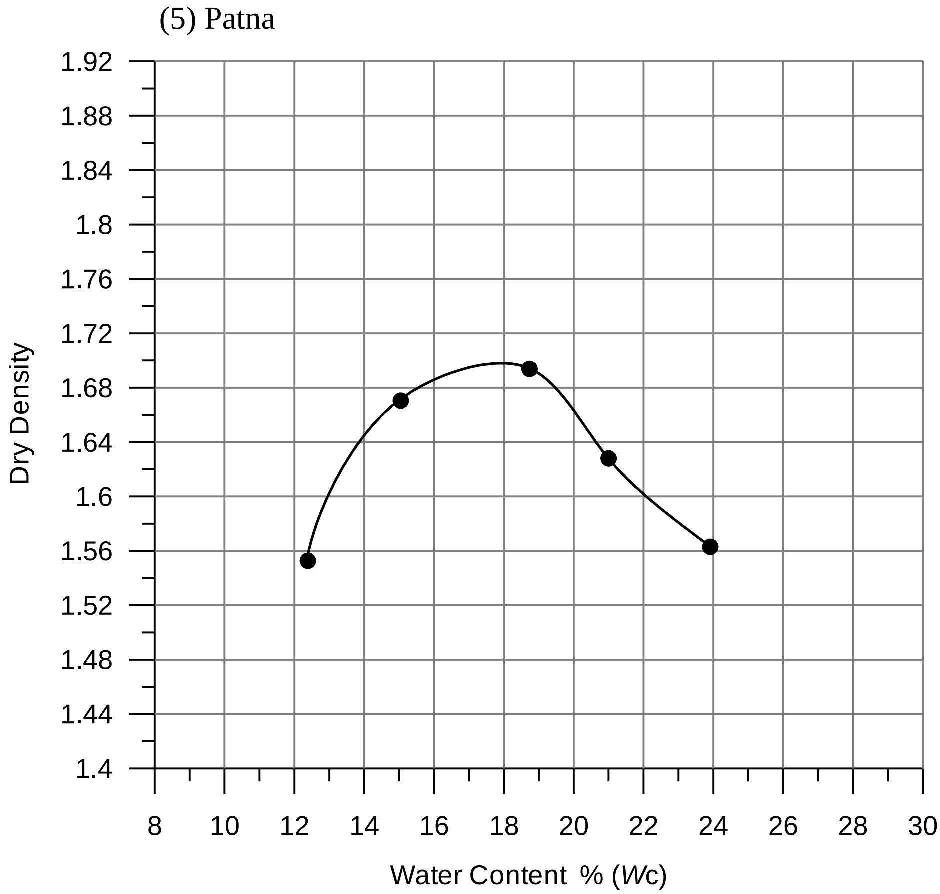


Fig. 5.2.5 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Patna

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L5	Patna	1.70	18.00

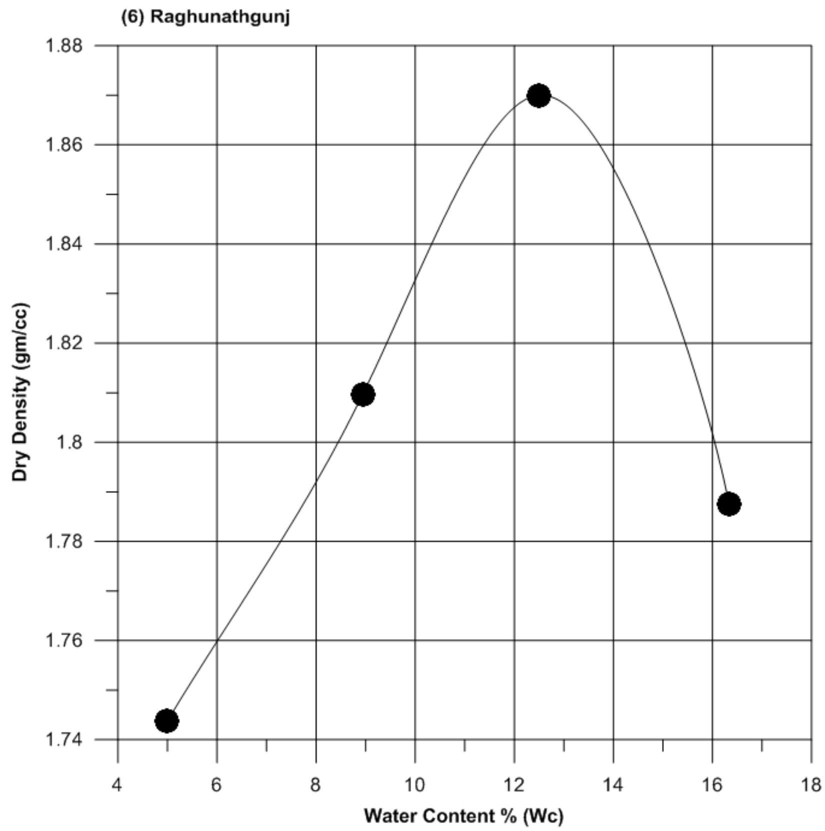


Fig. 5.2.6 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Raghunathgunj

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L6	Raghunathgunj	1.87	12.5

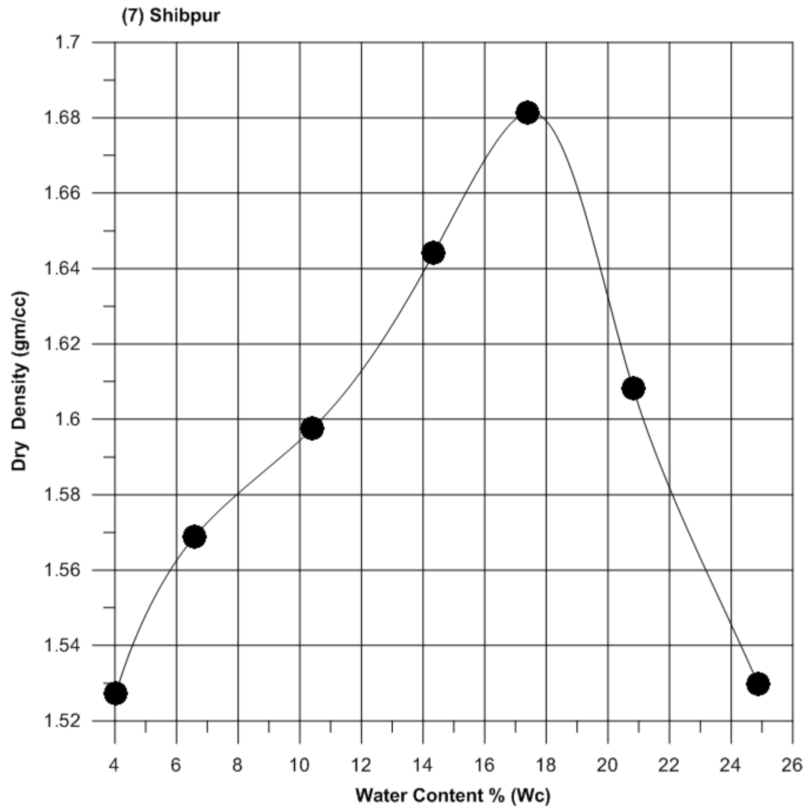


Fig. 5.2.7 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Shibpur

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L7	Shibpur	1.68	17.37

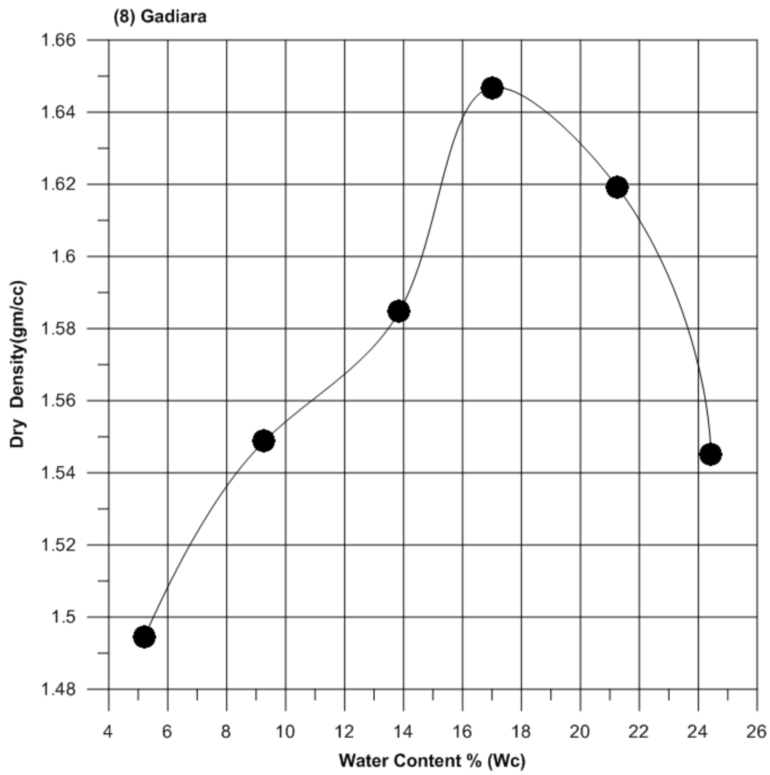


Fig. 5.2.8 Plots of dry densities against water contents as obtained by Proctor compaction test for the soil sample of Gadiara.

Sample no.	**Location**	**Max Dry Density (gm/cc)**	**OMC (%)**
L8	Gadiara	1.65	16.99

5.2.3 Discussion on results of compaction test

By means of compaction an increase in dry density would produce a soil which is stronger less compressible and less permeable. Where the compaction does not lead to significantly different structures in a soil, this is true to a large extent. But when the structural changes become important, the logic fails. In such soils, therefore, the effect of compaction on structure and consequently on the engineering behaviors has to be properly understood (Ranjan and Rao. 2009) and in all the cases the OMC and related dry density of the soil depend upon the composition; grain size characteristics; and biological content of the soil. These are all have a direct relation with the depositional history and the environmental of the soil.

