Chapter IX

IMPACT OF IRRIGATION ON SOIL & WATER REGIMES

IMPACT OF IRRIGATION ON SOIL & WATER REGIMES

GENERAL BACKGROUND

Irrigated agriculture is crucial to the economy, health and welfare of a very large part of the developing world. It is too important to be marginalized, as it is vital for world food security. However, irrigated agriculture offer radically changes land use and is a major consumer of freshwater. Irrigation development thus has a major impact on the environment.

All new irrigation and drainage development results in some form of degradation. Seepage losses from canals and laterals throughout the irrigation distribution systems are extremely high. Added to this problem is the excessive application of water on farm fields, which results in surface runoff from the lower end of the field and/or large quantities of water moving below root zone. The combination of seepage and deep percolation losses cause groundwater levels to rise and cause waterlogging.

In many irrigated regions, the groundwater levels have reached the vicinity of the root zone, which frequently results in the upward moving water reaches the soil surface and evaporates, the salts contained in the moisture are left behind on the ground surface. This process of salinization has not only resulted in declining agricultural production, but has caused many lands to become essentially barren. It is necessary to determine the acceptable level and to compensate for the degradation. The impacts caused irrigation development may be both to the physical and biological environment.

Voluminous work on impact assessment of an irrigation command exists world over. Some of the classic works on this vital aspect and the adopted management - mitigation practices can be found in the studies carried out by the workers viz. Hammad, 1959; Arar, 1971; El-Elgabaly, 1971; Abiodum, 1973; Skogerboe, 1981; Yaron, 1981; El-Ashry, 1985; Bhatnagar, 1986; Bowonder et al, 1987; Bapat, 1988; Hooja, 1993; Rastogi, 1993; Kumar et al, 1996; Gupta and Tyagi, 1996; Gajja et al, 1998; Singh, 2000; and Caballero et al, 2001.

IMPACT OF IRRIGATION IN CHALTHAN COMMAND AREA

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 (Table 4.2 and 4.3). 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.

RISE IN GROUNDWATER LEVELS

In the long term, one of the most frequent problems of irrigation schemes is the rise in the local water table, and if the water table rise reaches to the root zone i.e. 1.5 m below ground level, the area is said to be waterlogged. Waterlogging is not considered to be a soil degradation process, although it constitutes a limitation to plant growth (FAO, 1979). Waterlogging, however, can result in various types of soil degradation, for example, physical degradation (eg. Compaction), chemical degradation (eg. Manganese toxicity) or salinisation. In other cases waterlogging may be result of soil degradation example, when it is a consequence of a reduction in permeability, waterlogging is result of physical degradation. It may take several decades for the effect to become apparent, but the natural drainage of a basin is rarely sufficient to take away the excess drainage water.

According to Framji (1972) waterlogged land is defined as land made useless by saturation with water. Where the water table is 0 to 1.5 m relative to the ground level, the lands are recognised as being fully damaged, while with water table 1.5 to 3.0 m below ground they are likely to get partially damaged. The Central Board of Irrigation and Power had defined waterlogging as - "*An area is said to be waterlogged when the water table rises to an extent that soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon-dioxide*".

The problem of waterlogging in irrigation command may be ascribed to a variety of reasons. Important causative factors (Bowonder et al, 1987) of waterlogging are given in Fig. 9.1.

In the present study, the behavioral pattern of groundwater table in Chalthan Branch Command area is viewed from the angles like magnitude of water table fluctuation, magnitude & extent of water table rise and its spatial coverage.

