GEO-ENVIRONMENTAL STUDIES OF UKAI-KAKRAPAR COMMAND AREA, SOUTH GUJARAT: WITH SPECIAL REFERENCE TO IMPACT OF IRRIGATION ON SOIL AND WATER REGIMES IN CHALTHAN BRANCH COMMAND AREA

Summary of the

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SUMMARY

(1) During last three decades the Gujarat, a predominantly agrarian state, owing to its favourable geo-environmental conditions and ample natural resources has witnessed rapid growth and has become one of the most important industrial states of the country. Heavy industrialization and unprecedented expansion of the urban centers have resulted into a manifold increase in the demand of various terrain resources and agricultural produce. In order to keep pace with the demand, the land and water resources have been exploited to their optimum level, causing an irreparable damage to various environmental attributes.

(2) The presented study represents one such case example of Chalthan Branch Canal Command Area, which constitutes a part of Kakrapar Left Bank Canal Command Area in South Gujarat. The study aims at evaluating the consequences of canal irrigation and its impact on soil and water regimes; corroborating secular and the vector changes in water table, water chemistry and the salt balance in soil and sub-soil horizons. The information thus generated; to be utilized for conceptualising and suggesting appropriate management strategies, to mitigate the adverse effects.

The main thrust of the investigation pertains to a critical evaluation of the following parameters:

- Surface and subsurface geological conditions, sediment nature and extent,
- Basic terrain characteristics, landuse pattern and long term changes,
- Water table behaviour pattern – secular and vector changes and its causes,
- Canal water input and its contribution to groundwater regimes as return irrigation seepage,
- Soil-water chemistry vis-à-vis secular and vector changes,
- Surface and sub-surface outflow and the factors governing the outflow.
- Crop-water demand scenario and existing management practices.

A multi-disciplinary approach was adopted to achieve the above-cited objectives.

(3) The thesis is divided in to two parts. Part-I includes the Chapters I to V, giving broad appraisal of the geological information, terrain characteristics, water

resources and soil characteristics of the Kakrapar Left Bank Canal Command Area, based on available information, Part-II includes Chapters from VI to X incorporates an in depth study on geoenvironmental aspects of the Chalthan Branch Canal Command Area.

(4) On the basis of the elevation variations, the South Gujarat terrain can be divided into 04 physiographic zones, viz. (i) Trappean Highlands (> 100 m AMSL), (ii) Trappean Pediments (50-100 m), (iii) Alluvium Plain (10-50 m) and (iv) Coastal Plain (< 10 m). The South Gujarat drainage is characterized by a system of westerly flowing rivers. Most of the rivers are perennial in nature and originate from the eastern Trappean highlands and ultimately meets the Arabian Sea. In all seven major streams viz. Tapi, Mindhola, Purna, Ambica, Auranga and Par drain the South Gujarat area.

(5) Geologically the command area comprises the sediment record ranging from Cretaceo-Eocene to Recent time. The Deccan lava flows constitutes the base above which younger sediments lies. Tertiaries on the left bank command area are concealed beneath the Quaternary - Recent alluviums. The eastern part of the area is rocky and as one moves westerly the trappean rocks goes beneath the alluvium under the influences of N-S trending fault system.

The climate of the study area is predominantly falling under humid conditions, characterized by a hot summer and general dryness except during the southwest monsoon. The average annual rainfall in the area is 1282 mm.

(6) It is quite natural that in a high rainfall riverine area like South Gujarat, surface water has always received priority in the field of irrigation in addition to groundwater, which is well evident from a close perusal of past records. This accrues primarily from the perennial character of the rivers, the rapidly deteriorating drainage system and the necessity of intensive agriculture due to accelerating growth of population.

A changing scenario with regard to the sources of irrigation is observed throughout the decades. During the 1950s i.e. before Kakrapar irrigation project the primary source of irrigation was wells and tanks, also at places government canals did irrigation locally. By the late 1960s, irrigation by government canals has increased due to implementation of the Kakrapar Project i.e. 1958. Canal irrigation assumed importance in the alluvial plains of the area. Irrigation through wells and tanks has attained 2nd and 3rd preference respectively. The irrigation data for the last decade i.e. 1990s shows considerable increase in canal irrigated area. Almost 61% of the total irrigated area is irrigated by canal while wells come on second place with 32% and tanks and other sources irrigate remaining area.