The present results on compaction tests show that there is no such specific relation with the transportation distance of the soils and the maximum dry densities at OMC, rather it is clear from the result that the overall grain size distribution pattern of the soil affect the dry density of the soil. Dry density for the sandy soils i.e. soil with d_{50} near to the size of 75μ decrease with the distance of transportation. From the obtained results (Table 5.2.1) is clear that dry density is maximum for the soil from Rishikeh (1.87 gm/cc) where as it is minimum for Allahabad (1.47 gm/cc), Except the soil from Saharanpur, where from the grain size analysis is has been found the soil is poorly sorted and there is a dominancy of grain sizes ranging between 110μ to 800μ and constitute almost 85% of the soil mass. Therefore, for well graded sandy soils dry density decreased with the distance of deposition and has direct correlation with that. The OMC is the maximum for Haridwar and minimum noted for Raghunathgunj, as poorly graded sand normally exhibit low water content at its highest dry density and because of high turbulance. In case of Patna as the nature of the soil is almost near to silt the OMC increased substantially compare to that of sandy soil and in accordance with the soil characteristics dry density decreased. OMC of the soils do not show any specific trend in relation to the distance traveled in the fluvial regime. Fig 5.2.9 reveal a three dimensional graphical plots of dry densities and corresponding OMC for the soils of different locations along the course of the river.

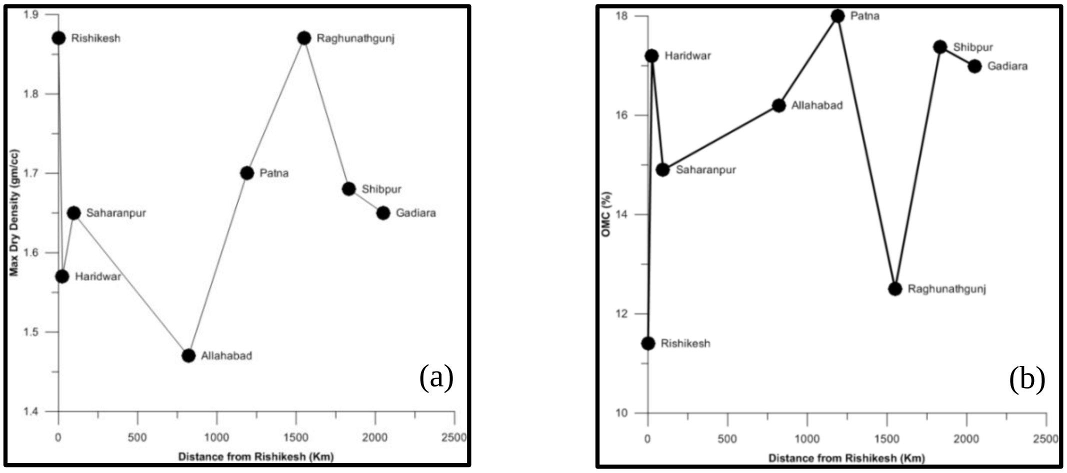


Fig 5.2.9 Two dimensional plots of Max Dry Densities (a) and OMC (b) for the sediments with respect to Distance from Rishikesh (Km)

5.2.4 Concluding Summery

It is clear from the Proctor compaction test of the eight samples (sample no 1, 2, 3, 4, 5, 6, 7 & 8) that for well sorted sandy soil up to the location of Allahabad the dry density of the soils decrease with the increase of the transportation and subsequent deposition distances of the soil, though it has a considerable correlation with the grain size distribution pattern of the soil. In case of silty soil from the bank of Patna it show a sharp increasing trend, which is naturally expected due to the fineness of the constituent grains. At Raghunathgunj there is sharp increase in Dry Density because of the erection og Farakka Barrage, which produce high turbulence recurrently during flood time because of disposal of barrage water. After, Raghunathgunj there is decreasing trend upto Gadiara. As quantity of the sample not match with the laboratory proctor mould with collar this test could not be performed for Varanasi and Diamond Harbour.

Optimum moisture content (OMC) of the soils virtually not show any specific trend that can match with the location distances. Several other factors like the spherisity, roundness, minerological composition of the constituting grains pay a significant role on the porosity and permeability of the soil, which is the main responsible factor for OMC of a particular soil sample. Highest OMC was recorded for Patna is 18% with maximum dry density of 1.70 gm/cc and it was the minimum at Rishikesh, having an OMC of 11.4% when dry density was 1.87.