(i) **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 (Table 9.1). That has successively been reduced to 0.4 m by 1980 and then recorded slight increase up till 1999. This pattern of change in the magnitude of fluctuation from 1950 to 1999 may be attributed to:

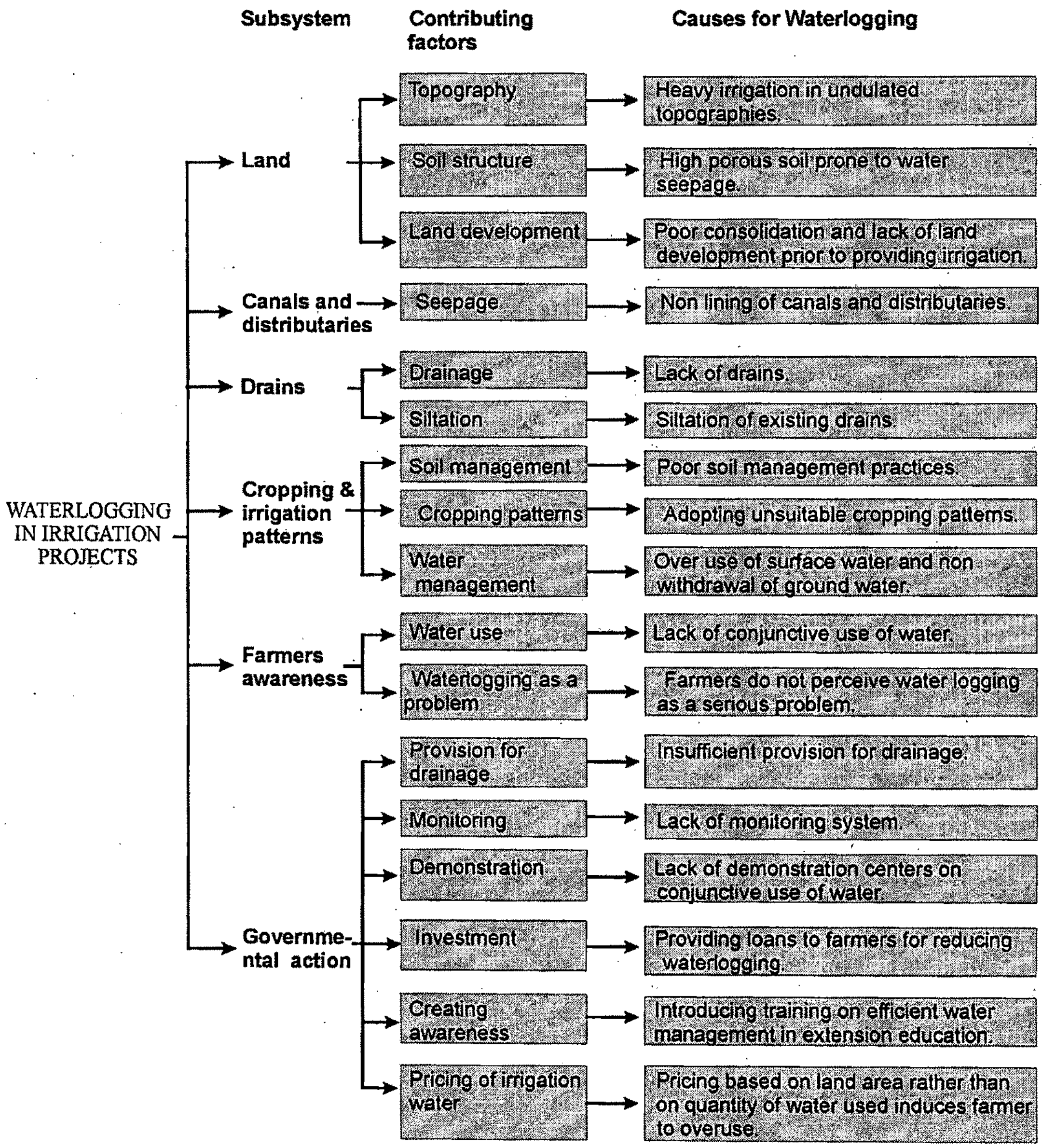

Fig. 9.1 Flow Sheet Depicting Sources & Causative Factors of Waterlogging in Irrigation Project (after Bowonder et al, 1987).

(a) 1950 was the pre canal irrigation period, where in groundwater and rainfed based irrigation was in practice. Therefore the seasonal fluctuation in water table used to be rainfall recharge and groundwater utilization dependent and invariably causing high magnitude seasonal changes in water table.

