Chapter V

SOIL AND SUB SOIL CHARACTERISTICS

SOIL AND SUB SOIL CHARACTERISTICS

INTRODUCTION

Soils are one of our basic important resources. It is a commodity that needs to be protected and used to be wisely.

In any irrigation project there is a set of soil characteristics imparting peculiar soil which qualities, which are significant to design and operation of the project. Soil evaluation provides information and recommendations for deciding specific crops to be grown. Soil resources evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable.

REGIONAL SOIL RESOURCES

The Gujarat State is endowed with a wide range of macro and microclimates, physiography, landforms, geology and vegetation, which have influenced on the genesis of soils (Kanzaria and Patel, 1985; Kalyanisundaram and Patel, 1995).

The soils of Gujarat have been classified into nine groups viz. black soils, mixed red and black soils, residual sandy soils, alluvial soils, saline/sodic soils, lateritic soils, hilly soils, forest soils and desert soils (Kanzaria and Patel, 1985). Taking the basis of 'soil taxonomy' as proposed by Soil Survey Staff (1978), the Gujarat soils have been classified into five orders namely Alfisol, Aridosol, Entisol, Inceptisol and Vertisol, and eleven suborders namely Ustalfs, Argids, Orthids, Aquents, Psamments, Fluvents, Orthents, Aquepts, Tropepts, Ochrepts and Usterts (Roy and Verma, 1988; Tiwari and Patel, 1997). Fig 5.1 shows the association of these sub-orders and their distribution in Gujarat State. Of these first four association and fifth and sixth together have extensive occurrence in the state.

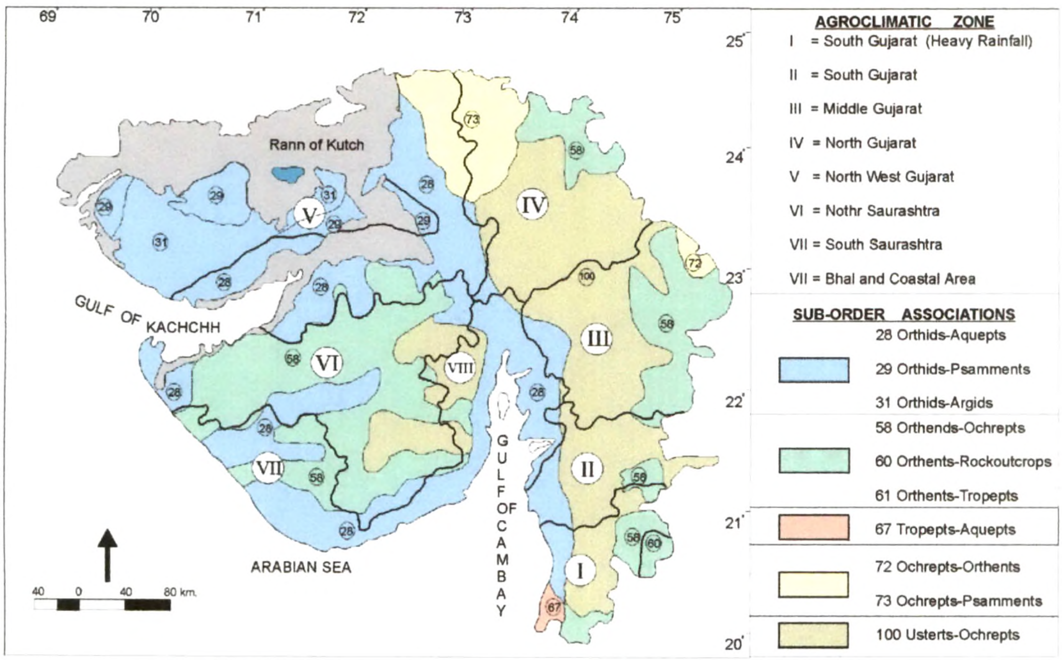

Fig. 5.1 Soils of Gujarat (after Kalyanasundaram and Patel, 1995)

SOIL CHARACTERISTICS OF THE KLBC AREA

Soil composition and its textural characteristics are the manifestation of geological and climatic factors. Geological factors define the nature of parental sediments and the surficial processes, which are responsible in characterizing the complete denudational system for providing the material influx. Whereas, the climatic factors governs the process of weathering and subsequent pedogenization thereby the development of soil.

The soils of the KLBC area are predominated by clayey composition with the dominance of montmorillonite clays (Bapat and Shah, 1984). As the area has been classified into four distinct physiographic units viz. Trappean highlands, linear pediment zone, alluvial plain and coastal plains; the soils also accordingly exhibits variations in composition and nature. However, by and large majority of soils in the South Gujarat area have been commonly designated as the Black Cotton Soil.

Considerable work on the soils of South Gujarat has been carried out by the various workers belonging to Gujarat Sate Soil and Agriculture Development. The author has carefully scrutinized the available information. A critical appraisal on the various soils and their characteristics is discussed as under:

CLASSIFICATION OF SOILS

Taking in to account the textural characteristics soils and the various geomorphic units; the soils of the KLBC area and its surroundings has been classified in to 09 subsequent sub groups and 4 orders (Table 5.1). It can be seen from the soil map (Fig. 5.2) that the Typic chromusterts is the most dominating soil type in the area, followed by Typic halaquepts. The other soil types occupy smaller patches in coastal plain.

Table 5.1 Soil Taxonomic Classification of KLBC Area.

Interstream Zone	Predominant Soil Type	Order
Between Tapi and Mindhola Rivers	Chromic haplusterts	Vertisols
	Typic haplusterts	Vertisols
	Typic chromusterts	Inceptisols
Between Mindhola and Purna Rivers	Typic chromusterts	Inceptisols
	Vertic ustochrepts	
Between Purna and Ambica Rivers	Typic chromuderts	Inceptisols
	Typic ustochrepts	
	Chromic haplusters	Vertisols
Between Ambica and Kaveri Rivers	Typic chromusterts	Inceptisols
	Chromic haplustepts	Vertisols
Between Kaveri and Auranga Rivers	Typic chromusterts	Inceptisols
	Chromic haplustepts	Vertisols
Between Auranga and Par Rivers	Typic chromusterts	Inceptisols
	Chromic haplustepts	Vertisols