5.3. Liquid Limit, Plastic Limit and Plasticity Index

5.3.1 General

Liquid limit and plastic limit of a soil generally refers to its consistency i.e the relative ease with which soil can be deformed. This term is mostly used for the fine grained soil for which the consistency is related to a large extent to water content. Consistency denotes degree of firmness of the soil which may be termed as soft, firm, stiff and hard. Fine grained soil may be mixed with water to form a plastic paste which can be moulded into any form by pressure. Farther addition of water reduces the cohesive bond of the soil and after certain water content it start to behave like liquid. Water content at this stage is the liquid limit of the soil. Plasticity index indicates the degree of plasticity of the soil. Greater the plasticity index, greater the plasticity of the soil. Generally fine grained clayey soil posses high values of liquid limit and plasticity index. All this properties of fine grained soil depend upon the type and amount of clay present in the soil and with respect of that required measures generally provided for consolidation to upgrade the strength parameter of the soil during any construction project.

5.3.2 Liquid and Plastic Limit of the Fine Sediment

Experimental procedure for detecting the liquid limit (W_L) and plastic limit (W_P) of the soil samples of Varanasi, Patna and downward locations presented in detail in the Chapter 4. These samples have the d_{50} below or near to 75µ. Table 7.1 is presented below to reveal the liquid limit (W_L), plastic limit (W_P) and plasticity index (I_P) of the tested samples of three locations at the mid to downstream part of the river flow.

Table 5.3.1 Liquid limit (W_L), plastic limit (W_P) and plasticity index (I_P) of the tested samples

Sample No.	Sample Location	Distance along course from Rishikesh (km)	W_L	W_P	I_P
5	Varanasi	908	28.90	22.60	6.30
6	Patna	1188	30.00	21.40	8.60
7	Raghunathgunj	1550	19.90	Can't Measured	Can't Measured
8	Shibpur	1835	25.9	18.76	7.14
9	Gadiara	2050	29.9	22.75	7.15
10	D. Harbour	2500	32.65	19.28	13.37

5.3.3 Discussion on Results Obtained

From the Liquid Limit and Plastic Limit Test perform it was clear from the obtain data that the liquid limit of the sediments increase Varanasi to patna because the clayey sediments come to picture in the Varanasi prior to that there is no such existence non cohesive fine grained particles of the clay sized. From Varanasi to Patna we start to get fine grained sediments for which we can able to perform the liquid limit test and enhancement of liquid limit is directly tell us the abundance of clayey mineral of the particular sediments so it is clear from this figure that from Patna to Diamond Harbour where downstream ridge where the depositional phase is mainly dominated in the river the liquid limit is gradually increasing except in case of Raghunathgunj and it is also evident from the Grain size distribution pattern and Proctor Compaction Test cannot be obtain out of this. In the Raghunathgunj the sediments is quite anomalous with respect to normal trend of sediments and it is being intervent substantially by means of the err action of Farakka Barrage and gradual dislocation of the flow regime of the river Ganga which enhance the turbidity of the particular area and thereby flow energy which causes the grain size higher in the particular location and from Raghunathgunj if we see the Shibpur , Gadiara, Diamond Harbour it is almost a span of 25-35 and gradually increase in trend in small amount but obviously the liquid limit that the content of liquid, how maximum liquid it can able to contain. It is gradually increase downstream wise which is natural trend for the clayey sediments and the depositional regime imparts a steady depositional regime of the fluvial flow. Plasticity index (I_P) also reveals a definite trend with the distance of flow as it value gradually increased with the fineness of the constituting particles towards the downstream of flow. Increase in clay fraction in the soil increase the value of liquid limit as well as the plasticity index of the soil as a whole (Taylor, D.W. 1948) and in our observation it also have definite proportionate correlation with the distance of transportation of the soil mass in case of fluvial deposition. Fig. 5.3.1 to 5.3.6 has been presented to reveal the curve as obtained by the plots of water content (Wc) against the number of blows of A.Casagrande's apparatus for the determination of liquid limit (W_L) of the soil samples. Water content (Wc) corresponding to 25 blows i.e. W_L for the soil mentioned in different colour in the graph obtained.

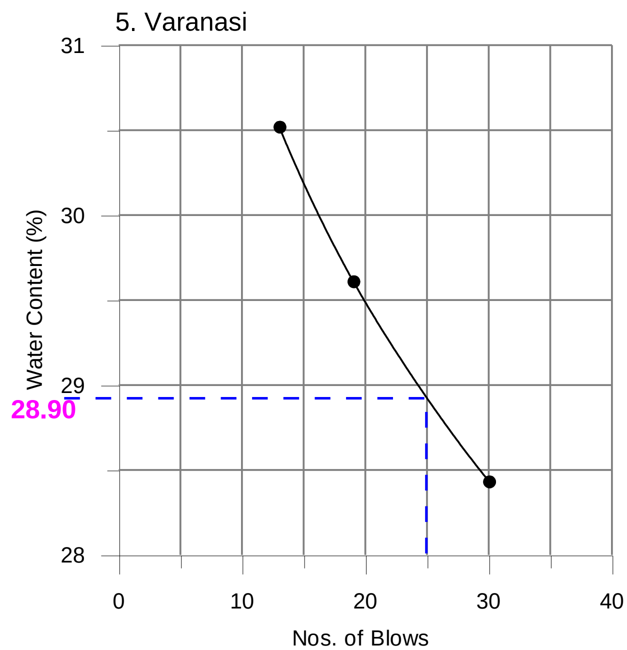


Fig. 5.3.1 Plots of the water content (*W*c) against the number of blows and the W_L of the soil of Varanasi (Sample – 5)

