Chapter 5
Soil & Sub-soil Characteristics

CHAPTER 5

SOIL AND SUB-SOIL CHARACTERISTICS

Efficient use of water for sustained irrigated agriculture necessitates an in depth knowledge on different kind of soils, soil morphology, physico-chemical characteristics, soil irrigability problems (salinity and alkalinity), their extent and distribution in the command area. Therefore, the information on soil and sub-soil characteristics within a potential irrigation area is prerequisite for its various stages of planning and development. Soil is the natural dynamic body developed as a result of pedogenic processes that take place during and after weathering of rocks and it supports plants and other biotic lives. The weathered mineral matter is generally transformed in to the soil through a variety of residual processes such as (i) humification, (ii) eluviation and illuviation, and (iii) horizonation (Bear, 1964). The pedological processes are governed by the number of factors viz., parental material type, climate, topography, biota (plants and animals) and time. Combination of these factors and their inter play ultimately develop the soil, however, the major role is played by the climatic factor.

SOILS OF GUJARAT

The Gujarat is a unique state in India, which is characterised by a large number of agro-climatic zones. The diversity in its climatic zones i.e. humid-sub-humid, semi-arid and arid coupled with a variety of surficial processes has given rise to different soil types. The soils of Gujarat have been broadly classified in to nine groups viz., Black Soil, Mixed Black and Red Soil, Residual Sandy Soil, Alluvial Soil, Forest Soils, Lateritic Soils, Hilly Soils, Saline/sodic Soils, and Desert Soil (Kanzaria and Patel, 1985). Following the International Standard Classification of soils (7^{th} Approximation, USDA, 1978), the National Bureau of Soil Survey and Land Use Planing (NBSS-LUP) have classified the soils of Gujarat in to ten sub-orders, i.e., (i) Uster-Ochrepts, (ii) Orthents-Ochrepts, (iii) Orthid-Aquepts, (iv) Ochrepts-Psamments, (v) Orthids-Argids, (vi) Orthid-Psamments, (vii) Orthents-Rock outcrops, (viii) Orthents-Tropepts, (ix) Tropepts-Aquepts, and (x) Ochrepts-Orthents.

As the climate plays an important role in soil genesis; the characteristic type and aerial extent of the various soil orders are accordingly dominating (Fig. 5.1). Out of these ten orders the first four soil associations along with fifth and sixth (in combination) have extensive distribution in the state. Detailed account on the soil genesis, taxonomic characters, physico-chemical environment and agroclimatic significance of the various soil taxa have been studied by Roy and Verma (1988).

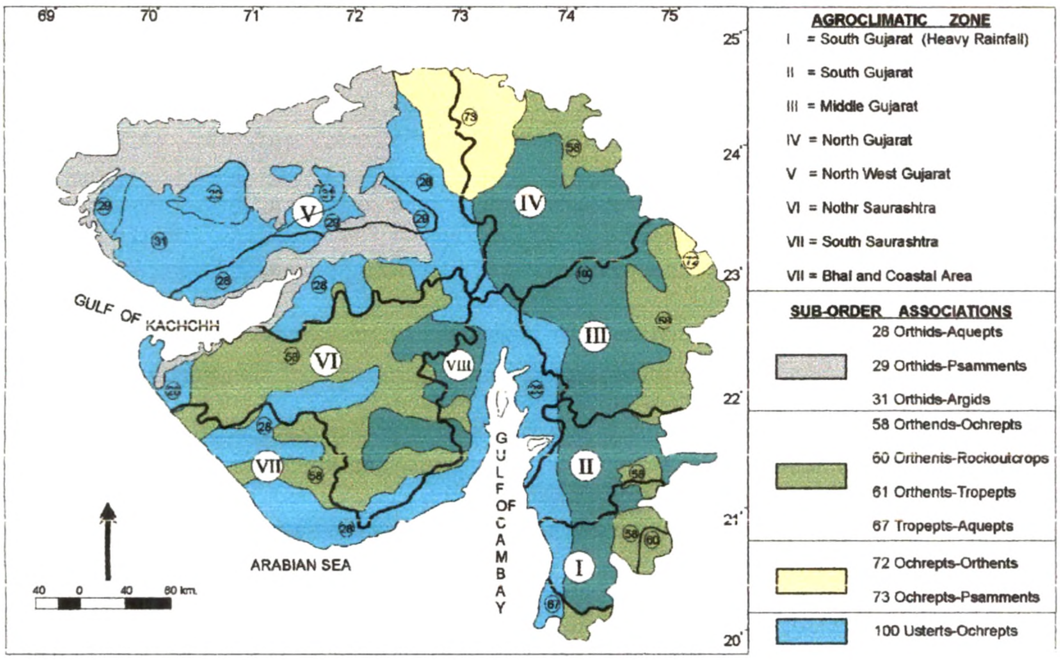

Fig. 5.1 Soils of Gujarat (After Kalyanasundaram and Patel, 1995)

SOIL CHARACTERISTICS OF MRBC AREA

Soil compositions and textural characteristics are the manifestation of geological and climatic influences. Geological factors encompass the nature of parental sediments and surficial processes responsible in defining the complete denudational system for providing the material influx. On the other hand, the climatic factor governs the process of pedogenization and the development of soil.

It has already been discussed in the preceding chapter on Geological set-up that the study area constitutes a part of central Gujarat alluvium plains; comprising the admixture of sand-silt-clay derived under the fluvial and fluvio-marine environments (Islam, 1986). These alluvial materials have been brought by the rivers viz. Mahi, Watrak, Shedhi and Sabarmati; draining through varied provenance of Pre-Cambrian metasedimentaries and crystalline, Deccan Traps and the sedimentary sequence belonging to Tertiaries and Cretaceous age. Therefore, owing to varied and complex nature of parental sediments, the MRBC area is characterised by the mixed soil types. The soils are by and large brown to reddish brown in color and of varying in textures i.e. sandy loam-loamy sand and clayey texture (Kanzaria and Patel, 1985).

BASIC SOIL TYPES IN MRBC AREA

Nature of sediments and relative abundance or absence of a particular mineralogical content in any soil ultimately develops the soil texture. The pedogenic process governed by the factors of climate and interstitial drainage coupled with degree of base saturation further helps in fixing the compositions of soil and its various intergrades. The soils in MRBC area are pre-dominated by montmorillonite to illite clay minerals and their intergrades. Based on the available works (e.g. Maliwal, 1989; Singh et. al. 1993; Singh and Nayak, 1999; amongst others) the author has compiled the information on different soil types in MRBC area. A critical appraisal on MRBC area soils, encompassing the details on various soil types, soil boundaries (Fig. 5.2) based on morphological and textural characteristic have been described.

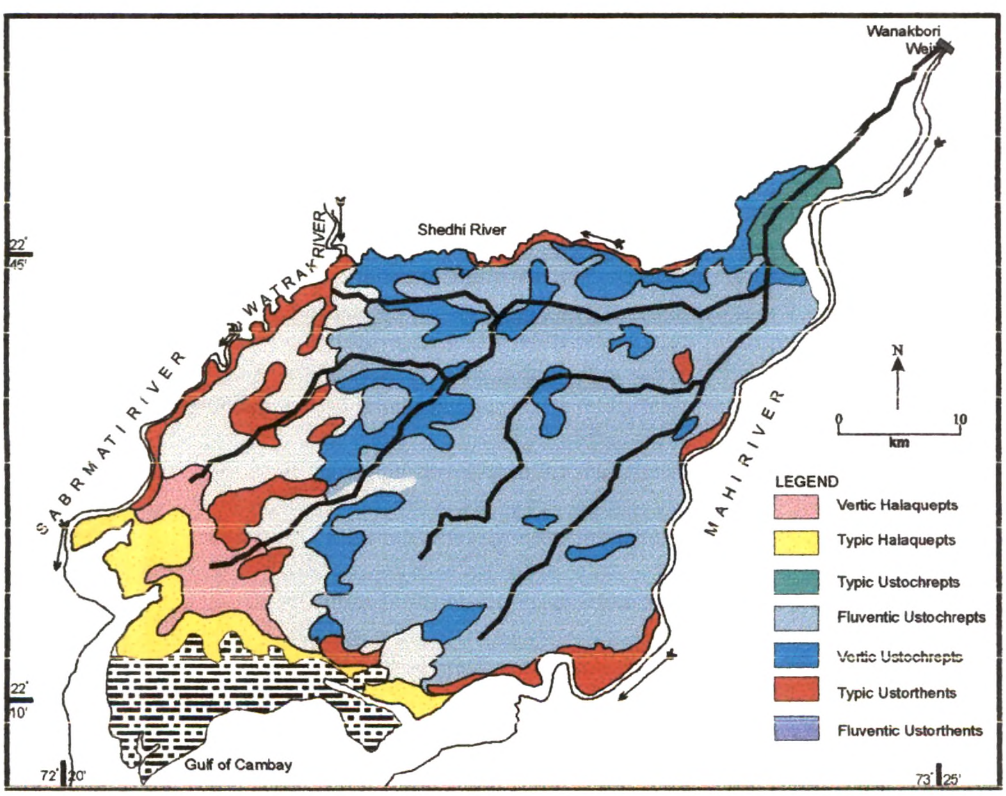

Fig. 5.2 Soils of MRBC command Area

Vertic Halaquepts soils are characterised by Montmorillonitic saline clayey nature. These soils are by and large occurring at the terminal end of the command area i. e. at the mouths of the Mahi and Sabarmati rivers. These soils are poorly drained, very deep and montmorillonitic in compositions with alluvial origin. Occupying nearly leveled to very gently sloping mid-low land situation of the flood plain, the pedon exhibits A-B-C horizon sequence. Average thickness of solum varies from 90-120 cm. Some times lime nodules of 2-3 mm diameter and coarse rock fragments of similar size occur within the solum. C-horizon is characterised by abundant lime nodules. Also exhibits cracks of about 2 to 3 cm wide with the maximum depth upto 50 cm especially under dry condition. Soils vary from saline to alkaline in nature. The electrical conductivity varies from 1.5 to 40 ds/m in 1:2 soil water suspension. Soils have very poor water transmission characteristics and effective rooting depth varies from 30 to 50 cm. Annual ground water fluctuations between 0.5 to 3.0 m.

Typic Halaquepts soils are characterised by saline clay soil with mixed mineralogy and bordering the saline montmorillonitic soils, as a part of the raised mud flats along the Gulf of Cambay and occupying slightly elevated and gently sloping positions as compared to saline montmorillonitic soils. The soils are characterised by mixed mineralogy and poor drainability, the pedon exhibit A-B-C horizons and the solum thickness varies from 90 to 120 cm; saline to alkali in nature and have highly saline water table in the substratum. The annual water table fluctuates between 40 cm to 3.0 m with shallow effective root zone.