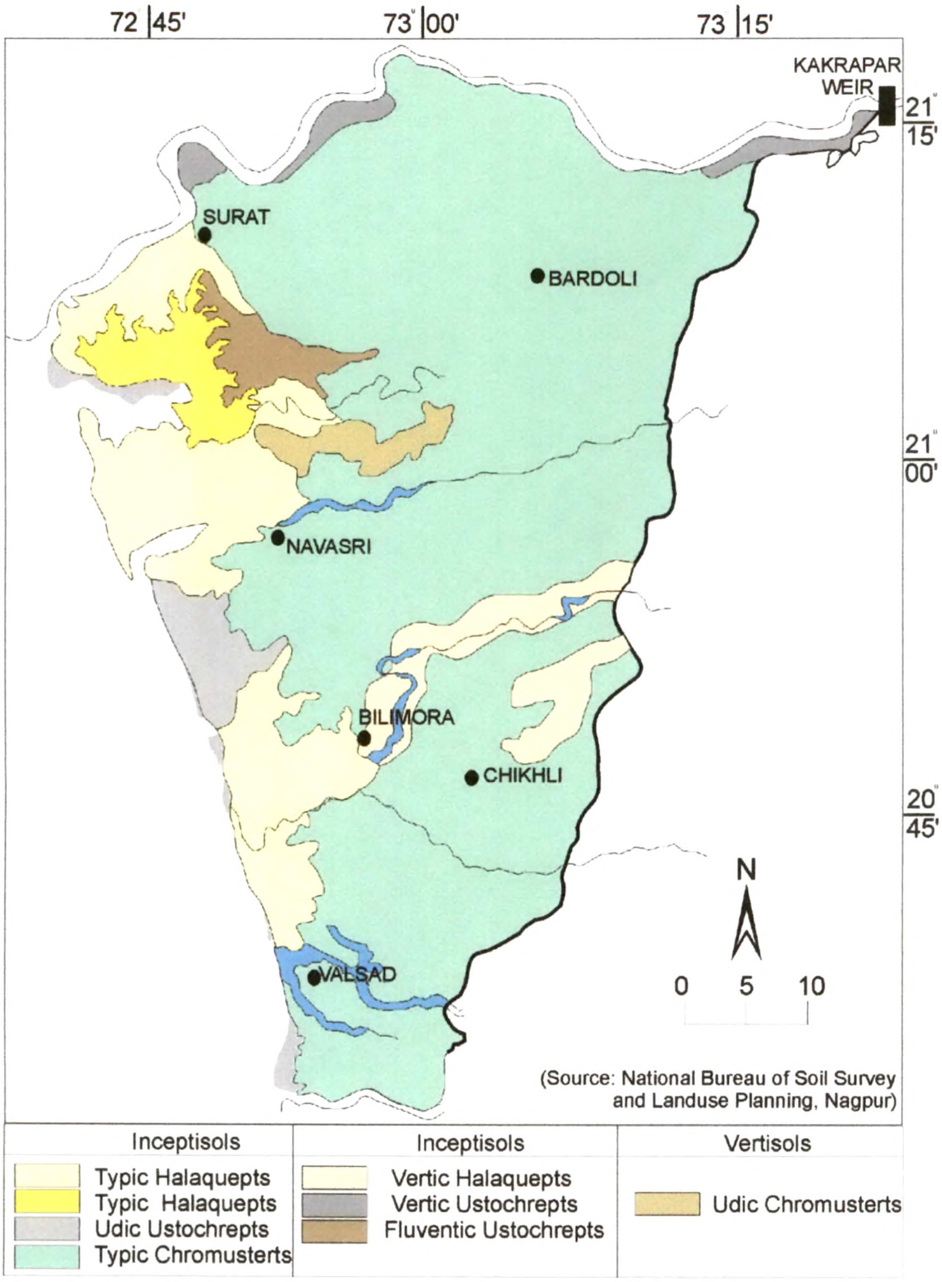

Fig. 5.2 Classification of Soils in KLBC Area.

SOIL PROPERTIES

The information on soil properties needed for planning land use development under irrigated lands and thus form an important basis for planned land use. In order to have a broad assessment of soil properties of KLBC area, author has carried out exhaustive literature survey. For the convenience the author has divided the KLBC are in to 07 different zones by considering inter stream areas. A concise account on the various soil properties is provided here under.

PHYSICAL PROPERTIES OF SOILS

The morphological characteristics are manifestation of the parameters like texture, structure, soil depth, colour, temperature etc. Also, the physical properties of soil determine the availability of oxygen in soils, the mobility of water into or through soils, and the ease of root penetration.

Soil Depth

Soil depth refers to the depth of soil material which can readily be penetrated by plant roots (root room) and which provides nutrients and soil moisture for cultivated crops. Further soil depth is very important to evaluate land leveling, drainage, aligning and design of irrigation and drainage.

Based on available data, the soil depth in KLBC area shows conspicuous variations from north to south (Table 5.2). The thickness of the soil column in the area is very deep, i.e. more than 90 cm.

Table 5. 2 Aerial Extent (ha) and Classification of Soil Depth in the KLBC Area.

Interstream Zones	Soil Depth (cm)		
	< 45	45 - 90	> 90
Between Tapi and Mindhola Rivers			75011
Between Mindhola and Purna Rivers			38243
Between Purna and Ambica Rivers			44987
Between Ambica and Kaveri Rivers		644	24150
Between Kaveri and Auranga Rivers		1731	27131
Between Auranga and Par Rivers	109	730	10061
Total Area	109	3105	219583
Percentage	0.05	1.39	98.56

(Source: Soil Drainage and Reclamation Circle Reports 1993-2001)

Soil Texture

The relative proportion of the various soils separates (i.e. sand -silt-clay) in a particular soil determines its soil texture. Particle size distribution gives a broad indication on physical and chemical properties of soils (Miller and Donahue, 1997). However, particle shape and surface properties, particularly of the clay size fraction significantly modifies the texture of soil (Rowell, 1994). Since the soil texture forms the basic matrix of a soil, the geometry of voids created in the soil matrix dependent on the class of soil texture. Also the soil texture influences considerably the other two soil phases contained in the pore spaces i.e. water and air (USDA, 1970). Coarse textured soils are very permeable and allow the rapid movement of air and water between the soil particles, but they do not hold and store plant nutrients or water very well and hence it is droughty and infertile. On other side fine clay particles hold most of the plant nutrients, but soil consisting predominantly of clay is not permeable to air, water and plant roots. When plant roots are not able to grow well the crop yield accordingly will be reduced (Richards, 1968). Medium textured soils are most desirable one because they allow the movement of air and water readily and hold the plant nutrients and moisture well. Salient features of the various soil types based on its textural characteristics, as suggested by USDA (1970) are given in Fig. 5.3.

In the KLBC area the soils display vast variation in its textural characteristics. These identified textural variations may be attributed to the different surficial processes and physiographic controls. The surface soils i.e. upto 30 cm depth are predominantly comprising clayey fractions while the deeper soils i.e. > 30 cm depth, the soils are of sandy clay factions. The spatial distribution pattern of various soil textural classes and sub-soil textural classes, as worked out by the State Soil Survey Department is given in Table 5.3 and 5.4.

Table 5.3 Textural Variation and Spatial Distribution (ha) of Surface Soils in KLBC Area (0 - 30 cm depth).

Interstream Zones	S & LS	SL & FSL	L, SIL, SI	SICL, CL, SCL	SC, SIC, C
Between Tapi and Mindhola Rivers	314	431	856	12272	61138
Between Mindhola and Purna Rivers	71	464	1235	7700	28773
Between Purna and Ambica Rivers			241	6410	38336
Between Ambica and Kaveri Rivers	134			2408	22252
Between Kaveri and Auranga Rivers				3289	25573
Between Auranga and Par Rivers			22	2344	8534
Total Area	519	895	2354	34423	184606
Percentage	0.23	0.40	1.06	15.45	82.86

(Source: Soil Drainage and Reclamation Circle Reports, 1993-2001)

S = Sand, LS = Loamy Sand, SL = Sandy Loam, FSL = Fine Sandy Loam, L = Loam, SIL = Silty Loam, SI = Silt, SICL = Silty Clay Loam, CL = Clay Loam, SCL = Sandy Clay Loam, SC = Sandy Clay, SIC = Silty Clay, C = Clay.