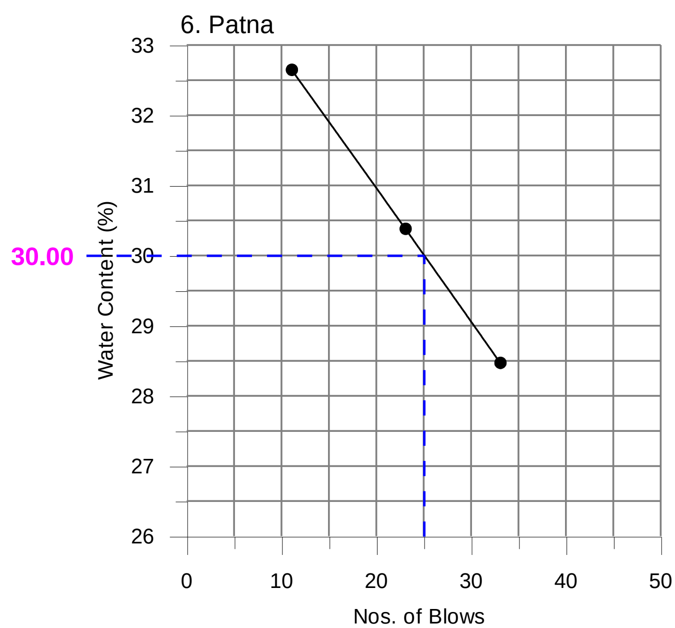


Fig. 5.3.2 Plots of the water content (*W*c) against the number of blows and the W_L of the soil of Patna (Sample – 6)

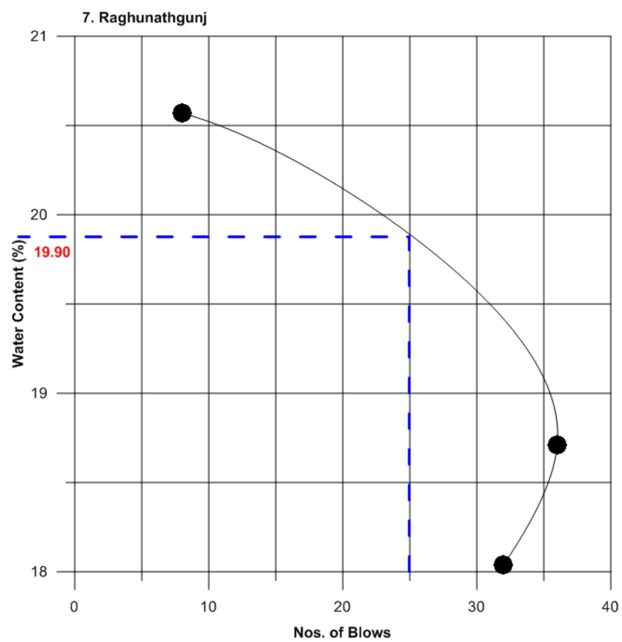


Fig. 5.3.3 Plots of the water content (*W*c) against the number of blows and the W_L of the soil of Raghunathgunj (Sample – 7)

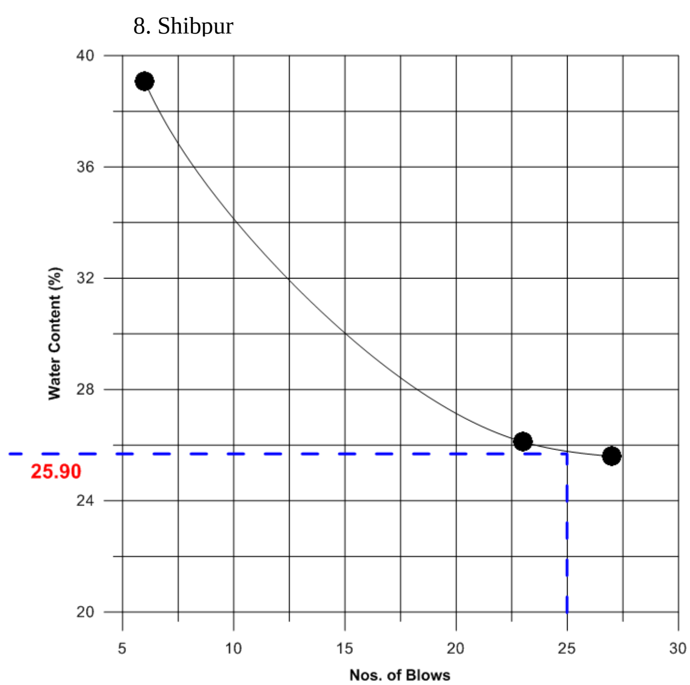


Fig. 5.3.4 Plots of the water content (*W*c) against the number of blows and the W_L of the soil of Shibpur (Sample – 8)