Typic Ustrochrepts, typical of non-saline medium textured soils of lower piedmont plain with mixed mineralogy. Occupying nearly level to very gently sloping upper terraces of the alluvial plain; the pedon exhibits A-B-C horizons with soil texture varying from sandy loam to sandy clay loam and weak to moderate sub-angular blocky structure. The groundwater table varies from 0.5 to 2 m below the surface with varying in composition from non-saline to slightly saline.

Fluventic Ustrochrepts, the coarse textured illitic non-saline soils of the upper terraces and occurs beyond the levees occupying upper and flat flood plains with gentle slopes in middle portion of the command area. Very deep non-calcareous soils; pedon exhibits A-B-C horizons with sandy loam to clay loam texture and loose to moderate medium sub-angular blocky structure; average thickness of the solum varies from 100 to 130 cm and the effective rootzone depth varies from 4 to 6 m depth.

Vertic Ustrochrepts characterised by non-saline clay soils with montmorillonitic mineralogy. These soils are associated with level to very gently sloping lower piedmont plain in middle part of the command area. The pedon exhibits A-C or A-B-C horizon; soil texture usually remains clayey and the structure varies from moderate to strong coarse angular blocky; a typical black soils suffering from salinity and alkali hazards. Effective root zone varies from 40 to 60 cm, the annual ground water fluctuation between 0.5 to 3.0 m depth.

Typic Ustorthents, typical coarse textured illitic and stratified non-saline soils of recent origin and occupies levees associated with palaeochannels in command area. These soils represent indistinct horizons and can be denoted as immature soils. Average thickness varies form 50 to 120 cm and coarse texture with low salinity levels.

Fluventic Ustorthents, the non-saline medium texture soils with mixed mineralogy occupying an elevated position than the previously discussed Vertic Halaquepts and Typic Halaquepts. Moderately drained very deep soils of alluvial origin with distinct A-B-C horizons. Soil texture usually remains loam however structurally moderate, medium sub-angular blocky. Usually characterised by the deeper water table, seldomly getting shallower than 1 m. Effective root zone depth remains more than 1 m with favorable texture and lack of saline/alkaline condition.

SOIL PROPERTIES

Study and evaluation of physical and bio-chemical properties of the soils are of foremost importance in exploring the suitability of soils for irrigation and landuse planning. In order to have a broad assessment of MRBC areas' soil characteristics, the author has carried out an extensive and critical survey on the available information. An overall quantitative appraisal on study on soils' physical and biological attributes is given in Table 5.1. Also the soils have been classified by taking the basis of land capability ratings for irrigation practices (USDA, 1978). Soils' property specific details are discussed as under:

Table 5.1 Physico-Chemical Characteristics of the Soil Series in the MRBC Command Area.

Soil Series	Location	Soil Depth cm	Sand %	Silt %	Clay %	Tex Class	pH	EC mmohs/cm	Bulk Density gm/cc	K (m/s X 10^{-7})	OM %
1	2	3	4	5	6	7	8	9	10	11	12
Vertic Halaquepts	Khaksar Cambay	0-22	40.60	13.00	46.40	C	8.30	8.50	1.50	2.80	0.90
		22-58	36.90	13.60	49.50	C	8.60	8.50	1.40	2.60	0.78
		58-96	35.80	14.90	49.30	C	9.30	3.50	1.20	2.60	0.55
		96-122	33.20	14.00	52.80	C	9.40	2.30	1.20	2.50	0.34
		122-150	33.50	12.50	54.00	C	9.40	1.60	1.30	2.40	0.28
Typic Halaquepts	Mitli Cambay	0-18	44.80	10.50	44.70	C	8.00	9.00	1.20	3.90	0.95
		18-46	42.70	10.40	46.90	C	8.20	8.10	1.06	3.70	0.52
		46-88	43.80	8.50	47.70	C	8.40	7.00	1.30	3.60	0.45
		88-118	35.90	12.60	51.50	C	8.50	6.30	1.30	3.50	0.34
		118-150	36.30	12.00	51.70	C	8.80	3.60	1.40	3.40	0.24
Typic Ustochrepts	Agarwa Thasara	0-16	47.50	18.50	34.00	CL	8.20	0.30	1.40	16.50	1.03
		16-48	46.20	18.00	35.80	CL	8.20	0.32	1.20	14.20	0.90
		48-62	46.00	19.00	35.00	CL	8.30	0.28	1.20	15.60	0.69
		62-92	45.10	20.50	34.40	CL	8.50	0.26	1.10	14.30	0.62
		92-122	41.00	21.00	38.00	CL	8.60	0.24	1.20	13.00	0.34
		122-150	38.70	31.50	39.80	CL	8.60	0.22	1.20	11.40	0.24
Fluventic Ustochrepts	Mogri Anand	0-20	56.40	23.00	19.80	CL	7.20	0.36	1.40	32.30	0.90
		20-50	54.00	24.40	21.60	SCL	7.60	0.36	1.40	29.40	0.62
		50-80	54.20	23.70	22.10	SCL	7.70	0.30	1.10	26.40	0.52
		80-120	56.10	22.90	21.00	SCL	8.00	0.28	1.20	30.10	0.33
		120-150	51.80	25.20	23.00	SCL	8.00	0.28	1.20	25.00	0.31
Vertic Ustochrepts	Bhadrapura Thasara	0-20	33.70	26.10	40.20	C	7.80	0.20	1.30	5.70	0.97
		20-70	32.80	20.50	46.70	C	7.70	0.15	1.20	6.00	0.86
		70-110	36.50	18.70	44.80	C	7.60	0.10	1.20	5.30	0.69
		110-150	32.40	21.80	45.80	C	7.50	0.10	1.20	5.00	0.55
Vertic Ustochrepts	Ratanpur Anand	0-25	37.60	24.00	38.40	CL	7.90	0.11	NA	NA	0.81
		25-60	34.10	26.10	39.80	CL	7.80	0.11	NA	NA	0.79
		60-120	37.70	24.00	38.30	CL	7.70	0.10	NA	NA	0.34
		120-150	37.30	24.70	38.00	CL	7.60	0.10	NA	NA	0.34

1	2	3	4	5	6	7	8	9	10	11	12
Vertic Ustochrepts	Bamangam Cambay	0-20	38.30	21.00	40.70	C	7.60	0.18	NA	NA	0.86
		20-50	37.80	21.70	40.50	C	7.60	0.12	NA	NA	0.79
		50-90	37.70	21.20	41.10	C	7.70	0.10	NA	NA	0.72
		90-120	34.40	24.10	41.50	C	7.80	0.10	NA	NA	0.55
		120-150	27.80	28.50	43.70	C	7.80	0.10	NA	NA	0.52
Typic Ustorthents	Rel Cambay	0-20	65.30	19.60	15.10	SL	8.40	0.43	1.30	46.80	0.55
		20-45	62.00	22.00	16.00	SL	8.40	0.40	1.10	45.60	0.52
		45-90	64.00	18.50	17.50	SL	8.60	0.17	1.20	42.10	0.38
		90-120	65.20	16.50	18.30	SL	8.60	0.10	1.10	38.10	0.31
		120-150	60.40	20.60	19.00	SL	8.60	0.10	1.20	38.00	0.24
	Harkhol Cambay	0-15	67.40	15.40	17.20	SL	8.20	0.42	NA	NA	0.72
		15-40	64.80	16.80	18.40	SL	8.40	0.31	NA	NA	0.69
		40-65	60.40	20.60	19.00	SL	8.40	0.20	NA	NA	0.62
		65-115	60.60	21.20	18.20	SL	8.60	0.17	NA	NA	0.52
		115-150	58.50	22.70	18.80	SL	8.60	0.10	NA	NA	0.48
	Vasna Cambay	0-20	62.00	22.40	15.60	SL	8.10	0.34	NA	NA	0.45
		20-60	61.90	20.60	17.50	SL	8.10	0.34	NA	NA	0.45
		60-90	57.10	23.60	19.30	SL	8.20	0.17	NA	NA	0.41
		90-115	58.30	23.00	18.70	SL	8.40	0.10	NA	NA	0.34
		115-150	56.60	24.40	19.00	SL	8.40	0.10	NA	NA	0.31
	Matar Matar	0-15	69.50	16.40	14.10	SL	8.40	0.48	NA	NA	0.52
		15-45	63.10	18.20	18.70	SL	8.40	0.31	NA	NA	0.53
		45-90	56.20	24.60	19.20	SL	8.40	0.16	NA	NA	0.55
		90-130	59.80	29.80	20.40	SL	8.60	0.15	NA	NA	0.34
		13-155	57.80	21.60	20.60	SL	8.60	0.10	NA	NA	0.24
Fluventic Ustorthents	Dhundakuva Petlad	0-20	62.90	18.40	18.70	SL	7.80	0.08	1.20	37.50	0.69
		20-50	61.60	20.00	18.40	SL	8.00	0.08	1.20	34.70	0.52
		50-90	57.20	20.60	22.20	SL	8.20	0.06	1.20	33.00	0.41
		90-120	55.20	21.40	23.40	SL	8.50	0.07	1.20	NA	0.45
		120-150	54.60	21.60	23.80	SL	8.50	0.06	1.20	NA	0.34

C = Clay, SCL = Sandy clay loam, SL = Sandy Loam, CL = Clayey loam, NA = Data not available

PHYSICAL CHARACTERISTICS

Soil Depth

It refers to the thickness of the soil, which normally provides structural support, nutrients, and water to the plants. The vertical extent of soil is an important guiding factor for penetration of plant roots and its irrigability. Root penetration in the soil inhibited by mechanical factors (hard or impenetrate horizon), chemical factors (zone of high lime or gypsum content) or poor drainage (Scherer, 1996). According to the USDA (1978) the suitability of soils based on rated depth classes is

Irrigation Suitability Group	Depth in cm
Highly Suitable (S_1)	> 90
Moderately Suitable (S_2)	45-90
Marginally Suitable (S_3)	30-45
Currently not Suitable (N_1)	20-30
Permanently not Suitable (N_2)	<20

Looking to the physical data (Table 5.1) of the different soil series, it is inferred that entire MRBC area soil has thickness of soil more than 90 cm and hence it falls under the Highly Suitable class (S_1).

Soil Structure

Soil structure refers to the grouping of particles of sand, silt, and clay into larger aggregates of various sizes and shapes. The processes of root penetration, wetting and drying cycles, freezing and thawing, and animal activity combined with inorganic and organic cementing agents produce soil structure (USDA, 1978). Structural aggregates that are resistant to physical stress are important for maintaining the soil tilth and productivity. Practices such as excessive cultivation or tillage of wet soils disrupt aggregates and accelerate the loss of organic matter causing decreased aggregate stability. The movement of air, water, and plant roots through a soil is affected by soil structure.