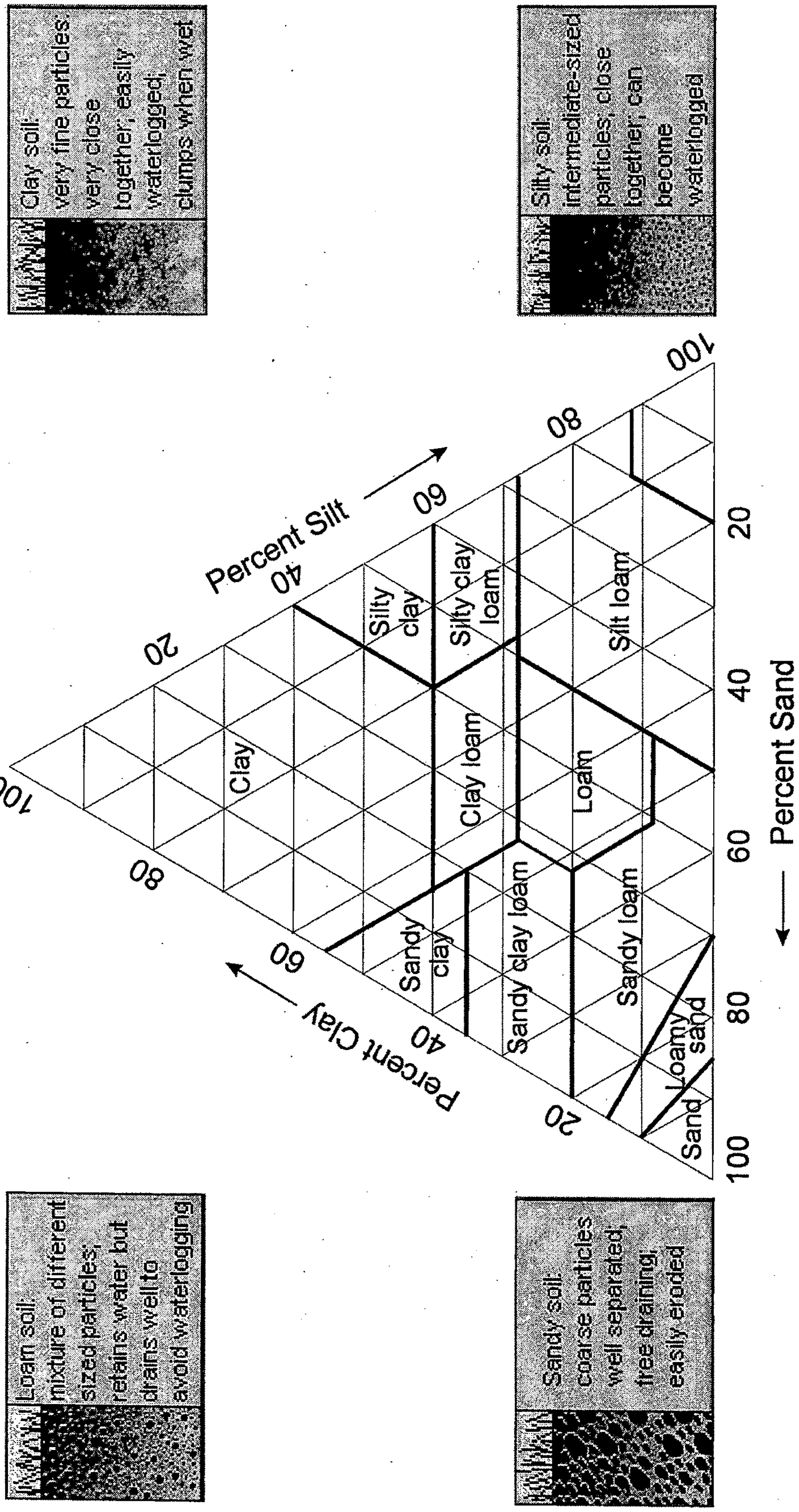

Fig. 5.3 Standard Textural Classification of Soils (USDA, 1970).

From the data it can be seen that 82.86 and 78.59 percentage of the KLBC area is covered by clay to sandy clay texture within the surface and subsurface soil respectively, followed by clayey loam to sandy clay loam texture. As overall soils are representing fine texture, such soils although are less permeable but contain good amount of plant nutrient hence highly fertile in nature.

Table 5.4 Textural Variation and Spatial Distribution (ha) of Sub-Surface Soils in KLBC Area (more than 30 cm depth).

Interstream Zones	S & LS	SL & FSL	L, SIL, SI	SICL, CL, SCL	SC, SIC, C
Between Tapi and Mindhola Rivers	68	1166	1889	14000	57888
Between Mindhola and Purna Rivers	641	381	3333	10144	23744
Between Purna and Ambica Rivers		347	232	8089	36319
Between Ambica and Kaveri Rivers	340		642	810	23002
Between Kaveri and Auranga Rivers			97	2840	25925
Between Auranga and Par Rivers	54		22	2605	8219
Total Area	1103	1894	6215	38488	175097
Percentage	0.50	0.85	2.79	17.27	78.59

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Soil Structure

Soil structure defines the arrangement of various soil separates in to stable aggregates or peds. Peds are held together by soil organic matter and other binding agents like iron oxides, carbonates, clays and/or silica in turn stabilize the arrangement of pore spaces and particles (Miller and Donahue, 1997). Soils with good structure allow air, water, and nutrients to move through the spaces within and between peds. They also retain their arrangements of solids and pore spaces when exposed to the stresses of cultivation, harvesting a crop, and the impact of raindrops, among others (Topp et al, 1995). Soil structures are generally described by three important ped characteristics (Miller and Donahue, 1997). These are -

(i) Type or shape: angular, granular, blocky, columnar, platy & prismatic),

(ii) Class or size: fine, medium, coarse, very fine, very coarse, and

(iii) Grade or strength: weak, moderate or strong.

Good structure implies that the state and stability of aggregates do not limit a crop's yield potential, that the soil is suitable for maximum root growth and penetration, and that the soil is stable against forces causing soil degradation (USDA, 1966). The various types of soil structure and their effect on movement of water are depicted in Fig. 5.4. Various ratings for irrigation suitability based on structure as defined by USDA are given as under:

Structure of Soil	Irrigation Suitability Group
Sub-angular, blocky, crumbled	Highly suitable
Single grain, angular blocky	Moderately suitable
Prismatic columnar	Marginally suitable
Massive	Permanently not suitable

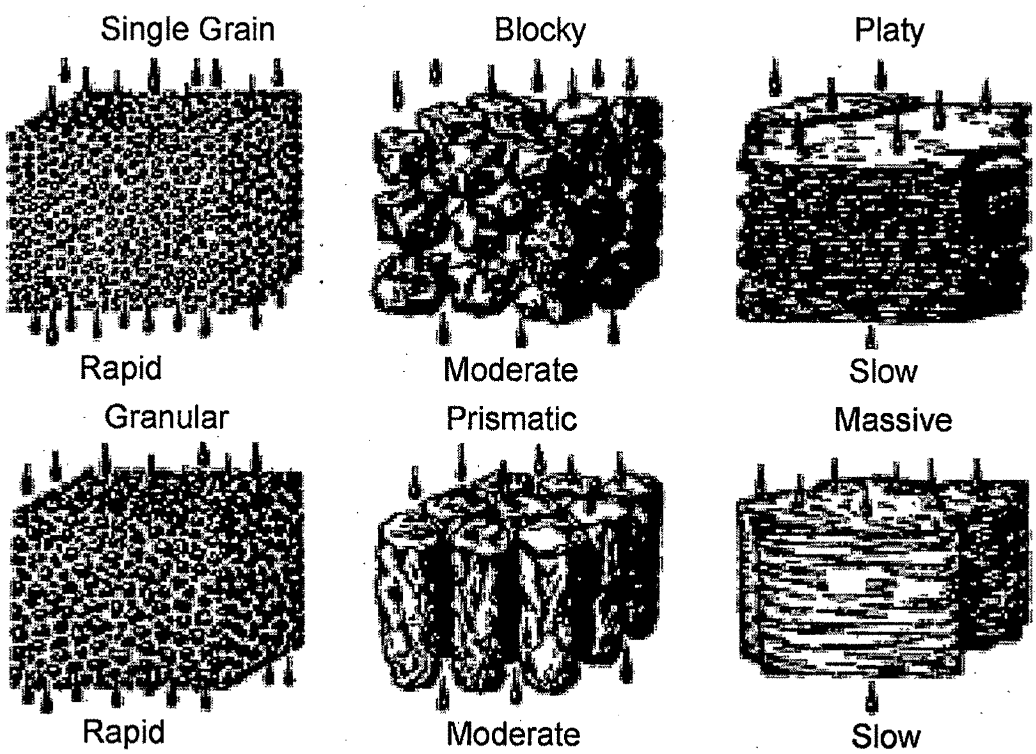

Fig. 5.4 Schematic Diagrams of the Most Common Soil Structures and their Effect on Downward Movement (infiltration) of Water (USDA, 1970).

Taking into consideration the soil's structures, the KLBC area soils fall under the categories of angular to sub-angular soil structures, thereby moderate to highly suitable for irrigation purposes (USDA, 1970).

Soil Colour

It is the most obvious property, which gives an immediate indication on the condition of the soil system. Spatial variation in soil colour through the soil profile distinguishes different soil horizons and provides an indirect measure of important soil characteristics including drainage, aeration, organic matter content and fertility (USDA, 1970). In some regions, particularly those with young soils, the colour of the soil may represent the mineral parent material. However, in general, soil colour is controlled by soil forming processes. Organic matter is generally brown/black in colour and is predominantly associated with the A-horizon of the soil profile (Table 5.5). Similarly iron compounds, in various states of oxidation and reduction (hydration) is major colouring agents of sub-soil horizons. The colour of soil containing iron oxide varies from red and rust brown to yellow depending on the degree of hydration. Reduced iron normally displays a green-blue tinge.

Table 5.5 Important Soil Characteristics Based on Surface Soil Colours.

Soil Characteristics	Dark (dark grey, brown to black	Moderately dark (brown to yellow brown)	Light (pale brown to yellow)
Organic matter	High	Medium	Low
Erosion factor	Low	Medium	High
Aeration	High	Medium	Low
Available nitrogen	High	Medium	Low
Fertility	High	Medium	Low

(Source: Website.geog.plym.ac.uk)

Soils in anaerobic conditions, such as those in poorly drained depressions, will normally have dull, grey B-horizons (Table 5.6). Alternatively, aerobic soils on well-drained and aerated slopes have bright reddish-brownish colours.

