Characterising representative soil types of India based on their major exchangeable cation concentration

MS Thesis Submitted to

Department of Earth and Climate Science

Indian Institute of Science Education and Research Pune

Submitted by Asish Tanay Behera,

20226407

Supervisor: Dr. Shreyas Managave,

IISER Pune

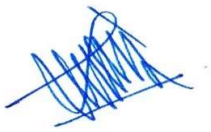
Expert: Dr. Gyana Ranjan Tripathy

IISER Pune

Date: 05/04/2024

Certificate

This is to certify that this dissertation entitled **Characterising representative soil types of India based on their major exchangeable cation concentration** towards the partial fulfilment of the MSc (Geology) programme at the Indian Institute of Science Education and Research Pune represents original research carried out by **Asish Tanay Behera** at Indian Institute of Science Education and Research (IISER) Pune under the supervision of Dr. Shreyas Managave, Associate Professor, Earth and Climate Science Department during the academic year 2023-2024.



Dr. Shreyas Managave

Committee:

Dr. Shreyas Managave

Dr. Gyana Ranjan Tripathy

Declaration

I Asish Tanay Behera, hereby declare that the matter embodied in the report entitled '**Characterising representative soil types of India based on their major exchangeable cation concentration**' are the results of the work carried out by me at the Department of Earth and Climate Sciences, Indian Institute of Science Education and Research Pune, under the supervision of Dr. Shreyas Managave and the same has not been submitted elsewhere for any other degree.

Asish Tanay Behera

Abstract

In this project I have tried to characterize representative soil types of India based on their cation exchange capacity in relation to other physical and chemical parameters. The samples for the measurement are collected from different locations across India. Various parameters like organic matter content, pH, clay percentage are measured along with the exchangeable cation concentrations to find any meaningful relation that may exist between them.

Acknowledgements

I am grateful to my thesis supervisor, Dr. Shreyas Managave (IISER Pune) for his constructive guidance throughout my project. I thank my Expert Dr. Gyana Ranjan Tripathy (IISER Pune) for allowing me to use the instruments I needed for my experiments. I thank Vikrant and Rakesh Kumar for helping me in the instrumentation during the analysis. I would like to thank all my lab mates Maheshwari, Sindoora, Shushant, Amrita, and Athul for being helpful and giving suggestions whenever I needed the most. I would also like to thank my friends Tanushri, Samarpan, Sanket, Amir, Pradyumna, Debashish and Surajit for helping me with the samples. Again, I thank to the Dept. of ECS and members for the support during my thesis.

Outline

Contents

LIST OF FIGURES AND TABLES

List of Tables

List of Figures

LIST OF ABBREVIATIONS

CEC- Cation Exchange Capacity

CEC_K- Cation Exchange Capacity of element K or Equivalent charge concentration of element K

AS- Alluvial Soil

BS- Black Soil (Western Ghats)

CS- Coastal Sandy Soil

BS(P)- Black Soil (Panchwati Hill, Pune)

CHS- Charnockitic Hill Soil

LS- Laterite Soil

RYS- Red and Yellow Soil

LOI- Loss on Ignition

1. Introduction

India is unique considering its diversity in landforms, geomorphology, climatic conditions, or it's geological history. The diverse geological history of India has led to occurrence of different types of rocks in different regions of India. As the rocks, India homes various types of soils those have influenced various crop practices, vegetation, and land use across its boundaries. Though soil properties vary a lot from places to places influenced by various factors like, pH, clay and organic matter content, rainfall, land use practices, etc. there is a need to classify the soils of India for the agricultural and land use planning. the soils of India can be broadly classified into 8 types by Indian Council of Agriculture and Research (ICAR) (Balasubramanian, 2017) based on their genesis, composition, colour, and location can be deciphered. These 8 major soil types are namely, a) Alluvial soil b) Black soil c) Red soil d) Laterite soil e) Desert soil f) Mountain soil g) Saline soil and Alkaline soil and h) Peaty soil. From these eight major soil types, the Mountain soil type is mostly limited to Northen most region of India such as Jammu & Kashmir, Ladakh, Himachal Pradesh, Sikkim Uttarakhand, and some parts of Arunachal Pradesh and the Arid soil type is mostly limited to the western parts of the Rajasthan. In this project I will be trying to characterize the other four types of soil namely Alluvial soil, Red & Yellow Soil, Black Cotton Soil, and Laterite Soil, along with Coastal sandy soil (Alkaline soil) and Charnockitic Hill soil with respect to their Cation Exchange Capacity (CEC).

The definition of Cation Exchange Capacity is given as a measure of the amount of the easily exchangeable cations those neutralize the negative charge in the soil. The exchange occurs such that the charges are balanced. CEC of a soil is measured as the sum of equivalent charge concentrations of all the exchangeable cations. The soil's cation exchange capacity is measured in centimoles charge per Kg of soil ($cmol_c Kg^{-1}$). The fact to notice here is that the CEC for a given is not the actual concentration of the given cation but the ability of that cation to neutralize the negative charges present in the soil. Hence CEC measures the total charge equivalent. i.e., exchangeable concentration of a given cation multiplied by its valency. The CEC of a given soil can be used to predict a wide varieties property like the fertility and soil health, capacity to act as a buffer to prevent ground water pollution (by adsorption of pollutant Cations), determining the amount of limestone to be applied to acid soils, measuring rate and degree of weathering, etc. Also, exchangeable forms of cations like Calcium and Magnesium are regarded as good sources that promote good soil structure and tilth.

Cation Exchange Capacity occurs as a result of the adsorption of the cations onto the surface of negatively charged particle surfaces. As the adsorption is a surface process the CEC in a soil is caused due to the organic matter and clay content of the soil as they have considerably high surface to volume ratio than the sand and silt and high residual negative charge on the surface. The counter positive charges in soil originate from isomorphous substitution within the layer silicate structures, adsorption of specific ions preferentially, dissociation induced by the pH of acidic functional groups in organic compounds, and the exposed broken bonds at mineral surfaces and edges. Except for the first reason for negative charge in soil (which is constant for same type of soil), all other sources vary with different environmental factors even within similar soi type. As the CEC is a function of the negative charge concentration on particle surface it is a soil property that is dependent of the conditions under which it is measured. Hence in an ideal condition the CEC of a given soil should be measured in conditions mimicking its natural occurrence.

1.1 Soil map of India representing major soil types. Credit- mapsofindia

The force with which a cation is adsorbed to the particle surface can be obtained simply from the Coulomb's law of attraction between two charged particles. Though this law explains adsorption of cations onto the clay particle surface, the selectivity of a cation over another is explained by considering ionic and hydrated radii. The hydrated radius the hydrated radius is the radius of the cation including its associated water molecules. For same valency, these two radii are generally inversely proportional to each other. Whereas the force with the cation is adsorbed is inversely proportional to each other. The stronger is the force of adsorption, more difficult it is being replaced by another. The order of increasing capacity to replace another cation is known as lyotropic series and is given as: $Li^+ \sim Na^+ > NH_4^+ \sim K^+ > Mg^{2+} > Ca^{2+} > Al^{3+}$. As we move from left to right in the lyotropic series harder it becomes to being displaced. Another parameter that influences the replacing power is the concentration of the cation. Higher is the concentration of a given cation in soil solution, greater is the replacing power and vice-versa. Dilution of a soil solution prefers retention of higher valency cations over lower ones. On the top of electrostatic force of attraction, great preference for specific cations is shown by few colloids, e.g., Mg in vermiculite. The water network between parallel sheets of vermiculite appears to accommodate the hydrated magnesium ion so effectively that Mg^{2+} is preferred over Ca^{2+} in a wide range of concentrations. The retention of K^+ and NH^{4+} by vermiculite and weather mica is another illustration of an atypically strong affinity for a specific ion. These ions are easily dehydrated, shrink, and are firmly maintained by mica and vermiculite because it appears that they have a low hydration energy.

A number of cation exchange equations have been proposed to calculate the relative change of one exchangeable ion over another as the composition of the soil solution changes, each having pros and cons of its own. The choice of an exchange equation is frequently determined by the reader's familiarity with it. Few of such equations are Kerr equation/mass-action equation, Vanselow equation and Gapon equation. Among these the Gapon equation is most commonly used to calculate the relative change of one exchangeable ion over another.