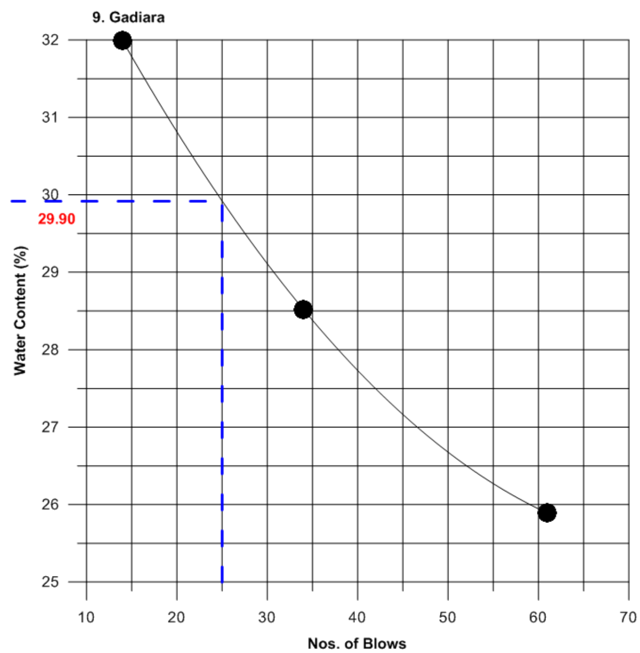


Fig. 5.3.5 Plots of the water content (*W*c) against the number of blows and the *W*L of the soil of Gadiara (Sample – 9)

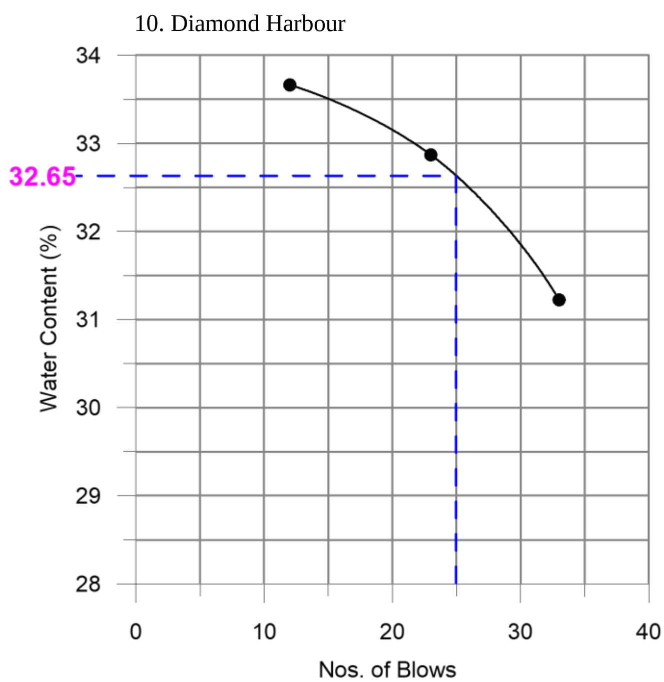


Fig. 5.3.6 Plots of the water content (*W*c) against the number of blows and the *W*L of the soil of Diamond Harbour (Sample – 10)

Plastic limit (W_P) of the samples obtained by standard method of threading and the obtained values of W_c has been given in the Table 5.3.2 with the plasticity index (I_P).

Table 5.3.2 as given below show the standard classification of soil related to the plasticity index of the soil according to Ranjan and Rao. 2009.

Table 5.3.2 Standard soil classification of related to the plasticity index according to Ranjan and Rao. 2009.

Plasticity Index	Soil Description
0	Non-plastic
< 7	Low-plastic
7 - 17	Medium-plastic
> 17	Highly plastic

Therefore according to the standard classification the soil of Varanasi is low plastic whereas soil of Patna, Shibpur, Gadiara are medium-plastic and Diamond Harbour is highly plastic. Fig. 5.3.7 has been presented to show the relation between the liquid limit and plastic limit of the examined soil with the distance traveled by it by the river flow. Figs 5.3.8 reveal the variation of plasticity index with the distance of flow of the fine silty to clayey soil. For both the graph presented distance of the places taken along the course of the river from the Rishikesh.