Stable aggregates result in a network of soil pores that allow rapid exchange of air and water with plant roots. (Scherer, 1996; USDA, 1978). Bulk density serves as an important means for classifying the soil structure, as well as its irrigability (Klocke, 1999; Rai, 1995 and Brady, 1995). USDA (1978) ratings defining various soil groups are:

Structure of Soil	Irrigation Suitability Group	Bulk Density 'gm/cc'
Sub-angular blocky, crumbled	Highly Suitable (S_1)	< 1.50
Single Gram, angular blocky	Moderately Suitable (S_2)	1.50-1.70
Prismatic, columnar	Marginally Suitable (S_3)	> 1.70
Massive	Permanently not Suitable (N_2)	-

As the soil in MRBC area falls within the limits of maximum 1.5 gm/cc (Table 5.1); they may be rated in (S_1) group, highly suitable for irrigation.

Particle Size Distribution (Soil Texture)

The particle size i.e. granulometric parameters have important bearing in shaping the textural characteristics of the soils. Soil particles may be comprised of either mineral or organic substances. In most soils, the largest proportion of particles is mineral and is generally referred to as "mineral soils." The soil texture which depends on the relative proportion of sand, silt and clay particles, the soil texture classes may be accordingly modified if greater than 15% of the particles are of organic content (e.g. mucky silt loam) (USDA, 1966, Sherer, 1996, Brady 1990). The soils comprising > 2.0 mm size particles more than 15 % of volume, such soils are texturally named as Gravelly soils (USDA, 1978). Taking in to account overall soil textural characteristics of MRBC area having organic matter less than 15 % (Table 5.1) the soils may be placed under the generic name mineral soils. Depending on the nature of soil particles the soils in MRBC area can be texturally placed as

(i) Vertic Halaquepts, Typic Halaquepts and Vertic Ustochrepts : Clayey Soils (Clay > 40 %)

(ii) Typic Ustochrepts : Clay loam (Clay 34-39 %)

(iii) Fluventic Ustochrepts, Typic Ustorthents, Fluventic Ustorthents: Sandy clay loam and sandy loam.

The coarse textured and fine textured soils are unsuitable for irrigation whereas the moderate and marginally fine textured soils are highly suitable for irrigation (USDA, 1978)

Soil Color

The color of soil is important indicator in identifying the soil characteristics and soil forming process, particularly the micro-environmental changes. Some important soil characteristics, which can be determined through this property, are viz. (Rai, 1995)

(i) The higher content of organic matter and unhydrated ferric oxides (Fe_2O_3) gives the soil darker shade of color viz. Dark Brown, Dark Red, etc. normally indicates good drainage and aeration.

(ii) The yellow color of soil is attributed to the abundance of hydrated ferric oxide (Fe_2O_3, $2H_2O$).

(iii) The deeper soil with yellow color indicates the moist climatic condition.

(iv) The soil showing presence of Quartz, Kaolinite and other clay mineral, Calcium and/or Magnesium Carbonate, Gypsum and various salts gives soil grey or whitish shade.

(v) Poorly drained soil and soil with high water table fluctuation shows grey, brown and yellow color and are typically of mottled in nature.

The color of coarse textured soil in upper reaches of the MRBC command area varies from yellowish brown (10 YR 5/4) to brown (10 YR 4/3). The soil in middle command varies from dark yellowish brown (10 YR 4/4) to dark brown (10 YR 3/3) whereas in the western part i. e. beyond the Alang Drain the soil color ranges from Brown (10 YR 5/2) to dark grayish brown (10 YR 3/2). Therefore, the soils in MRBC area, which are predominated by ferric oxides, and reddish brown in color are well drained and possess good aeration. However, in the lower reaches owing to higher clay content they are grayish yellow and poorly drained. From the foregoing account on the evaluation of physical properties of soils in MRBC area it can be inferred that the soils are highly suitable for irrigation; except the soil groups viz. Vertic Halaquepts, Typic Halaquepts, and Vertic Ustorchrepts.

SOIL- WATER INTERACTION

The soil water constitutes an important and the most vital medium for plant growth. Importance of water in soil is manifold viz. (i) promotes bio-physical activities, (ii) acts as nutrient solvent and carrier of nutrients, (iii) functions as an agent in photosynthesis, (iv) maintains turgidity of plants, and (v) acts as an agent in soil forming processes. Apart from above listed functions, water also determines the soil-air and soil-temperature relationship (Rai, 1995). Interaction between soil and water is basically governed by the textural characteristics of soils. The textural parameters in terms of grain size-shape and the mineralogical composition and their arrangement, are the decisive factors in imparting basic hydraulic characteristics of the soil and sub-soil horizons. Porosity is foremost important hydraulic property governing movement and storage of water in soil. Taking the basis of soil-water relationship, soil water may be classified as (Richards, 1965):

(i) The **Hygroscopic water** includes all that moisture present at the Hygroscopic Coefficient* and is held with a tension of more than 31 atmospheric pressure. (* Water molecules below the wilting point mostly being absorbed by colloidal soil surface. The water is held so tightly (-31 bar atmosphere), can only move only in vapor phase. The moisture content of the soil at this point is termed as hygroscopic coefficient.)

(ii) **Capillary Water**: The water held between the Field Capacity* and hygroscopic coefficient. Most of the water used by the plants belongs to this category with an excerted potential pressure ranging between -0.1 and -0.31 bars. (* defined as the level of soil moisture left in the soil after drainage of the gravitational water and marking the upper limit of the available water.)

(iii) **Gravitational Water**: Water, which is generally associated with the larger interstices and drain under the gravity, pull i.e. in excess of field capacity (-0.1 to -0.31 bar). Due to its short time availability, this water is of no use to the plants.

Another important aspect in soil-water interaction is Wilting Point. This may be defined as the soil moisture content where most plants cannot exert enough force to remove water from small pores. The tension of soil water when permanent wilting point occurs is about 15 atmosphere (Sherer, 1996; Pearson, 1998).

Evaluation of irrigation practices and various hazards attributed to the irrigation mainly depend on a nature of soil, their compositional and hydraulic characteristics and the chemical content of the water used for irrigation. The combined effects of these factors given rise to the problems of salinity and soil-water quality degradation. A quantitative and qualitative detail for MRBC area on important soil properties causing these adverse effects are discussed as under:

Water Retentivity (Moisture Holding Capacity)

The soil holds the water in to two ways (i) as a film coating on soil particle and (ii) as a pore space filled fluid. When water infiltrate the soil from rain or irrigation, majority of the water runs off and part of it is held because of capillary force (Scherer, 1996).

Mean water retention characteristics of MRBC area for all the soil groups are presented in Fig 5.3. From the figure it can be corroborated that at any given suction, magnitude of water retention follow the order Vertic Halaquepts > Typic Halaquepts > Vertic Ustochrepts > Typic Ustochrepts > Fluventic Ustochrepts > Fluventic Ustorthents > Vertic Ustorthents. This is attributed to the differences in the available quantity and nature of colloidal materials present, soil pH and salt content in respective group (Miller and Donahue, 1992). In Vertic Ustochrepts, Typic Halaquepts, and Vertic Halaquepts, the dominating clay mineral is montmorillonite while in Fluventic Ustochrepts, Typic Ustorthents and Fluventic Ustorthents the dominating clay mineral is Illite (Singh and Nayak, 1999).

Statistical analysis using correlation matrix has been attempted by Singh and Nayak, 1999. The data thus obtained (Table 5.3) showed that the water retention at various suction correlated negatively with sand and silt and positively correlated with clay, organic carbon, EC and pH. The highest correlation coefficient was observed with sand and clay. The saturated hydraulic conductivity correlated highly and negatively with clay and soil water content at different suction.

Table 5.3 Simple Correlation Coefficient between Different Soil Properties in MRBC Area

Soil	Sand	Silt	Clay	OC	EC	pH	θ_1	θ_2	Av. W.	Ks
Sand	1									
Silt	0.237	1								
Clay	-0.932+	-0.550*	1							
OC	-0.032	-0.143	0.057	1						
EC	-0.0364	-0.780+	0.608*	0.178	1					
pH	-0.236	-0.418	0.379	-0.510*	0.222	1				
θ_1	-0.933+	-0.481	0.969+	0.054	0.575*	0.253	1			
θ_2	-0.916+	-0.532*	0.971+	-0.012	0.604*	0.348	0.981+	1		
Av. W	-0.878+	-0.353	0.880+	0.162	0.473	0.067	0.943*	0.861+	1	
Ks	0.950+	0.433	-0.965+	-0.155	-0.518*	-0.105	-0.975*	-0.946+	-0.438	1

* 5 % + 1 % θ_1= 0.3 MPa; θ_2= 1.5MPa (Singh and Nayak, 1999)

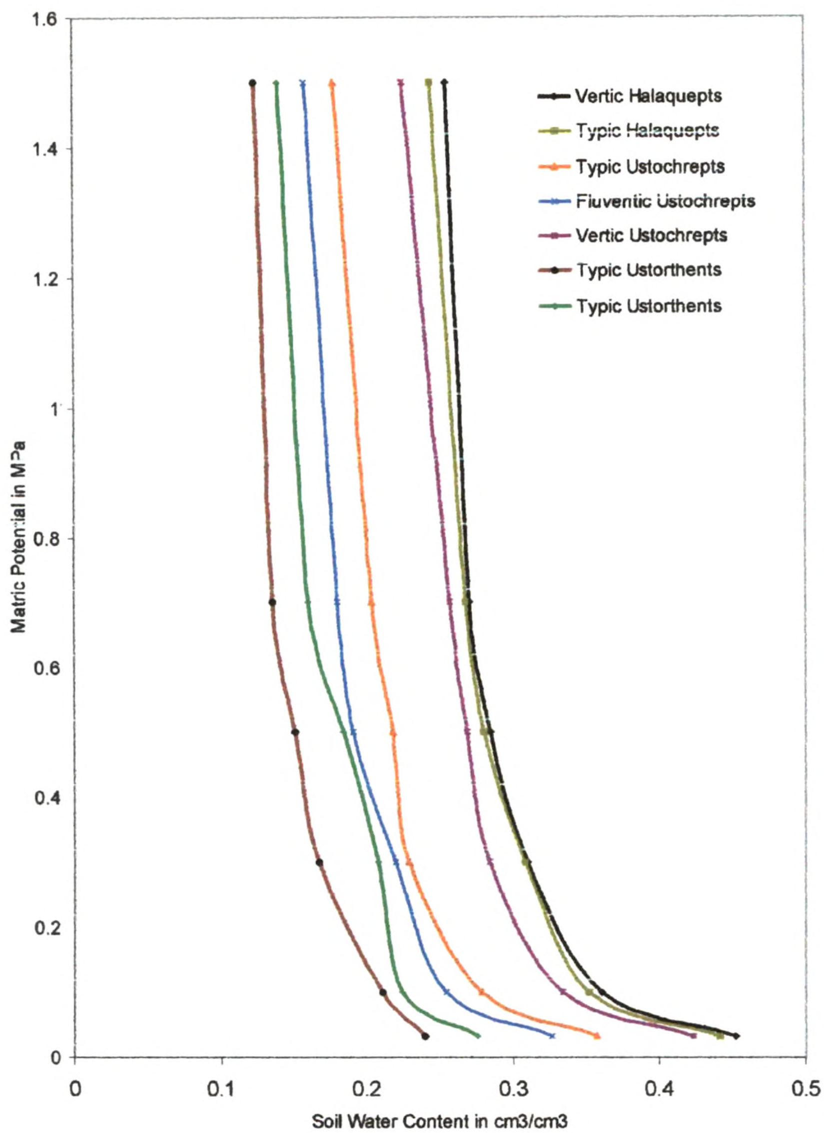

Fig. 5.3 Graph Showing Relationship between Matric Potential and Water Content for Different Soil Series in MRBC Command Area

Available Water Holding Capacity (AWHC)

The characterization of soils' water holding capacity is very important from the point of view of irrigation management. This is directly related with porosity and thereby to soil texture.