If the Na^+ in the solution is replacing the Ca^{2+} ion from the exchangeable site, the Gapon equation is given by, $\frac{[Na\text{–X}]}{[Ca_{1/2}\text{–}X]} = K_G \frac{[Na^+]}{[Ca^{2+}]^{1/2}}$

$[Na\text{–}X]$ and $[Ca_{1/2}\text{-}X]$- exchangeable cation concentrations in meq/g, (or mmol of charge/g)

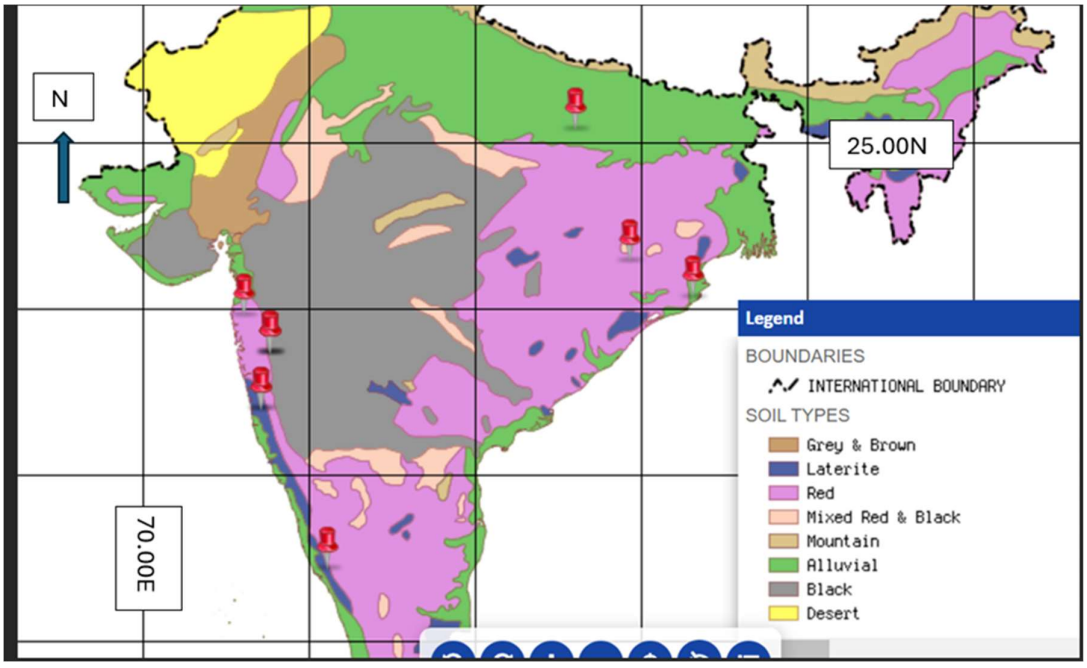
$[Na^+]$, $[Ca^{2+}]$- solution cation concentrations in mmole/liter and K_G – Gapon's constant

2. Methodology

SAMPLING

Samples are collected from different regions of India representing the major soil types of India through friends. The soil sample was collected not exceeding the depth of 15cm from the surface to ensure only topsoil that potentially interacts with the rainwater is taken. Around 15 to 18 Kg of Soil sample is collected from one location. The location of the sampling point is noted, and the field pictures from sampling point is taken.

Upon receiving the soil sample, the samples were oven dried at 50℃ overnight to ensure all soil moisture is lost. The roots and visible organic matters are picked. Large boulders and hard stones are picked up. The samples are gently crushed with Agate and Moulder to break the soil aggregates. From here a representative sample around 150g is taken from each soil sample through coning and quartering. Now the representative samples are sieved through 2mm pore size to remove coarser rock fragments and packed in Ziplock bags and levelled properly. 7 different soil samples of 6 representative soil types namely, Alluvial soil, Black Cotton soil, Coastal Sandy Soil, Laterite Soil, Red and Yellow Soil and Charnockitic Hill Soil, were collected such. The sampling locations are plotted in the following map.



2.1 Sampling locations plotted on the soil map of India. Grid size- '5× 5'. Credit- National Atlas and Thematic Mapping Organisation (https://geoportal.natmo.gov.in/)

2.2 Colelction of Alluvial Soil sample, UP

2.3 Collection of Black Cotton Soil sample from Panchwati Hill, Pune

2.4 Collection Red & Yellow Soil sample from Deogarh, Odisha

EXPERIMENTATION

MEASUREMENT OF CLAY, SAND AND SILT PERCENTAGE USING PIPETTE METHOD

PRINCIPLE

The measurement of clay, silt, and sand fraction using this method is designed on the basis of Stoke's Law which states the amount that a particle sink depends on diameter and density of the particle. i.e., smaller (less dense) particles sink less than larger (denser) particles more when suspended in a liquid.

The mathematical expression is given by,

$$v = D^2 g (\rho S - \rho L) / 18n$$

where v- settling velocity, D- Diameter of the particle, ρS- density of the particle,

ρL- density of the liquid, n – viscosity (Paul R. Day, 1965)

Using this equation with a generalized assumption for settling velocity of clay, the clay fraction can be separated from silt when suspended in water. Whereas the sand fraction can be mechanically separated through sieving.

REAGENTS

10% (w/v) Sodium Hexametaphosphate- Chemical formula- $Na_6[(PO_3)_6]$. Prepared by adding 10g of Sodium Hexametaphosphate in 100ml de-ionised water. Used as flocculating agent.

Hydrogen peroxide- Chemical formula- H_2O_2. Absolute hydrogen peroxide is taken as oxidising agent for removing organic matters.

PROCEDURES

For the measurement of sand, silt, and clay percentage of soil samples around 25g of representative sample is taken from each soil type by coning and quartering technique. The samples are then weighed using microbalance and the weight is noted with sample id. The weighed sample is taken in a tall form beaker and soaked with ~600ml de-ionised water for 16h. This step is done for loosen and break the soil aggregates. Now the water is discarded out gently leaving approximately 250ml of water in each beaker. Proper care is taken to ensure that no sample is lost during discarding especially the clay fraction. Now 10ml Hexametaphosphate solution is added to each sample and kept overnight. This helps in flocculation of soil particles

and further breaking of soil aggregates those are still present. As when most of the soil particles are present in their original individual size 15ml of Hydrogen peroxide (H_2O_2) is added to each sample and kept overnight for removing organic matters that are there in the sample.

Figure 2.5 Coning.

Figure 2.6 Quartering.

Figure 2.7 Samples after being treated with hydrogen peroxide during the sand-silt-clay separation experiment.

Now these samples are filtered through 63-micron sieve and transferred to 1000ml measuring cylinder. The remnant in the sieve is now washed by deionised water using retentive filter papers (pre-weighed) till 900ml and the cylinder is filled with de-ionised water up to 1000ml.

The samples are stirred thoroughly and then allowed to stand undisturbed, and the time of stirring is noted. Clay fraction is then collected in separate small beakers from the top with pipette from a depth calculated using Stokes's law which is a function of time it is kept undisturbed. Meanwhile the filter papers containing the sand fraction are dried in the oven at 50℃ for overnight. The collected clay fraction is labelled properly, and oven dried at 50℃ for overnight. After completely dried the filter papers along with the sand fraction is weighed and the weight of filter papers are subtracted from it to get the weight of the sand fraction. The dried clay flakes are scratched properly and collected in a butter paper and weighed to calculate the clay fraction.

CALCULATIONS

Filter papers used for the filtration of sand particles from the sample are weighed before filtration and the weight is noted with sample ID.

After the sand is dried overnight it is again weighed with sand fraction in it. Then the sand weight is calculated as,

Sand weight = *(Combined weight of Filter paper and sand) – Filter paper weight*

Now the sand percentage is calculated as,

$$Sand\% = \frac{Weight\ of\ Sand}{total\ weight\ of\ sample\ taken} \times 100$$

For the collection of clay fraction, the time and depth are calculated simplified equation of Stoke's law. The clay fraction is collected from 8cm from the top, and the volume of the water is noted. After oven drying for around 36 hours the clay is scratched and weighed.

Now assuming the clay distribution to be uniform throughout, the clay percentage is calculated as,

$$Clay\% = \frac{Weight\ of\ the\ clay}{volume\ of\ water\ taken(in\ ml) * weight\ of\ the\ sample} \times 10^5$$

After getting the percentage values for Sand and Clay the silt percentage is simply determined as,

Silt% = 100 – (sand%+ Clay%)

MEASUREMENT OF pH

10g of representative soil samples are taken in 50ml beakers and 25ml of deionised water is added to it. It is then thoroughly stirred repeatedly in between for 30minutes. The pH meter is then dipped in the soil solution and allowed to pH reading becomes stabilized. The final reading is then noted along with the sample ID.