(b) The subsequent changes in groundwater regime i.e. after the inception of canal irrigation, shows tremendous influence of surface water irrigation as well as drastic reduction in groundwater utilization. This could have resulted in to an overall rise in groundwater levels hence decrease in the magnitude of seasonal changes in water table.

(c) An intermittent rise in average fluctuation i.e. 1995 and 1999 may be attributed to changes in rainfall recharge, canal water input and adopted practices by way of changes in cropping pattern.

Table 9.1 Long Term Changes in Seasonal Fluctuations in Groundwater Table.

Year	Avg. SWL (m)		Seasonal Fluctuation (m)	Canal Discharge (cusec)	Rainfall (mm)
	Pre Monsoon	Post Monsoon			
1950	8.97	6.56	2.41	-	1150
1980	3.16	2.76	0.41	125723	960
1990	3.87	2.21	1.66	102318	887
1995	4.08	3.01	1.07	123386	1241
1999	4.42	3.65	0.77	135735	823

(ii) **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 (Fig. 9.2) 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.

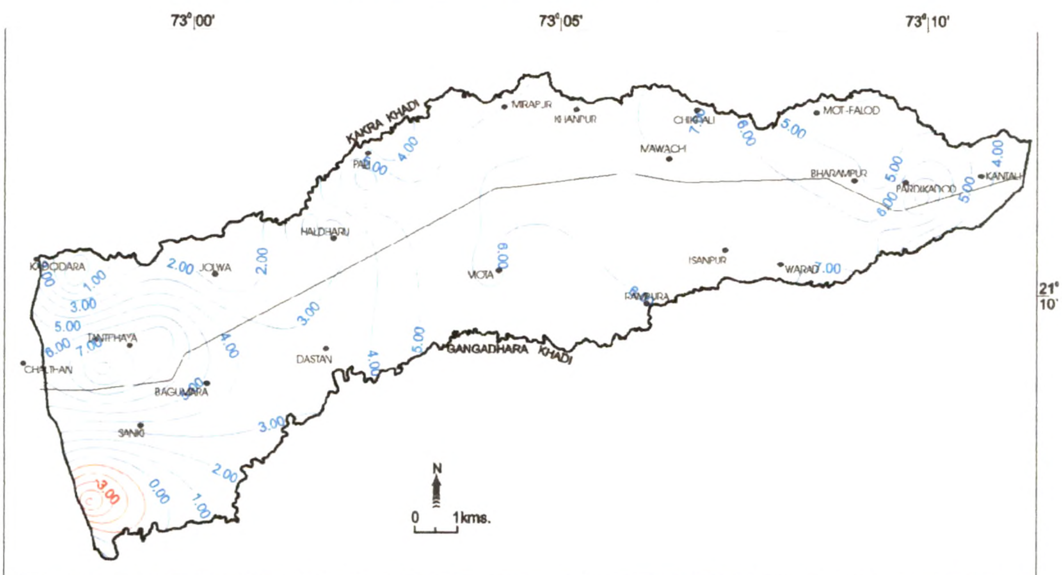

Fig. 9.2 Secular (Net) Change in Groundwater Levels, Chalthan Command Area (1950-99).

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. The observed fall (i.e. net changes of 5 m in groundwater storage) in water level around Baleshwar area is attributed to number of industries and settlements utilizing groundwater resource at large extent. The hydrographic profiles for 1950 and 1999 prepared along Karan - Kantali (A-A') transact (Fig. 9.3) is also in conformation to above cited observations.