The Kakrapar irrigation system comprises a network of Main canal, branch canal, distributaries, minors, sub-minors, field drains and outlets of different dimensions and different capacities. The region has one main canal having 64-km length and having capacity to discharge 3020 cusecs of water to irrigate total 145335 hectares area through its branch and distributaries having length 306 km and 877 km respectively.

(7) Chemistry of canal water is prerequisite to study the impact of irrigation on soil-water quality regimes. The available canal water quality data for the KLBC system, analyzed by the state Soil Survey Department for 48 locations suggests majority of samples fall under the good category of irrigation water quality standards, as prescribed by W.H.O. and I.S.I.

From the potability point of view, majority of canal water samples fall under field VI in Piper Trilinear diagram, indicating canal water is characterized by non carbonate hardness and of Calcium-chloride types (Ca-Mg-Cl-SO_4).

(8) The groundwater studies of the KLBC area has been carried out with a view to understand, (i) Hydrogeological setup of the area, (ii) Aquifer nature and extent, (iii) Groundwater level and its fluctuation, movement, gradient etc., (iv) Anthropogenic impact of irrigation on groundwater level and (v) Groundwater quality and its behavioral pattern with time.

From the hydrogeological point of view major geological formations in the area can be categorized as consolidated and unconsolidated sediments. Basaltic aquifers are characterized by the wide range of, transmissibility i.e. 478 to 2.35 m^2/day; permeability 7.08 to 0.03 m/day; and specific capacity 0.83 to 0.1 lps/m. Unconsolidated aquifer characteristics based on aquifer performance tests, show transmissibility values ranging between 2965 and 11.47 m^2/day; permeability values from 148.25 to 0.31 m/day; specific capacity between 23.88

& 0.18 lps/m and discharge on an average 1440 lpm, indicative of high groundwater potential.

For evaluating the seasonal and long-term groundwater level fluctuations the author has divided the entire command area into 25 sq. km equal area grids and selected a representative observation wells at each node by carefully scrutinizing the well performance records.

Prior to the inception of canal irrigation the groundwater was one of the major source for irrigation, accounting for almost 88% of the irrigation need. For the purpose of evaluation of groundwater regime in the command area, the water table data for the year 1950 have been utilized. Based on these data, the Static Water Level (SWL) and Reduce Water Level (RWL) maps were prepared. The SWL map indicates the existence of moderate to shallow groundwater conditions with an average depth, ranging between 4 and 10 m.

Contrary to this, the Reduced Water Level map drawn for the same period, categorically suggests strong influence of the topography. The overall groundwater movement direction remains westerly, so as the surface drainage. However, local variations in groundwater movement may be attributed to lithological controls. In the proximity of river valleys, almost all the rivers are characterized by their affluent nature.

In order to evaluate the net effects of the canal irrigation on groundwater regime, the author has taken into account pre monsoon (1999) water level data and has prepared the Reduced Water Level (RWL) map.

To study the seasonal behavioral pattern of the water table in the command area, Reduced Water Level (RWL) maps for the pre and post monsoon seasons (1999) have been utilized.

a) Average seasonal groundwater level fluctuations are to the tune of 1.8 m.
b) The highest observed positive fluctuation in water table is more than 11 m around the Dived village. There is significant fall in water level i.e. upto – 5.0 m around Pipala village.
c) The water table fluctuation is more pronounced in the hard rock terrain than in alluvial area.

For the evaluation of secular changes in groundwater storage, the observation well hydrographs have been prepared,

a) During the last 30 years spell of irrigation, majority of the command area shows positive response (i.e. rise in water levels) to the canal irrigation.

b) Majority of the observation wells point to sudden rise in water levels between 1975 and 1985. The period between 1985 - 95 is by and large marked with stabilization in water levels. The hydrographs also depicts steep fall in water levels during pre monsoon 1999 period. This indicates restricted use of canal water and scanty rainfall in the previous years there by less recharge to the groundwater regime.

c) The response to returned irrigation seepage as recharge to the groundwater regime varies from area to area.

The Hydro-Iso-Bath (HIB) maps prepared by the Soil survey division, Surat for the periods 1957, 1985, 1995 and 1999 categorically point to the fact that inception of canal irrigation has made a serious impact on the soil and groundwater regimes of the command area.

(9) Quality of groundwater is as important as the quantity. In irrigation, water quality is relevant to its effects on soil and crop.

For the determination of suitability of water for irrigation purpose, author has considered the parameters such as Electrical Conductivity (EC), Sodium Percentage (Na%), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Potential Soil Salinity (PS).