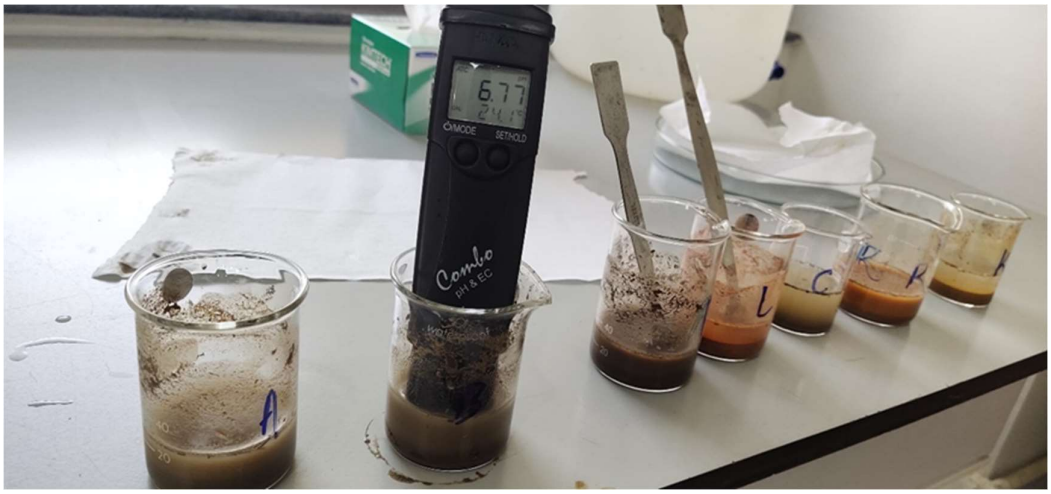


Figure 2.8 Measurement of pH of the soil samples by pH meter.

MEASUREMENT OF MAJOR EXCHANGEABLE CATION CONCENTRATIONS

PRINCIPLE

The soil particle has some residual negative charge on their surface which adsorbs and exchanges cations with surrounding soil solution. The dissociation of functional groups of acidic nature in organic compounds, broken bonds at the edges and external surfaces of minerals, isomorphous substitution within layer silicate mineral's structures, and the adsorption of specific ions preferentially on particle surfaces due to chemical reactions are the sources of negative charges found in soil. The force with which a cation adsorbs to the soil surface is directly proportional to its valency, ionic radii and concentration in the soil solution provided other parameters remains constant. In general, a di-valent cation can easily replace two mono-valent cations from the soil surface whereas for a monoi-valent cation to replace a divalent cation from its site the mono-valent cation concentration in the soil solution must be sufficiently high. The general sequence of the cations with increasing strength to adsorb to soil surface where the concentration of each is cation in the soil solution kept same is known as "lyotropic series".

Hence it is possible that a specific cation solution of sufficiently higher concentration can be used to replace and extract the adsorbed cations from the soil. Again, as the CEC is dependent on the conditions in which it is measured, ideally the CEC of a soil should be measured in a condition mimicking its natural occurrence. As it difficult to create a natural like conditions, for each soil types, a standard globally accepted procedure is followed to measure CEC of a soil. This process is done in three fundamental steps, i.e., Saturating with a selected cation, Washing the excess saturating cation, and finally replacing the selected cation with another cation and measure the concentration of the selected cation to know the total exchangeable cation concentration. The lyotropic series is given as,

$$Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} > Na^{+} > Li^{+}$$

REAGENTS

1M Ammonium Acetate- Chemical formula- $NH_4CH_3CO_2$. It is prepared by adding 77.08g of Ammonium Acetate in 1L de-ionised water.

95% Ethanol- 12.5ml of water is taken in a 250ml volumetric flask and absolute ethanol is added up to 250ml mark to make 95% ethanol.

1M Potassium Chloride (KCl)- 74.55g of Potassium Chloride salt is added in 1 litre of de-ionised water to make 1M Potassium Chloride.

Stock Solution- Around 700ml de-ionised water is taken in a volumetric flask and 2.542g of NaCl, 3.917g of $MgCl_2$, 1.907g of KCl and 2.769g of $CaCl_2$ salts are added to it and the total volume then made up to 1000ml. The salts are mixed thoroughly and a 1000ppm stock solution for all the cations is made. Chloride salts of all the respective cations are taken to maintain a homogenous matrix.

Working Solution1- A working solution of volume 100ml and concentration 100ppm is prepared from the stock solution by taking 10ml of it in a volumetric flask and making it up to 100ml.

Working Solution2- Another working solution of volume 100ml and 2ppm concentration by dilution of the working solution1.

PROCEDURE

For the measurement of cation exchange capacity of soil samples around 25g of representative sample weighed and taken from each soil type by coning and quartering technique. Then the samples are taken in a 250ml narrow mouth bottle along with 125ml of 1M

NH_4OAc is added to it and shaken thoroughly and allowed to stand undisturbed for 16h. Then it is shaken thoroughly and centrifuged for 20mins at 6000rpm and decanted through retentive filter paper with extra care so that no sample loss occurs. This process is repeated with another 100ml NH_4OAc, and the leachate is collected in a 250ml flask and made up to 250ml with 1M NH_4OAc for the measurement of exchangeable cation concentration.

Now two separate additions of 100ml each 95% ethanol are added to the sample, shaken thoroughly, centrifuged, and decanted with extra care to remove excess saturating solution present in the soil sample. This decanted ethanol is collected in a waste beaker and discarded. This step is called washing.

The adsorbed NH_4 is then extracted by leaching the soil with two separate additions of 100ml each 1M KCl solution in the process like the leaching with 1M NH_4OAc.

For the measurement of different cations like Na, K, Mg, and Ca the first collected leachate with 1M NH_4OAc as medium is diluted accordingly to bring down the expected concentration within the detectable range of Atomic Absorption Spectrophotometer (AAS), i.e., 0 to 7ppm and the samples are ready for the measurement of concentrations using AAS.

Preparation of Standards

To obtain the calibration for the measurement of Na, K, Ca, and Mg concentrations standards of respective cations were prepared from the working solution1 and working solution2. The concentrations of standards prepared are 0.1ppm, 0.2ppm and 0.5ppm, 1ppm, 2ppm, 4ppm, and 6ppm. The standards of 1ppm, 2ppm, 4ppm, and 6ppm were prepared from the dilution of the working solution1 2% HNO_3 and others were prepared from the dilution of working solution2 with 2% HNO_3. Now a known standard is prepared from dilution of a stock solution of known concentration and taken for the measurement of accuracy of the result.

WORKING PRINCIPLE OF ATOMIC ABSORPTION SPECTROPHOTOMETER (AAS)

AAS is an elemental technique that has the capability to provide quantitative information about more than 70 elements. It is used for analysis of metallic and trace elements such as Al, Cd, Pb, Ni, Mo, Mg, K, Zn, etc. It is a highly sensitive technique and can measure the elements up to ppm to ppb level. Another benefit is that the concentration of the element concerned can be determined in the presence of other elements those don't interfere with the absorption to the analyte wavelength. Food, soil, water samples are generally analysed by AAS for the presence of trace elements.

The samples are fed into the AAS in solution form and the sample solution is atomised in an atomiser (Flame atomiser). Sample solution droplets evaporates in flame giving some residue of sample. The residue then gets evaporated, and the solid sample molecule is converted into gaseous sample molecule due flame temperature. Further gaseous molecule dissociates to give gaseous neutral atoms (Ground State). In response to flame temperature of the ground state gaseous metal atoms will get excited but most of atoms will remain in ground state.

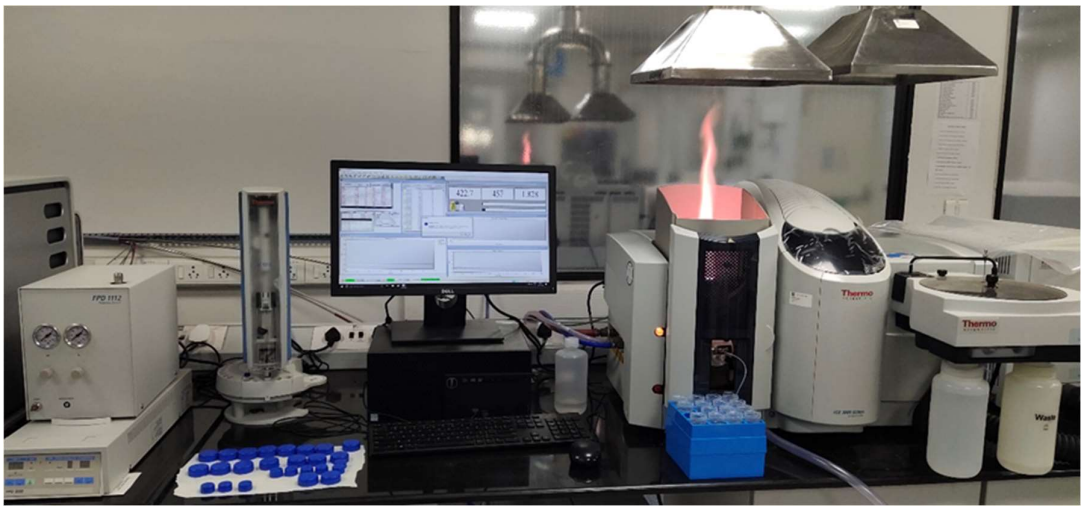


Figure 2.9 Measurement of concentration of samples using Atomic Absorption Spectrophotometer

The Electro-magnetic radiations of specific wavelength are passed through these ground state (un-excited) gaseous metal atoms which will absorb those radiations. The absorption radiations follow Beer- Lambert's law.

$$log\left(\frac{I_0}{I_t}\right) = KLN_0$$

I_0: intensity of the incident radiation

I_t: intensity of the transmitted radiation

K: Characteristic constant

L: Path length of flame in cm

N_0: Number of atoms in the ground state

The intensity of absorption is a function of the concentration in the solution, and the radiance comes as the signal. This radiance is then converted to concentration using the equation obtained from the calibration. Natural gas, Hydrogen, Acetylene, etc. are used as fuel

gases in Atomic Absorption Spectrophotometer to atomize the sample solution. Oxidants like Oxygen, Air, Nitrous oxide, are used to atomize resistant cations those are not easily atomized simply by the fuel gases.