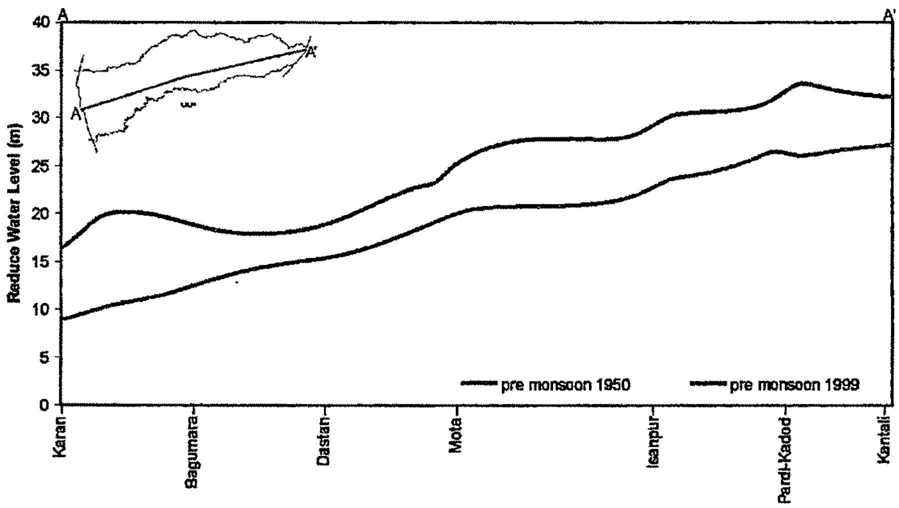

Fig. 9.3 Spatial Hydrographic Profiles Along Karan - Kantali (A-A') Transact Showing Secular Changes in Groundwater Regime, Chalthan Command Area (1950-99).

(iii) **Spatial Coverage (Hydro-Iso-Bath)**: Based on the available and measured data on seasonal water level patterns, the author has prepared Hydro-Iso-Bath (HIB) maps. For this author has taken in to account the last 50 years of available water table records. The evaluation has been made at the intervals of 20, 15, 10 and 4 years i.e. 1950 - 70 - 85 - 95 and 1999, for both pre and post monsoon seasons. In the year 1950, water table in entire command was at more than 6 m depth, the prepared Hydro-Iso-Bath maps for subsequent years (Fig. 9.4 -9.7) have provided spatial coverage of various water levels. Fig. 9.4 shows that during pre monsoon 1970, major part of the study area was having water table depth 6.0 and more than 6.0 m. However, the lower extremity of study area and area around north of Isanpur has reported the HIB less than 3 m. During pre monsoon 1985 (Fig. 9.5) the middle and lower command area shows the development of HIB 1.5 and 3 m, whereas the area south of Sanki village, the development of 6 m HIB was observed. During 1995 maximum area was having HIB of 1.5 and 3 m (Fig. 9.6), while the command area in its lower and upper extremes shows the HIB with 6 m. Hydro-Iso-Bath map for the year 1999 depicts similar trends as observed in case of 1995, except the slight increase in area of 6 m HIB (Fig. 9.7). These observed aerial changes in HIB may be attributed to the overall rise in groundwater levels due to returned irrigation seepage.

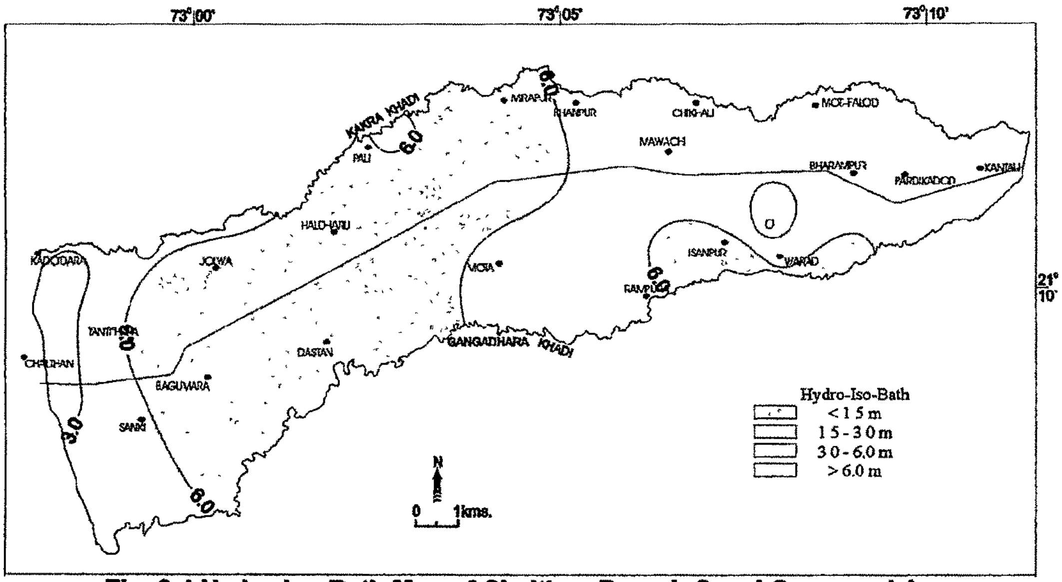

Fig. 9.4 Hydro-Iso-Bath Map of Chalthan Branch Canal Command Area (pre monsoon 1970).

