SOIL REGIME

'It takes half a millennia to build two centimetres of living soil and only seconds to destroy it'

-Anne Glover

Soil is a natural resource of fundamental importance as societies' major necessities are fulfilled by the plant and animal communities that depend on it. Soil is a heterogeneous medium having interactions among physical, chemical and biological systems. It is considered as important productive economic factor in sectors like agriculture, forestry, mining and construction as soil type plays a substantial role in land capability studies as a part of land-use planning and resource utilization.

REGIONAL SOIL RESOURCES

For any region, the soil characteristics at a given point of time are a function of both natural influences and human activities. Gujarat is bestowed with a wide range of geological, geomorphic and floral diversities coupled with macro and microclimatic variations that influence the genesis of soil (Kalyanisundaram & Patel, 1995). The soils of Gujarat have been classified into nine groups (Fig 5.1) viz. Coarse soils, Coastal Alluvium soils, Deep Black soils, Desert soils, Goradu sandy loamy soils, Medium Black soils, Mud, River Bank Sandy soils and Sandy soils (Narmada Water Resources &Water Supply, 2010).

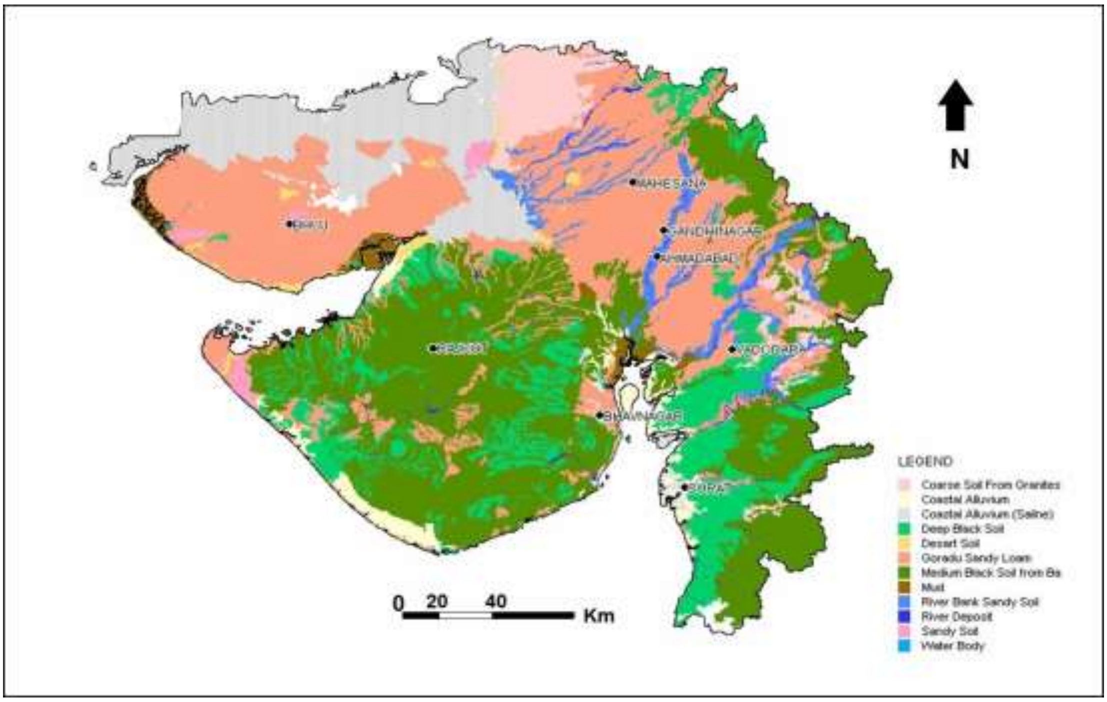

Figure 5. 1 Soil Map of Gujarat (After, NWRWS, Govt. of Gujarat, 2010)

Soil Sampling:

Soil sampling in any study solely depends on its basic objectives. The candidate's endeavour to study the physical and chemical characteristics of various soils with a view to assess the impact of anthropogenic interventions impending land-use and agronomic practices in the study area and to prepare a soil map of the Kim River Basin. For soil sampling, the candidate has divided the study area into 10 x 10 km grids and one random stratified sample was collected from each grid.

Plate 5. 1a Field Photo Depicting process of Augering for Soil Sampling

Plate 5. 1b Collection of Soil Sample and Preservation

In order to assess the seasonal changes in physico-chemical characteristics in soils; sampling was carried out for both pre and post-monsoon seasons. In all 30 samples were collected during the course of investigation. To collect a representative sample from shallow surface hand auger has been used. (Plate 5.1a & b). The samples were then collected in zip-lock bags for textural and physico-chemical analysis. For soil sample collection, the following criteria and precautions were adopted (USDA, 1978)

i. The site should be away from permanent structures like roads, building, railways, etc.
ii. The collected sample should be representative of the field conditions.
iii. Soil bands containing fertilizers should be discarded to avoid contamination in results.
iv. Sampling should be from in-situ soil environment.
v. Sampling location shall remain same for all the seasons.
vi. The depth of soil sample should be maintained (*In present case 30cm from surface*).
vii. The soil samples were preserved individually in neatly labelled transparent moisture retaining bags.

BASIC CHARACTERISTICS OF SOIL

Soil Properties:

Study and evaluation of physical and bio-chemical properties of a soil plays a significant role in deciding its suitability for irrigation and land use planning as well as facilitate the investigator in assessing the impact of anthropogenic activities. For this purpose, the author has carried out a comprehensive study of the soils of the Kim River watershed which using standard laboratory procedures (Table 5.1).

Sr. No.	Parameter		Adopted Analytical Techniques
1.	Texture	-	Sieve Analysis
2.	Colour	-	Visual Identification
3.	pH	-	pH meter
4.	Electrical Conductivity	-	EC meter
5.	Organic Carbon	-	Walkley and Black Method
6.	Calcium	-	EDTA Complexometric Titration
7.	Magnesium	-	EDTA Complexometric Titration
8.	Potassium	-	Flame Photometer
9.	Sodium	-	Flame Photometer
10.	Carbonates & Bicarbonates	-	Sulphuric Acid Titration
11.	Chlorides	-	Argentometric Titration
12.	Nitrogen	-	Kjeldah's Alkaline Permanganate Method
13.	Phosphates	-	Bray & Kurtz's Method using ammonium acetate

Table 5.1 Index of Standard Methods Adopted for Soil Analysis

Soil Texture:

Study of soil texture plays a significant role in understanding gradation parameters that are governing its basic hydraulic characteristics (porosity & permeability), moisture retention capacity and cation exchange capacity. Soil texture is determined by quantifying the relative proportion of sand, silt and clay in a particular soil. Texturally soil may be classified as coarse-medium-fine textured soils (Miller & Donahue, 1997). Coarse textured soils are very permeable and allow rapid movement of air and water between the soil particles, but they do not hold and store water or plant nutrients very well and hence are infertile. The fine clayey soils, on the other hand, hold most of the plant nutrients, but are not permeable to air and water. When plant roots are unable to grow well, the crop yield accordingly reduces (Richards, 1968). Medium textured soils are more desirable as they allow the movement of air and water readily as well as are capable to hold plant nutrients and moisture, leading to good fertile conditions (Rowell, 1994). Standard soil types based on their relevant textural characteristics and other salient features are represented in Figure 5.2