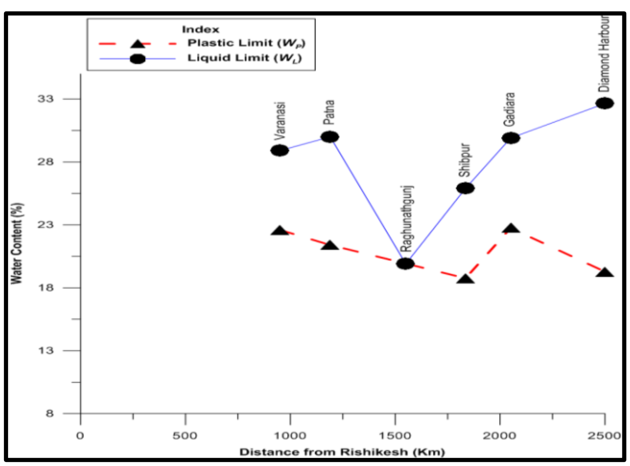
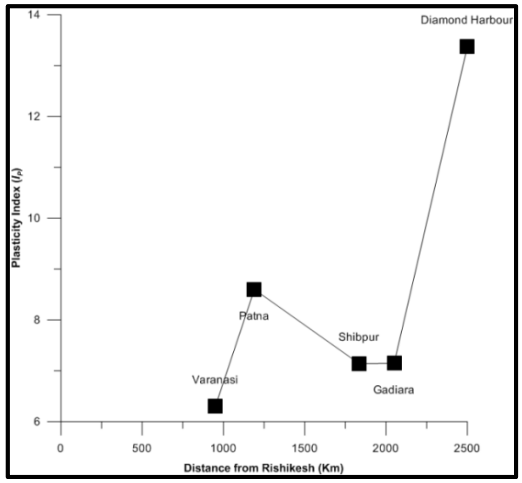


Fig. 5.3.7 Plot showing relation between the liquid limit and plastic limit of the soil with the distance



Figs 5.3.8 Plots showing the variation of plasticity index (I_P) with the distance

5.3.4 Concluding Summery

From the liquid limit and plastic limit test of fine grained silty soils as collected from the locations of Varanasi and downward locations it clearly revealed that with the increase of the fineness of the soil the corresponding values of liquid limits and plastic limits vary substantially, as expected theoretically except in case of Raghunathgunj. Liquid limit values increases with the distance of transportation of constituting grain particles whereas values of plastic limit decreases. Again it is quite interesting to note that the gradients of variations for of liquid and plastic limits decrease with the distance downstream that is slope of the river also have a direct influence on both the parameters of the soils. Plasticity index of the soils increases significantly along the river flow , again this increment is much steeper towards the downstream. If liquid limit enhance more than 30% the strength of the particular sediments will goes down. So can conclude out of these that is we get 20, 25, 29 these sediments are mostly stable in the in the nature but in case of Diamond Harbour it not that much stable because it exceeds 30% and it is also not if we take 20-30% it is most suitable for the population and compaction of particular sediments. As far as liquid limit is concern and the result which we receive from the liquid limit test that from Varanasi. It is more or less stable in Patna, Gadiara and Diamond Harbour is not much stable of the other location. Before impart any load for the construction it has to be developed by means of some engineering application

Chapter 6

Summary and Conclusions

6. Summary and Conclusions

Experimental study on the variation of major index properties of soil along the course of the river Ganga, starting from its foot hill flow at Rishikesh to extreme downstream at Diamond Harbour, reveals that all the studied properties varied considerably with its spatial location and have a direct influence of transportation distance, and over all energy parameter of the fluvial flow. Broadly it can be said that from Rishikesh to Vararnasi the soil characteristics resemblance considerably , after that it shows a change and from Patna onwards, along the downstream upto Diamond Harbour nature of soil diverge to a great extent. From the grain size analysis and consistency limits tests all the soil samples classified according to the '*Indian Standard Soil Classification System* (1970)' as finally presented by Table 6.1

Table 6.1 Classification of soil types accoding to the ISSCS, 1970

Sample No.	Sample Location	Soil Type
S-1	Rishikesh	Coarse Sand , Well graded
S-2	Haridwar	Medium Sand, Well graded
S-3	Saharanpur	Fine Sand, Poor graded
S-4	Allahabad	Fine Sand, Well graded
S-5	Varanasi	Fine Sand, Well graded
S-6	Patna	Silt with low plasticity index
S-7	Raghunathgunj	Silt with low plasticity index
S-8	Shibpur	Silt with low plasticity index
S-9	Gadiara	Silt with low plasticity index
S-10	Diamond Harbour	Silt with high plasticity index

Grain size distribution pattern of the soils of different locations shows a significant variation with the distance of sample location from the foot hill position of the river Ganga i.e. Rishikesh. There is a significant decrease in overall grain size of the soil along the course of the river Ganga. At its entry to the plains from Rishikesh to Saharanpur , there is a rapid decrease of the soil grain size compare to the rest of the portion of the river. After Allahabad a comparatively fare decrease is recorded, which probably a reflection of a significant increase of discharge to the joining of 'Yamuna' and accordingly may be the velocity of the flow. Though having a considerable size difference, soils up to Varanasi fall in the class of 'Sand' as per the 'Indian Standard Soil Classification System'. Soil samples from the bank of Patna and downward location are of the class of 'Silt' with an appreciable amount of cohesiveness. C_C and C_U of the soils also show a decreasing and increasing trend respectively with its distance of deposition from the source up to Patna. From Patna to Diamond Harbour the trends for both the coefficients is just opposite to the previous trends. Fineness of the soil sample may be a probable cause for this change.