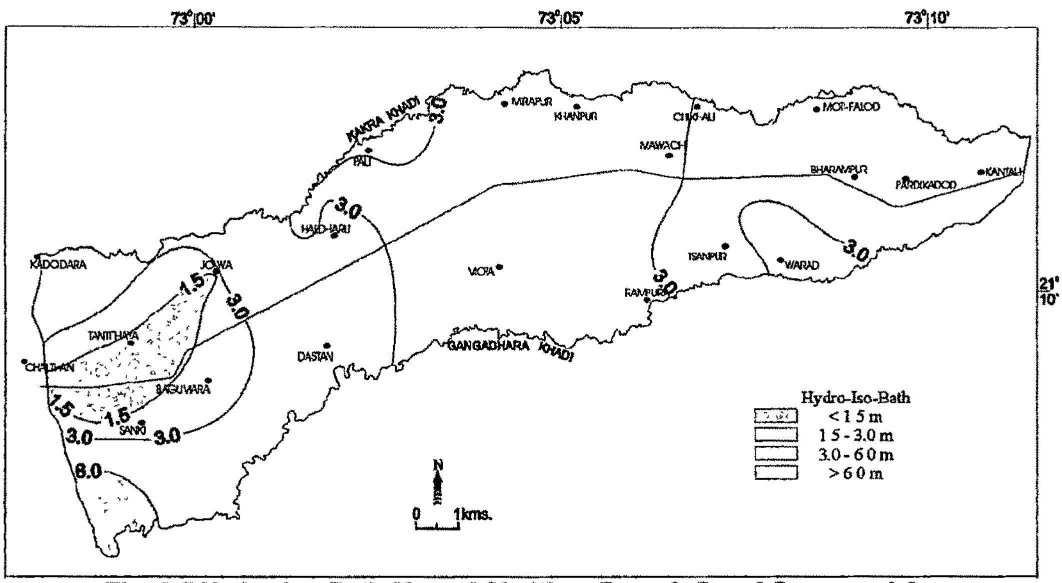

Fig. 9.5 Hydro-Iso-Bath Map of Chalthan Branch Canal Command Area (pre monsoon 1985).