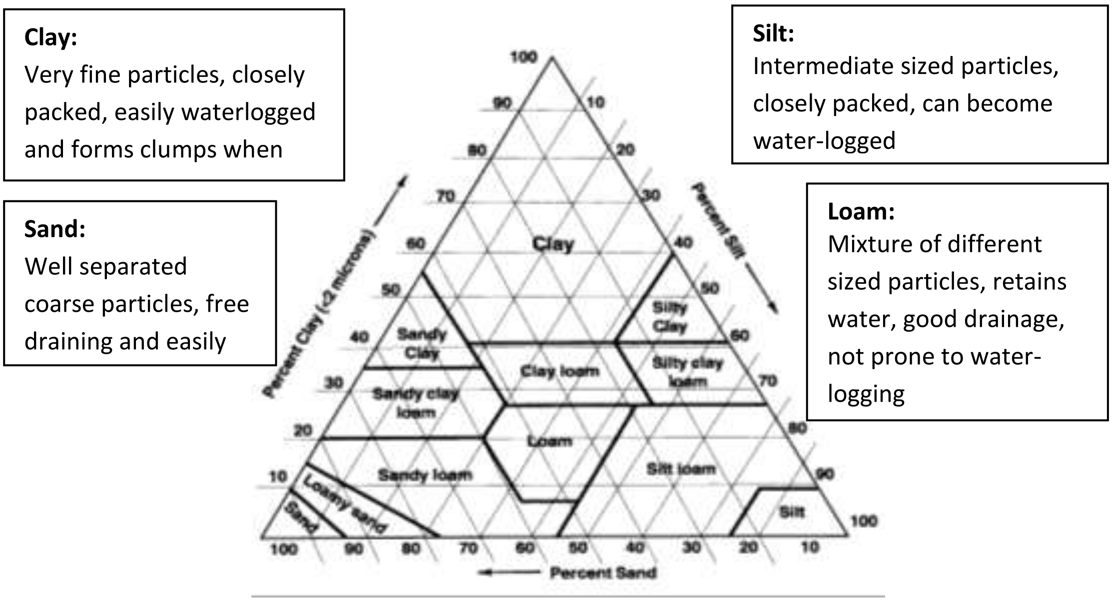

Figure 5. 2 Textural Classification of Soils (USDA, 1970)

In order to understand basic soil characteristics of different soil types available in the study area; the candidate has carried out the mechanical analysis using standard ASTM sieves and sieve shaker. For this, a bulk sample weighing 100gm was placed in the top sieve and shaked for 10 minutes. Then the retained size fractions in lower sieves were collected separately and weighted using digital balance. Based on the calculated percentage of passing of relevant size fractions, a grain size distribution curve was plotted using standard granulometric graph (Fig 5.3 A & B). Later curve patterns have been interpreted in terms of particulates gradation & sorting and for other textural parameters, viz. Coefficient of Uniformity (Uc) and Effective Diameter (Pettijohn, 1984).

Uniformity Coefficient (C_U): This gives the slope of the major portion of the grain size distribution curve and is defined as-

$$C_U = \frac{D_{60}\ \text{(40\% Retained)}}{D_{10}\ \text{(90\% Retained)}}$$

A Value $C_U < 4$ indicates poorly graded soils and $C_U > 4$ indicates well graded materials

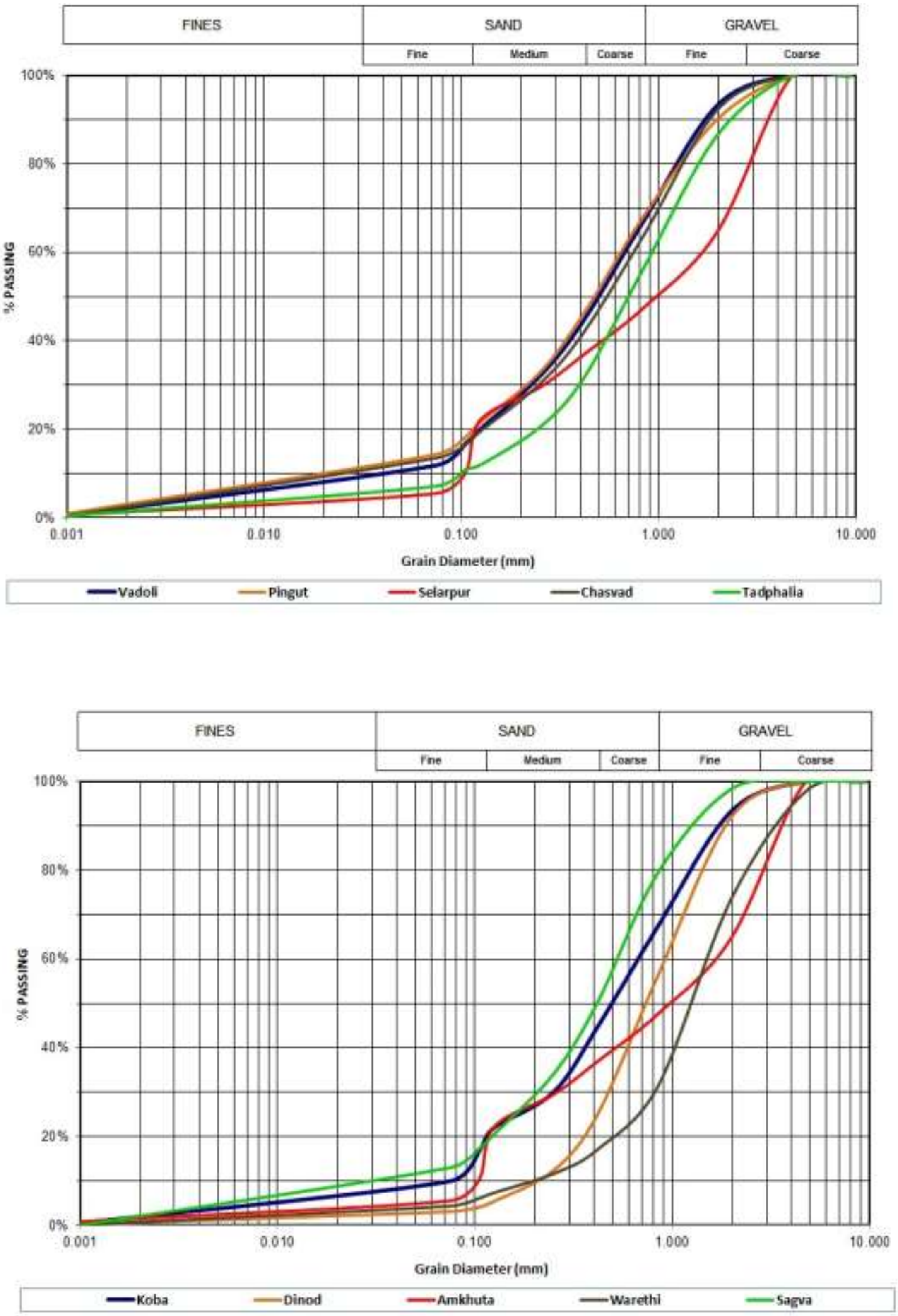

Figure 5.3 A & B Particle Size Distribution Curves for Different Soil Types in the Study Area