CALCULATIONS

Each sample is weighed and labelled with sample Id and the respective weights were noted down. Let's the sample weight (in grams) to be "SW".

The dilution factor for each sample per each measurement is noted. Let's the dilution factor to be "f".

After the measurement with AAS the absorbance is converted to respective concentration from the equation of the straight line obtained from the Calibration standards as

$$Concentration\ in\ ppm = \frac{(\text{Absorbance} - \text{Y intercept})}{\text{slope of the line}}$$

This concentration is multiplied with dilution factor to get the actual concentration of the sample leachate. Let's this concentration (in ppm) to be "C".

Conversion of ppm to Molar concentration,

$$\text{Molar concentration(M)} = \frac{\text{Concentration in ppm(C)}}{\text{molar mass of the element}} \times 1000$$

Conversion of Moles per litre to $cmolKg^{-1}$

Exchangeable Cation concentration in the sample for element A in ($cmolKg^{-1}$),

$$= \frac{\text{M} \times \text{Volume of the leachate (in Litre)} \times 1000}{\text{SW} \times 100}$$

Hence the final equation for conversion of the concentration of the leachate in ppm to exchangeable cation concentration in the sample in $cmolKg^{-1}$ becomes,

$$= \frac{Concentration\ in\ ppm \times 25}{molar\ mass\ of\ element\ A \times\ Sample\ weight}$$

Repeat samples are measured during each cation measurement to calculate the reproducibility of the results. The reproducibility is calculated as

$$Precession\ (\%) = \frac{(Concentration\ of\ repeat\ sample - Concentration\ of\ actual)}{Concentration\ of\ actual} \times 100$$

The reproducibility for all the cations is found to be within 5 percentage.

Element Name	Reproducibility (%)
Na	0.2
K	3
Mg	3
Ca	4

Table 1 Showing reproducibility for the cation concentration measurement.

MEASUREMENT OF TOTAL ORGANIC MATTER BY LOSS ON IGNITION

PRINCIPLE

Organic matter of the soil cannot be measured in any direct method due to its complex and varied chemical nature and close association with soil particles. The Loss on Ignition (LOI) method is commonly used method for indirect estimation of organic matter because organic matters burn at lower temperatures relative to other inorganic constituents of the soil. Here the simple assumption is all the mass loss is due to organic matters. So, the possibilities of sources of mass loss due to other factors are minimized before the measurement for organic matter.

METHODOLOGY

15g of soil sample is taken and dried at 60℃ overnight to ensure the moisture loss. Crucibles are thoroughly clean and dried to avoid any source of contamination. Then the dried soil sample is weighed and taken in the crucibles to the furnace. The crucibles are place sequentially in the furnace and the position of each crucible along with sample ID is noted in a notebook. Now the samples are heated at 350℃ for more than 2 hours. After more than 2 hours the furnace is turned off and allowed to cool. When the temperature fell below around 100℃ the sample weight is measured, and the organic matter lost is calculated.

CALCULATIONS

The total organic matter percentage is calculated as,

$$\frac{Weight\ of\ sample\ at\ 60C^{\circ} - Weight\ of\ sample\ after\ ignition\ at\ 350C^{\circ}}{Weight\ of\ sample\ at\ 60C^{\circ}} \times 100$$

3. RESULTS AND DISCUSSION

RESULTS

The total clay percentage values for the given soil samples varies from the least 4.68% in Coastal Sandy soil to the highest 27.90% in Lateritic soil. Similarly, for sand the variation is from minimum 4.78% in Alluvial soil to maximum 92.81% in Coastal sandy soil and for silt the minimum and maximum values are 2.51% for Coastal sandy soil and 73.05% for Alluvial Soil. The result shows that for Alluvial soil the clay and silt makeup more than 95% of the soil mass whereas opposite to this in Coastal sandy soil only sand fraction makeup more than 90% of the soil mass.

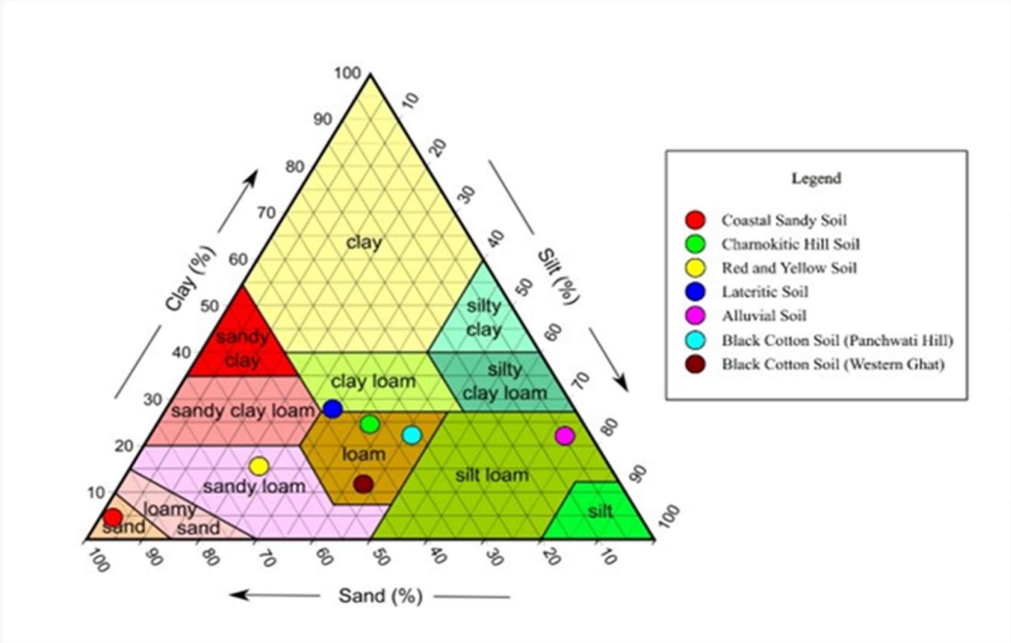


Figure 3.1Shows positions of different soil samples in Sand- Slit- Clay triangle.