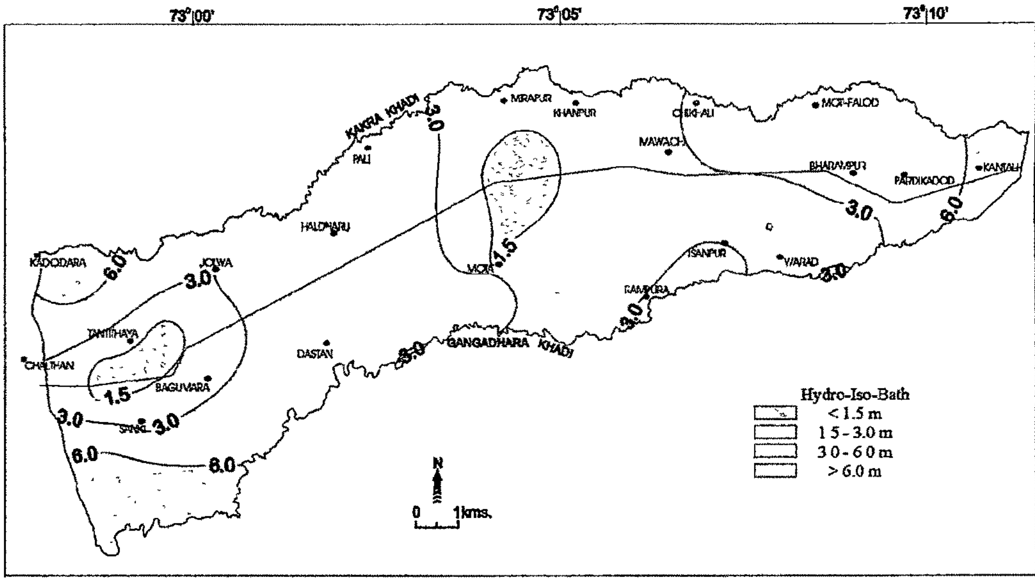

Fig. 9.6 Hydro-Iso-Bath Map of Chalthan Branch Canal Command Area (pre monsoon 1995).

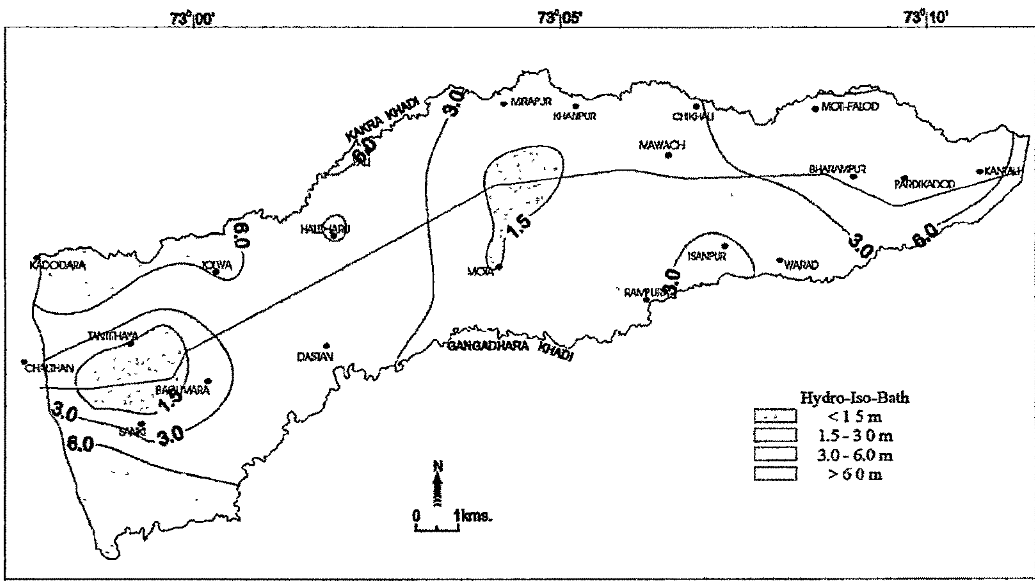

Fig. 9.7 Hydro-Iso-Bath Map of Chalthan Branch Canal Command Area (pre monsoon 1999).

The spatial distribution pattern of the various range of Hydro-Iso-Baths for various periods and range of water levels may be characterized as 0.0-1.5 m (waterlogged), 1.5-3.0 m (prone to waterlogged), 3.0-6.0 (rise in water level) and more than 6.0 m (deep water level) are given in Table 9.2.

Table 9.2 Hydro-Iso-Bath Estimates of Chalthan Branch Canal Command Area.

Year	Hydro-Iso-Bath							
	< 1.5 m		1.5 - 3 m		3 - 6 m		> 6 m	
	Waterlogged		Prone to waterlogged		Water table rise		Deeper water table	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Pre monsoon								
1950*	0.00	0.00	0.00	0.00	0.00	0.00	109.45	100.00
1970	0.03	0.03	4.54	4.14	54.21	49.53	50.67	46.30
1985	5.85	5.35	51.44	47.00	49.86	45.56	2.29	2.10
1995	4.48	4.10	47.70	43.58	47.51	43.41	9.75	8.91
1999	5.92	5.41	44.84	40.97	48.32	44.15	10.37	9.47
Post monsoon								
1950*	0.00	0.00	0.00	0.00	46.39	42.38	63.06	57.62
1970	NA	NA	NA	NA	NA	NA	NA	NA
1985	13.48	12.32	67.07	61.28	26.22	23.95	2.68	2.45
1995	6.21	5.67	70.89	64.77	30.82	28.16	1.53	1.40
1999	11.73	10.71	50.54	46.17	39.13	35.75	8.06	7.36

* - Pre canal irrigation scenario

Based on data placed in Table 9.2 it can be observed 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 < 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. The prepared histogram (Fig. 9.8) with the help of hydro-Iso-Bath data clearly establishes the above stated inferences.