Coefficient of Gradation (C_c): This property of grain size distribution curve points to the available gaps in particle size. Therefore, it represents sorting of a particular grain size. This is also said to be coefficient of curvature and is defined as-

$$C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})}$$

Soil samples showing C_c <4 are said to be well-sorted, thereby representing predominance of a particular size fraction. The value of C_c >1 (Taylor,1948)

Soil Type	Sample Locality	D_{10}	D_{30}	D_{60}	Coefficient of Uniformity (C_U)	Co-efficient of Gradation (C_c)
Coastal Alluvial	Koba	0.07	0.25	0.68	9.7	1.3
	Vadoli	0.04	0.24	0.67	16.8	2.1
Black Cotton	Warethi	0.20	0.81	1.6	8.0	2.1
	Chasvad	0.26	0.25	0.75	2.9	0.3
Laterite	Amkhuta	0.11	0.27	1.8	16.4	0.4
	Selarpur	0.11	0.28	1.7	15.5	0.4
Brown	Dinod	0.20	0.48	0.93	4.7	1.2
	Pingut	0.20	0.22	0.63	3.2	0.4
Mixed	Tadphalia	0.10	0.39	0.9	9.0	1.7
	Sagva	0.03	0.21	0.52	17.3	2.8

Table 5.2 Particle Size Distribution of Different Soils of the Kim River Basin

The derived Coefficient of Uniformity (C_U) and Coefficient of Gradation (C_C) suggests that except samples collected from Pingut and Chasvad (Table 5.2), rest all samples fall within well graded soils. For well graded soils, the value of Co-efficient of Gradation (C_C) should be in the range of 1 and 3. The Laterites in the study area, have low C_C = 0.4(Table 5.2), which implies that they are gap-graded soils, having patchy occurrence along the slopes. Soils in and around Pingut show poor gradation as they have C_C = 0.4 and C_U < 4. Rest all samples are well graded soils having diversity in their particle sizes.

SOILS OF THE KIM WATERSHED

Proper identification and classification of soils in accordance with the obtained physico-chemical characteristics is necessary for developing and adopting appropriate strategies for their sustainable use and management. The soils in the study area exhibit wide variation with respect to their textural, physical and chemical behavioural aspects. It has been observed that the development of soils in the Kim River Basin is noticeably influenced by parameters like parental rock mass, weathering, climate, slope, altitude and vegetation. Overall distribution pattern of various soil types identified in the Kim River Basin is given in Figure 5.4. A brief account on the basic soil characteristics (Table 5.3) of the study area soils is enumerated as under-

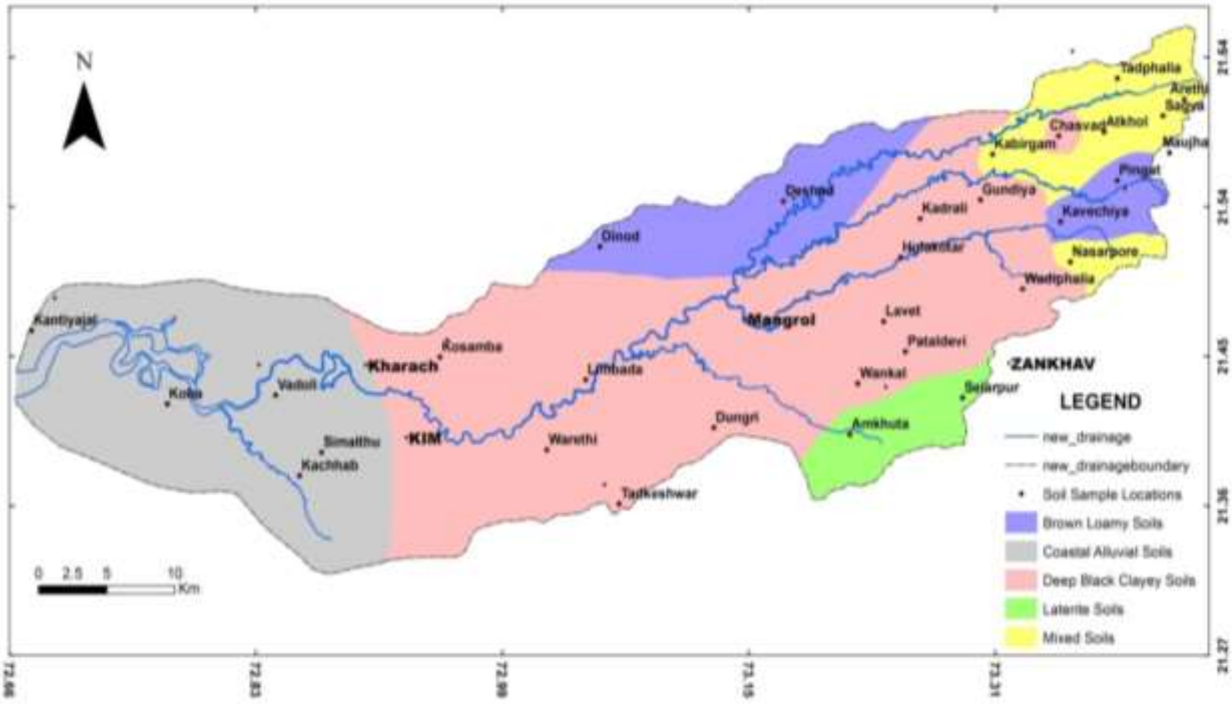

Figure 5. 4 Soil Map of Kim River Watershed

Sr. No.	Soil Type	Texture	Area Covered (km^2)	% of Total Area
1	Black Cotton	Clayey	662	49.8
2	Coastal Alluvium	Clayey loam	365	27.5
3	Mixed soil	Silty loam & Sandy Loam	110	8.3
4	Laterite	Sandy loam	49	3.7
5	Brown	Loamy	141	10.6

Table 5. 3 Textural Characteristics of Identified Soils in the Kim River Basin

The textural characteristics of soil reflect the relative abundance of particulate size. Clayey soil is fine soil, cohesive in nature and possesses high porosity and low permeability. Therefore, clayey soils are poorly drained but typified by high fertility. Contrary to this, the sandy soils are granular in nature having high porosity and Permeability. Such soils are well drained and typified by low fertility.

Therefore, aspect of textural study of soils has greatly facilitated the candidate in understanding the geohydrologic characters of the soils as well as soil's impact on land use pattern of the basin area.

CHEMICAL CHARACTERISTICS OF THE SOILS

COASTAL ALLUVIAL SOIL:

The coastal alluvial soils are normally associated with the river mouth areas or developed along the flood plains that presently fall within the limits of the inter-tidal zone. Therefore, the occurrence and distribution of these soils is restricted to the estuarine region of the river. It covers about 365 km^2 area and is greyish in colour, characterized by clayey texture. Being clayey and cohesive in nature, the soil is characterized by poor drainage. Although soil displays a very poor soil profile, it is fertile in nature for variety of crops (Plate 5.2). The candidate has determined important physico-chemical parameters of the study area soils (Table 5.4) using standard procedures.