Majority of groundwater samples (2000) fall within the moderate groundwater category specifying C4-S2, C4-S3 and C5-S3 classes of U.S. Salinity Chart. However the groundwater samples (1981) are also of moderate category but falling under C3-S1, C3-S2 and C3-S3 classes. In the case of 2000 groundwater are characterised by increase in salinity and needs adequate treatment.

Taking into account the ionic concentrations of major constituents the groundwater facies have been constructed. In the KLBC area the groundwaters are dominated by three major facies viz. (i) Na-Mg-Ca-K – Cl-HCO_3-SO_4-CO_3, (ii) Mg-Na-Ca-K – Cl-HCO_3-SO_4-CO_3; and iii. Na-Mg-Ca-K – Cl-SO_4-HCO_3-CO_3.

(10) Soil evaluation provides information and recommendations for deciding specific crops to be grown.

Taking in to account the textural characteristics of soils and the various geomorphic units; the soils of the KLBC area and its surroundings have been classified in to 09 subsequent sub groups and 4 orders. It can be seen from the soil map 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.

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.

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. The soils of the KLBC area vary from yellowish brown (10YR 5/4) to very dark brown (10 YR 3/3).

(11) In the KLBC area the observed water holding capacity varies from minimum 17.1 to as high as 77.2 percentage. 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.

Almost 97% of the soils show the available water holding capacity greater than 12 cm. 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 comprise large finer fractions i.e. silty clay - clayey nature, a fine textured soils.

Majority of data on KLBC soil permeability fall within the range of 0.09 - 3.7 cm/hr and may be categorized in slow - moderate class.

The KLBC area shows marked variation in infiltration capacity. 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.

(12) 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 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 quantitative data on the Electrical Conductance of surface and sub-surface soils and the aerial coverage of KLBC area, 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 in the EC values as high as 25 have been observed at Atta village.

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. This observed increase in CEC might be attributed to subsequent breaking of the soil under intensive tilling, irrigation and change in Eh - pH conditions.

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

(13) Soil irrigability classes are useful to make grouping of soils according to their suitability for sustained use under irrigation. In the initial phase of canal irrigation, it can be seen that almost half of the command area (48%) was under Soil Irrigability Class - III and about 33% under Class - II and the Class - I constitutes barely a half percent of the total command area.

In contrast to this, the present (2001) irrigation scenario, 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 %). The soil irrigability Class - IV is predominantly occurs in Tapi-Purna and Ambica-Kaveri interstream areas, where degradation of soil is attributed to excess irrigation, poor drainage conditions causing waterlogging.

THE CHALTHAN BRANCH COMMAND AREA

(14) The Chalthan Branch Canal Command Area sprawl in about 31,460 ha area and administratively constitutes a part of Bardoli, Palsana, Kamrej and Choryasi Talukas of Surat District. The command area is bounded by Kankra Khadi (rivelute) in the north and west, Gangadhara Khadi and Mindhola River in the south and Bardoli branch in the east. Geographically, the study area lies between the 21^0 01" and 21^0 12" N latitude and 72^0 44" and 73^0 11" E longitudes.

(15) The study area constitutes a part of the fertile alluvium plain of South Gujarat with an average altitude ranging from 16 to 37 AMSL. The ground is slopping with an average gradient 1:1333 towards west, thereby signifying terrain to be nearly leveled land. The Chalthan branch command area does not have any significant drainage system, however it comprises a few ill defined rivulets viz. Kankra Khadi and Gangadhara Khadi, constituting a part of Mindhola River drainage system. Chalthan Branch acts as a major divide with a few 1^{st} and 2^{nd} order streams flowing to Gangadhra and Kankra Khadi.

The rainfall-time-series curve plotted for last 30 years i.e. 1971-1999 indicates that for about 14 years the area has received rainfall above average and remaining years below average. The lowest rainfall experienced in this area was in year 1987 (444 mm) and the highest rainfall is in year 1976 (2236 mm).

(16) In the Chalthan Command area irrigation is predominantly carried out through canal water. The canal network, which is 25 km long, off taking from Bardoli

branch near Kantali village. The branch canal in the command area is unlined, where as the other lower order network is lined/unlined. The average annual canal flow of last 10 years based on observed discharge data, at 0 R.D. (Kantali) stands at 112368 cumsecs/year where as at 66 R.D. (Bagumara) it is 57572 cumsecs/year therefore almost 54796 cumsecs/year water is released annually in command area.