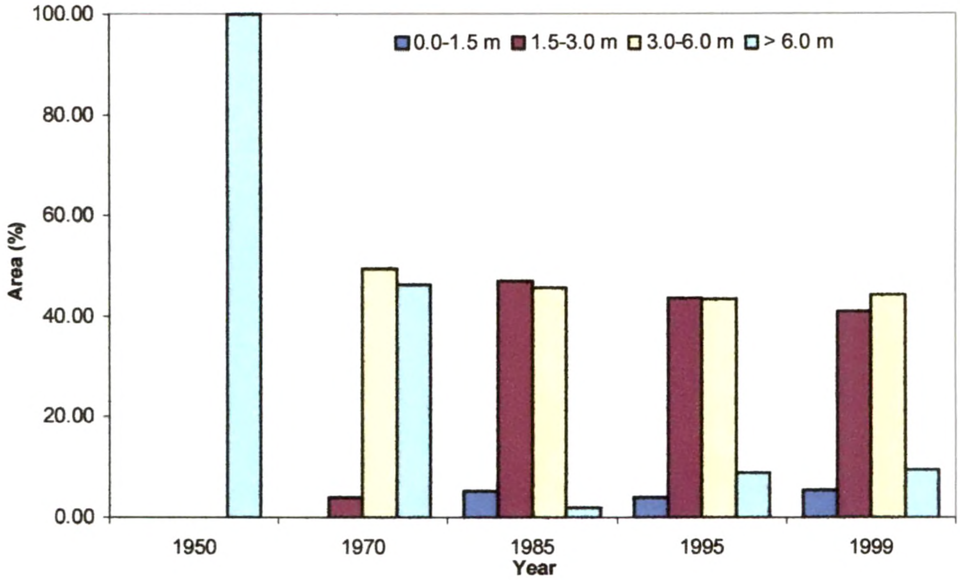

Fig. 9.8 Hydro-Iso-Bath Trends in Chalthan Branch Canal Command Area.

Waterlogging is caused by both natural as well as man-made factors (Fig. 9.1). A noteworthy contribution on the study of waterlogging problems of irrigation projects has been made by the following workers viz., Todd, 1959; Mehta et. al., 1968; Walton, 1970; Arar, 1971; Framji, 1973; Gupta and Pandey, 1979; Agrawal and Malik, 1982; Raman, 1984; Bapat and Shah, 1984; Gupta, 1985; Bhatnagar, 1986; Sondhi and Sharma, 1987; Bowonder et al, 1987; Batta et al, 1990; Bouwer et. al., 1990; Chitale, 1991; Varade, 1992; Abott, 1997; Finney, 1997; Gupta and Gupta 1994; Gajja et al, 1998; Salama et. al.; 1999, Valenza, et. al., 2000; Vishwakarma et. al., 2000; Singh, 2000; Babu Rao, et. al., 2001 and Sarwar et. al., 2001.

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.

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.

Salient controls exercised by above-mentioned factors in causing the waterlogging phenomena are discussed as under:

i. Topography

As it has already been discussed in the preceding chapter on the Terrain characteristics that the study area is having altitude ranging from 16 to 37 AMSL. The ground is slopping with an average gradient 1:1333 towards west, signifying terrain to be nearly leveled land (Fig. 6.2). Flat gradient coupled with featureless topography, lead to higher rate of infiltration than the surface run-off.

ii. Drainage

Improper drainage is an important causative factor that contributes to rise in groundwater table thereby waterlogged condition. The overall drainage density in the study area is extremely low i.e. 0.46 km/sq.km. Due to the poor surface drainage facility (Fig. 6.3), the water remains stagnant over the study area for considerable time. This gives rise to heavy percolation thereby, groundwater table rise in the command area.