Plate 5. 2 A Field View of Poorly Drained Coastal Alluvial Soil (Loc. Vadoli village)

Parameters	Sample Locality		
	Simalthu	Vadoli	Koba
	$21^0$23 N 72^0 52 E	$21^0$25 N 72^0 50 E	$21^0$25 N 72^0 46 E
pH	8.27	7.23	8.3
EC (dS/m)	0.6	11	1.8
Organic Carbon (%)	0.83	0.75	0.86
Calcium(mg/l)	410	235	360
Magnesium(mg/l)	95	318	235
Potassium(mg/l)	134	211	258
Sodium (mg/l)	340	930	528
Bicarbonates (mg/l)	71	122	99
Carbonates (mg/l)	Absent		
Chlorides(mg/l)	410	1015	590
Nitrogen(kg/hec)	250	445	550

Table 5. 4 Physico-chemical Parameters of Coastal Alluvial Soils

The coastal soils fall within the category of neutral to alkaline soils with a pH range of 7.2-8.3 (Table 5.4). The pH values ≥ 8 suggest the accumulation of non-exchangeable ions in these soils that may be attributed to salinity and water logging conditions (Richards, 1954). The EC is ranging from 0.5 to 11.0 dS/m. Only 15% of the collected soil samples fall within in the non-saline category. Majority of soil samples (85%) show EC > 1.4 and thus belong to categories of moderately saline to strongly saline conditions, whereas remaining

(15%) are non-saline in nature (Table 5.9). This observed deterioration in soil quality is attributed to synergistic effect of soil texture, water logging conditions, poor drainage, over irrigation and downstream salt accumulation (Dhanke & Whitney, 1988). In terms of ionic concentrations, the collected soil samples show great variation (Table 5.4). Cations like calcium, magnesium, sodium and potassium show higher enrichment which may be attributed to the accumulation of flushed ions from the upstream region and the prevailing water logging conditions leading to sodicity in the soils (Table 5.4). Similarly, observed higher concentration of chloride (400 to 1100 mg/l) may be ascribed to salt water intrusion in the coastal aquifers and use of saline water for irrigation.

BLACK COTTON SOIL (VERTISOL):

This is the most common soil type occurring in the study area. The black soils (Regur soil) are formed under the residual weathering process of basaltic rocks (the Deccan Trap) that occupies the eastern and central parts of the basin (Fig. 5.4). Leaching of minerals like amphiboles, pyroxenes and olivine families form iron and magnesium oxides which are responsible in imparting grey and black colour to the soil (Hem, 1959). These soils are predominantly fine textured clayey in nature and characterized by high porosity and low permeability. Due to compositionally montmorillonite rich, this soil exhibit phenomenal expansive behaviour under saturation (manning, 1987). On desiccation and shrinking, this soil develops deep wide polygonal cracks, particularly summer season (Hans, 1980). Soil being clayey and porous alternate shrinking and swelling due to fluctuating moisture content causes self-mulching. Therefore, the black soils have characteristic deep ‘A’ and ‘B’ horizon (Hans, 1994).They are considered to be matured soils having good fertility and moisture retention capacity, therefore, best suited for cultivation of cotton in areas characterized with low rainfall. Crops like sugarcane, rice, wheat and fruits are also favourable to grow on such soils. This clayey black soil covers about 662km^2 area widely distributed in the central parts of the Kim Basin (Plate 5.3).

Plate 5. 3 A Field View of Black Clayey Soil (Loc. Kadrali, Tal. Mangrol)

Parameters	Sample Locality				
	Kosamba	Dungri	Lavet	Chasvad	Warethi
	$21^0 27$ N 72^0 56 E	$21^0 24$ N 73^0 07 E	$21^0 28$ N 73^0 14 E	$21^0 35$ N 72^0 21 E	$21^0 23$ N 73^0 01 E
pH	7.4	7.2	6.7	7.4	8.1
EC (dS/m)	0.5	0.84	0.52	0.7	0.51
Organic Carbon (%)	0.4	0.75	0.68	0.82	0.6
Calcium(mg/l)	310	526	261	326	538
Magnesium(mg/l)	135	98	121	265	106
Potassium(mg/l)	103	140	87	145	210
Sodium (mg/l)	302	345	124	98	186
Bicarbonates (mg/l)	61	50	54	73	69
Carbonates (mg/l)	Absent				
Chlorides(mg/l)	340	550	190	342	130
Nitrogen(kg/hec)	210	326	362	453	304

Table 5. 5 Physico-chemical Parameters of Clayey Black (Cotton) Soils

The Black Clayey soil samples collected from the central part of the study area show EC < 1.2 dS/m, therefore, fall in the category of non-saline soil (Table 5.5 & 5.9). This soil due to its fine texture tend to accumulate salts that are carried from upstream regions as a part of returned irrigation seepage, which ultimately contributes to the groundwater storage; thereby making the groundwater saline. It is further observed that in the study area such clayey soils at places are in the influence of water logging possessing slightly higher pH i.e. 7.8 -8, else their normal pH ranges between 6.7 and 7.5. This fine textured soil show slightly higher organic matter content (0.4 to 0.9%), making these soils more suitable as a nutrient pool for plants and agricultural practices in the region. These soils are a product of residual weathering process of basaltic or other mafic igneous rocks. This accounts for enrichment of cations like calcium (300-540 mg/l), magnesium (120-280 mg/l) and sodium (150- 300 mg/l) (Table 5.4). Due to pH <8.3, no free carbonates occur in these soils. Bicarbonate concentration ranges between 50 and 90 mg/l. The black cotton soils are very fertile in terms of availability of macro plant nutrients and thus, show maximum agricultural activity in the study area. In terms of available nitrogen, these soils have adequate nitrogen (150- 450kg/ hec) to support plant life (Husain, 2010).

BROWN LOAMY SOILS:

This soil type occurs in small patches in the eastern and north-central parts of the study area. The important localities of its occurrence are Pingut and Maujha in the upper parts and the villages Dinod and Desad in the north-central part of the basin. Overall, this brown loamy soil covers an area of 141 km^2 (Table 5.4). Physically, this soil is characterized by various shades of brown and lacks proper soil profile and represented by a mixture of clay silt and sand (Plate 5.4). Having pH in the range of 7.14 to 7.65, soils are neutral to alkaline (Table 5.6).

Plate 5. 4 A Field View of Loamy Brown Soil Adjacent to the Pediment Zone (Loc. Pingut)

Parameters	Sample Locality		
	Desad	Dinod	Pingut
	$21^0$32 N 73^0 10 E	$21^0$31 N 73^0 03 E	$21^0$33 N 73^0 23 E
pH	7.14	7.65	7.5
EC (dS/m)	0.99	0.45	0.47
Organic Carbon (%)	0.45	0.15	0.23
Calcium(mg/l)	358	316	223
Magnesium(mg/l)	186	114	138
Potassium(mg/l)	116	107	85
Sodium (mg/l)	345	158	94
Bicarbonates (mg/l)	95	71	41
Carbonates (mg/l)	Absent		
Chlorides(mg/l)	310	196	226
Nitrogen(kg/hec)	148	89	56

Table 5. 6 Physico-chemical Parameters of Brown Loamy Soils

This soil type supports legumes, groundnut, vegetables and wheat. This soil being characterized by loamy texture is least preferred for crops like sugarcane, paddy and cotton and also necessitates proper irrigation practices and addition of fertilizers to enhance fertility. The observed cationic content in this soil (Table 5.6) is higher, therefore, offers high Cation Exchange Capacity, e.g. Dinod and Desad villages. Calcium tends to dominate (220-360mg/l) followed by sodium (110-230 mg/l), Magnesium (100-190 mg/l) and potassium (80-120 mg/l); whereas, the anionic species, viz. chloride show maximum concentration of 200-300 mg/l, followed by bicarbonates (40-100 mg/l). Further, this soil, being poor in nitrogen (50-150 kg/hec) periodically require addition of fertilizers and soil conditioners to enhance agricultural production (Husain, 2010).