(17) Chemistry of canal water is important to understand the possible hydrochemical impact of irrigation on soil and groundwater regime. The obtained quantitative estimates on the ionic content and physico-chemical parameters indicates that canal water, fall within the desirable limits of irrigation as well as drinking water quality norms.

(18) As the study area constitutes a part of flood plain system of Tapi and Mindhola rivers, these riverine deposits display intercalations of sands-silts and clays. Study through the bore hole logs of deeper tube wells and shallow bore wells adequately exhibits this pattern. The prepared fence diagram based on shallow bore hole log records display the top semi-confined to confined aquifer is overlained by an almost 10-20 m thick silty clay aquitard layer. As the thickness of alluvium tends to increase westerly, the aquifer also enlarged accordingly and gets branched into multi layered aquifer system. The data has further revealed the presence of 3-4 aquifers within the depth range of 32 to 177 m.

The hydraulic characteristic based on pumping results shows a wide range of parameters viz. transmissibility (79 - 2965 m^2/day), specific capacity (0.088 - 18.15 m3/min/m), and discharge (200 - 3156 lpm) thereby indicating moderate to high potential of aquifers.

(19) For the purpose of precise evaluation of groundwater table fluctuations and movement and to establish prolonged changes in groundwater regime, the author has divided the entire study area into equal area grids of 10 sq.km each and selected a representative observation wells at each node; by carefully scrutinizing already available well hydrograph records for further monitoring. The seasonal and secular changes in the groundwater levels have been studied through the reduced water level contours, spatial and temporal hydrographs, and hydrographic

profiles. The evaluation has been made at the interval of 20, 10 and 5 years changes in the groundwater regime i.e. 1950 - 70 - 80 - 90 - 95 and 1999.

Prior to the inception of canal irrigation, groundwater was the main source of irrigation. The constructed RWL maps for the pre and post monsoon seasons depicts marginal change in groundwater storage. In the study area RWL contours are showing range from 7 to 27 m (pre monsoon) and 10 to 29 m (post monsoon). Therefore indicating an overall variation in groundwater altitude to the order of 20 m in both the seasons.

The minimum change in groundwater storage has been observed at Rayam (1.4 m) where as at Kadodara the maximum change (4.8 m) has been observed. However, the average annual change in the groundwater storage in command area stands at 3 m or so.

The seasonal behavior of groundwater level and storage has been studied by overlapping pre and post monsoon reduced water level contours. Through the study of these maps following inferences may be drawn. The RWL exhibits an overall rise from pre canal irrigation phase to the present day. The RWL values are ranging between 2 and 32 m during pre monsoon season and between 4 and 34 m during post monsoon season.

The seasonal rise and fall in RWL indicates, 0.5 - 4.15 m rise. This seasonal rise in water levels is maximum in the lower reaches around Jolwa. Significantly the area around Kadodara (lower reaches) exhibits 1.3 m fall in water levels. The net rise in RWL may be attributed to the returned irrigation seepage and the monsoonal recharge. However, fall in water level around Kadodara could be on account of sub-surface outflow to Kankra Khadi.

Secular data on water level fluctuations in the study area (since 1950) has clearly revealed, a continuous rise in water table. The average rate of rise has been estimated to the order of 15 cm/year. The rise in water levels is more pronounced in the upper and middle parts of the command than the lower command area

The canal irrigation, which is meant for kharif season, has greatly neglected the groundwater abstraction. The returned irrigation seepage coupled with monsoon recharge is primarily responsible for the ultimate rise in water level. The groundwater flow, with relation to the bordering Kankra Khadi and

Gangadhara Khadi is of effluent in nature. Thereby indicating its shallow and near surface nature.

(20) The groundwater quality shows considerable variation. The continual rise in water table and upward migration of dissolved salts are possibly the causative factors for deterioration in the groundwater quality.

Taking the bases of Drinking Water Quality Standards, majority of the groundwater samples have established the potability and water is safe for drinking purpose.

Irrigation water classification of groundwater samples shows that almost 50% of the groundwater samples fall under the category of permissible to unsuitable categories and remaining 50% under Excellent - Good categories.

A common chemical attribute of groundwater samples for all the three seasons suggest that the groundwater is characterized by the dominance of alkalies ($Na+K$) exceeds alkaline earth ($Ca+Mg$) and strong acids ($Cl+SO_4$) exceeds weak acids (CO_3+HCO_3). In terms of hydrochemical facies, groundwater of the study area mainly belongs to $Na+K$ - $Ca+Mg$ -- $Cl+SO_4$ - HCO_3 hydrochemical facies.