Table 5.6 Important Soil Characteristics Based on Sub-Surface Soil Colours.

Condition	Sub-surface Soil Colour
Water logged soils, poor aeration	Dull grey (if in low rainfall soils 0 - 20 in)
Well drained soils	Yellow, red-brown and black (if in forest soils)
Poorly drained soils	Mottled grey (if in humid soils)

The soils of the KLBC area vary from yellowish brown (10YR 5/4) to very dark brown (10 YR 3/3). The soils of the coastal plain shows dark grayish brown to dark yellowish brown colour with in the pedon while the soils of the alluvial plain are characterized by dark brown to dark yellowish brown colour. As soils of alluvial plain area are dark in colour therefore rich in organic matter content having good agriculture potential. On the other hand the soils of the trappean pediplain area ranges from dark reddish brown to yellowish red colour which is attributed to intensive weathering of the soil profile, therefore having less fertile value and poor agriculture potential.

Soil-Water Interaction

Water is important to plant, both qualitatively and quantitatively. Soil is a medium that stores and moves water. Therefore soil-water interaction constitutes the most vital mechanism for the growth of plant and its produce. The significance of soil-water is manifold (Rai, 1995) viz. (i) promotes bio-physical activities, (ii) act as nutrient solvent carrier of nutrients, (iii) functions as an agent in photosynthesis and metabolic activities, (iv) maintains turgidity of plants, (v) act as an agent in soil forming processes, and (vi) maintains soil-temperature regimes.

There are four levels of soil moisture content that reflect the availability of water in the soil. These levels are commonly referred as: saturation, field capacity, wilting point and oven dry. The textural characteristics of soil plays very important role in soil-water interaction. The manifestation of soil texture holds important bearing in imparting the hydraulic characteristics of soil. The soil porosity is one such property, which channelies and store the water within soil mass. Therefore, considering a soil-water relationship soil-water may be classified in different forms (Richards, 1954).

(i) Hygroscopic water: This water is on the surface of the soil grains and is not capable of movement by the action of gravity or capillary forces.

(ii) Capillary water: That part in excess of hygroscopic water, which exists in the pore space of the soil and is retained against the force of gravity in a soil that permits unobstructed drainage. It is this water on which the growth of plant sustains.

(iii) Gravitational water: That part in excess of hygroscopic and capillary water, which will move out of the soil if the favourable drainage is provided.

There exists another soil moisture property i.e. Wilting Point, denoting the content of soil water in the soil at a water potential of -1500 *kPa* (Fig. 5.5); where most plants can't exert enough force to remove water from small pores.

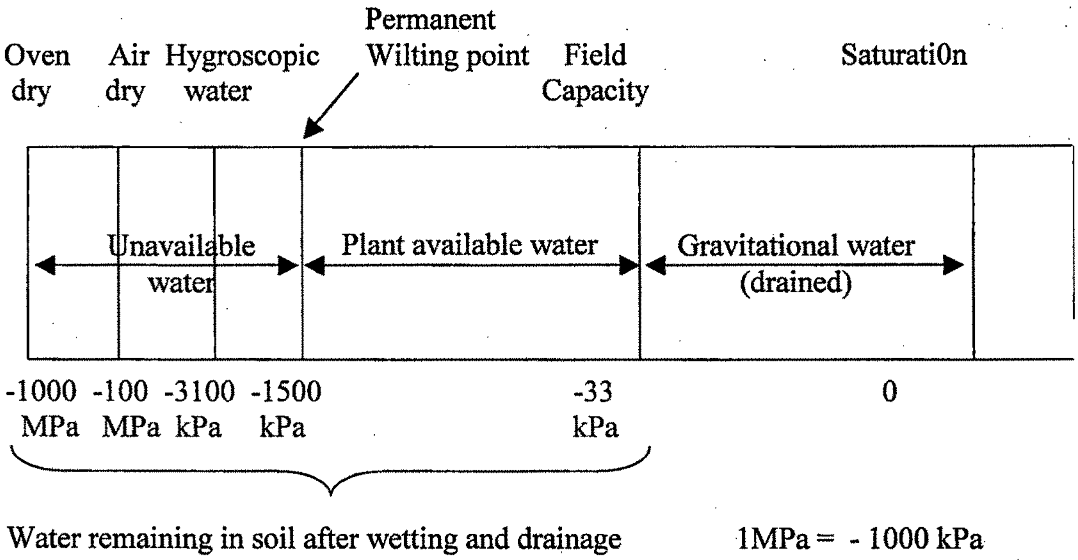

Fig. 5.5 Soil Water Constants and their Approximate Equivalents in kPa of Water Potential as They Affect the Relative Availability of Water to Plants.

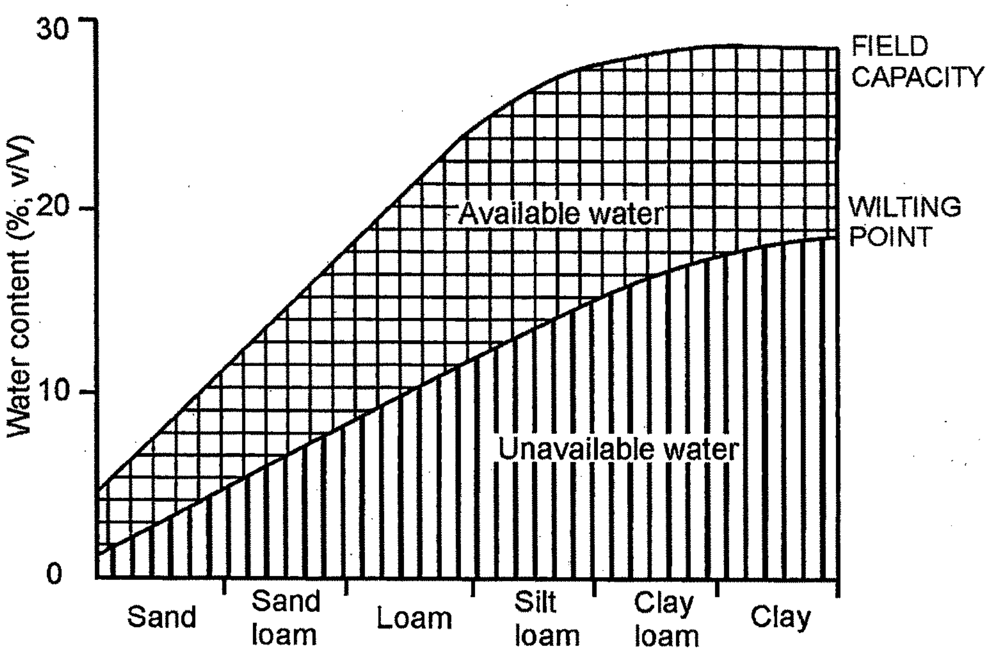

Fig. 5.6 Relationship Between Soil Texture, Field Capacity, Permanent Wilting Point, Available Water Capacity (Mclaren And Cameron, 1990).

The relationship between soil texture, field capacity, wilting point and soils' water holding capacity has been adequately depicted in the diagram (Fig. 5.6) by McLaren and Cameron (1990).

As the study area constitutes a part of major canal irrigation command, perennial irrigation has considerably influenced the basic soil characteristics thereby a variety of soil-water interrelated hazards like soil and water salinity, alkalinity etc. Some of the important soil-water interaction properties and their spatial level of variance are discussed as under:

The important properties that contribute to the soil salinity and waterlogging are water retentivity, hydraulic conductivity (permeability), and infiltration.

Moisture Holding Capacity (MHC)

This represents the approximate amount of water that a soil can retain following an irrigation (i.e. about 24-48 hours after the irrigation). By that time excess water is drained from the macro pores and the soil is at field capacity (Scherer et al, 1996).

In the KLBC area the observed water holding capacity varies from minimum 17.1 to as high as 77.2 percentage (Table 5.7). The highest range of MHC has been observed in Mindhola-Purna; Kaveri-Auranga; and Auranga-Par interstream areas, which are predominated by Chromic haplustepts type of soil, a relatively fine textured soil with abundance of clayey composition. In other interstream segments of KLBC this property shows marked variation, which may be attributed to minor textural changes in the soil fabric. Therefore the range of moisture holding capacity as indicated by the soil of the command area correlates well with the texture of the soils.

Table 5.7 Moisture Holding Capacity of the Soils in KLBC area.