In the MRBC area the Available Water Holding Capacity of the soil upto 1.5 m depth was categorized as higher in Vertic Halaquepts (29.66 cm), Typic Halaquepts (29.72 cm) and Vertic Ustochrepts (28.56 cm), medium in Typic Ustochrepts (27.45 cm) and Low in Fluventic Ustochrepts (23.52 cm), Typic Ustorthents (17.41 cm) and Fluventic Ustorthents (21.19 cm).

Hydraulic Conductivity

A soil's permeability is a measure of the ability of air and water to move through it. Permeability is influenced by the size, shape, and continuity of the pore spaces, which in turn are dependent on the soil bulk density, structure and texture beside these temperature also causes significant effect (Franzen 1996, Scherer, 1996, USDA, 1996). Most soil series are assigned to a single permeability class based on the most restrictive layer in the upper 5 feet of the soil profile. However, soil series with contrasting textures in the soil profile are assigned to more than one permeability class (Table 5.4). In most cases, soils with a slow, very slow, rapid or very rapid permeability classes are considered poor for irrigation (Scherer, 1996).

Table 5.4. Soil Permeability Classes

Permeability	Infiltration Rate (cm/hour)	Irrigation Potential
Very Slow	< 0.152	Poor
Slow	0.152-0.508	Poor
Moderately Slow	0.508-1.52	Good
Moderate	1.52-5.08	Good
Moderately Rapid	5.08-15.24	Good
Rapid	15.24-50.80	Poor
Very Rapid	>50.80	Poor

Wide variations have been observed in the saturated hydraulic conductivity of the soil of MRBC command area. From Table 5.5 it is clear that the highest permeability is 36.4 cm/day in Typic Ustorthents and lowest 2.2 cm/day observed in Vertic Halaquepts. The low saturated hydraulic conductivity may be attributed to the high degree of sodium saturation as indicated by high pH and higher clay content. Irrespective to soil type, values of unsaturated hydraulic conductivity invariably decreases with the increase in moisture content (Singh, et. al., 1993).

Table 5.5 Permeability of Soil for Different Classes in MRBC Area

Soil Type	Permeability cm/hr
Vertic Halaquepts	0.09
Typic Halaquepts	0.15
Typic Ustochrepts	0.51
Fluventic Ustochrepts	1.03
Vertic Ustochrepts	0.19
Typic Ustorthents	1.52
Fluventic Ustorthents	1.20

Infiltration

Infiltration is the downward flow of water from the surface through the soil. The infiltration rate (also called as intake rate) of a soil is a measure of its ability to absorb an amount of rain or irrigation water over a given time period. It is quantitatively expressed in cm per hour. The infiltration is dependent on the permeability of the surface soil, moisture content of the soil and surface conditions such as; roughness (tillage and plant residue), and slope, and plant cover, structure, sodicity and bulk density. Coarse textured soils such as sands and gravel usually have high infiltration rates. The infiltration rates of medium and fine textured soils such as loam, silts, and clays are lower than those of coarse textured soils and more dependants on the stability of the soil aggregates (Rai, 1995, Franzen, 1996).

The available study and data on the infiltration in MRBC area, carried out by the Central Soil Salinity Research Institute for clay, clay loam and sandy loam. Soils suggests that initial rate of infiltration is high being 105.6, 146.4 and 126.6 cm/hr in clay, clay loam and sandy loam respectively. The higher infiltration rate in case of the clay and clay loam soil it may be attributed to the presence of deep cracks, which permits the mass flow of water whereas in case of sandy loam is attributed to the void filling. It has also been observed that soon after the cracks are closed and because of filling of open voids, there is drop in infiltration rate, after 15 sec for clay, clay loam and sandy loam respectively. However, the observed constant rate of infiltration for 328 minutes 17.4, 45.0 and 57.6 cm/hr for clay, clay loam and sandy loam respectively. Accordingly cumulative infiltration rate also varies as 33.2, 52.6 and 109.8 cm/hr for clay, clay loam and sandy loam respectively after 328 minutes. Thus both infiltration and cumulative infiltration rates have been the highest in sandy loam, intermediate in clay loam and low in clay soils.

From the foregoing discussion of the soil water characteristics in MRBC area it can be inferred that Fluventic Ustochrepts, Typic Ustorthents, and Fluventic Ustorthents soils are characterised by very high permeability, low water retentivity and low available water holding capacity, the soil is suitable for frequent light irrigation. The soils of Vertic Halaquepts, Typic Halaquepts and Vertic Ustochrepts has shown high water retentivity and available water holding capacity and moderate to low permeability, these soils are suitable for the frequent irrigation with the cropping the plant requiring high water. The soils of the Vertic Halaqupets and Typic Halaquepts are saline in nature and hence the probable measure has to be taken or the cropping should be done with the salt tolerance plants (Singh et. al. 1993). The soil water properties of Typic Ustochrepts falls in the intermediate category of the above two classes. Further depending on the soil type the response of water table rise varies. The rise in water table is also depends on the nature of crops, as the root zone system for an individual cropping plants varies. Studies on the limits for critical water table depths the various soil types in MRBC area and the depth of active root zone for common crops (Singh et. al., 1993) are given in Table 5.6.

Table 5.6 Critical Water Table Depth for Soil in MRBC Area

Soil Type	Critical Water table Depth cm
Vertic Halaquepts	142
Typic Halaquepts	164
Typic Ustochrepts	206
Fluventic Ustochrepts	178
Vertic Ustochrepts	162
Typic Ustorthents	124
Fluventic Ustorthents	150

SOIL AND LAND IRRIGABILITY CLASSIFICATION

For any irrigation projects the soil and Land Irrigability Classification for sustained use under the different water regime introduced after the irrigation system is of utmost importance. This classification the soil are first grouped in to soil Irrigability classes depending upon its physico-chemical characteristics (viz. soil texture, soil depth, available water holding capacity, type of clay mineral, soil permeability, salinity and alkalinity, soil erosion etc). While the soil may be suitable for irrigation, the associated features like topography and drainage and to some extent socio-economic condition may or may not be favorable for irrigation. Therefore, it is vital to identify land irrigability classes for the suitability of soil for irrigation. The various soils and land classes for the arid and semi-arid regions by IS, 5510; 1969 are given in Table 5.7 a & b. Accordingly the MRBC soils have also been classified in to the different land irrigability along with their percentile aerial coverage is given in Fig. 5.4.

Table 5.7 a Specification for Soil Irrigability Classes for Arid and Semi-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
AWHC (cm)	12	9-12	6-9	2-6	< 2
Coarse Fragments (>75 mm)	< 5	5-15	15-35	35-65	> 65
Gravel and Kankar (25-75 mm)	< 15	15-35	35-55	55-70	> 70
Salinity (EC X 10^3) mmohs/cm	< 4.0	4-8	8-12	12-16	> 16
Salt Affected *(visual)* %	< 20	< 20	20-50	20-50	>50
Severity of Alkali Problem (ESP %)	< 15	< 15	> 15	> 15	> 15

(Source: IS: 5510:1969, IARI, 1970, WALMI, 1987)

SIC	Irrigability of Soil
A	None to Slight Soil Limitation for sustained use under irrigation
B	Moderate Soil Limitation for sustained use under irrigation
C	Severe Soil Limitation for sustained use under irrigation
D	Very Severe Soil Limitation for sustained use under irrigation

Table 5.7 b Specification for Land Irrigability Classes for Arid and Semi-Arid Regions

Land Characteristics	Irrigable Land Classes				
	I	II	III	IV	V
SOILS					
Soil Irrigability Class	A	A to B	A to C	A to D	Non-irrigable
TOPOGRAPHY					
Slope %	< 1	1-3	3-5	5-10	
Surface Grading	No Restriction	Moderate Restriction	Moderate to Severe Restriction	Severe Restriction	
DRAINAGE					
Outlets	Suitable Outlets Available	Suitable Outlets Available	Suitable Outlets Available	No drainage Outlets Available	
Sub-surface Drainage	Not Needed	Not Needed	Needed		
Depth of Water Table (m)	> 5.0	3.0-5.0	1.5-3.0	Excessive (1.5 m and below)	

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

LIC	Irrigability of Soil
I	Lands that have few Limitation for sustained use under irrigation
II	Lands that have moderate Limitation for sustained use under irrigation
III	Lands that have severe Limitation for sustained use under irrigation
IV	Lands that have very severe Limitation for sustained use under irrigation