(21) The study of soil regime has been carried out in the Chalthan Branch Canal Command Area to assess the impact of canal irrigation on soils and quantifying the magnitude of change in physical and chemical parameters of soils. The soil sampling was done with the help of soil auger. In addition to this some existing open excavated pits have also been examined to study soils' pedomorphological characteristics.

The extensive field studies have revealed that in the Chalthan Branch Canal Command Area there is a prevalence of the mineral soil profile. It has also been observed that there exists, different kind of matured soil profiles with the distinct development of "A" and "B" horizons comprising number of smaller units. So far surface soil and upto 50 cm depth are concern, except soils of Sanki village, which is of medium textured i.e. *Typic chromusterts*; all other soil types are fine textured and dominated by clay fractions.

The spatial soil profile across the study area depicts variation in the clay, silt and sand percentage along the section line as well as with depth. In general, clay proportion is above 50 % with in a depth of 0 to 100 cm. while at a depth of 100 - 150 cm it decreases between Isanpur and Ruwa villages thereby indicating change in soil texture with depth. The soil structure of study area falls within the categories of angular to sub angular blocky structures.

Based on the obtained results the MHC of various soil sub group may be arranged in decreasing order as, Kantali (*Typic chromuderts*) > Mota (*Typic chromusterts*, calcareous) > Khoj-Pardi (*Typic chromusterts*) > Bagumara (*Fluventic ustochrepts*) > Sanki (*Typic ustifluvents*). Since MHC is governed by the textural characteristics of the soil; the soil texture in the study area is predominantly clayey; therefore the MHC values does not show much change upto 100 cm depth. At this depth almost 93 % of the study area is characterised by MHC more than 50%.Further deep owing to change in soil texture i.e. from fine to moderately coarse texture, particularly between 150 - 200 cm depth, MHC shows sharp decrease and almost 46% of the command area has MHC ranging between 40% and 50%.

The data on AWHC of soils of the study area is ranging between 9 and 15.3 cm. The lower portion of command area i.e. between Sanki village and Gangadhara Khadi is characterised by the lower available water holding capacity, which is very well correlated with the soils texture. The infiltration rate varies in between 0.12 and 0.44 cm/hr and the highest infiltration rate was observed around Mirapur village (0.44 cm/hr) while lowest rate at Chikhli (0.12 cm/hr), this variation in rate of infiltration may be attributed to the change in percentage of clay content.

The spatial distribution pattern of the various range of hydraulic conductivity at various depths of soil in the study area shows that more than 90% of the study area is having hydraulic conductivity less than 0.5 cm/hr upto 100 cm soil depth. Whereas the hydraulic conductivity tend to increase, wherein almost 50% of the study area shows hydraulic conductivity in the range of 0.5 - 1.0 cm/hr between 150 and 200 cm soil depths.

(22) In this presented study the author has attempted to chemically examine the soils of Chalthan Branch Canal Command Area to assess the impact of irrigation on the soil regime, by evaluating the various parameters viz. pH, Electrical Conductance, Soluble Cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) and Anions (Cl^{-}, CO_3^{--},

HCO_3^-, and SO_4^{--}), Exchangeable Cation (Na & K), Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP), Organic Carbon (OC), P_2O_5, K_2O_5, Organic Matter (OM), and nutrients (N, P, and K).

Taking in to account the typic soils, the pH of clayey textured dominated soils at Mota, Khoj-Pardi and Kantali villages is ranging between 7.5 and 8.0. While pH of Bagumara and Sanki soils is slightly higher and ranging between 7.9 and 8.1, here soils are characterised by loam to sandy loam texture. These observations on pH variation categorically indicate to this fact that the percentage of soil fractions does affect the pH of soils.

The pH profiles clearly shows that with in a depth of 0-50 cm pH of soil is considerably high during pre monsoon 1991 than the pre monsoon 1999 except the area around Ruwa village. While pH levels within a depth of 50-200 cm, remained more or less same for pre monsoon 1991 and 1999, except the command area between Mota and Ruwa villages, displaying slight increase. The seasonal fluctuations in pH from pre monsoon to post monsoon (1999) the surface soils (0-50 cm) exhibits rise in pH while there is marginal decrease in pH with in a soil depth from 50 to 200 cm. This may be attributed to the change in field temperature, as during summer more carbon dioxide is evolved due to greater microbial activity; and roots of plants gives away acid exudates; thus increase in acidity. The reverse is true in spring or winter seasons.