From the Proctor compaction test of the soil samples (sample no 1, 2, 3, 4, 5, 6, 7 and 8) that for well sorted sandy soil up to the location of Allahabad the dry density of the soils decrease with the increase of the transportation and subsequent deposition distances of the soil, though it has a considerable correlation with the grain size distribution pattern of the soil. In case of silty soil from the bank of Patna it show a sharp increasing trend, which is naturally expected due to the fineness of the constituent grains. Optimum moisture content (OMC) of the soils virtually not show any specific trend that can match with the location distances. Several other factors like the sphericity, roundness, mineralogical composition of the constituting grains pay a significant role on the porosity and permeability of the soil, which is the main responsible factor for OMC of a particular soil sample. Highest OMC was recorded for Patna is 18% with maximum dry density of 1.70 gm/cc and it was minimum at Rishikesh, having OMC of 11.4% when dry density was 1.87.

Liquid limit and plastic limit tests of comparatively fine grained soils of Varanasi, Patna, and downward locations revealed that with the increase of the fineness of the soil the corresponding values of liquid limit and plastic limit vary substantially, as expected theoretically. Liquid limit values increases with the distance of transportation of constituting grain particles whereas values of plastic limit decreases. Again it is quite interesting to note that the gradients of variations for of plastic limits decrease with the distance downstream that is slope of the river also have a direct influence on both the parameters of the soils.

Plasticity index of the soils increases significantly along the river flow, again this increment is much steeper towards the downstream.

Overall it can be concluded that:

- Sediment properties directly influenced by - Transportation distance, & Energy parameter of fluvial flow.
- A general trend and resemblance of sediment characteristics was noted from Rishikesh to Vararnasi.
- Gradual change on overall grain size was quite acute up to Patna, But from Patna up to Diamond Harbour the variation of grain size was quite anomalous.
- From source up to Patna, C_C is increasing and C_U decreasing up to Patna then these were just opposite.
- Dry density of the soils decrease with the increase of the transportation distance up to Varanasi.
- Liquid limit increases with transportation but plastic limit decreases (except for Raghunathgunj and Gadiara).
- Plasticity index of the soils increases significantly along the river flow - much steeper from its initiation of downstream that is from Patna onwards.

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This is to certify that Prof./Dr./Mr./Ms. **Mukul Roy**
is the Presenting Author / Co-author / Corresponding author in oral / poster session, titled Variations of major … to Gadiara, West Bengal of the 3rd Regional Science and Technology Congress (Southern Region), 2018 jointly organized by Bidhannagar College, Government of West Bengal and the Department of Science and Technology and Biotechnology (DSTBT), Government of West Bengal on December 18-19, 2018 at Bidhannagar College, Kolkata-700064.

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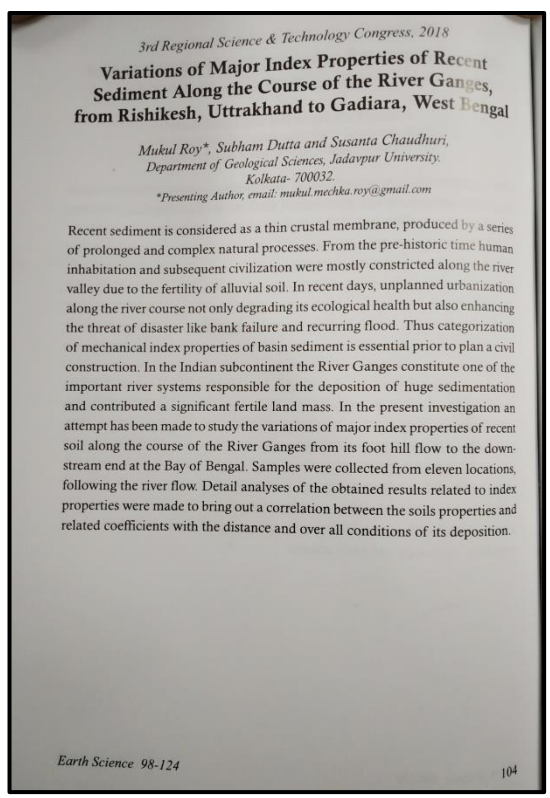

Variations of Major Index Properties of Recent Sediment Along the Course of the River Ganges, from Rishikesh, Uttrakhand to Gadiara, West Bengal

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Recent sediment is considered as a thin crustal membrane, produced by a series of prolonged and complex natural processes. From the pre-historic time human inhabitation and subsequent civilization were mostly constricted along the river valley due to the fertility of alluvial soil. In recent days, unplanned urbanization along the river course not only degrading its ecological health but also enhancing the threat of disaster like bank failure and recurring flood. Thus categorization of mechanical index properties of basin sediment is essential prior to plan a civil construction. In the Indian subcontinent the River Ganges constitute one of the important river systems responsible for the deposition of huge sedimentation and contributed a significant fertile land mass. In the present investigation an attempt has been made to study the variations of major index properties of recent soil along the course of the River Ganges from its foot hill flow to the down-stream end at the Bay of Bengal. Samples were collected from eleven locations, following the river flow. Detail analyses of the obtained results related to index properties were made to bring out a correlation between the soils properties and related coefficients with the distance and over all conditions of its deposition.