MIXED SOILS:

Light mixed soil covers a majority of eastern hilly and undulatory terrain of the Kim River Basin (Fig.5.4). This soil is light brown to reddish in colour and occupies hilly terrain and reserved forests covering about 110km^2 part of the study area. These soils are characterized by its coarse to intermediate texture and exhibit good drainage characteristics. This soil type occurs along the gentle hill slopes, pediment zones predominantly in the upper parts of the watershed. Majority of the forest cover in the study area covers this soil type.

Parameters	**Sample Locality**			
	Tadphalia	**Atkhol**	**Sagva**	**Nasarpore**
	$21^0$37 N 73^0 23 E	**$21^0$35 N 73^0 23 E**	**$21^0$36 N 73^0 25 E**	**$21^0$30 N 73^0 21 E**
pH	7.2	7.1	7.2	6.9
EC (dS/m)	0.22	0.29	0.42	0.26
Organic Carbon (%)	0.8	0.5	0.2	0.9
Calcium(mg/l)	205	146	264	188
Magnesium(mg/l)	125	150	194	156
Potassium(mg/l)	95	104	124	166
Sodium (mg/l)	68	93	122	82
Bicarbonates (mg/l)	198	251	145	248
Carbonates (mg/l)	Absent			
Chlorides(mg/l)	205	246	178	235
Nitrogen(kg/hec)	210	158	96	172

Table 5. 7 Physico-chemical Parameters of Mixed Soils occurring in the Kim River Basin

These mixed soils are acidic to neutral in nature (6.9 -7.3) with EC ranging between 0.2-0.4 dS/m (Table 5.7). The clay content in this soil is low and thus acts as low nutrient pool. The organic content varies from 0.2 -0.9 %. As this soil is formed from differential weathering of basalts few cations like calcium, magnesium and potassium are present in moderate concentration (Table 5.7).

In terms of available nitrogen (90-210 kg/hec), these soils solely depend on the addition of artificial fertilizers due to poor fertility. Chlorides in this soil are less prone to leaching and due to less mobility tend to get accumulated in moderate concentrations, i.e. 150-250mg/l.

Therefore, considering an overall soil chemistry, the mixed soils are low in fertility and thus, are more suitable for forests where nutrient cycling takes place at a faster rate, while for agriculture practices, addition of agro fertilizers is necessary to maintain its fertility.

LATERITES/ RED SOILS:

The lateritic/red soil in the study area show patchy occurrence and predominantly restricted in the south-eastern parts of the upper basin. Important localities of its occurrence are villages around Selarpur and Amkhuta (Fig 5.4). Soil covers about 49 km^2 area. Red soil is characteristically formed from chemical weathering and leaching of basalts. Genetically, these soils are formed as a result of repetition of dry and wet climatic conditions, which predominantly leave insoluble ions of iron and aluminium (Buol et al, 2011). The oxidation of iron imparts red colouration to this soil. As this soil type is typically formed along the regions having appreciable gradient, most of the nutrients are either washed away by runoff or if infiltrated, are leached down to deeper soil strata, that results in poor fertility and lack of humus (Buol et al, 2011). Utilizing these soils for cultivation requires addition of adequate fertilizers and proper irrigation practices to increase their fertility.

Parameters	Sample Locality	
	Amkhuta	Selarpur
	$21^0$24 N 73^0 13 E	$21^0$25 N 73^0 17 E
pH	7.9	7.2
EC (dS/m)	0.63	0.34
Organic Carbon (%)	0.56	0.18
Calcium(mg/l)	310	230
Magnesium(mg/l)	110	170
Potassium(mg/l)	142	104
Sodium (mg/l)	110	88
Bicarbonates (mg/l)	78	72
Carbonates (mg/l)	Absent	
Chlorides(mg/l)	188	135
Nitrogen(kg/hec)	290	215

Table 5. 8 Chemical Characteristics of Red/Laterite Soils in the Kim River Basin

Physico-chemical characteristics (Table 5.8) of these lateritic soils are found to be neutral to alkaline in nature. In the study area, they exhibit a pH range of 7.2-8.0. This soil type has EC < 1.2 (dS/m), which indicates that the soil belongs to the non-saline class (Smith & Doran, 1996). Organic Carbon in the soil is comparatively low (0.2 to 0.6%) which may be attributed either due to poor nutrient cycling or leaching phenomena. Cations like calcium, magnesium and potassium occurred in moderate concentrations. Sodium and Chloride concentration is observed low, that may be ascribed to flushing effect during the rainy season. The nitrogen in the soil display range of 200-300 kg/hec, which is indicative of need for addition of chemical fertilizers.

STATUS OF VARIOUS SOIL TYPES IN THE KIM RIVER BASIN:

The Kim River Basin shows occurrence of five different soil types distributed over an area of 1320km^2. Depending on the factors like parent rock, topography climate and anthropogenic activities, significant variation is seen in terms of its texture, physico-chemical characteristics and fertility. Based on the range of physico-chemical parameters; available soils of Kim River basin have been characterized as under: (Table 5.9)

SOIL TYPE	Clayey Black		Coastal Alluvial		Loamy Brown		Mixed		Laterite	
PARAMETERS	***Min***	***Max***	***Min***	***Max***	***Min***	***Max***	***Min***	***Max***	***Min***	***Max***
pH	7.1	8.0	7.2	8.3	7.1	7.7	6.9	7.3	7.3	7.8
EC (dS/m)	0.2	1.2	0.5	11	0.5	1.0	0.2	0.5	0.2	0.6
Organic Carbon (%)	0.2	0.8	0.3	0.8	0.2	0.5	0.3	0.9	0.4	0.9
Chlorides(mg/l)	150	600	400	1100	200	300	150	250	120	200
Nitrogen(kg/hec)	150	450	250	600	50	150	100	200	200	300
Calcium(mg/l)	300	540	240	410	220	360	120	260	190	320
Magnesium(mg/l)	120	280	95	320	100	190	110	190	110	180
Sodium (mg/l)	150	350	310	700	110	230	80	120	70	120
Potassium(mg/l)	100	220	130	260	80	120	110	160	90	140
Carbonates (mg/l)	Absent									
Bicarbonates (mg/l)	50	75	70	125	40	95	35	75	70	80
CEC(meq/100gm)	5	13	10	40	6	15	7	10	5	10

Table 5. 9 Chemical Constituents of Different Soil Types of the Kim River Basin

pH:

Soil pH measures hydrogen ions primarily occurring as exchangeable cations. There is stability between these hydrogen ions and the exchangeable cations in soil (Gupta, 1987). The pH of the soils occurring in the study area is slightly acidic to alkaline (6.9 to 8.3) in nature. Soil pH being an important parameter to measure the severity in soils, pH is considered to be a good indicator of soil health (Rowell, 1984). The coastal alluvial and black cotton soils in the downstream and central part of the study area show high pH values (Table 5.9) that may be ascribed to accumulation of salts due to prevailing sea water intrusion and water logging conditions in the study area. These soils are harmful for growing crops (Muher et al, 1963). Lateritic soils occurring in the south-eastern part of the basin (Fig 5.4) are found to be neutral to slightly acidic in nature, which can be either due to addition of agrochemicals to soils or low leaching activity. The mixed and brown soils occurring as patches in the upstream region show slightly acidic to neutral pH range. Figure 5.5 summarizes the comparison of optimum pH range required for proper plant growth with the pH range of different soil types occurring in the Kim River Basin.