The EC profiles for 1991 (pre monsoon) shows the average EC values (< 2 mmhos/cm) across the study area. The subsequent overall decrease in EC values during pre and post monsoon seasons (1999), may be attributed to the leaching of salts through various measures, adopted by the command area authority, to nullify the effects of soluble salts on plant growth in the past 9 years. The available peaks of higher EC values near Mota and Ruwa villages are on account of excessive salt built up due to waterlogging problems.

In the study area sodium is ranging between 1.30 and 8.58 meq/l during pre monsoon 1999, while during post monsoon it is ranging between 1.24 and 16.2 meq/l. The higher concentration of sodium is observed at the localities viz. Khoj-Pardi, Dastan, Mota and Tanti, which may be attributed to the development of salts, in accordance with high groundwater table and also due to Base Exchange reactions where by sodium replaces other cations in clay minerals.

In the study area calcium is ranging between 0.17 and 3.5 meq/l (pre monsoon) while during post monsoon it is between 0.13 and 2.41 meq/l; this observed reduction in calcium from pre to post monsoon season may be attributed to the dissolution effect due to precipitation and excessive irrigation.

Soils of the command area posses rich concentration of magnesium after sodium and its concentration ranges between 0.19 and 7.10 meq/l during pre monsoon and between 0.16 and 3.04 meq/l during post monsoon.

The concentration of potassium is comparatively very less among the soluble cation in the study area, and is ranging between 0.03 and 1.24 meq/l (pre monsoon) while 0.06 and 1.26 meq/l (post monsoon), these measured value for both the season does not show much fluctuation in potassium.

Scrutiny of quantitative data on various anions has indicated Cl > HCO_3 > SO_4 order of concentration of the soluble anions in soils of the study area.

The chloride is the most dominant among the anions in study area. The chloride concentration in the soil during pre monsoon 1999 is found to be ranging between 1.24 and 16.8 meq/l while during post monsoon it is between 1.48 and 7.49 meq/l. In the study area higher concentration of chloride is observed around the localities viz. Mota, Sevni and Dastan. These higher concentrations may be attributed to the higher values in EC.

The bicarbonate concentration is the second most among the anions and is ranging between 0.67 and 9.6 meq/l during pre monsoon while during post monsoon it is ranging between 0.61 and 5.85 meq/l. Exceptionally higher levels of bicarbonate is observed around Mota and Dastan villages. Further the bicarbonate concentration also varies with the soil depth.

The exchangeable sodium during 1991 was ranging between 0.6 and 0.8 meq/100 gm. Exceptionally higher values have been observed around Mota (2.2 meq/100 gm) and Ruwa (2.0 meq/100 gm) villages. Further the level of exchangeable sodium tends to increase in the sub-soil horizons, between 50-100 cm (i.e. 4.6 meq/100 gm) near Mota. Also there is an overall increase in ES in the western parts of the command area. These higher levels of exchangeable sodium may be attributed to the saline nature of soils. While during pre monsoon 1999 scenario exchangeable sodium is found to be ranging between 0.80 and 1.2 meq/100 gm. The study of ES data of 1991 and 1999 suggests, slight increase in exchangeable sodium throughout the study area from 1991 to 1999. Wherein the upper command area is marked with higher exchangeable sodium as compared to lower command area having development of maxima around Isanpur and Warad villages i.e. 2.0 meq/100 gm. This observed higher levels in exchangeable sodium in upper command area may be attributed to the presence of fine clayey soils, having poor drainability.

In the study area an overall concentration EP has been observed to be less, as compare to exchangeable sodium. The observed range of soils exchangeable potassium during pre monsoon 1999 is between 0.15 and 2.87 meq/100 gm while during post monsoon 1999 it is ranging between 0.15 and 1.53 meq/100 gm.

The CEC profiles for pre monsoon 1991 and pre and post monsoon 1999 shows an overall reduction in the cation exchange capacity with depth, which may be attributed to the change in soil texture from fine to moderate, as the clays are having higher amount of CEC as compared to silt and sand. Seasonal changes in CEC i.e. pre to post monsoon 1999, with in soil depth of 0-50 cm is marked with reduction in CEC in between Chalthan and west of Mota villages and also between Isanpur and Kantali villages, while the CEC is increased between Mota and Isanpur villages.