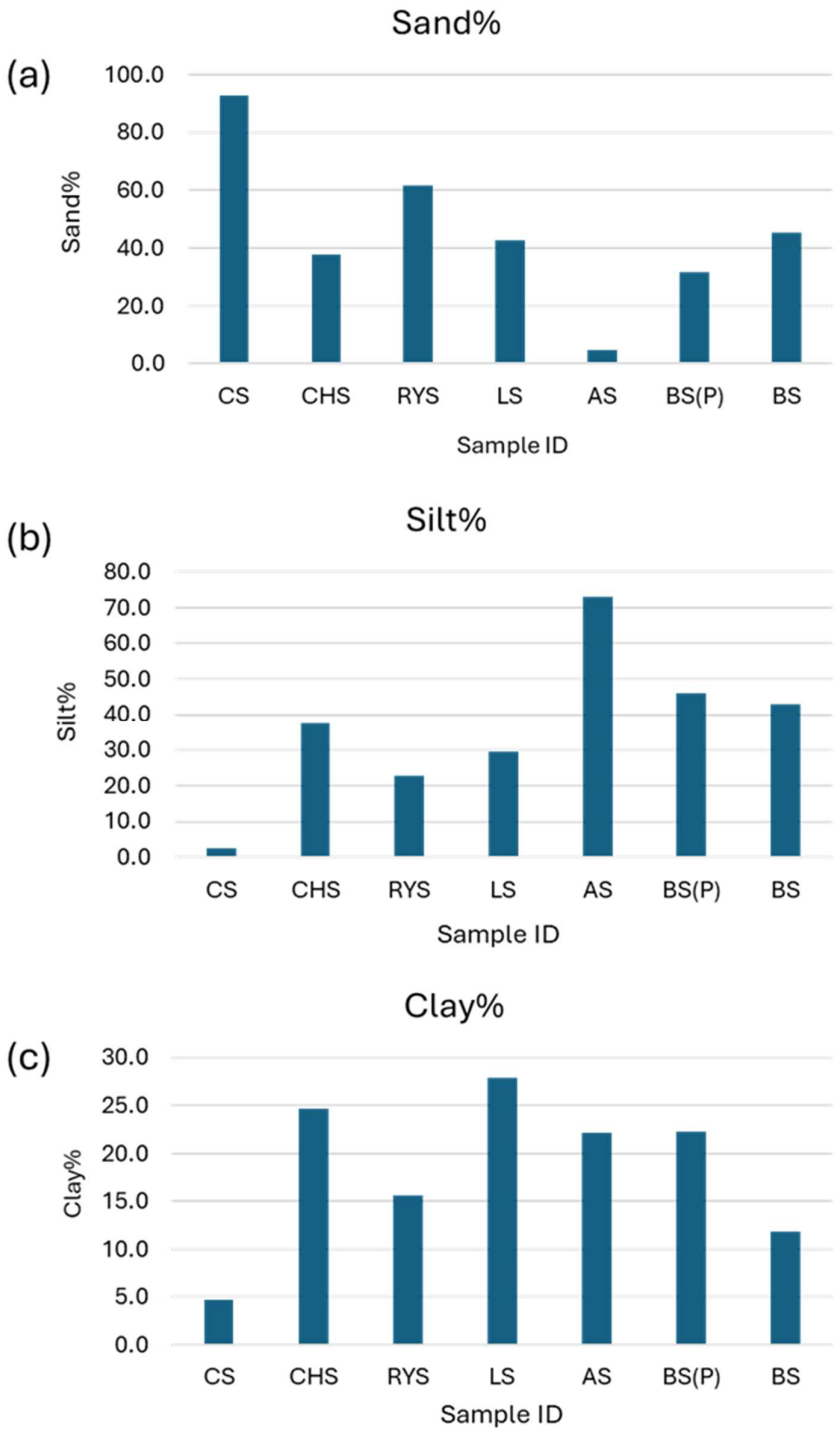


Figure 3.2 (a-c) shows Sand, Silt and Clay percentage.

The pH values of the soil samples vary from most acidic 4.2 for the Charnokitic Hill soil to most basic 7.9 for the Alluvial soil among the collected soil samples. The total organic matter percentage as represented by loss on ignition (LOI) value shows that Coastal sandy soil has the least organic matter content of only 1.4% and the Charnokitic Hill soil has the highest organic matter content of 12.3%. It can also be seen that along with Charnokitic Hill soil both the black cotton soil types have the similar organic matter content whereas Alluvial soil, Red & Yellow soil, and coastal sandy soil have less than 5% organic matter content. The exchangeable cation concentration shows that the coastal sandy soil has the lowest exchangeable cation concentration whereas the both the black soil samples have similar and highest among all other soil samples mentioned here. Here it should be noted that the cation concentration mentioned here is not the actual concentration of the given cation but the charge equivalent of it. i.e., for monovalent cation the charge concentration is same as the concentration of the given cation but for a divalent cation the charge concentration is twice as that of the given cation. This equivalent cation concentration is otherwise mentioned as Cation Exchange Capacity of the given cation (CEC_A). Where 'A' is the cation's symbol.

Sample ID	sand%	silt%	Clay%	LOI%	pH
Coastal Sandy Soil (CS)	92.81	2.51	4.68	1.4	4.45
Charnokitic Hill Soil (CHS)	37.74	37.57	24.68	12.3	4.28
Red and Yellow Soil (RYS)	61.68	22.67	15.65	2.3	4.62
Lateritic Soil (LS)	42.67	29.43	27.90	7.7	5.52
Alluvial Soil (AS)	4.78	73.05	22.17	4.5	7.87
Black Cotton Soil (Panchwati Hill, Pune) BS(P)	31.52	46.16	22.32	9.9	6.15
Black Cotton Soil (Western ghats) (BS)	45.29	42.86	11.85	10.0	6.67

Table 2 Table showing sand-silt-clay, loss on ignition (LOI/total organic matter) concentrations and pH of the given soil samples.

The measurement major exchangeable cation concentration of the collected soil samples shows that Calcium followed by Magnesium ions dominates the total exchangeable cation concentration with jointly accounting for more than 95% of the total exchangeable cations in the solution. The exchangeable Calcium and Mg concentrations varied from 1.1 and 0.39 centimoles per Kg for Coastal sandy soil to 28.4 and 6.45 centimoles per Kg for Black cotton soil collected from Western Ghats respectively. The exchangeable Na and K concentrations

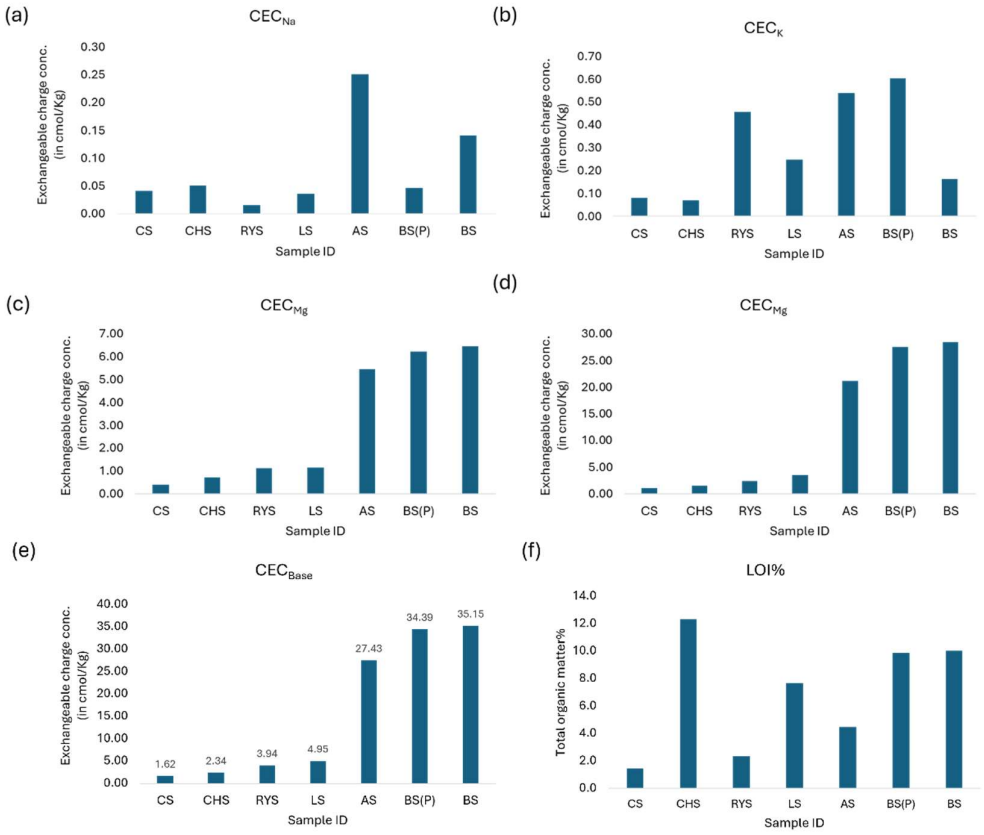
remained less than 1 centimoles per Kg of soil for all the soil samples and Sodium having lower concentrations than Potassium in all samples.