Interstream Zones	MHC Range in %	
	Minimum	Maximum
Between Tapi and Mindhola Rivers	17.1	73.5
Between Mindhola and Purna Rivers	41.1	73.0
Between Purna and Ambica Rivers	18.9	72.6
Between Ambica and Kaveri Rivers	23.9	75.3
Between Kaveri and Auranga Rivers	43.7	77.2
Between Auranga and Par Rivers	41.6	76.0

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Available Water Holding Capacity (AWHC)

Available water holding capacity is the amount of water that a soil can store and is readily available for use by plants. It is that water, which is held between field capacity and the wilting point (Fig. 5.5). In areas where plants remove more water than the amount supplied by precipitation, the amount of available water that the soil can supply may be critical. This water is necessary to sustain the plants between rainfall events or periods of irrigation. The soil effectively buffers the plant root environment against periods of water deficit. Available water is expressed as a volume fraction (0.20), as a percentage (20%), or as an amount (in cm or inches). Available water capacity is commonly addressed for a common depth of rooting i.e. where 80 percent of the roots occur (USDA, 1998).

Numerous soil related parameters influencing the AWHC (USDA, 1970) are

(i) Presence of rock fragments reduces the available water capacity in direct proportion to their volume unless the rocks are porous.

(ii) Increased ratio of organic matter content increases the AWHC. Each 1 percent of organic matter adds about 1.5 percent to available water capacity (USDA, 1998).

(iii) Bulk density plays a role through its control of the pore space that retains available water. High bulk densities for a given soil tend to lower the available water capacity.

(iv) Osmotic pressure exerted by the soil solution is 0.3 - 0.4 times the electrical conductivity in mmhos/cm. A significant reduction in available water capacity requires an electrical conductivity of more than 8 mmhos/cm.

Table 5.8 Spatial Distribution (ha) of AWHC of Soils in KLBC Area.

Interstream Zones	AWHC Range			
	>12 cm	9-12 cm	6-9 cm	3-6 cm
Between Tapi and Mindhola Rivers	72973	1557	481	0
Between Mindhola and Purna Rivers	37213	590	394	46
Between Purna and Ambica Rivers	44987			
Between Ambica and Kaveri Rivers	24074	496	224	
Between Kaveri and Auranga Rivers	27694	192	976	
Between Auranga and Par Rivers	10376	316	99	109
Total Area	217317	3151	2174	155
Percentage	97.54	1.41	0.98	0.07

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

In the KLBC area almost 97% of the soils show the available water holding capacity greater than 12 cm (Table 5.8). Some of the area, which is lying between Mindhola-Purna and Auranga-Par interstream areas, depicts less than 6 cm AWHC. This again points to the fact that majority of soils in KLBC area are comprising large finer fractions i.e. silty clay - clayey nature, a fine textured soils.

Permeability

It's an ease of soil through which water is allowed to pass. The permeability is greatly influenced by the geometry of interstices and pore size distribution. On the effect of soil characteristics vis-à-vis permeability (Table 5.9), in the KLBC area, it is observed that rate of permeability is markedly reduced from coarse texture to fine textured soils i.e. from pediment plain - alluvium plain to coastal plain.

Table 5.9 Permeability Classifications of Saturated Soils (Smith and Browing, 1946).

Class	Permeability (cm/hr)	Comments
Extremely slow	< 0.0025	Nearly impervious, leaching is insignificant.
Very slow	0.0025 - 0.025	Poor drainage, too slow for artificial drainage.
Slow	0.025 - 0.254	Too slow for favourable air-water relations and for deep root development.
Moderate	0.254 - 2.54	Adequate permeability.
Rapid	2.54 - 25.4	Excellent water holding relations as well as excellent permeability
Very rapid	> 25.4	Associated with poor water holding capacity.

As majority of data on KLBC soil permeability (Table 5.10) fall within the range of 0.09 - 3.7 cm/hr and may be categorized in slow - moderate class of Smith and Browing (1946).

Table 5.10 Observed Permeability Range in KLBC Area.

Interstream Zones	Permeability (cm/hr.)	
	Minimum	Maximum
Between Tapi and Mindhola Rivers	0	3.2
Between Mindhola and Purna Rivers	0	2.37
Between Purna and Ambica Rivers	0.09	2.2
Between Ambica and Kaveri Rivers	NA	NA
Between Kaveri and Auranga Rivers	0.09	2.94
Between Auranga and Par Rivers	NA	NA

NA - not available (Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Infiltration

The length of time required for a given amount of irrigation water to be absorbed by the soil is one of the most important soil qualities to be considered in selection and design of irrigation methods. The basic infiltration rate is important in the design of drainage system and the fastness with which a soil can be leached. This is solely dependent on infiltration property of soil. Infiltration rate is dynamic and subject to change with elapsed time. When excess water is applied continuously to the soil surface, infiltration rate decreases with time (Garg and Gupta, 1997). The size of pores and structure of the soil also affect infiltration rate. Soils with coarse textured and blocky structure invariably having high infiltration capacity than the light textured soils. Based on textural characteristics of soils the National Cooperative of Soil Survey has classified the infiltration rates in to four distinct classes (Table 5.11).

Table 5.11 Classes of Infiltration Rates for Soils.

Sr. no.	Rate (in cm/hr)	Class	Remarks
1	< 0.25	Very Low	Very high percentage of clay
2	0.25 to 1.25	Low	Soils are shallow, high in clay and low in organic content.
3	1.26 to 2.5	Medium	Loamy and silty soil.
4	> 2.5	High	Deep sands, deep well aggregated silt loam and some tropical soils with high porosity.

The KLBC area shows marked variation in infiltration capacity (Table 5.12). The interstream area between Tapi and Mindhola Rivers, rate of infiltration varies from 0.19 cm/hr to 0.58 cm/hr, where in minimum rate 0.11 cm/hr has been observed at Dethali village while the maximum rate 0.76 cm/hr near village Bhairav. The highest infiltration rate has been observed at Tajpor village i.e. 7.62 cm/hr, which is attributed to the presence of very coarse textured soil.

Table 5.12 Infiltration Rate of Soils in KLBC Area.

Interstream Zones	Infiltration (cm/hr)	
	Minimum	Maximum
Between Tapi and Mindhola Rivers	0.11 (Dethali)	0.76 (Bhairav)
Between Mindhola and Purna Rivers	1.88 (Afwa)	7.62 (Tajpor)
Between Purna and Ambica Rivers	1.48 (Vedachha)	3.24 (Mahudi)
Between Ambica and Kaveri Rivers	0.18 (Samroli)	0.94 (Matwad)
Between Kaveri and Auranga Rivers	0.19 (Khambhada)	0.48 (Dhanori)
Between Auranga and Par Rivers	0.3 (Tithal)	1.05 (Dived)

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

SOIL CHEMISTRY

The chemical property of soil includes mineral solubility, nutrient availability, soil reaction (pH), cation exchange capacity, organic matter etc. Chemical properties of soil are more influenced by the clays and humus than by equal weights of the large silt and sand particles (Miller and Donahue, 1995). So far soil chemistry aspects of KLBC area are concern, the available information from the irrigation command authority on previous monitoring is very fragmentary. This has become a major constrain for the author to critically evaluate the secular changes and/or temporal and spatial behavioral pattern on the various parameters of soil chemistry. Hence, the evaluation of soil chemistry of KLBC area is solely based on scarcely available data, merely providing broad range of characteristics.

Soil pH

The pH of an aqueous solution is defined as the negative logarithm of the hydrogen ion activity in the solution. The hydrogen ions in soils are present primarily as exchangeable cations and an equilibrium exists between the hydrogen ions in solution and those on the exchange (Gupta, 1972). Since pH is a measure of hydrogen ion in solution; a change in salt concentration; CO_2 content or more dilution will result in pH change. Soil pH is important parameter to measure the severity in soils, i.e. alkalinity and acidity of soils (Rowell, 1994). The most productive normal soils having pH in the range of 6 to 8. Soils, which have pH >9.0 are harmful for growing crops (Muhur, et al, 1963).

Table 5.13 Chemical Characterization of Soils Based on pH of soil.