ESP values during pre monsoon 1991 were ranging between 1 to 3% while during pre monsoon 1999 it is between 2 and 3%. Therefore there is not much significant change in ESP and the soils of the study area are by and large free from sodicity hazards.

The OM levels during pre monsoon 1991 were ranging between 0.6 to 1.4 %. By and large lower command area was characterized by comparatively higher values of OM than the upper command area. Contrary to this in pre monsoon 1999 OM level is ranging between 0.8 and 2.0% and it is comparatively high in upper command area as compared to lower command area. The organic matters are comparative less during pre monsoon 1991 than 1999 with in a depth of 0-150 cm. While the seasonal fluctuation i.e. 1999 is marked by an overall reduction in organic matter content during post monsoon. Such seasonal reduction in OM may be attributed to (i) excess application of irrigation water and (ii) the change in soil temperature because cold periods retard plant growth and organic matter decomposition.

(23) In the Kakrapar Left Bank Canal Command Area of which the study area also forms a part, the irrigation by utilization of canal water has increased from 243 ha in 1953-54 to 1,35,589 ha in 1991. Prior to introduction of canal, the farmers were mostly going for well and tank irrigation. Owing to extended perennial irrigation facilities to the command area; a drastic shift in cropping pattern as well as landuse, i.e. sustainable increase in the cash and commercial crops such as sugarcane, paddy etc. (high water consumptive crops) has been witnessed. This modification in landuse pattern has caused considerable impact on the soil and water regimes of the command area. Some of the problems, which have already reached to an alarming level, are (i) rise of groundwater levels, (ii) increase in groundwater salinity, (iii) soil salinisation and (iv) soil alkalinization.

Water Table Fluctuations: In order to review the long-term changes in magnitude of water table fluctuation, author has considered an average water level data for pre and post monsoon seasons for the years 1950, 1980, 1990, 1995 and 1999. During pre canal irrigation i.e. 1950 the average fluctuation in groundwater table was about 2.4 m. That has successively been reduced to 0.4 m by 1980 and then recorded slight increase up till 1999.

Rise in Water Levels: In order to evaluate the net change in the groundwater regime, i.e. from pre-canal irrigation phase (1950) to present period (1999); the author has derived net rise and fall in groundwater levels by superimposing the 1950 and 1999 RWL contour plans. The net change in groundwater levels depicted as positive and negative contours are suggestive of an average rise of 6.0 m in water levels in the command area during 40 years time span. Thereore the average annual rate of rise in water level stands at 15 cm/year.

The maximum rate of rise i.e. 22.5 cm/year has been observed around Tantithaiya village while the area around Baleshwar displays almost 5 m fall and Kadodara exhibits negligible change in groundwater storage.

Evaluation of data point to the fact that during pre canal irrigation (i.e. pre monsoon 1950) no area has been found which has Hydro-Iso-Bath < 6.0 m while during pre monsoon 1985 i.e. in a span of 25 years, almost 98 % of the command area has come in to influences of Hydro-Iso-Bath $\leq$ 6 m, out of that 47 % of the area fall under the 1.5 - 3 m Hydro-Iso-Bath category indicating prone to waterlogged area and about 5 % of the area to be the waterlogged area. The present conditions i.e. during pre monsoon 1999, almost 40 % of the area is now prone to waterlogged and said to be the alarming zone, while 5.4 % of the area fall under fully waterlogged area category. Contrary to this the post monsoon data shows about 10 % of the area is waterlogged, 46 % of the area prone to waterlogged and 36 % of the area fall under rise in water level zone during post monsoon 1999.

(24) In the Chalthan Command area the author has identified a complex interplay of following factors, which ultimately led to the rise in water level and are responsible for the problem of waterlogging viz. (i) Topography, (ii) Drainage, (iii) Lateral facies variations in aquifer material and the hydraulic characteristics, (iv) Seepage from canal, (v) Soil structure and texture, (vi) Damaged structure of the canal, (vii) Excessive surface water Utilization, (viii) Changes in cropping pattern.

(25) There has been considerable increase in the area covered under saline water, after the introduction of canal irrigation. Wherein during pre monsoon 1970 about 67% of the command area was having groundwater EC less than 1000 mmhos/cm while during pre monsoon 1999 it is reduced to only 6 percentage. Earlier, there has been no area having EC more than 3000 mmhos/cm in 1970, now about 7 % of the area is having EC more than 3000 mmhos/cm. Hence, there is considerable increase in salinity in groundwater. This rise in salinity may be attributed to the rise in water table, causing concentration of salts and their enrichment due to more evaporation.