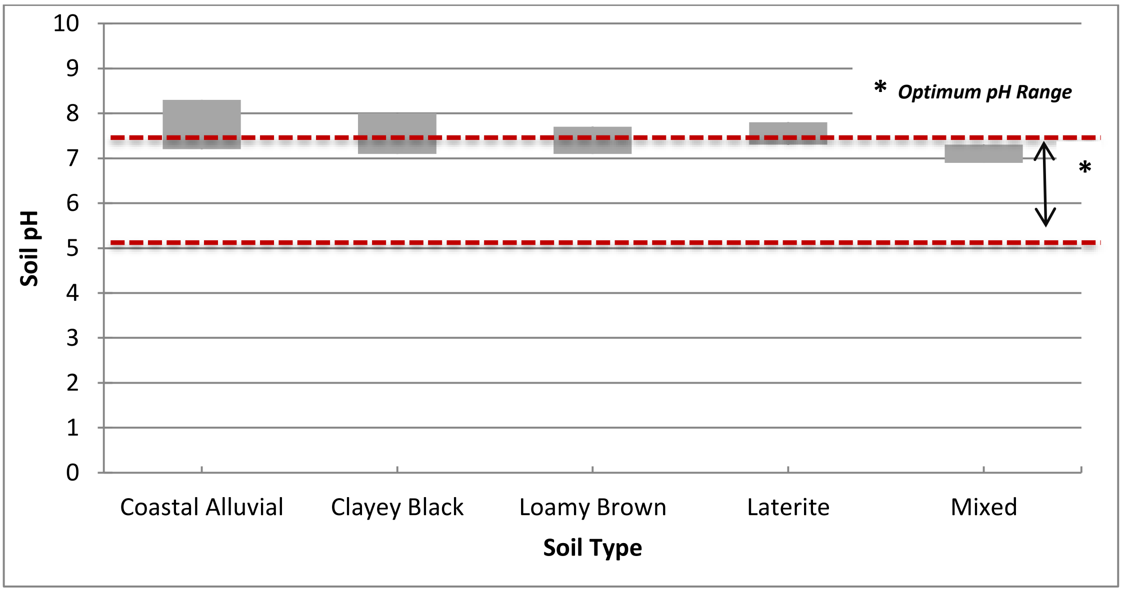

Figure 5. 5 Range of Soil pH across the Kim River Basin

Thus, the overall soil pH increases, as we move down the gradient from the upper to the lower part of the basin.

Electrical Conductivity (EC):

The existing soils in the study area display a large variation in the Electrical Conductivity. However, overall EC tends to increase down the gradient. Electrical Conductivity (EC) is important indicator of soil health as it indirectly measures the amount of salts present in the soil. Excess salts hinder plant growth by affecting the soil-water balance (Dahnke & Whitney, 1988). The EC of a soil is measured through a soil solution extract from a saturated soil paste in 1:1 ratio (soil: water) at 25^{o}C.The electrical conductivity of soils varies depending on the amount of moisture held by soil particles and correlates strongly to soil particle size and texture (Table 5.9).

Soil Texture	Degree of Salinity (Salinity Classes)				
	Non-Saline (dS/m)	Slightly Saline (dS/m)	Moderately Saline (dS/m)	Strongly Saline (dS/m)	Very Saline (dS/m)
Coarse to loamy sand	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	9.0+
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	9.5+
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	10.1+
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	11.5+

**Smith and Doran(1996),Dahnke & Whitney(1988).*

Table 5. 10 Salinity Classes of Soils based on Electrical Conductivity

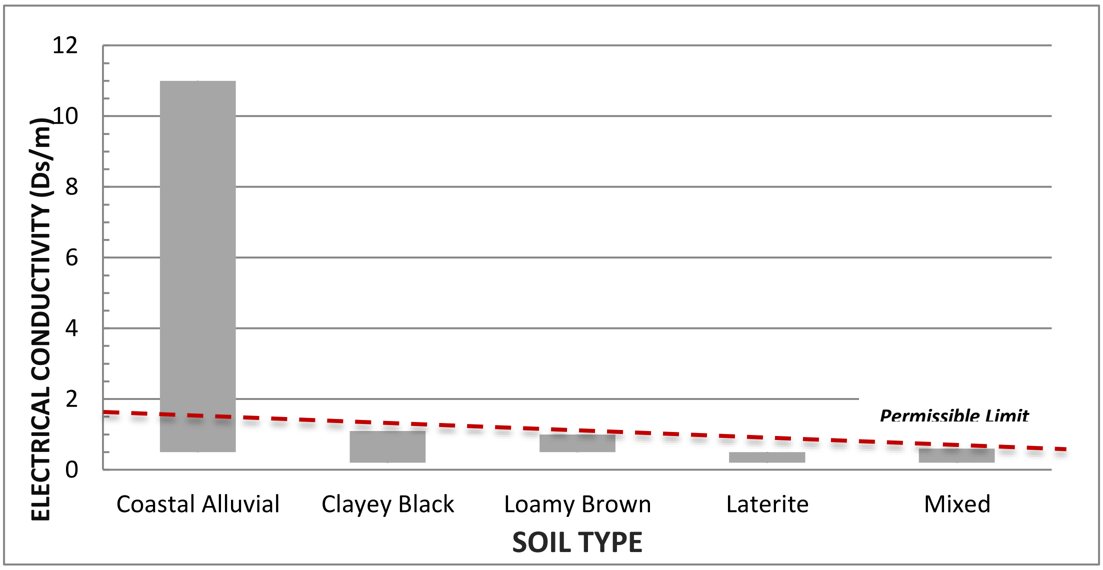

Figure 5. 6 Electrical Conductivity vis-à-vis Soil Types in the Kim River Basin

The coastal alluvial soils show highest EC values ranging from 0.5 to 11.0 dS/m. Further, based on EC, 15% of the collected soil samples belong to the non-saline category while rest 85% fell in the category of moderately saline to strongly saline(Smith & Doran, 1996). The soil quality deterioration may be attributed to synergistic effect of soil texture, poor drainage conditions, saline water intrusion, over irrigation and downstream salt accumulation (Dahnke & Whitney, 1988). These soils due to their texture tend to accumulate salts that are carried from either upstream or on account of flood irrigation practices, but soon are flushed deep beyond the root zones in the ground water systems, making them slightly saline. The mixed soils and brown soils that occur in the upstream area have lower EC values in the range of 0.2-1.0 dS/m which makes them non-saline in nature. (Table 5.10). The Lateritic soils that occur along the sloppy south- eastern part of the basin also show EC < 0.6dS/m, where similar conditions of salt flushing occur and very little salts are able to retain in the soil (Fig 5.6).