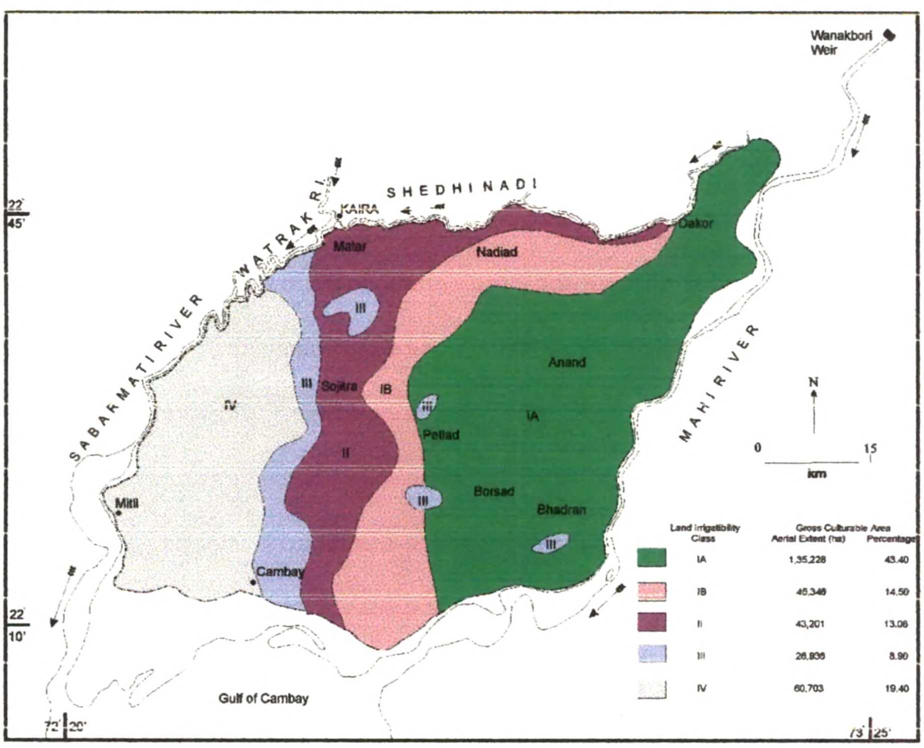

Fig. 5.4 Land Irrigability Classification of MRBC Area

SOIL CHEMISTRY

Like the soil texture and hydraulic properties of soil is also an important parameter, to be observed for better crop yield in any irrigation command. The monitoring of soil chemistry in MRBC area has been carried out by the various governmental agencies. Based on the information available, the author has carefully scrutinized the data and attempted to evaluate an overall soil chemistry using ten years i.e. 1980-90 data records (Table 5.9 and 5.10). Quantitative as well as quantitative details on the various soil chemistry parameters for MRBC area is enumerated as under.

Hydrogen Ion Concentration (pH)

The pH of an aqueous solution is defined as the negative logarithm of the hydrogen of the hydrogen ion activity in that solution. The hydrogen ions in soils are present primarily as exchangeable cations and equilibrium exists between the hydrogen ions in solution and those on the exchange. This equilibrium will shift with changes in salt concentration, CO_2 content of water, or soil:water ratios.

On referring pre-irrigation data it is found that the entire command has pH values ranging between 7.5 to 8.5. After the introduction of irrigation the pH has been modified and shows irregular pattern of rise through out the command area. A comparative account on soil pH changes for ten years time span is given in ensuing table.

Range of pH	1980		1990	
	Area in ha	%	Area in ha.	%
7.5 - 8.5	125096	43.57	251545	79.70
8.5 - 9.0	72701	24.74	59479	18.80
> 9.0	96063	32.69	4766	1.50
Total	293860	100	315790	100

It can be seen from the above data that majority of the soils has came under the pH range 7.5 - 8.5 and there is an overall decrease in area within all soil categories. Thus initially there was rise in the alkalinity of the soils which has reduces with the time. This observed initial rise in pH may be attributed to the change in crop pattern i.e. cropping the waterloving plants, i.e. from rainfed irrigation to the irrigated agriculture and increase in intensity of cropping causing repetitive cycle of drying and wetting of the field. The change in crop pattern demanding excess irrigation caused accumulation of Ca as $CaCO_3$ and increased accumulation of sodium carbonate and/or sodium Bicarbonate (Sodication)

Table: 5.9 Physico-chemical Characteristics of the Soils of the Mahi Right Bank Canal Command Area [Year : 1980]

[Source: Water Technology Centre 1981]

Name of Village	Sampling Depth Cm	Textural Class	Clay %	MHC %	K cm/hr	EC Mmhos / cm	pH	CEC %	Ex. Ions meq / 100 gm		ESP meq / 100 gm	$CaCO_3$ %
									Na	K		
1	2	3	4	5	6	7	8	9	10	11	12	13
Upper Command												
Ode	0-15	SL	15.0	34.7	1.70	0.19	8.2	41.2	0.3	6.8	0.72	1.03
	15-65	SL	18.2	41.8	2.13	0.12	8.1	34.0		4.8	0.88	1.28
	65-87	SCL	21.6	42.8	0.75	0.13	8.0	37.0	0.3	3.2	0.30	1.03
	87-120	L	14.7	40.5	0.94	0.13	8.3	39.8	0.3	3.0	0.76	1.54
	120-180	SL	16.8	44	1.32	0.14	8.4	49.5	0.3	3.0	0.60	16.16
Saloon	0-17	SL	14.9	36.9	2.36	0.14	8.3	35.0	0.46	7.9	1.31	1.28
	17-60	SCL	21	44.0	0.94	0.26	8.6	35.0	0.52	6.8	1.50	1.03
	60-85	SL	18.9	46.9	0.87	0.22	8.7	31.2	0.58	4.0	1.86	1.54
	85-120	SL	18.8	46.9	0.57	0.21	8.8	34.8	3.58	4.0	1.70	1.03
	120-160	SL	14.1	35.0	0.37	0.26	9.1	39.8	0.58	3.2	1.50	10.52
Kalsar	0-12	SCL	20.5	42.5	0.18	1.68	8.1	73.5	6.8	1.0	9.30	-
	12-55	L	16.8	39.6	0.23	0.61	8.2	64.5	3.2	0.8	4.96	-
	55-160	SiC	40.0	50.0	0.09	0.69	8.0	75.4	4.9	0.6	6.50	0.29
Lingda	0-15	SiL	20.5	44.3	0.28	0.11	8.1	70.8	2.3	1.6	3.24	0.57
	15-35	L	19.1	39.6	1.04	0.07	7.8	78.2	2.1	2.0	2.68	0.86
	35-105	CL	25.7	48.8	0.38	0.16	7.8	91.8	3.8	2.3	4.14	0.57
	105-150	CL	30.0	44.4	0.38	0.14	7.8	94.6	4.0	3.6	4.32	0.57
Middle Command												
Sandhana	0-12	SCL	20.3	38.0	0.66	0.26	8.8	-	-	-	-	-
	12-45	SCL	21.8	40.6	0.94	0.29	8.7	-	-	-	-	1.03
	45-70	SCL	25.4	43.7	0.75	0.35	8.4	-	-	-	-	0.51
	70-100	CL	22.4	50.2	0.37	0.5	8.3	-	-	-	-	1.03
Sojitra	0-12	L	19.0	38.8	1.04	0.25	8.4	23.8	0.4	3.6	1.68	0.51
	12-45	CL	25.5	46.0	Imp	0.30	9.0	21.0	0.64	2.3	3.04	0.77
	45-80	CL	28.9	55.9	Imp	0.32	9.0	20.8	0.62	2.6	2.98	1.28
	80-160	CL	92.7	58.3	Imp	0.88	8.0	28.5	0.66	2.1	2.32	0.77

1	2	3	4	5	6	7	8	9	10	11	12	13
Bochasan	0-15	SL	13.4	40.0	4.73	0.14	8.0	21.0	0.32	4.6	1.71	0.77
	15-40	SL	14.7	38.2	1.70	0.14	8.2	23.5	0.36	5.6	1.36	0.51
	40-115	SL	18.9	46.9	1.89	0.11	8.2	29.2	0.32	3.8	1.07	0.77
	115-150	SCL	22.3	48.1	2.36	0.07	8.1	31.5	0.32	3.2	1.02	1.28
Vastana	0-15	L	22.3	45.0	1.04	0.23	8.6	-	-	-	-	27.96
	15-60	L	18.5	48.2	0.09	0.35	8.9	-	-	-	-	23.08
	60-100	CL	29.8	51.9	Imp	1.08	9.1	-	-	-	-	23.85
Vadtal	0-12	SL	14.5	38.6	1.89	0.10	8.2	30.6	0.50	1.20	1.63	1.15
	12-30	SL	15.1	42.0	2.74	0.06	8.1	32.5	0.60	0.8	1.84	0.29
	30-105	SL	18.5	48.4	0.75	0.07	8.3	33.6	1.0	0.7	3.47	0.29
	105-150+	SiC	53.5	43.3	1.42	0.08	8.3	239.2	1.5	12.1	0.63	0.7
Nar	0-10	SCL	20.2	42.3	Imp	0.75	9.6	135.2	7.6	3.8	5.62	1.72
	10-40	SCL	23.8	48.5	Imp	0.93	9.4	137.5	7.6	2.9	5.52	1.15
	40-80	C	36.1	48.5	Imp	1.39	8.8	160.8	9.2	3.9	5.72	1.15
	80-150	CL	25.9	49.0	0.18	2.69	8.1	176.4	12.0	4.1	6.80	1.72
	>150	CL	29.3	51.8	Imp	2.69	8.1	205.6	15.6	4.2	7.58	10.63
Kosiial	0-25	L	21.7	38.5	0.28	0.23	9.2	38.7	1.6	1.2	4.13	3.45
	25-65	L	15.4	42.2	0.09	0.32	9.5	43.9	4.0	0.8	9.11	2.59
	65-110	L	16.0	40.3	0.18	0.33	9.5	47.0	6.6	1.7	14.04	5.75
	110-150+	CL	24.8	44.0	0.18	0.38	9.3	49.8	2.6	1.5	5.22	7.47
Amliara	0-15	SiL	21.0	54.2	0.09	0.27	8.7	35.6	4.2	1.8	4.98	2.3
	15-50	SiC	34.0	45.3	0.09	0.57	9.0	92.5	4.6	1.6	4.98	1.15
	50-115	SiC	32.1	59.0	Imp	0.51	8.9	96.5	4.2	0.9	4.35	1.5
	115-140+	C	34.0	51.9	Imp	0.37	8.9	128.7	6.4	0.6	4.97	5.74
Rohini	0-12	SiC	51.4	56.0	Imp	0.34	9.1	208.8	0.60	9.2	0.28	11.29
	12-40	SiC	44.5	55.7	Imp	0.67	8.3	216.9	0.80	9.6	0.37	12.82
	40-80	SiC	46.5	63.4	Imp	3.40	8.7	223.4	0.70	10.20	0.31	32.57
	80-120	C	49.5	56.2	Imp	4.85	8.8	229.2	1.20	11.10	0.52	27.19
	120-150	C	55.3	67.5	Imp	5.18	9.0	229.2	1.20	11.10	0.52	25.14