(26) Study of geochemical reactions is important in understanding the sources and pathways of dissolved ions. For discerning the nature of geochemical interaction in the study area, the author has evaluated ionic ratio of different chemical constituents such as Na/Ca, Ca/Mg, and Na/Cl.

The Na/Ca of the groundwater varies from 1.5 to 24 (pre-monsoon) and 1.4 to 35 (post-monsoon). Spatial variations in Na/Ca exhibits lower values in the upper command and higher values in the lower command groundwaters. This possibly indicates enrichment in Na concentration due to evaporation and precipitation of Ca as $CaCO_3$ in the lower zone. Based on the Ca/Mg ratio the majority of the samples of pre monsoon 1999 shows more than 0.7 while during post monsoon the ratio is decreased, indicating the contribution of magnesium ion from both the groundwater and anthropogenic activity. The higher values of the Ca/Mg ratio indicate the dominance of the decomposition whereas the lower values indicate that contribution is more from the agricultural practices and also because of base exchange, whereby most calcium is displaced by sodium. The ratio of the Na/Cl ranges between 0.71 to 2.94 in pre-monsoon and 0.59 to 2.26 in the post monsoon season. The higher values of the ratio indicates higher sodium concentration; this may be assigned to the process of decomposition of sodium bearing mineral or due to the exchange reaction between the calcium and magnesium with sodium. The lower ratio i.e. < 1 indicate reverse ion exchange phenomenon where Ca and Mg replace Na from soil.

The calculated values of Schoeller index for the groundwater in study area indicates that about 20% of well samples shows the positive values, indicating the base exchange for all the three seasons; where as about 80% of the well water shows the negative values. The figure also indicates that the Base Exchange is more pronounced during the post monsoon 1998 while cation and anion exchange is more pronounced during pre monsoon 1999.

(27) Based on soil chemistry, in Chalthan Branch Canal Command Area no soil shows the sodic or saline-sodic characters. The saline soil is restricted to the small patches with the development of white crust on its surface soil. Particularly soils of the area around Mota, south of Mavachhi and south of Bagumara villages are of saline in nature having very high salinity. The term "saline soil" is used for those soils having the conductivity more than 4 mmhos/cm, exchangeable-sodium-percentage is less than 15 and pH is less than 8.5.

The saline soils around Mota, Mavachhi and Bagumara villages are characterised by high EC (5.4 - 6.30 mmhos/cm). The pH and ESP are in the range of 7.9 - 8.1 and 4 - 8% respectively. Study of the soluble anions and cations from the soil extract indicates the dominance of sodium among the cations whereas chloride among the anions. The dominance of sodium may lead to the sodication of soils, by excess accumulation of sodium carbonate/sodium bicarbonate as well as increase in the exchangeable sodium content.

(28) Owing to extended perennial irrigation facilities to the command area a drastic shift in cropping pattern as well as landuse, i.e. sustainable increase in the cash and commercial crops such as sugarcane, paddy etc. (high water consumptive crops) has been witnessed. This modification in landuse pattern has caused considerable impact on the soil and water regimes and hence there has been observed noticeable change in land irrigability classes (LIC) of the command area.

During early phase of canal irrigation (1970) majority of the area (81.5%) was falling under LIC - III while some of the area (12%) was falling under LIC - II and IV. The data analyzed for 1991 shows some alarming changes in land irrigability classes. The comparison on land irrigability classes for the years 1970 and 1991 categorically suggests almost 10% increase in LIC - IV and the proportionate reduction in LIC - III. Also some areas, especially in the lower reaches of the Chalthan Command show slight improvement from LIC - IV to LIC - III.

(29) Taking in to account the inferences drawn from the preceding chapters on water regime, soil regime and the impact of irrigation on soil and water regimes of the Chalthan Branch Canal Command Area; the following interrelated constraints, which needs an appropriate remedies, and management practices have been identified:

- Rising trend in groundwater table - waterlogging,
- Deterioration in overall groundwater quality,
- Concentration of salts in soil and sub-soil horizons - soil salinity.

The study area is greatly affected by rising trend in water table i.e. waterlogging and brackish or saline groundwater quality. To prevent these adversities, no single strategy can provide fruitful results; therefore an integrated approach has to be devised, that can combat the earlier cited two fold problems. Accordingly, the various management strategies have been worked out for mitigating the command area problems.