Soil pH	Type of Soil	Most Influential Cations
< 5.0	Very strongly acidic	Na+
5.0 - 5.5	Strongly acidic	
5.5 - 6.0	Medium acidic	
6.0 - 6.5	Slightly acidic	Ca^{++}, Mg^{++}, K^{+}, H^{+}, Al(OH)x
6.5 - 7.0	Very slightly acidic	
7.0	Neutral	
7.0 - 7.5	Very slightly alkaline	
7.5 - 8.0	Slightly alkaline	
8.0 - 8.5	Medium alkaline	H2SO4
8.5 - 9.0	Strongly alkaline	
> 9.0	Very strongly alkaline	

(After Way, 1968)

Table 5.13 amply demonstrates the chemical characterization of various soils (Way, 1968) with relation to pH, under field conditions.

pH is considered to be an important parameter as it is useful (i) in ensuring availability of plant nutrients e.g. Fe, Mn, Zn and Cu are more available in acidic than alkaline soils; (ii) in maintaining soil fertility; and (iii) to quantify amendments used for soil amelioration (Daji, 1996).

The data indicates that prior to inception of canal irrigation the pH was ranging between 7.1 and 8.7. After the introduction of canal irrigation there is perceived rise in the pH through out the command area. The latter data shows the pH is ranging between 7.1 and 9.6. The quantitative details on the observed ranges of pH values and the respective aerial coverage of the command area for surface and sub surface soils are given in Table 5.14 and 5.15. The pH data for both surface and subsurface soil shows that almost 80% of the KLBC area is having a pH ranging between 7.9 and 8.4, thereby indicating slightly to moderately alkaline nature of soils. The soils with in the Chalthan Branch in Tapi and Mindhola interstream area shows exceptionally higher pH i.e. more than 9. The higher pH, which is an indicative of very strong alkaline nature of soil, is attributed to waterlogging conditions. The decreasing trends in the aerial coverage of various pH ranges in surface and subsurface soils from north to south may be attributed to depleting thickness of alluvium aquifer.

Table 5.14 Aerial Extent (ha) of Surface Soil (< 90 cm) pH in KLBC Area.

Interstream Zones	pH range and Area (ha.)				
	6.6 - 7.3	7.4 - 7.8	7.9 - 8.4	8.5 - 9.0	>9.0
Between Tapi and Mindhola Rivers	45	5914	55565	13283	204
Between Mindhola and Purna Rivers		801	34643	2799	
Between Purna and Ambica Rivers			38361	6626	
Between Ambica and Kaveri Rivers	4234	5647	13864	1049	
Between Kaveri and Auranga Rivers	313	2228	24505	1816	0
Between Auranga and Par Rivers		894	9003	1003	
Total Area	4592	15484	175941	26576	204
Percentage	2.06	6.95	78.97	11.93	0.09

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Also, the initial rise in pH may be attributed to the change in crop pattern i.e. from rainfed irrigation to the irrigated agriculture and the increased intensity of cropping causing repetitive cycles of drying and wetting of the field. This has possibly causes accumulation of calcium as calcium carbonate and excess accumulation of sodium carbonate and/or sodium bicarbonate, ultimately leading to increase in pH (Way, 1968).

Table 5.15 Aerial Extent (ha) of Sub-surface Soil (> 90 cm) pH in KLBC Area.

Interstream Zones	pH range and Area (ha)				
	6.6 - 7.3	7.4 - 7.8	7.9 - 8.4	8.5 - 9.0	> 9.1
Between Tapi and Mindhola Rivers	16	5354	51381	17875	385
Between Mindhola and Purna Rivers		375	36350	1518	
Between Purna and Ambica Rivers			39282	5705	
Between Ambica and Kaveri Rivers	1988	4089	16326	2391	
Between Kaveri and Auranga Rivers	0	745	23822	3319	976
Between Auranga and Par Rivers		512	9570	818	
Total Area	2004	11075	176731	31626	1361
Percentage	0.90	4.97	79.32	14.19	0.61

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Electrical Conductance (EC)

Electrical conductance, which indicates the presence or excess of soluble salts in the soil, is considered to be a desirable beyond a certain limit. The electrical conductance of the soil is generally measured through electrolyte conductivity of the soil solution extracted from the saturated soil paste and it is denoted as EC. Conventially a soil having EC more than 4 mmhos/cm has been addressed as saline and less than 4 mmhos/cm as non-saline (Garg and Gupta, 1997). Also the most productive normal soils have EC less than 1.0 mmhos/cm (Richards, 1968). Owing to excessive salinity there is increase in the salt concentration in soil solution, as a result the flow of water into the plant by osmosis is reduced or reversed and the plant is starved of water even though the soil is moist. The conductivity scale indicating effect of salinity over plant growth and yield characteristics has been suggested by Garg and Gupta (1997) is given as under:

EC mmhos/cm	Plant Growth
< 1.5 (normal)	Normal for all crops
1.5 - 3.0 (low salinity)	Yields of very sensitive crops
3.0 - 5.0 (medium salinity)	Yields of many crops restricted
5.0 - 10.0 (high salinity)	Only tolerant crops yield satisfactory
> 10.0 (very high salinity)	Only few very tolerant crop yield satisfactory

The quantitative data on the Electrical Conductance of surface and sub-surface soils and the aerial coverage of KLBC area are given in Table 5.16 and 5.17. The data categorically shows that almost 80 % of the command area soils exhibits EC < 1. There is only 3 % command area showing higher than 3 EC values. These observed higher EC values may be attributed to the inherent saline nature of soils in coastal plain areas, where the EC value as high as 25 have been observed at Atta village.

Table 5.16 Aerial Extent (ha) of Salinity in Surface Soil (< 90 cm) of KLBC Area.

Interstream Zones	EC (mmhos/cm) Range and Area in ha.				
	<1	1 - 1.5	1.5 - 2.5	2.5 - 3.0	> 3.0
Between Tapi and Mindhola Rivers	55914	11623	3491	878	3105
Between Mindhola and Purna Rivers	31918	2319	1216	629	2161
Between Purna and Ambica Rivers	37232	4764	2838	153	
Between Ambica and Kaveri Rivers	23520	486	668	120	0
Between Kaveri and Auranga Rivers	27701	671	448	42	0
Between Auranga and Par Rivers	10322	280	135		163
Total Area	186607	20143	8796	1822	5429
Percentage	83.76	9.04	3.95	0.82	2.44

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Table 5.17 Aerial Extent (ha) of Salinity in Sub-surface Soil (> 90 cm) of KLBC Area.

Interstream Zones	EC (mmhos/cm) Range and Area in ha.				
	<1	1 - 1.5	1.5 - 2.5	2.5 - 3.0	> 3.0
Between Tapi and Mindhola Rivers	58971	8259	3446	794	3541
Between Mindhola and Purna Rivers	31401	2482	1912	284	2164
Between Purna and Ambica Rivers	28539	8994	6890	57	507
Between Ambica and Kaveri Rivers	19614	920	3674	466	120
Between Kaveri and Auranga Rivers	23981	1708	1618	0	1555
Between Auranga and Par Rivers	9728	131	523	175	343
Total Area	172234	22494	18063	1776	8230
Percentage	77.31	10.10	8.11	0.80	3.69

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Cation Exchange Capacity (CEC)

The soil is a heterogeneous poly dispersed material comprising solid, liquid and gaseous components in various proportions. In this heterogynous material system the soil solution acts as a medium by which numerous chemical and physical processes viz. weathering, nutrient adsorption, swelling and shrinkage of clay and leaching of electrolytes are facilitated. These processes are predominantly governed by the Base Exchange reactions, popularly known as cation exchange. The quantity of these cations that can be hold as exchanged, by a given amount of soil is the cation exchange capacity of that soil and generally expressed as the amount of exchangeable cations per unit weight of oven dry soil in centimoles/kg. Cation exchange is an important reaction influencing soil fertility, soil acidity and alkalinity, altering soil physical properties, and acts as mechanism for altering the quality of percolating waters. The plant nutrients calcium, magnesium and potassium are supplied to plants in large measure in exchangeable forms (Miller and Donahue, 1997).

The CEC is greatly dependent on textural characteristics of soils. The coarse textured soils are having far less CEC than the fine textured soils. A generalized relationship between CEC and the soil textures as suggested by Miller and Donahue, 1997 is given in Table 5.18.

Table 5.18 A Generalized Correlation Between Soil Texture and CEC.

Soil Texture	CEC (meq/100 gm)
Sands	1 - 5
Fine sandy loam	5 - 10
Loam and silt loam	5 - 15
Clay loam	15 - 30
Clay	> 30

Taking into account the major soil colloids responsible for most soil CEC; the humus represents the higher range of CEC (100 - 300) followed by vermiculite (80 - 150), montmorillonite (60 - 100) and kaolinite (2 - 8).