1	2	3	4	5	6	7	8	9	10	11	12	13
						Lower Command						
Malu	0-18	CL	31.6	41.2	0.47	0.37	9.1	166.8	5.6	1.6	3.35	5.17
	18-60	C	35.2	US	Imp	1.07	9.4	180.5	15.6	1.2	8.64	6.03
	60-150–	CL	31.5	44.7	Imp	2.56	9.8	206.9	32.6	1.0	15.75	23.56
Kharenti	0-15	CL	23.9	46.6	0.56	0.22	8.5	153.6	3.0	1.0	1.95	0.86
	15-65	C	40.5	54.2	0.09	0.32	9.0	160.6	3.2	1.2	2.00	1.15
	65-110	CL	26.8	41.9	Imp	0.37	9.1	154.1	4.1	3.2	2.66	0.29
	110-140	CL	25.8	52.3	0.09	1.18	8.6	152.5	14.1	1.8	9.25	12.93
Fatehpura	0-15	SiCL	27.3	39.0	0.09	0.22	8.7	164.4	12.8	2.6	7.80	13.22
	15-55	SiCL	20.8	38.0	Imp	0.26	9.5	163.8	30.6	2.0	18.70	13.22
	55-110	SiCL	25.6	52.4	Imp	1.98	9.2	180.2	35.8	3.6	19.86	16.95
	110-150+	CL	24.8	48.4	Imp	3.76	8.8	205.2	40.1	3.0	19.54	25.29
Vadgam	0-15	CL	26.0	47.1	0.39	9.9	8.2	139.6	30.6	2.8	21.92	6.32
	15-90	L	17.3	40.9	0.57	12.87	8.1	170.2	36.0	2.8	21.15	7.18
	90-150–	SiC	41.7	56.1	Imp	21.78	8.1	182.5	38.6	2.1	21.15	7.47
Lunej	0-10	SiCL	38.8	41.2	0.47	0.25	9.0	156.8	4.8	1.7	3.10	5.75
	10-80	SiC	43.4	56.5	Imp	2.47	9.0	130.2	20.4	2.2	11.32	6.03
	80-150–	SiCL	35.7	50.4	Imp	5.77	8.8	169.8	30.4	4.4	17.90	6.03
Piplao	0-20	C	39.6	47.0	0.09	0.40	9.1	85.4	5.6	1.3	6.56	-
	20-70	L	20.5	46.4	0.09	0.37	9.1	76.8	6.4	08	8.33	-
	70-115	CL	30.0	50.2	0.09	0.54	8.7	90.5	7.2	1.2	7.95	0.29
	115-150+	CL	28.4	48.6	0.09	0.86	8.2	92.8	6.0	0.6	6.50	0.57
Khatnal	0-12	SiC	14.1	34.2	0.09	0.27	9.0	67.7	1.6	0.25	2.36	-
	12-40	SCL	24.7	45.8	Imp	0.27	9.0	74.6	4.2	0.20	5.36	0.57
	40-96	SCL	22.3	45.6	0.28	0.33	9.0	80.5	4.0	0.18	4.97	-
	96-150–	SCL	20.7	50.4	1.42	0.46	7.6	76.1	6.4	0.1	8.33	0.29
Kalodara	0-14	SCL	18.3	49.2	Imp	0.70	9.5	89.6	7.2	1.2	8.03	0.57
	14-44	CL	31.9	50.9	Imp	1.11	9.4	96.8	9.6	0.9	9.91	1.44
	44-105	CL	30.8	45.0	Imp	1.67	9.0	113.7	13.2	1.0	11.60	0.57
	105-150	CL	34.0	45.8	Imp	1.76	8.7	116.8	9.6	0.8	8.21	0.86
		S = Sand		C = Clay		-- = Data Not Available		Imp = Impervious		CEC = Cation Exchange Capacity		K = Hydraulic Conductivity
		Si = Silt		L = Loam		US = Unsaturated		110+ = Depth > 110 cm		ESP = Exchangeable Sodium Percentage		SiCL = Silty Clay Loam

Table 5.10 Physico-chemical Characteristics of the Soils of the Mahi Right Bank Canal Command Area [Year: 1990]

[Source: Soil Survey Organization]

Name of Village	Sampling Depth	Texture	M. H. C. %	K cm/hr	AWHC cm	EC Mmhos/cm	pH	C.E.C. meq/100 gm	Ex. Cations Na	Ex. Cations K	E.S.P. %	$CaCO_3$ %
1	2	3	4	5	6	7	8	9	10	11	12	13
						Upper Command						
Ode	0-10	SL	39.10	2.75	10.20	0.31	8.20	11.20	0.74	0.45	6.60	0.00
	10-27	SL	39.40	2.27		0.26	8.30	11.20	0.65	0.29	5.80	0.00
	27-65	L	49.90	1.42		0.17	8.30	17.20	0.87	0.19	5.10	0.00
	65-104	L	45.70	1.61		0.16	8.30	17.40	0.72	0.18	4.10	0.00
	104-150	L	42.30	1.89		0.19	8.30	17.60	1.02	0.22	5.80	0.00
Salun	0-13	SL	35.40	2.37	12.80	0.38	8.30	11.70	1.15	0.28	9.83	0.00
	13-37	SCL	43.50	1.52		0.21	8.10	15.00	1.59	0.24	10.60	0.00
	37-61	SCL	48.40	1.14		0.21	8.10	18.40	1.70	0.33	9.24	0.00
	61-97	SCL	47.90	1.33		0.18	8.00	17.80	1.80	0.31	10.11	0.00
	97-131	SCL	47.20	1.43		0.18	8.00	20.20	1.54	0.32	7.62	0.00
	131-150	SCL	48.50	1.32		0.23	8.10	20.60	1.38	0.40	7.67	0.00
Kalsar	0-14	SL	36.70	2.46	12.80	0.21	7.80	8.00	0.80	0.60	10.00	0.00
	14-35	SCL	41.60	1.42		0.20	8.20	13.20	1.00	0.28	7.80	0.00
	35-57	SCL	47.60	1.52		0.17	8.10	17.00	1.09	0.23	6.40	0.00
	57-94	SCL	44.70	1.42		0.21	8.10	18.40	1.20	0.31	6.50	0.00
	94-150	SCL	42.50	1.33		0.13	8.10	17.80	1.00	0.26	5.60	0.00
Lingda	0-15	L	46.30	1.14	14.00	0.17	7.80	17.50	0.89	0.18	5.10	0.00
	15-42	L	45.50	1.95		0.17	7.50	22.60	0.67	0.24	2.90	0.00
	42-86	CL	49.10	0.95		0.11	7.70	30.00	0.65	0.18	2.20	0.00
	86-120	CL	50.80	0.85		0.11	7.90	23.20	0.76	0.31	3.30	0.00
	120-150	CL	54.30	0.76		0.15	7.90	29.40	0.98	0.40	3.30	0.00

1	2	3	4	5	6	7	8	9	10	11	12	13
						Middle Command						
Sadhana	0-12	L	43.60	1.89	11.80	1.21	8.40	12.80	1.04	0.31	8.10	0.00
	12-35	L	44.80	1.61		1.39	8.50	14.80	1.96	0.23	13.20	0.00
	35-70	CL	46.70	1.14		1.52	8.00	19.00	1.22	0.22	6.40	0.00
	70-105	CL	45.50	1.23		2.00	8.00	17.40	0.87	0.18	5.00	0.00
	105-135	CL	49.70	0.95		2.24	7.90	28.40	1.61	0.15	5.70	0.00
	135-160	CL	45.70	1.14		2.06	7.70	28.00	1.41	0.12	5.00	0.00
Sojitra	0-13	LS	31.50	3.60	13.20	0.55	8.50	10.20	1.43	0.44	14.00	0.00
	13-24	SL	32.40	3.20		0.42	8.50	15.60	1.91	0.50	12.20	0.00
	24--55	CL	47.30	0.95		0.50	8.50	24.40	2.43	0.47	9.90	0.00
	55-80	CL	57.90	0.47		0.80	8.30	35.00	1.61	0.41	4.60	0.00
	80-113	CL	54.10	0.95		0.99	8.40	24.80	2.13	0.44	8.60	0.00
	113-148	CL	53.00	0.87		1.10	8.30	25.20	2.33	0.38	9.20	0.00
	148+	CL	50.50	0.47		1.27	8.40	24.00	3.13	0.37	13.00	0.00
Bochasan	0-12	SL	38.30	2.94	12.10	0.85	8.50	17.30	1.17	0.76	6.76	0.00
	12-35	L	46.00	0.95		0.38	8.50	18.50	0.95	0.85	5.13	0.00
	35-66	L	47.30	1.14		0.29	8.30	14.40	1.21	0.40	8.40	0.00
	66-112	L	50.80	1.04		0.24	8.40	16.40	1.56	0.16	9.51	0.00
	112-150	L	45.70	1.33		0.15	8.40	17.60	0.80	0.28	4.55	0.00
Vastana	0-10	C	57.5	0.09	14.70	1.05	7.90	40.20	2.83	0.68	8.30	2.00
	10-35	C	57.9	0.00		0.81	8.50	42.20	3.35	0.64	7.90	1.50
	35-60	C	54.9	0.00		1.45	8.10	31.20	4.78	0.42	12.10	1.00
	60-100	CL	42.9	1.61		2.44	8.10	25.60	1.96	0.23	7.70	1.00
	100-150	L	41	1.52		3.08	8.10	24.20	2.04	0.13	8.40	1.00
Vadtal	0-14	SL	45.50	1.99	12.00	0.35	8.50	18.00	0.50	0.11	2.98	0.00
	14-42	L	46.20	1.14		0.27	8.60	17.10	0.93	0.46	5.44	0.00
	42-77	L	49.80	1.23		0.29	8.60	18.20	2.54	0.47	13.96	0.00
	77-112	L	48.90	1.04		0.24	8.40	18.60	2.17	0.38	11.70	0.00
	112-150	L	51.80	0.95		0.30	8.40	18.70	2.19	0.23	11.71	0.00