Organic Carbon:

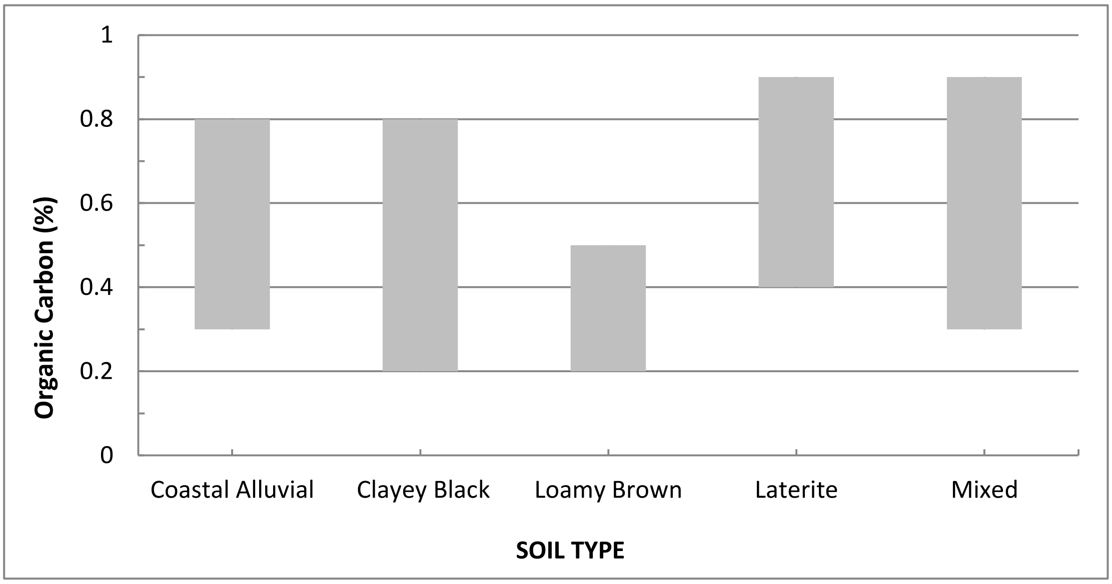

Figure 5. 7 Observed Range of Organic Carbon Percentage in Various Soil Types of the Kim River Basin

Organic matter content in different soil types of the Kim River Basin show a remarkable variation (Fig.5.7). The loamy brown soil occurring in patches of upstream and northern part of basin area show minimum percentage of organic matter in the range of 0.2-0.5%. This is attributed to sparse vegetation, enhanced soil erosion in hilly terrain and low clay content. The mixed soil in the upstream region comprising silty and sandy texture signifies by high rainfall and dense vegetation (forest), the organic matter occurs in the range of 0.3 - 0.9%. The Clayey black soils that dominate the Kim Basin show organic matter in the range of 0.2- 0.8% are characterized by the dominance of clay and large scale agricultural practices (Husain, 2010). The coastal alluvial soils available in the lower reaches of the basin are characterized by poor drainage and higher salt accumulation. These soils show organic matter in the range of 0.3-0.8%.

Ionic Concentrations:

The ionic concentration of soil is a mixture of various cations as well as anions. Weathering of parent rock is the primary source of these soluble ions in soil, while surface or groundwater is the secondary source (Hem, 1959). Major soluble ions in soils comprise of calcium, magnesium, potassium and sodium as cations and bicarbonates, carbonates, chlorides, sulphates and nitrates as anions. As excessive ion or a particular group of ions accumulate in the soil, tend to have adverse effects on the physical and chemical properties of soil as well as are harmful for plant growth. (Rai, 1995).

Calcium ion(Ca^{+2}) in soil ensures proper soil porosity due to its property to flocculate clay and organic matter particles (Hem, 1959). Magnesium ions are principally associated with the minerals like olivine, amphiboles and pyroxenes (Hem, 1959) It is essential constituent of chlorophyll and is absorbed by plants in its divalent form (Rai, 1995). Feldspar and feldspathoid groups are major sources of sodium in soil. Also, in soils where Base Exchange reactions are high, sodium replaces other cations in clay minerals. Potassium ion concentration in soil depends on the parent rock containing feldspar and mica minerals and the degree of weathering (Hesse, 1994). The potassium content of soil is comparatively less among other cations in soil.

Chlorides in soil are highly mobile and if present in higher concentration can hinder plant growth and also are responsible in balancing osmotic pressure in plants. (Miller and Donahue, 1997). The Cl anion is not adsorbed on soil particles at neutral and alkaline pH values, and therefore is easily leached. Carbonates and bicarbonates in soil tend to bind with calcium and magnesium and if present in higher concentrations, are responsible for soil alkalization process. Mineralisable nitrogen in soil is one of the macro nutrient required by plants and usually exists in combination with organic matter. Plants generally take up this nitrogen in the inorganic form of either NH_4^+ or NO_3^- (Rai, 1995).

Cation Exchange Capacity of Soils:

The Cation Exchange Capacity (CEC) estimates the ability of soils to attract, hold and replace cations. Clay minerals and organic matter in soil, using electrostatic forces tend to attract a large number of cations on their surface and holding them in the root zone. This in turn prevents the loss of cations through the process of leaching and act as buffer zones by replenishing the ions when the concentration in the soil decreases due to plant uptake (Miller and Donahue, 1997). CEC is thus the measure of the total negative charges present within the soil that attract plant nutrient cations like Ca^{2+}, Mg^{2+}, Na^{2+} and K^+. It is represented in meq/100g of soil. A significant percentage of clay and organic matter in the soil attract a large number of cations that are ultimately contributing to higher CEC. Thus, soils having higher CEC hold more cations and therefore require higher rate of lime or fertilizers to compensate the CEC values. Further, the CEC in most soils increases with an increase in soil pH (Jackson, 1973).

Moreover, the CEC greatly depends on soil texture. The fine textured soils have far high CEC as compared to coarse textured soils. A generalized relationship between CEC and the soil textures (Table 5.11) is given below:

Soil Texture	CEC (meq/100 gm)
Sandy	1 – 5
Fine sandy loam	5 – 10
Loam and silty loam	5 – 15
Clayey loam	15 – 30
Clayey	> 30

(After Miller and Donahue, 1997)

Table 5. 11 A Generalized Correlation between Soil Texture and CEC

Taking into account the major soil colloids responsible for most soil CEC; the humus represents the higher range of CEC (100-300 meq/100 mg) followed by the clay minerals like vermiculite (80-150 meq/100 mg), montmorillonite (60-100 meq/100 mg) and kaolinite (2-8 meq/100 mg). Soils with poor drainage tend to accumulate more ions, resulting in greater CEC while those have good drainage help to leach out the excess ions from the soil, thus, maintaining the ionic concentration in the soils (Miller and Donahue, 1997).