Sample ID	Ex. Na	Ex. K	Ex. Mg	Ex. Ca	Ex. Base
Coastal Sandy Soil (CS)	0.04	0.08	0.39	1.11	1.62
Charnokitic Hill Soil (CHS)	0.05	0.07	0.72	1.50	2.34
Red and Yellow Soil (RYS)	0.02	0.46	1.13	2.35	3.94
Lateritic Soil (LS)	0.04	0.25	1.14	3.52	4.95
Alluvial Soil (AS)	0.25	0.54	5.44	21.20	27.43
Black Cotton Soil Panchwati Hill, Pune (BS(P))	0.05	0.60	6.23	27.51	34.39
Black Cotton Soil (Western ghats) (BS)	0.14	0.16	6.45	28.40	35.15

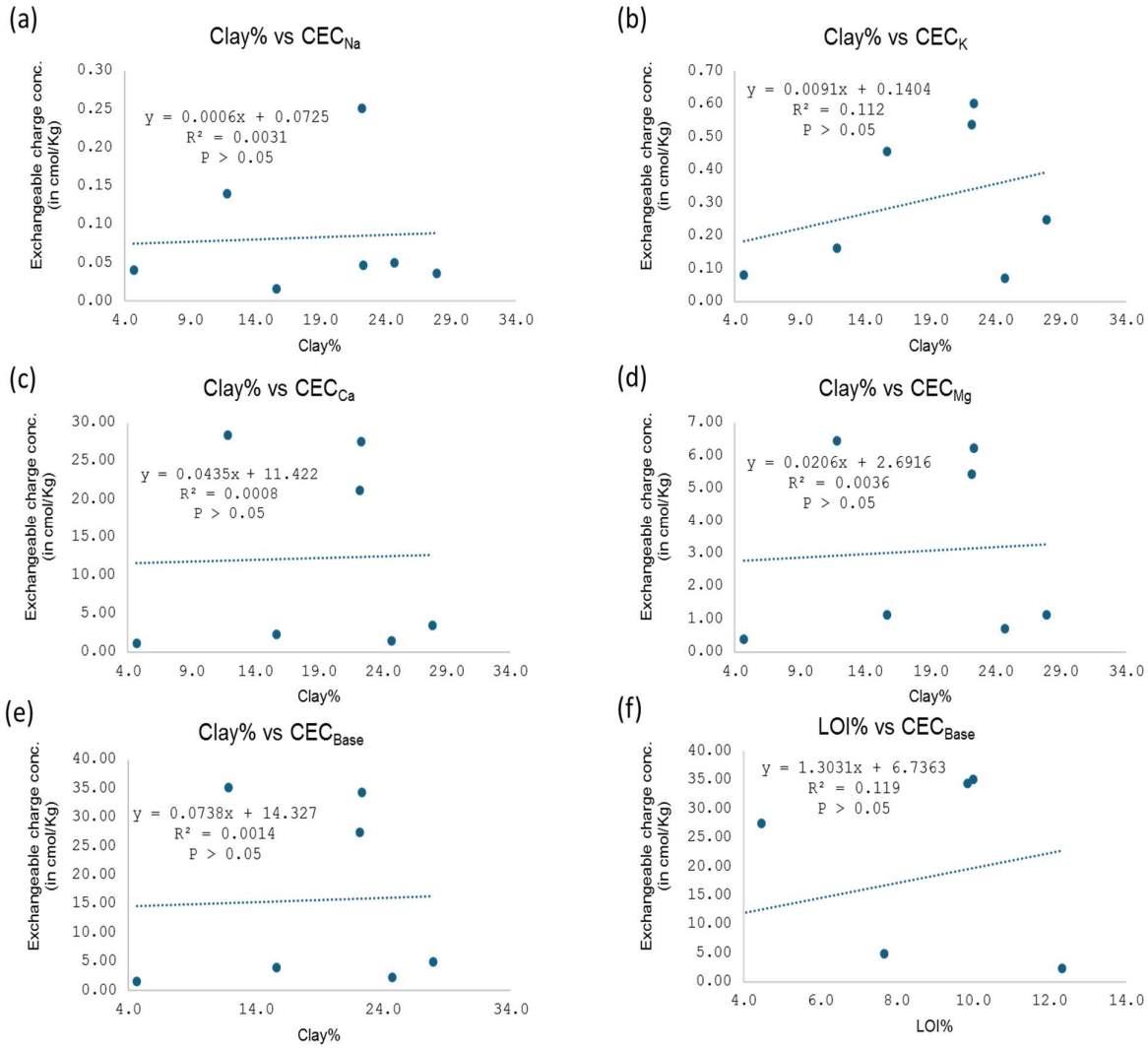
Table 3 Table showing exchangeable cation concentrations of Individual cations and sum of all the base cations of different soil types. (Ex. – Exchangeable, Base- Base Cations)

Sample Name	exchangeable cation concentration in cmolcKg-1				pH	LOI%	Clay%	Silt%	Sand%
	Na	K	Mg	Ca	Base Cations				
Coastal Sandy Soil (CS)	0.04	0.08	0.39	1.11	1.62	4.4	1.4	4.7	2.5	92.8
Charnokitic Hill Soil (CHS)	0.05	0.07	0.72	1.5	2.34	4.3	12.3	24.7	37.6	37.7
Red and Yellow Soil (RYS)	0.02	0.46	1.13	2.35	3.94	4.6	2.3	15.6	22.7	61.7
Lateritic Soil (LS)	0.04	0.25	1.14	3.52	4.95	5.5	7.7	27.9	29.4	42.7
Alluvial Soil (AS)	0.25	0.54	5.44	21.2	27.43	7.9	4.5	22.2	73.0	4.8
Black Cotton Soil (Panchwati Hill, Pune) (BS(P))	0.05	0.6	6.23	27.51	34.39	6.2	9.9	22.3	46.2	31.5
Black Cotton Soil (Western Ghats) (BS)	0.14	0.16	6.45	28.4	35.15	6.7	10	11.8	42.8	45.3

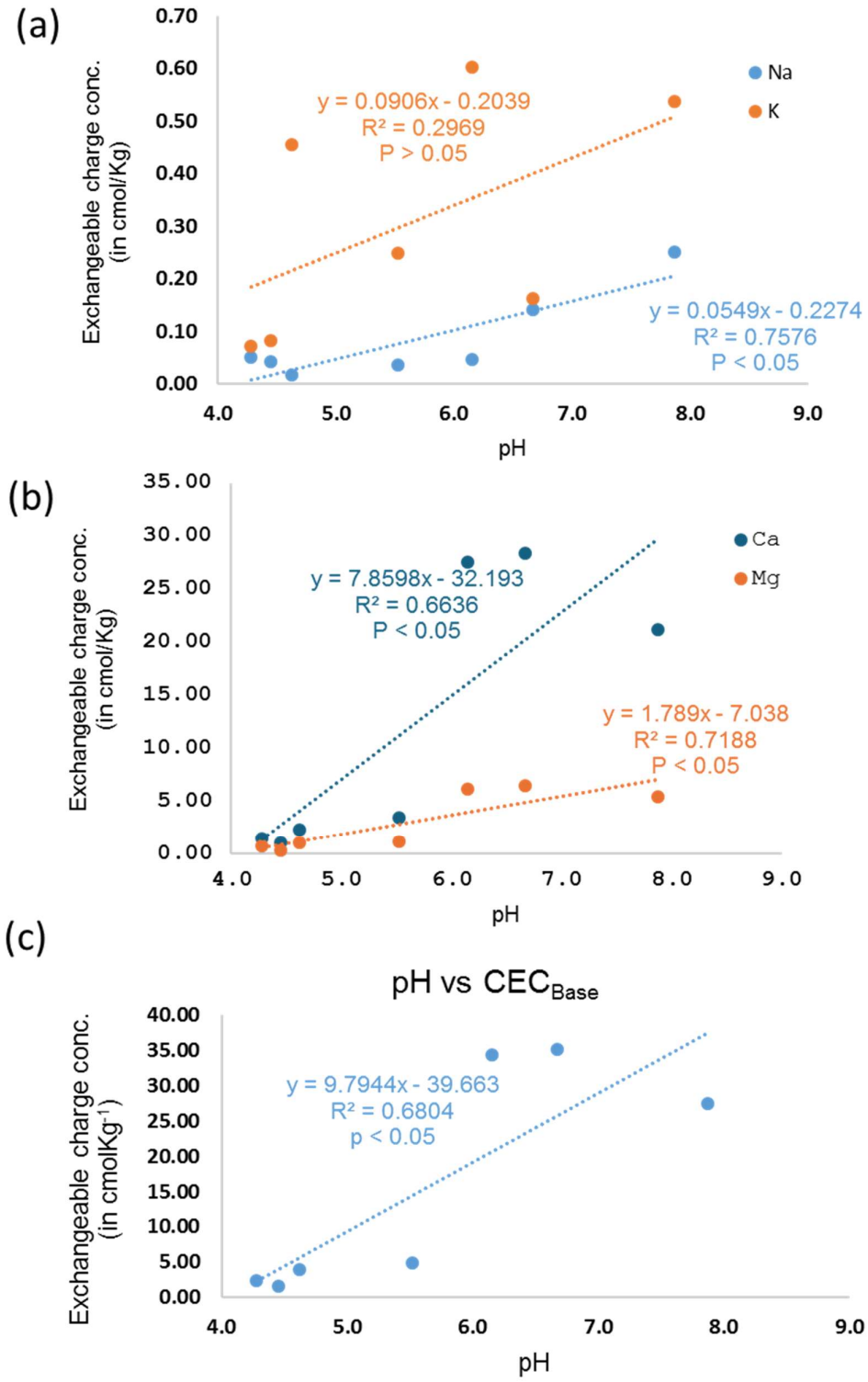
Table 4 Combined table showing various measured parameters of the soil samples.