1	2	3	4	5	6	7	8	9	10	11	12	13
Nar	0-18	CL	51.80	0.00	14.60	0.42	8.50	31.40	1.41	0.40	4.49	0.00
	18-40	C	62.40	0.00		0.49	8.50	34.10	1.85	0.85	5.43	0.00
	40-75	C	60.10	0.00		0.53	8.40	36.70	2.17	0.74	5.91	0.00
	75-108	C	61.90	0.00		0.61	8.30	38.30	1.74	0.69	4.54	0.00
	108-130	SiCL	53.20	0.85		0.78	8.30	32.70	1.74	0.65	5.32	0.00
	130-150	SiCL	51.70	0.95		0.67	8.40	29.80	1.63	0.67	5.47	0.00
Kosiyal	0-15	SL	33.70	2.37	9.00	0.55	8.00	10.20	1.35	0.42	13.20	1.00
	15-40	SL	37.40	2.18		0.42	8.40	14.20	1.48	0.15	11.40	1.00
	40-70	SL	36.10	1.99		0.24	8.50	9.60	0.70	0.12	11.70	1.00
	70-140	SL	38.50	2.84		0.24	8.50	7.80	0.89	0.12	11.40	1.50
	140-160	SiL	42.60	1.42		0.22	8.50	23.40	2.17	0.28	9.30	5.00
Amliyara	0-10	C	56.20	0.00	15.20	0.66	8.60	40.40	2.17	0.55	5.37	2.00
	10-42	CL	54.90	0.85		0.94	8.60	34.40	2.39	0.47	6.95	3.00
	42-57	CL	54.90	0.76		2.10	8.30	31.60	4.24	0.53	13.42	3.00
	57-102	CL	54.00	0.47		3.38	8.50	23.90	2.82	0.41	11.80	3.00
	102-150	L	50.40	1.04		2.94	8.60	22.60	2.47	0.36	10.90	10.00
Rohini	0-16	C	52.90	0.00	14.40	0.38	8.50	39.60	1.74	0.97	4.39	10.00
	16-42	C	62.50	0.00		0.47	8.50	39.80	1.27	1.12	3.19	12.50
	42-75	C	65.30	0.00		0.68	8.60	40.40	1.72	1.06	4.25	12.50
	75-105	C	63.60	0.00		0.90	8.60	39.50	2.93	1.12	7.42	14.00
	105-120	C	68.50	0.00		2.70	8.60	38.60	1.72	1.12	4.45	15.00
	120-165	SiCL	59.60	0.00		4.02	8.60	29.50	1.55	0.72	6.61	15.00
Lower Command												
Malu	0-9	L	41.20	1.19	14.90	1.89	8.30	18.90	2.06	0.50	10.90	0.00
	9-19	L	42.30	1.23		1.06	8.40	16.40	0.96	0.37	11.55	0.00
	19-32	CL	57.20	0.38		0.89	8.30	23.30	1.85	0.37	7.94	0.00
	32-70	CL	56.40	0.47		0.84	8.20	23.50	1.74	0.38	7.40	0.00
	70-100	CL	54.60	0.57		0.84	8.30	28.50	2.17	0.38	7.61	0.00
	100-150	L	49.10	0.38		0.89	8.30	22.10	2.06	0.27	9.32	0.00

1	2	3	4	5	6	7	8	9	10	11	12	13
Kharenti	0-10	SL	34.90	1.79	9.00	0.97	8.00	9.40	1.04	0.15	6.80	3.50
	10-40	SL	37.10	2.84		0.44	8.30	9.40	0.89	0.10	9.50	4.00
	40-65	SL	38.60	2.94		0.44	7.90	10.60	0.91	0.15	8.60	4.50
	65-125	SL	33.70	2.94		0.25	8.10	10.00	0.80	0.12	8.00	4.50
	125-160	SL	32.10	2.55		0.23	8.00	10.40	0.89	0.08	8.50	5.00
Fatepura	0-15	C	59.80	0.19	15.40	1.14	8.50	38.50	3.26	0.85	8.47	8.50
	15-35	C	58.00	0.00		0.78	8.60	39.20	4.02	0.55	10.26	8.50
	35-50	C	54.50	0.00		0.84	8.90	30.40	3.52	0.42	11.58	5.50
	50-110	C	50.20	0.00		1.74	9.00	29.50	3.15	0.33	10.68	8.50
	110-135	CL	45.10	0.95		4.62	9.40	30.50	3.52	0.35	11.50	9.50
	135-150	CL	52.00	0.85		5.04	8.40	35.50	4.02	0.73	11.30	10.00
Vadgam	0-15	C	56.30	0.00	15.30	1.72	8.70	44.90	1.52	0.56	3.39	10.00
	15-30	C	54.20	0.00		4.38	8.90	43.80	1.96	0.76	4.48	13.00
	30-70	CL	53.40	0.38		4.88	8.80	28.90	2.07	0.74	7.16	15.00
	70-100	CL	59.60	0.47		5.65	8.80	28.40	3.15	1.08	11.10	13.00
	100-150	L	44.40	1.80		8.31	8.70	18.60	2.61	1.10	14.00	12.00
Lunej	0-10	SL	40.00	2.37	9.00	0.54	8.40	15.20	1.57	1.12	10.33	0.50
	10-30	SL	36.30	2.46		0.42	8.50	14.30	1.63	0.56	11.40	0.50
	30-85	SL	35.40	2.27		0.34	8.50	15.60	1.52	0.36	9.74	0.50
	85-120	SL	36.80	2.18		0.42	8.50	16.60	1.61	0.38	9.70	0.50
	120-160	SL	36.90	2.46		0.40	8.30	14.90	1.70	0.33	11.41	0.50
Piplao	0-11	C	55.60	0.00	15.40	1.10	8.30	37.40	2.09	0.92	5.60	0.50
	11-22	C	53.10	0.00		0.63	8.20	34.20	1.61	1.08	4.70	0.50
	22-47	C	51.60	0.00		0.61	8.40	35.80	1.57	1.00	4.40	0.00
	47-70	C	52.30	0.00		0.42	8.40	36.00	1.33	0.83	3.70	0.00
	70-104	C	52.40	0.00		0.41	8.30	38.40	1.11	0.85	2.90	0.00
	104-150	C	5.40	0.00		0.48	8.20	34.20	1.11	0.75	3.20	0.00

1	2	3	4	5	6	7	8	9	10	11	12	13
Khatnal	0-15	SL	36.10	2.84	13.40	0.67	8.50	8.80	1.15	0.10	13.10	2.00
	15-27	SL	42.60	2.08		0.78	8.50	12.70	1.85	0.33	13.50	1.00
	27-50	CL	49.40	1.04		0.83	8.10	19.20	1.96	0.32	10.20	1.00
	50-85	CL	52.50	0.95		0.89	8.10	19.20	1.96	0.29	10.20	2.00
	85-150	CL	51.90	0.85		0.47	7.90	19.10	2.06	0.32	10.81	1.00
Kalodra	0-15	SL	39.30	2.46	12.00	0.30	8.20	10.60	1.46	0.21	13.60	0.00
	15-30	L	44.80	1.70		0.29	8.40	14.00	1.87	0.23	13.36	0.00
	30-60	L	48.20	1.52		0.33	8.50	12.70	1.54	0.21	12.13	0.00
	60-115	L	51.20	1.42		0.28	8.40	13.10	1.96	0.23	14.96	0.00
	115-150	L	51.20	1.61		0.25	8.50	14.10	1.85	0.17	13.12	0.00

whose concentration shows decrease with depth (Kovda, 1973; Bhargava et. al., 1980; Chhabra, 1996;). The alkalinity (CO_3 + HCO_3) is also related to the carbon dioxide pressure in its gaseous phase and soil under equilibrium (under 0.35 mbar or 35 X 10^{-3} Bar) where in the CO_2 pressure leads the pH value up to 8.5 (Chhabra, 1996). It is also known fact that on attaining waterlogging condition, the soil becomes poorly aerated. Under such condition CO_2 pressure increases to 35 X 10^{-2} bar. Such increase in CO_2 pressure may be responsible for overall decrease in pH of soil and therefore, majority of area shows drastic shift from higher category of pH (> 8.5) to lower category (7.5 -8.5) (Chhabra, 1996; Szabolcs, 1989).

Electrical Conductance (EC)

The electrical conductance is a measure of soil salinity. The evaluation of EC data for the soils in MRBC area shows considerable variation in the salt affected areas. The ensuing table depicts the variation in aerial coverage and percentage of total command.

Range of EC	1980		1990	
	Area in ha	%	Area in ha.	%
< 1.0	206936	70.42	235465	74.6
1.0 - 1.5	3556	1.21	43472	13.8
1.5 - 2.5	40435	13.76	27683	8.8
2.5 - 3.0	7170	2.44	1814	0.5
> 3.0	35763	12.17	7356	2.3
Total	293860	100	315790	100

The soil electrical conductance in MRBC area shows considerable variation in terms of temporal and spatial behaviour (Table 5.9 and 5.10). These changes on side show an overall decrease in soil conductance, specifically in lower command area. The data observed at Vadgam shows almost 50% decrease in conductance. There is also some sporadic location, which shows slight rise in soil conductance, particularly in the upper and middle commands. This rise may be concurrent to the water table rise. The locations like Sojitra, Matar, Ode, Limbasi displays rise in soil conductance. Similar decreasing trends in soil conductance are observed depth wise also. This overall decrease in soil conductance may be attributed to the dilution and flushing process of soil moisture and salt contents, through the added canal water, whose chemical content s considerably low.

Exchangeable Cations

The soils comprise innumerable clay minerals. These clay minerals are negatively charged and attract positively charged ions, the cations. Owing to the cations replaceable nature; the interchange between cation in solution and another cation on the surface of active material, the soil, it is referred as exchangeable cations. The cationic ionic exchange occurs as substitution of Aluminium by Magnesium in Alumina sheet and/or Silica by Alumina in silica sheet of clay minerals (Hendricks and Fry, 1930, Kelley, 1981).

The exchangeable sodium in the surface soil of MRBC area was ranging between 0.3 to 30.6 meq\100 gm of soil in year 1980 which has compressed to the 0.3 to 3.26 meq\100 gm of soil in 1990. Except few localities like Ode, Saloon of upper command; Sojitra and Bochasan in middle command area and Rohini in the lower command area show rise in the exchangeable sodium. The cation exchange capacity of the soil includes the total exchangeable cations. The subtraction of the exchangeable sodium and potassium indicates that there is general increase in the exchangeable calcium and magnesium, which may be accounted to the replacement of the exchangeable sodium by the calcium and/or magnesium.

The Cations Exchange Capacity (CEC), denote the sum total of exchangeable cations that a soil can adsorbed and has been expressed in terms of meq/100 gm of soil in this presented study. This parameter is an important measure for evaluating the quality of soils. Soils having higher the cation exchange capacity, the nutrient fixation to the root zones of the plants is fast, thereby a healthy growth of the plants.