In the KLBC area the studies carried out by CW & PRS (1957) corroborates the predominance of black cotton soils and red soils. The black cotton soils are predominantly comprising montmorillonite clay minerals followed by kaolinite. Whereas the red soils it is kaolinite prevailing upon montmorillonite clay minerals. Accordingly the CEC is more prevalent in black cotton soil than the red soils.

Available quantitative data on CEC, prior to the inception of canal irrigation varies from 10 to 49.5 meq/100gm. However, the CEC in present irrigation domain shows marked increase and varies from 10.8 to 73.5 meq/100 gm (Table 5.19). This observed increase in CEC might be attributed to subsequent breaking of the soil under intensive tilling, irrigation and change in Eh - pH conditions (Miller and Donahue, 1997).

Table 5.19 Range of Soil's CEC in KLBC Area.

Interstream Zones	CEC Range meq/100 gm	
Between Tapi and Mindhola Rivers	10.8	73.5
Between Mindhola and Purna Rivers	31.7	58.9
Between Purna and Ambica Rivers	33.5	63.2
Between Ambica and Kaveri Rivers	27.5	57.6
Between Kaveri and Auranga Rivers	25.3	69.6
Between Auranga and Par Rivers	15.3	64.5

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Exchangeable Sodium Percentage (ESP)

ESP is the percentage cation exchange capacity, occupied by sodium and usually defines the physical character of the salt affected soil. The ESP is usually considered as a good indicator of the structural stability of soil and of the physical response when the degree of saturation increases (Garg and Gupta, 1997). The presence of exchangeable sodium is in the form of sodium carbonate that causes considerable changes in the physical characteristics of soil, particularly the shrinkage. This shrinkage greatly influences the ultimate pore spaces; thereby soil salinity (Hesse, 1994). Sources of extractable sodium in alkali soil mainly derived from (i) losses originated by in-situ weathering of sodium rich feldspar or sodium bearing parent material (Wilding, 1963), (ii) transformation of sodium silicate in weakly mineralized groundwater from igneous rocks (His and Chao, 1962). Change in the ESP values is directly related with the clay content and the alkalinity of the soil. It has also been observed that the change of pH is directly proportional to the ESP (Abrol et al, 1980).

ESP is the most important parameter for characterizing the saline and alkaline nature of the soils. The saline soils are normally classified by taking the basis of ESP < 15 and saline-sodic soils > 15 (Richards, 1954).

Table 5.20 Range of Soil's ESP in KLBC Area.

Interstream Area	Range (%)	
	Min.	Max.
Between Tapi and Mindhola Rivers	0.35	13.0
Between Mindhola and Purna Rivers	1.00	12.4
Between Purna and Ambica Rivers	1.02	6.22
Between Ambica and Kaveri Rivers	1.37	5.43
Between Kaveri and Auranga Rivers	0.55	9.15
Between Auranga and Par Rivers	0.58	15

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

In the KLBC area ESP values show a wide range from 0.35 to 15 %. The highest value of ESP (21.19%) is observed in village Kosamba, of Valsad Taluka, indicating severe alkali hazards. Table 5.20 indicates high alkali hazard in Auranga and Par interstream area.

ORGANIC MATTER (OM)

Organic matter is an essential component of soil because it:

- Holds soil particles together and stabilizes the soil, thus reducing the risk of erosion,
- Aids crop growth by improving the soil's ability to store and transmit air and water,
- Stores and supplies many nutrients needed for the growth of plants and soil organisms,
- Maintains soil in an uncompacted condition, making it easier to work
- Retains carbon from the atmosphere
- Reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants; (Gregorich et al, 1995).

Soil organic matter is affected by climate, vegetation, parental composition, topography, land use pattern and agricultural practices (USDA, 1966).

In the KLBC area, soils' organic matter content varies between 0.03 and 0.99 % (Table 5.21).

Table 5.21 Range of Soil's Organic Matter in KLBC Area.

Interstream Area	OM Range (%)	
	Minimum	Maximum
Between Tapi and Mindhola Rivers	0.06	0.99
Between Mindhola and Purna Rivers	0.03	0.99
Between Purna and Ambica Rivers	0.03	0.99
Between Ambica and Kaveri Rivers	0.12	0.94
Between Kaveri and Auranga Rivers	0.20	0.92
Between Auranga and Par Rivers	0.09	0.98

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

Calcium Carbonate Content

Calcium carbonate in soil plays an important part in soil fertility. Though the amount of calcium, which is required by crops is not large and the crops rarely suffer by calcium deficiency, however the indirect effects of deficient calcium may be marked one, especially in neutralizing soil acidity, improving soil structure, soil tilth and soil permeability (CW&PRS, 1952). The presence of calcium carbonate affects both physical and chemical characteristics of a soil. Knowledge of the presence of high content very fine $CaCO_3$ particles gives warning of a risk that lime induced chlorosis may affect crops (Way, 1968). The presence of carbonates normally reduces the ability of calcareous soils to retain moisture.

Based on the available data of KLBC area it has been observed that the amount of calcium carbonate is ranging from nil to as high as 19.5 % in the surface and subsurface soil horizons (Table 5.22).

Table 5.22 Range of Soil's Calcium Carbonate in KLBC Area.

Interstream Zones	$CaCO_3$ range in %	
Between Tapi and Mindhola Rivers	0.5	15
Between Mindhola and Purna Rivers	0	19.5
Between Purna and Ambica Rivers	0	19
Between Ambica and Kaveri Rivers	1	14.5
Between Kaveri and Auranga Rivers	1	14
Between Auranga and Par Rivers	1	13.5

(Source: Soil Drainage and Reclamation Circle Report, 1993-2001)

LAND IRRIGABILITY CLASSIFICATION

The interpretation of soil and land conditions for irrigation is concerned primarily with predicting the behavior of soils under the greatly altered water regime brought about by introduction of irrigation. For irrigation projects, interpretation are required to indicate the areas suitable for irrigation, crops that may be grown and yields that may be expected, water delivery requirements, land development needs, problems in drainage and special reclamation practices.

For individual farms, which are under well irrigation, and water quality is good along with drainage is not likely to pose any problem; the land capability classification (Table 5.23) may be applicable for classifying the land (Klingediel & Montgomery, 1961).

Other side for irrigation projects, special interpretations and classification of soils for sustained use is advisable. Soil irrigability classes (Table 5.24 & 5.25) are useful to make grouping of soils according to their suitability for sustained use under irrigation. The classes are defined in terms of the degree of soil limitations. Criteria for each class are given in terms of ranges of soil properties, which are considered to be essential.

Table 5.23 Land Capability Classification for Well Irrigated Lands. (After IS: 5510, 1969 and Soil Survey Manual, 1970)

Class	Description
I	Soils in class 1 have few limitations that restrict their use.
II	Soils in class 2 have some limitations that reduce the choice of plants or require moderate conservation practices
III	Soils in class 3 have severe limitations that reduce the choice of plants, require special conservation practices, or both
IV	Soils in class 4 have very severe limitations that reduce the choice of plants, require very careful management, or both
V	Soils in class 5 have little or no erosion hazards but have other limitations, impractical to remove, that limit their use largely to intensive pasture or range, woodland, or wildlife food or cover. (Note: usually wet soils).
VI	Soils in class 6 have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food or cover.
VII	Soils in class 7 have very severe limitations that make them unsuited to cultivation and limit their use largely to extensive grazing, woodland, or wildlife.
VIII	Soils and landforms in class 8 have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or to aesthetic purposes.

Note: Increasing class number restricts the intensity of land use. There is thus an implicit ranking of major kinds of land uses: very intense cultivation (1), intense cultivation (1-2), moderately intense cultivation (1-3), limited cultivation (1-4), intense grazing (1-5), moderate grazing (1-6), limited grazing (1-7), forestry (1-7), wildlife (1-8).

Use of soil irrigability classes and slope criteria for land classes allows interpretation of soil surveys for irrigation before the completion of engineering and other studies such as location of main canals, quality of water and quantity available, economics and technical feasibility of drainage etc.

Table 5.24 Soils Irrigability Classes and their Characteristics.

Class	Irrigability of Soil
A	None to slight soil limitation for sustained use under irrigation
B	Moderate soil limitations for sustained use under irrigation
C	Severe soil limitations for sustained use under irrigation
D	Very severe soil limitations for sustained use under irrigation
E	Not suited for irrigation (or non irrigable soil class)

Table 5.25 Soil Irrigability Classes of Semi-Arid and Arid Regions.