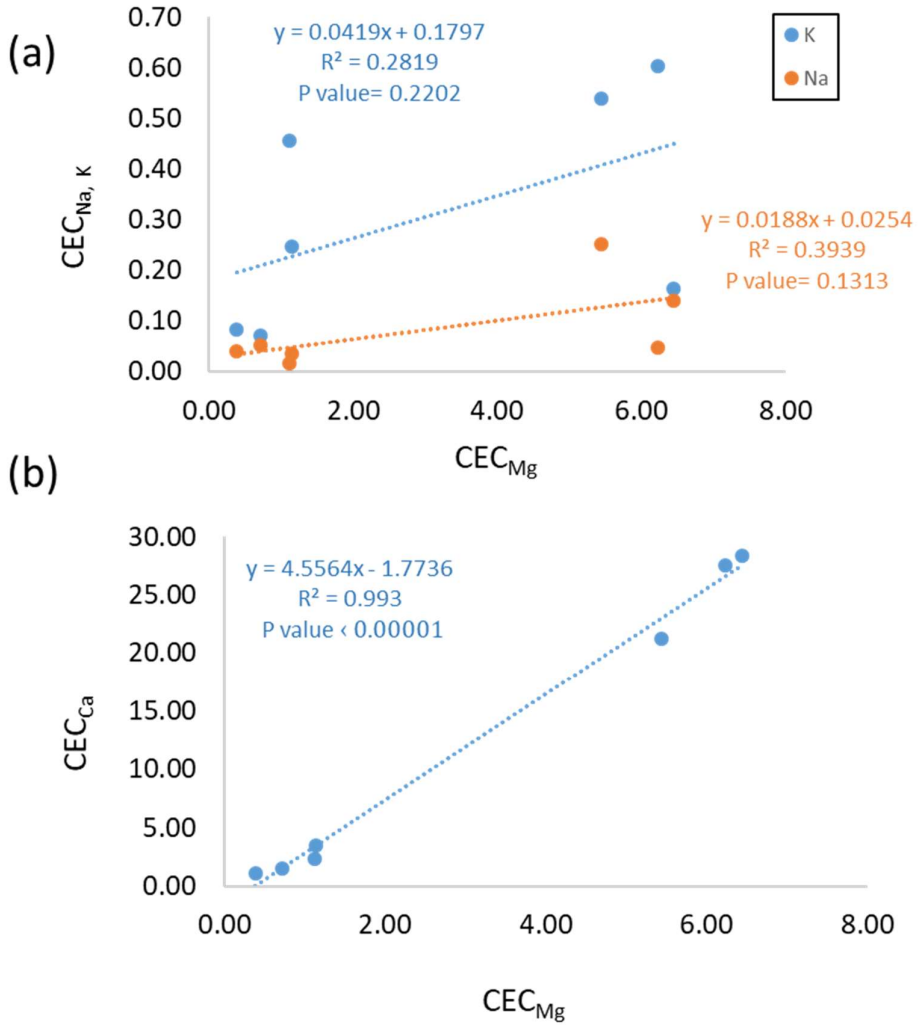
3.3 Figure (a-e) shows Cation Exchange Capacity of individual cations and the sum total of base cations for different soil types. (f) shows Loss on Ignition percentage of different soil types



3.4 Figure (a-e) Cation exchange Capacities of different cations and sum of all base cations is plotted against the Clay percentage, Figure (f) – Cation exchange Capacity of all base cations is plotted against the Total Organic Matter content represented as Loss On Ignition (LOI).



3.5 Figure (a-c) The exchangeable charge concentration/ Cation exchange capacity (CEC) of different cations and sum of all base cations plotted against pH



3.6 Figure (a, b) Cation exchange capacity (CEC) of different cation plotted against CEC of Mg,

DISCUSSION

The Sand- Silt- Clay percentage data of the soil types are plotted in the Sand- Silt- Clay textural triangle (Figure 3.1) and the textural nomenclature is assigned to the collected soil samples. From plot the Coastal Sandy Soil is classified as 'Sand', Charnokitic Hill Soil and Black Cotton Soils are classified as 'Loam', Red & Yellow Soil as 'Sandy Loam', Lateritic soil as 'Clay Loam' and the Alluvial soil is assigned to 'Silt loam' category.

According to the theory the cation exchange capacity increases with increase in clay and organic matter percentage of a soil as they possess high surface area and negative surface charge. But this fact should not be extrapolated to compare soils of different clay types as no strong correlation can be seen when cation exchange capacities of the individual cations, and total cation exchange capacity are plotted against clay percentage and total organic matter percentage 3.4 Figure). Whereas the cation exchange capacities of the individual cations, and total cation exchange capacity are plotted against the pH value, except for Potassium, the CEC value of all other cations along with the total CEC value showed a fair co-relation of increase in CEC with increase in pH value (3.5 Figure) as expected from theory i.e. the cation exchange capacity of a soil increases with increase in pH towards alkalinity. The cation exchange capacity also depends upon the type of clay a soil has because different clay types have different chemical composition as well as layer structure that greatly affect their capacities to accommodate or exchange other cations. Hence the cation exchange capacity of a soil is not only a function of the amount of clay it has but also depends on its clay type.

Clay Type	Cation Exchange Capacity (cmol/kg)
Kaolinite	1 to 10
Halloysite	5 to 50
Illite	20 to 40
Chlorite	20 to 40
Allophane	25 to 50
Montmorillonite	80 to 120
Vermiculite	120 to 150
Smectite	70 to 130

Table 5 Shows the Cation Exchange Capacity (CEC) of different clay types. Credit- (Al-Ani, 2008)), (Grim, 1968) and (Odom, 1984)

The lowest CEC value of the Coastal Sandy Soil can be attributed to its low pH, lowest clay content, and low organic matter content. So, the lowest CEC of the Coastal Sandy Soil holds good with theoretical expectations. In case of the Charnockitic hill soil the sample has 25% clay and 12% organic matter concentration which is comparable to the respective values of samples having very high CEC values (Table 4), but still the sample has a very low cation exchange capacity compared to similar counterpart. The very low CEC value for Charnockitic hill soil may be explained by two factors, first it has the lowest pH among all the measured soil samples and second its clay composition is dominated by Kaolinite clay type (Senthil Nathan, 2016), which has very low cation exchange capacity as compared to other clay types. The CEC values for the kaolinite clay varies from 1 to 10 centimoles per Kg (Al-Ani, 2008). Similarly, the low CEC values for the lateritic and Red & Yellow soil samples are explained based on the major constituent clay type. These two soil types are reported to have Kaolinite and Illite as the dominant clay type (Sahu et al., 1983). Where the CEC value for Illite clay type varies from 20to 40 centimoles per Kg (Al-Ani, 2008).

Coming to the samples with high CEC values, the Black Cotton Soil has the more cation exchange capacity values that the Alluvial soil though it has higher pH and clay percentage than Black cotton soil. This behaviour can also be explained based on the constituent clay type. Where the major clay constituents for the Alluvial soil are Illite, Kaolinite and Smectite (Singh, 1998) but the Black Cotton clay type is dominated by Smectite and Vermiculite those have higher CEC capacities compared to other Clay types (Pacharne, 1996).

4. Conclusion

The cation exchange capacity of a soil may seem simple chemical parameter, but the complexity of the value and dependency on various physical and chemical parameters makes it a useful tool for defining and predicting a wide range of soil activities and applications. Combined with clay type, pH, Organic matter content, clay percentage it can be said that undoubtedly percentage of Organic matter content and clay play a vital role in deciding the CEC of a particular soil type but when two different soil types are involved, equal attention should be given to the clay type as well because the total cation exchange capacity of a soil is a combined effect of its clay percentage, clay type, pH, and organic matter percentage.

5. REFERENCES

"A Computer Program for Soil Textural Classification - Gerakis - 1999 - Soil Science Society of America Journal - Wiley Online Library." Accessed April 5, 2024. https://acsess.onlinelibrary.wiley.com/doi/full/10.2136/sssaj1999.634807x.

Al Ani, Thair, and Olli Sarapää. "Clay and Clay Mineralogy." *Geological Survey of Finland, Report M19/3232/2008/41, Espoo*, January 1, 2008.

Aundhakar, A. V., P. H. Vaidya, A. J. Ingole, N. M. Patil, and M. K. Ghode. "Characterization, Classification and Evaluation of Soils in Cotton Growing Region of Beed District, Maharashtra." *Journal of Pharmacognosy and Phytochemistry* 7, no. 5 (2018): 1977–81.

Balasubramanian, A. "Soils of India." *Tech. Rep.*, 2017, 1–43.

Bhattacharyya, T., D. K. Pal, C. Mandal, P. Chandran, S. K. Ray, Dipak Sarkar, K. Velmourougane, A. Srivastava, G. S. Sidhu, and R. S. Singh. "Soils of India: Historical Perspective, Classification and Recent Advances." *Current Science*, 2013, 1308–23.