The studies of available data on CEC (Table 5.9 and 5.10) indicate overall decrease in CEC. Maximum decrease in CEC has been observed in the middle command area viz., Sojitra, Amliara. The CEC for the surface soil can be broadly categorized as under:

Command Area	CEC meq/100gm of soil	
	Range	Clay %
Upper	16.4 - 24.0	13.10 - 30.0
Middle	24.0 - 30.0	14.0 - 39.0
Lower	30.0 - 44.0	26.8 - 55.3

Exchangeable Sodium Percentage (ESP)

This parameter identifies the degree to which the exchange complex is saturated with sodium. This ESP is complementary to the Sodium Adsorption Ratio (SAR), which gives information on the comparative concentration of Na, Ca and Mg in soil solutions. ESP determined the degree of alkalinity in soils and may be expressed as

$$ESP\% = \frac{ExchangeableSodium}{CationExchnageCapacity} \times 100$$

The presence of exchangeable sodium in the form of sodium carbonate causes drastic change in soil's physical properties; the resultantly permeability and pore space are decreased and soil shrink in to hard surface (Hesse, 1994). Sources of extractable sodium in alkali soils are generally derived from (i) losses originated mainly in-situ by weathering of sodium rich feldspar or sodium bearing parent material (Wilding, 1963), (ii) transformation of sodium silicate in weakly mineralized groundwater and from igneous rocks (Hsi and Chao, 1962). The ESP is the most important parameter in classifying the non-saline alkali soils. Its upper boundary is fixed at 15 % with pH value of 8.5.

Careful examination of available data (Table 5.9 and 5.10) has divulged that during a time span of 10 years MRBC area exhibits significant rise in the ESP of both surface and sub-soils. The maximum rise from 0.72 to 6.60 % has been observed at Ode and minimum rise 9.3 to 10.00 % at Kalsar in the upper command area. However, taking in to account the 10 years ESP scenario the overall range remains within the limits of 4.1 - 71.4 %.

CHEMICAL CLASSIFICATION OF SOILS

In an irrigation command, the hazards of the salinization and alkalization of soil and waterlogging is frequently noticed phenomenon. Such hazards limit the optimum utilization of the soil. Using EC, ESP characteristics and pH, salt affected soils may be classified as saline, saline-sodic and sodic (USDA, 1954). In addition to this Indian Scientist by considering the nature of soluble salts as an important index, have grouped these soils in to two groups, and merged the saline-sodic group in to saline and sodic groups depending upon the parametric variations (Bhargava et. al. 1976; Bhumbla, 1977). The classification encompassing USDA and Indian criteria is given as under:

Soil Parameters	USDA			Indian	
	Saline	Sodic	Saline-Sodic	Saline	Sodic
EC	> 4.0	< 4.0	> 4.0	> 4.0	< 4.0
pH	< 8.5	> 8.5	> 8.5	< 8.2	> 8.2
ESP	< 15.0	> 15.0	≤ 15.0	< 15.0	> 15.0

SALINE SOILS

Saline soils are characterised by the presence of white crust of salt on the surface soil. It has been observed that the abundance of $CaSO_4$ and $CaCO_3$ gives a fine, fluffy, dusty surface, while a mixture of NaCl and Na_2SO_4 gives a crystalline white mass, $MgCl_2$ gives dark crust that is highly hygroscopic (Chhabra, 1996).

Salinization of soils is the complex interplay of following factors. (Chhabra, 1996).

1. **Climate:** Salt affected soils are ubiquitously developed in arid and semi-arid climatic domains. This is attributed to inadequate rainfall, higher evaporation, thereby upward salt influx and its accumulation near the surface. Other side, the humid climatic domain, owing to high precipitation and constant flushing of the salts from soil profile are free from the salinization.

2. **Soil:** The textural characteristics of an individual soil types greatly influences the salinization of soil. Light textured soils, by virtue of its good drainability capable to leached out the salt fast. Also, its low CEC and poor capillary rise further prevents the build up of salinity. The heavy textured soil owing to poor drainage, high CEC and capillary rise are highly vulnerable to salinization.

3. **Hydrological Conditions:** It is observed that an adverse terrain condition greatly enhances the chances for soil salinization. Low lying area in land as well as coastal are highly vulnerable to waterlogging and inundation monsoon run-off from upper reaches as well as the groundwater flow, brings considerable salts in solution; that gets accumulated in the soils during subsequent dry periods. Similarly, applying high salt containing ground waters in irrigation (Vander Molen, 1976), seawater incursion during tidal ingress is other hydrologic factors making soils saline.

4. **Introduction of Canal Irrigation:** Salinization of soils attributed to the canal irrigation is manifested by (I) Excessive application of water during period of low water requirement, (ii) non-utilization of groundwater resources and its continuous rise with the addition of returned irrigation seepage, causing imbalance in groundwater regime and salt build up. (iii) Bringing unsuitable land i.e. coarse textured soil under intensive irrigation.

Apart from above listed factors, there exists an intimate relationship of geology. The nature of soluble salts in weathered crusts of rocks (the parent material) from which the soil originated. In view of this, products of weathering from acid rocks like granites and gneisses, which are least, mineralized whereas those from basic rocks i.e. basalt, diabase etc. are highly mineralized. In addition to this the secondary source of the salt accumulation is the salts transported by the natural agencies like wind, water, and is called as cyclic salts.

The chemical characteristics of the saline soils are dependent on the kinds and amount of the salt present. Sodium ions usually do not exceed 50% of the cations present in the soil solution. Soluble and exchangeable potassium is usually present in minor amount. The main anion present may be sulfate and chloride and sometimes nitrates. Bicarbonates may be present in small amount. Beside the soluble salt the saline soils may contain the salt of low solubility, such as calcium sulfate and calcium and magnesium carbonates (Chhabra, 1995; Szabolcs, 1989). The amount of soluble salt controls the osmotic pressure of soil solution. Such soils having excess salts and no significant amounts of exchangeable sodium are flocculated and their permeability is equal to or higher than that of non-saline soils (Hansen, 1980; Dan and Yalon, 1981; Brady, 1990; Chhabra, 1995; Rai, 1995; Scherer, 1996).

Salinization of soils causes following deleterious effect (Bhargava et. al. 1976, Bhargava and Abrol, 1978; Chhabra, 1996) to the plant such as;

(a) Physiological Drought i.e. unavailability of water to plant even though it has been available of plenty of water. This is because of increase in osmotic pressure causing high electrical conductance.

(b) Reduction in evapotranspirative losses because of low water availability, restricted root growth, decreased leaf area, and dilution of absorbed salt by high water retention of plant.

(c) Disturbed normal nutrition and metabolic process.

ALKALI SOILS

Alkali soils, also known as sodic or solonetz soil, are those soils that contain measurable amount of soluble salts capable of alkaline hydrolysis, thereby causes the dissolution and dispersion of organic matter. Latter subsequent evaporation results in the salt accumulation in surface soils and causes the darkening of soil color. The produced salts are mostly CO_3 and HCO_3 of Na, which in presence of $CaCO_3$ give the soil high pH, leading to poor physical condition (Szabolcs 1989; Rai, 1995; Chhabra, 1996). The following conditions lead to the formation of alkali soils.

1. **Sodication due to repeated cycle of wetting and drying:** Under the normal condition, soils of the arid and semi-arid regions usually contain calcium and magnesium ions as the exchange complex solution. Repeated cycles of accumulation favor the precipitation of calcium sulfates, calcium carbonate and magnesium carbonate; due to their low solubility and excess accumulation of $NaHCO_3$ and Na_2CO_3. This in turn results in replacement of exchangeable Ca^{+2} by Na^{+1} and its subsequent precipitation (Chhabra, 1996). This phenomenon of the replacing of calcium and magnesium by sodium is referred as Sodication or Sodiumization. The top layer of such alkali soils are highly dispersed in nature and characterised by low permeability, free $CaCO_3$, hard impervious layer. Apart from this the alkali soils are also characterised by measurable and appreciable amount of CO_3 and HCO_3; Cl and SO_4. Whereas the cationic concentration is characterised by higher concentration of sodium followed by Magnesium and Calcium. These soils have pH > 8.2 and ESP > 15. Also highly sodic environment results in degradation of clay minerals. In vertisoils, sodication may lead to formation of chloride from montmorillonite (Pal and Bhargava, 1979).
2. **Sodication due to shallow brackish ground water:** areas characterised by shallow groundwater table, containing higher residual sodium carbonate and low divalent cation Ca results in to the soil sodication. These soils have good 'A' horizon but a natric (Sodic) sub-surface 'B' horizon (El-Elgabaly, 1971; Kovda, 1973).
3. **Sodication due to use of saline irrigation water low in $Cl:SO_4$ ratio:** In arid region (Rainfall less than 300 mm) the sodication is also favored by the use of saline water for irrigation having low $Cl:SO_4$ ratio. The high content of SO_4 in irrigation lowers the content of Ca in soil solution and formation of $CaSO_4$. This normally enhances the SAR of soil solution and Exchangeable Sodium of the Soil (Bhargava et. al. 1980)

SALINE - ALKALI SOILS IN MRBC AREA

Evaluation of available soil chemistry data for the years 1980 and 1990 (Table 5.10 and 5.11); from the point of view of the development of salinity and alkalinity in MRBC area has brought out following inferences.

Inspite of the prolonged irrigation practices, there is not much deterioration in the soil quality. There is considerable decrease in pH and EC values defining the saline and sodic soils. In 1980, more than 50% of the command area has recorded pH > 8.2 which has been observed to reduce to almost 20% in 1990. Similarly, there is drastic reduction in the area from 12.1% (1980) to 2.3% (1990) having EC values more than 3. The ESP values also have not changes much. However, the upper command area is characterized by ESP <15% and the middle to lower command area with >15% ESP. There are some sporadic areas (soil specific) showing the development of soil salinity and alkalinity. This may be attributed to the better soil drainability, which normally helps in flushing out the accumulated salts. Further, the MRBC area is characterized by the varied soils with varied physical properties. The studies carried out by the state government department on the severely affected soil specific area and taking into account the obtained parameters viz. MHC, AHWC, Infiltration, permeability (Table 5.12); the prospects of getting salinization of the MRBC area soils may be given as Typic Ustochrepts > Fluventic Ustochrepts > Verttic Ustochrepts > Typic Halaquepts > Fluventic Ustorthents > Verttic Halaquepts > Typic Ustorthents

The soils of moderately fine to fine textured viz. Verttic Ustochrepts, Typic Ustochrepts, Fluventic Ustochrepts and Typic Halaquepts; depending upon their hydro-physical characteristic have been found to develop the waterlogging. Subsequent evaporation and enrichment of the salts have resulted into the salinization and/or alkalization of soils.

In the upper command (Table 5.13) where the soil salinization has been observed mainly in the Typic- and Vertic Ustochrepts soils which are characterised by high MHC, AWHC, and low permeability. The important localities are Dakor, Nes, Kalsar and Lingda.

In the middle command area the salinity is seen developed by waterlogging conditions in the localities like Sandhana, Traj, Limbasi, Kathoda, Garmala, Limbali. Here the increasing trend in pH with depth indicates the initialization of Alkali hazards. Also, the localities around Sojitra, Nar, Kosiyal and Amliara where there is no significant