Soil Properties	Soil Irrigability Classes				Non-Irrigable Soils
	A	B	C	D	
Effective Soil Depth; Useful to crops (cm)	> 90	45-90	22.5-45.0	7.5-22.5	<7.5
Texture of Surface Soil (30 cm)	Sandy Loam to Clay Loam	Loamy Sand; Clay	Sand; Clay	Sand; Clay	Any Texture
Soil permeability (of least permeable layer) (mm/hr) +	5.0 - 50	(1-3.5) - (50-130)	(0.3-1.3) - (130-250)	<0.3 & >250	Not Applicable
Available water holding capacity (cm)	> 12	9-12	6-9	2-6	Less than 2
Coarse fragments >75 mm (%)	< 5	5-15	15-35	35-65	Less than 65
Gravel and Kankar 25-75 mm (%)	< 15	15-35	35-55	55-70	Less than 70
Rock out-crops (distance in m.)	40	20	15	5	Less than 5
Salinity (EC X 10^3) mmohs/cm	< 4.0 (<1.0)*	4-8 (1 - 1.5)*	8-12 (1.5 - 2.5)*	12-16 (2.5 - 3.0)*	> 16 (> 3.0)*
Salt Affected (visual) area in %	Less than 20		20 - 50		Less than 50
Severity of Alkali Problem (%)	ESP Less than 15		ESP More than 15		Less than 15
Sub-soil drainage characteristics	Lower sub-soil is at least moderately permeable or a permeable layer of at least 6" thickness occurs immediately below the soil but within 10 feet.		No moderately permeable sub-soil or other permeable layer of at least 6" thickness occurs within depth of 10 feet.		
Soil erosion status	Effects of sheets and rill erosion are reflected in effective soil depth, available moisture holding capacity and in some other factors shown above. Moderately of severely gullied soils may be classified based on local experience.				

+ - Soil permeability as a criteria is not applicable to deep black soils because of their unique properties. Deep black soils, which are inherently slowly permeable due to expanding 2:1 lattice type minerals, do not quality for being placed in B, C and D class.

* - Recommended by IS: 5510:1969.

The suitability of land for irrigation depends upon physical and socio-economic factors in addition to the soil irrigability class. Among these considerations, in addition to soil suitability in deciding upon suitability of land for irrigation are (I) quality and quantity of water, (ii) drainage requirements, (iii) economic considerations. The specifications for land irrigability classification are given in Table 5.26. The area is by and large having black cotton soil hence permeability is not considered for land irrigability classification.

Table 5.26 Land Irrigability Classification.

Land Characteristics	IRRIGABLE LAND CLASS					
	Class I	Class II	Class III	Class IV	Class V	Class VI
	SOILS					
Soil Irrigability Class	A	A to B	A to C	A to D	Further investigations needed	Includes lands, which do not meet the minimum requirements for the other land classes and are not suitable for irrigation or small isolated tracts not susceptible to delivery of irrigation water.
TOPOGRAPHY						
1 Slope	< 1%	1 - 3%	3 - 5%	5 - 10%		
2 Surface Grading	No restriction	Moderate restriction	Moderate to severe restriction	Severe restriction		
DRAINAGE						
1 Outlets	Suitable outlets available	Suitable outlets available	Suitable outlets available	No drainage outlets available		
2 Surface	Less than __ m of shallow surface drains required per acre	Less than __ m of shallow surface drains required per acre	Develop specifications			
3 Subsurface	No subsurface drainage needed; or land is within ___ m of adequate drainage way	No subsurface drainage needed; or land is within ___ m of adequate drainage way	Subsurface drainage needed. Specifications to be developed.	No natural drainage outlets available; cost of pump off drainage exceed ___ Rs/ha.		
4 Depth of Water Table	More than 5 m	3.0 - 5.0 m	1.5 - 3.0 m	< 1.5 m		

(Source: IS: 5510:1969, IARI, 1970)

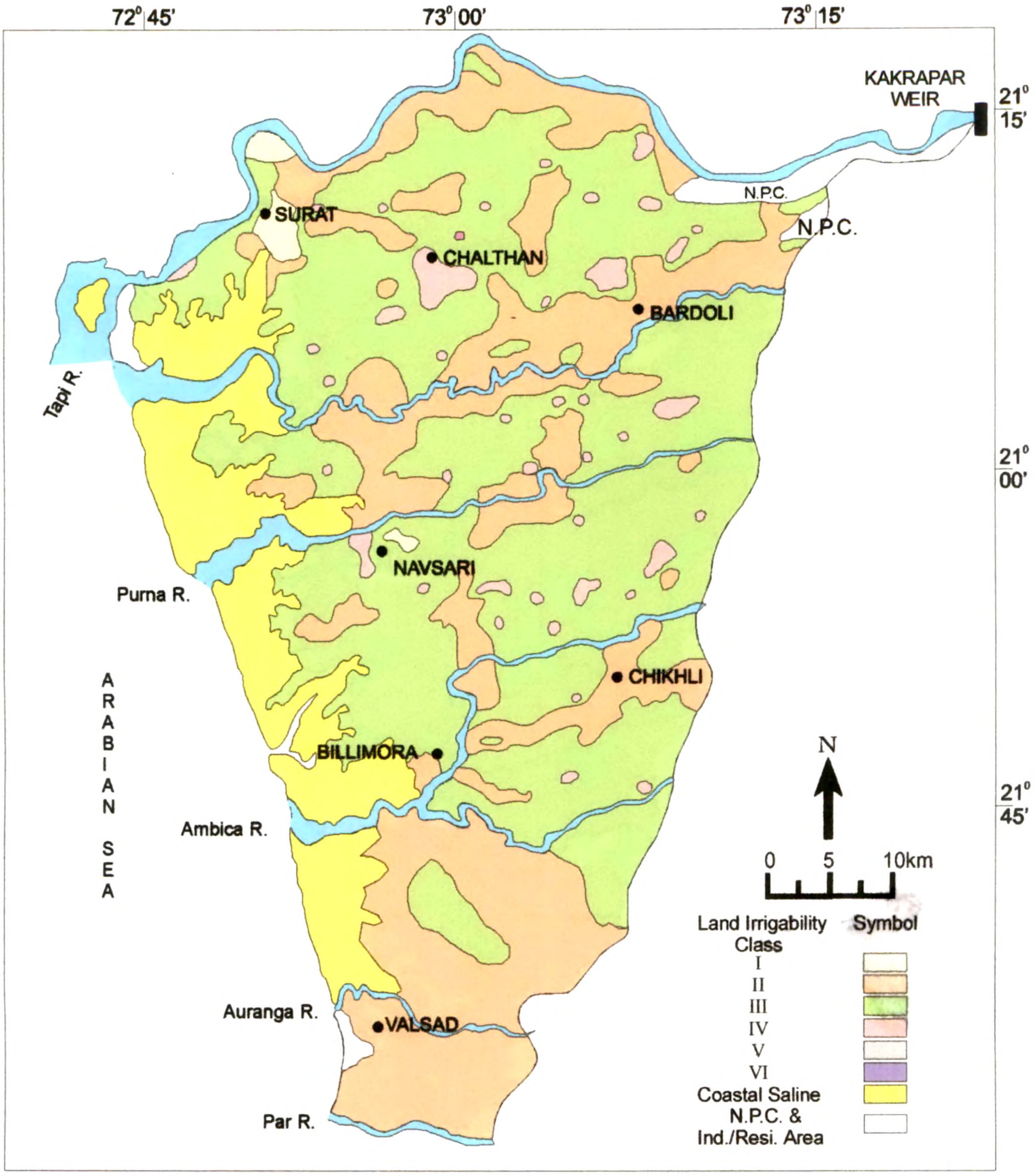

Fig. 5.7 Land Irrigability Classification During Initial Phase (1970) of Canal Irrigation in KLBC Area.

In contrast to this under the present (2001) irrigation scenario (Fig. 5.8); the command area shows sharp - moderate shift in various soil irrigability classes. Where in the Class - III shows sharp decrease i.e. 52% in its aerial coverage and significant increase (i.e. 15%) in Class - II. Similarly the other soil irrigability classes shows marked increase in their aerial coverage viz. Class - I (0.58 to 2.63 %), Class - IV (2.34 to 4.13 %) and Class - V (0.0 to 0.58 %).