Borkar, V. S., N. B. Gokhale, R. V. Dhopavkar, N. H. Khobragade, S. S. More, and M. C. Kasture. "Distribution of Nutrients in Different Soil Types in Konkan Region of Maharashtra." *Int. J. Chem. Stud* 6, no. 1 (2018): 275–79.

Carter, M. R., and E. G. Gregorich, eds. *Soil Sampling and Methods of Analysis*. 2nd ed. Boca Raton: CRC Press, 2007. https://doi.org/10.1201/9781420005271.

Carter, Martin R., and Edward Gerard Gregorich. *Soil Sampling and Methods of Analysis*. CRC press, 2007. https://www.taylorfrancis.com/books/mono/10.1201/9781420005271/soil-sampling-methods-analysis-gregorich-carter.

Chapman, H.D. "Cation-Exchange Capacity." In *Agronomy Monographs*, edited by A. G. Norman, 891–901. Madison, WI, USA: American Society of Agronomy, Soil Science Society of America, 2016. https://doi.org/10.2134/agronmonogr9.2.c6.

Christensen, Bent Tolstrup, and Per Åkesson Malmros. "Loss-on-ignition and Carbon Content in a Beech Forest Soil Profile." *Ecography* 5, no. 4 (October 1982): 376–80. https://doi.org/10.1111/j.1600-0587.1982.tb01051.x.

Day, Paul R. “Particle Fractionation and Particle-Size Analysis.” In *Agronomy Monographs*, edited by C. A. Black, 545–67. Madison, WI, USA: American Society of Agronomy, Soil Science Society of America, 2015. https://doi.org/10.2134/agronmonogr9.1.c43.

Dontsova, Katerina, and L Darrell Norton. “Effects of Exchangeable Ca:Mg Ratio on Soil Clay Flocculation, Infiltration and Erosion,” n.d.

Gautam, Mahendru Kumar, Amlan Kumar Ghosh, Kishan Lal, and Ajay Kumar Gautam. “Characterization and Study of Dominated Alluvial Soil Profile of Mirzapur in Indo-Gangetic Plain (IGPs) of India.” *International Journal of Plant & Soil Science* 35, no. 9 (2023): 160–77.

Ghode, M. K., P. H. Vaidya, A. S. Dhawan, and S. A. Adkine. “Characterization, Classification and Evaluation of Cotton Growing Soils of Nanded District, Maharashtra.” *Journal of Pharmacognosy and Phytochemistry* 7, no. 1S (2018): 1221–25.

Grim, Ralph Early, and Necip Guven. *Bentonites: Geology, Mineralogy, Properties and Uses*. Elsevier, 2011. https://books.google.com/books?hl=en&lr=&id=xeiv1p6HKF0C&oi=fnd&pg=PP1&dq=grim+1968+clay+mineralogy&ots=Nk5sS6Yh80&sig=BO3sz4NmOBEaEIF8aQGrDJm5Gx4.

Hasmot Saikh, Hasmot Saikh, Chandrika Varadachari Chandrika Varadachari, and Kunal Ghosh Kunal Ghosh. “Effects of Deforestation and Cultivation on Soil CEC and Contents of Exchangeable Bases: A Case Study in Simlipal National Park, India.,” 1998. https://www.cabidigitallibrary.org/doi/full/10.5555/19991903197.

Kabała, Cezary, and Beata Łabaz. “Relationships between Soil pH and Base Saturation – Conclusions for Polish and International Soil Classifications. | Soil Science Annual | EBSCOhost,” December 1, 2018. https://doi.org/10.2478/ssa-2018-0021.

Kabrick, John M., Keith W. Goyne, Zhaofei Fan, and Dennis Meinert. “Landscape Determinants of Exchangeable Calcium and Magnesium in Ozark Highland Forest Soils.” *Soil Science Society of America Journal* 75, no. 1 (2011): 164–80. https://doi.org/10.2136/sssaj2009.0382.

“Landscape Determinants of Exchangeable Calcium and Magnesium in Ozark Highland Forest Soils - Kabrick - 2011 - Soil Science Society of America Journal - Wiley Online Library.” Accessed April 2, 2024. https://acsess.onlinelibrary.wiley.com/doi/full/10.2136/sssaj2009.0382.

Ma, C. H. I., and Richard A. Eggleton. “Cation Exchange Capacity of Kaolinite.” *Clays and Clay Minerals* 47, no. 2 (1999): 174–80.

Nathan, Senthil, and Bijilal Bs. "Geochemistry and Clay Mineralogy of Weathering and Soil Profiles, Malappuram District, Northern Kerala, India: Its Implications on Paleoclimate," March 1, 2016, 1–13.

"NATMO Geoportal." Accessed April 5, 2024. https://geoportal.natmo.gov.in/map.php?id=3.

Nelson, Darreil W. "Determination of Ammonium in KCl Extracts of Soils by the Salicylate Method." *Communications in Soil Science and Plant Analysis* 14, no. 11 (August 1983): 1051–62. https://doi.org/10.1080/00103628309367431.

Pacharne, T K, D K Pal, and S B Deshpande. "Genesis and Transformation of Clay Minerals in the Formation of Ferruginous Inceptisols and Vertisols in the Saptadhara Watershed of Nagpur District, Maharashtra." *JOURNAL OF THE INDIAN SOCIETY OF SOIL SCIENCE*, n.d.

Ramasamy, Srinivasan, Lalitha Manickam, Shelton Padua, Tejashvini Ashwathappa, Jagdish Prasad, and Surendra Kumar Singh. "Effect of Landforms and Vegetations on Pedological Variability and Crop Yield along the Toposequence of Eastern Coastal Plain of Odisha, India." *Journal of Coastal Conservation* 28, no. 1 (January 6, 2024): 21. https://doi.org/10.1007/s11852-023-01018-x.

Ray, S. K., T. Bhattacharyya, K. R. Reddy, D. K. Pal, P. Chandran, P. Tiwary, D. K. Mandal, C. Mandal, J. Prasad, and D. Sarkar. "Soil and Land Quality Indicators of the Indo-Gangetic Plains of India." *Current Science*, 2014, 1470–86.

Ross, Donald S., and Quirine Ketterings. "Recommended Methods for Determining Soil Cation Exchange Capacity." *Recommended Soil Testing Procedures for the Northeastern United States* 493, no. 101 (1995): 62.

Sahu, G. C., N. Panda, and S. S. K. Nanda. "Genesis and Mineralogy of Some Red and Laterite Soils of Orissa." *Journal of the Indian Society of Soil Science* 31, no. 2 (1983): 254–62.

Shukla, Sanjay Kumar, ed. *Geotechnical Characteristics of Soils and Rocks of India*. London: CRC Press, 2021. https://doi.org/10.1201/9781003177159.

Sidhu, P. S., and R. J. Gilkes. "Mineralogy of Soils Developed on Alluvium in the Indo-Gangetic Plain (India)." *Soil Science Society of America Journal* 41, no. 6 (November 1977): 1194–1201. https://doi.org/10.2136/sssaj1977.03615995004100060037x.

Singh, Lalan P., B. Parkash, and A. K. Singhvi. "Evolution of the Lower Gangetic Plain Landforms and Soils in West Bengal, India." *Catena* 33, no. 2 (1998): 75–104.

"Smectite Clay Minerals: Properties and Uses." *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* 311, no. 1517 (June 14, 1984): 391–409. https://doi.org/10.1098/rsta.1984.0036.

Sulieman, Magboul, Ibrahim Saeed, Abdalhaleem Hassaballa, and Jesús Rodrigo-Comino. "Modeling Cation Exchange Capacity in Multi Geochronological-Derived Alluvium Soils: An Approach Based on Soil Depth Intervals." *Catena* 167 (2018): 327–39.

Suman, S. N., Nayan Ahmed, S. C. Datta, K. M. Manjaiah, R. Laik, V. Kumar, T. K. Das, and Rajesh Kumar. "Assessing Cation Exchange Capacity (CEC) in Old Alluvium Soils (Agro-Climatic Zone IIIB of Bihar) under Different Tillage and Management Practices." *Journal of Pharmacognosy and Phytochemistry* 8, no. 5S (2019): 196–99.

Tabatabai, M. A. "Soil Organic Matter Testing: An Overview." In *SSSA Special Publications*, edited by F. R. Magdoff, M. A. Tabatabai, and E. A. Hanlon, 1–9. Madison, WI, USA: Soil Science Society of America, 2015. https://doi.org/10.2136/sssaspecpub46.c1.

Walke, N., GP Obi Reddy, A. K. Maji, and S. Thayalan. "GIS-Based Multicriteria Overlay Analysis in Soil-Suitability Evaluation for Cotton (Gossypium Spp.): A Case Study in the Black Soil Region of Central India." *Computers & Geosciences* 41 (2012): 108–18.