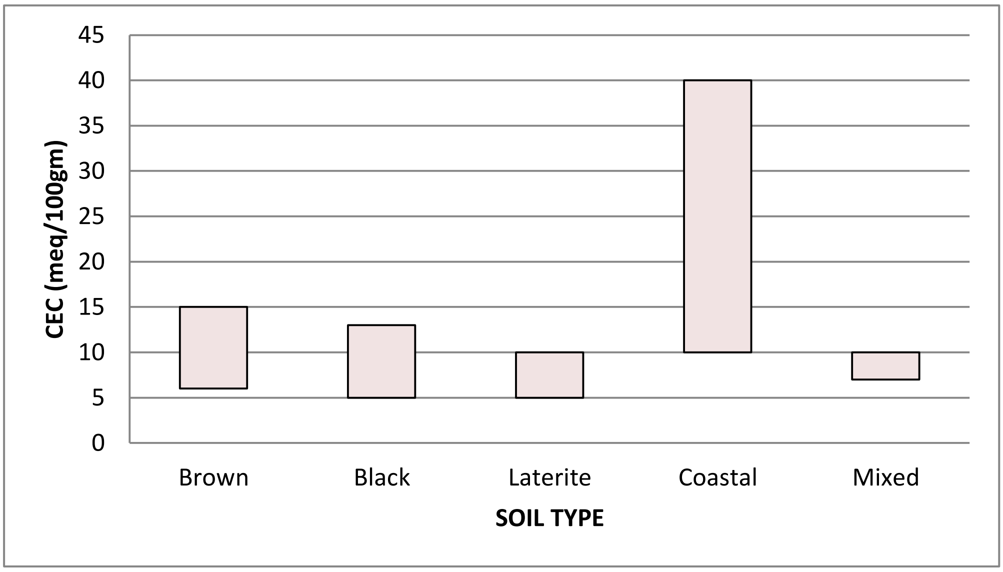

Figure 5. 8 Range of CEC available in of Various Soil Types of Kim River Basin

The soils of the hilly terrain in the upper parts of the Kim Basin show low CEC values due to excessive ground slope as well as availability of good soil drainage leading to excessive nutrients leaching from the soil (Fig. 5.8). Contrary to this, the alluvial soils in the central and lower parts of the basin have high clay content and poor drainage, show greater CEC values due to lack of leaching of nutrients on a periodic basis.

Percent Base Saturation:

The Percent Base Saturation is defined as the relative availability of cations in soil. Cations in soil are classified as either acidic (acid- forming) or basic. The common acidic cations are hydrogen and aluminium; common basic ones are calcium, magnesium, potassium and sodium (Webber M.D. et al, 1982). At pH ≤ 5.4 , Al^{3+} is present in a significantly high concentration, hindering plant growth and leading to Al^{3+} toxicity. Therefore, soils characterized by high percent base saturation are factually more fertile due to near absence of toxicity, where as in alkaline pH, the essential plant nutrient cations like K^+, Ca^{2+} and Mg^{2+} are present in greater amount (Blosser & Jenny, 1971).

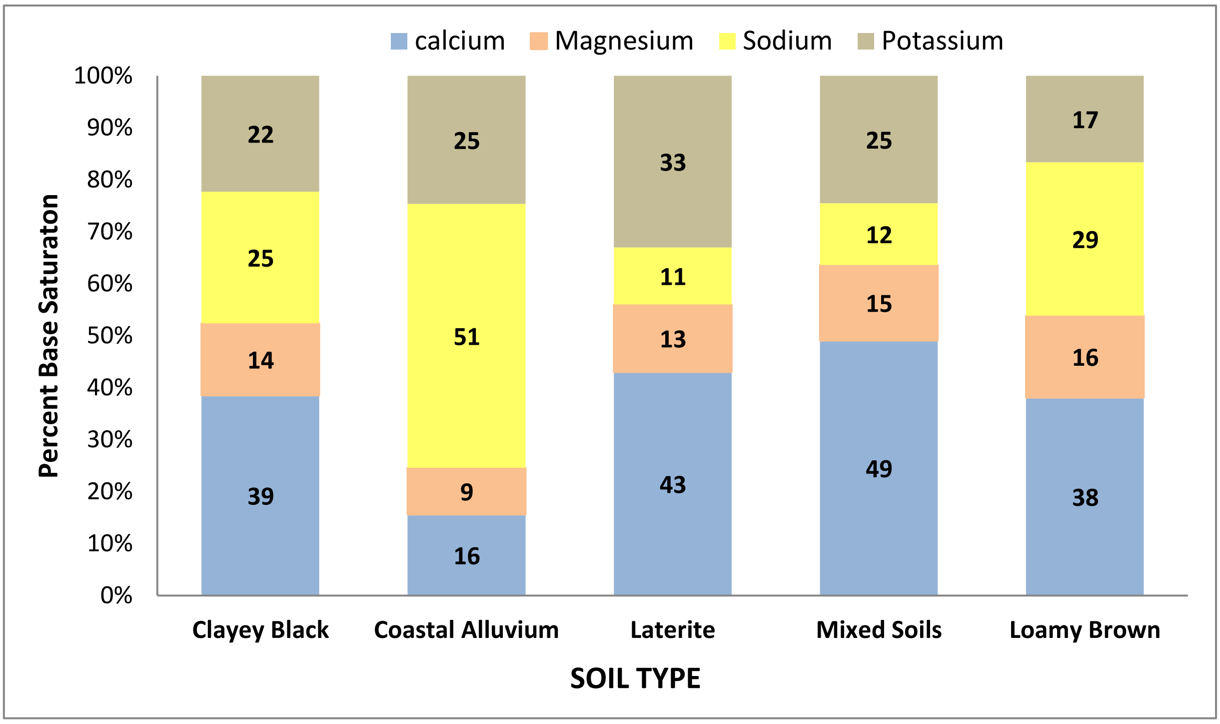

Figure 5. 9 Observed Base Saturation of Basic Soil Cations Found in Kim River Basin

On comparing the Percent Base Saturation of different soil types, it is evident that calcium ion predominates in all soil types except the coastal alluvium soil (Fig. 5.9). The soils show almost 40-50% of Exchangeable Calcium Ions. The lower values of exchangeable calcium ions in the coastal alluvium soils may be ascribed to shallow water table, inherent soil salinity, agricultural practice of growing water intensive crops, poor soil drainage and accumulation of flushed ions from upstream regions. These causative factors have led to higher concentration of sodium in soils and associated hazards like soil alkalinity.

Chlorides:

As stated earlier that chloride is considered to be one of the highly soluble and mobile anions found in soil (Miller and Donahue, 1997). The candidate's study on the spatial distribution of chloride ions in the study area soils suggest that the overall concentration of chloride ions in the soil regime tend to increase down the gradient from the river source to its mouth. Its lower concentration, particularly in the upper basin region may be ascribed to steep topography and groundwater gradients leading to its flushing to the middle and lower parts of the basin. Looking to soil specific concentration of chlorides; it is in the range of 120-200 mg/l (lateritic soils), 150-250 mg/l(mixed soils) and 200-300 mg/l(loamy brown soils). Moreover, in the central part of the basin, typified by clayey black soils, the chloride concentration is in the range of 160-600 mg/l.

Carbonates and Bicarbonates:

Since the observed pH of soils occurring in the study area is < 9.5, presence of soluble carbonate ions is less (Hesse, 1994). Contrary to this, the bicarbonate concentration varies across different soil types in the study area. Highest concentration of bicarbonate is found to occur in the coastal alluvium (70 to 125 mg/l). The loamy brown, black cotton, lateritic and mixed soils are characterized by low to moderate levels of bicarbonate.

Thus, in terms of soil chemistry, the Kim River Basin show varied distinctions. The mixed, brown loamy and lateritic soils that are by and large covering the upper part of the basin area exhibit low to moderate concentrations of various cationic and anionic species. The black cotton soils occurring in the central part of the basin, show slightly higher concentrations of various ionic species, which is on account of its fine texture and on-going extensive agricultural practices. The coastal alluvium soils in the lower part of the basin show diverse characteristics in terms of chemical content thereby pointing to factorial impacts of various parameters like soil texture, poor drainage; groundwater salinity and anthropogenic practices viz. lack of crop management and over irrigation leading to water logging.

The aforesaid findings of the soil regime in the study area has certainly impacted the land use system; therefore accounted in computing the Ecological Footprints of the basin in preceding chapter.