iii. Aquifer Characteristics

As fore going account on hydrogeological characteristics of the study area categorically points to inconsistent disposition pattern of the aquifer materials. The aquifer thickness tends to increase from east to west direction with minor difference in hydraulic gradient. Also change in lateral hydraulic gradient due to lensoidal nature of aquifers prevents the movement of the groundwater in some part of study area particularly in central and upper parts, causing stagnation of groundwater as well as the up rise in the water level (Plate 5 & 6).

iv. Seepage from Canal

One of the main contributing factors for the rise in water table is recharging of the groundwater by the seepage water of canal, which are unlined. The complete canal system i.e. branch canals, minors and sub minors of Chalthan Branch Canal system is unlined and hence the contribution through seepage can be anticipated to be substantial (Plate 7 & 8). This seeping water cause damage to agriculture land due to waterlogging.

Plate 5 High Water Level in a Well Located at Bagumara.

Plate 6 High Water Level in a Well Located at Mota.

Plate 7 Seepage Through Canal Structure Causing Water Ponding.

Plate 8 Unlined Sub minor in Chalthan Branch Canal Command Area (Loc. Bagumara).

The behaviour of the water table fluctuation in a high water table area near the bank of Navsari Branch studied by Raman (1984); clearly indicates that when the canal is under operation, the whole root system of the crop is completely submerged.

When the canal stops the water table goes down (Table 9.3). Thus canal seepage causes water table to increase almost by 50 percent during its operative periods.

Table 9.3 Water Table Fluctuations Observed During the Year (Sugarcane Research Farm, Navsari).

Month	Depth to water table (cm)	
	When canal runs	When canal stops
January	45-50	110-115
February	45-0	110-115
March	45-50	100-110
April	40-45	80-100
May	40-45	80-100
June	30-35	60-70
July	15-25	40-50
August	15-25	40-50
September	15-25	40-50
October	20-25	50-60
November	25-30	60-70
December	30-35	80-100

Source: Raman (1984)

Similar behaviour has also been observed in study area while carrying out water level monitoring in different seasons. A well located nearby at Chalthan Branch Canal at Mavachhi (E2) shows, that during post monsoon 1998 when canal was under operation, the static water level was 0.87 m, while during post monsoon 1999 when canal was non operational, the static water level has gone down to 4.7 m. This drastic change in well water levels is manifested by the seepage from unlined canal.

v. Soil Structure and Texture

Waterlogging also depend upon the structure and texture of the soil. Particularly the area covered by deep clayey soils, comprising 'montmorillonite' as the predominant clay mineral. These montmorillonitic heavy soils have a very high potential fertility, high moisture holding capacity and can sustain increased crop production under irrigation (Rai, 1995). But, at the same time, the soils being of low to very low permeability and characterized by inadequate vertical and horizontal drainage. Consequently, due to poor out-fall conditions and impeded drainage, caused the waterlogging, after the introduction of canal irrigation in the study area.

vi. Damaged Structure of Canals

Much more water is leaking through damaged Head Regulator, Cross Regulator, Drainage Siphons and other structures (Plate 9 & 10). This wasted water causes damage to agriculture land due to waterlogging. The natural drains and other major and minor drains are also not in proper condition. They are silted up, and obstructed by heavy growth of weeds. Resultantly the drains are not capable of drawing discharge to its capacity.

Plate 9 Damaged Embankment Structure of Canal of Chalthan Branch Canal (Loc. Near Mota village).

vii. Excessive Surface Water Utilization

Tiwari and Singh (1997) have studied the crop water requirement (Fig. 9.9) in the Chalthan Branch Canal Command Area during three seasons of an annual cycle by considering the parameters viz. (i) the adopted cropping pattern in the last three years, (ii) the average annual precipitation received in the kharif season during last 10 years and (iii) the average irrigation waters applied (cm/ha) during last 10 years.

Plate 10 Damaged Canal Structure of Chalthan Branch Canal (Loc. Near Head Regulator of Canal).

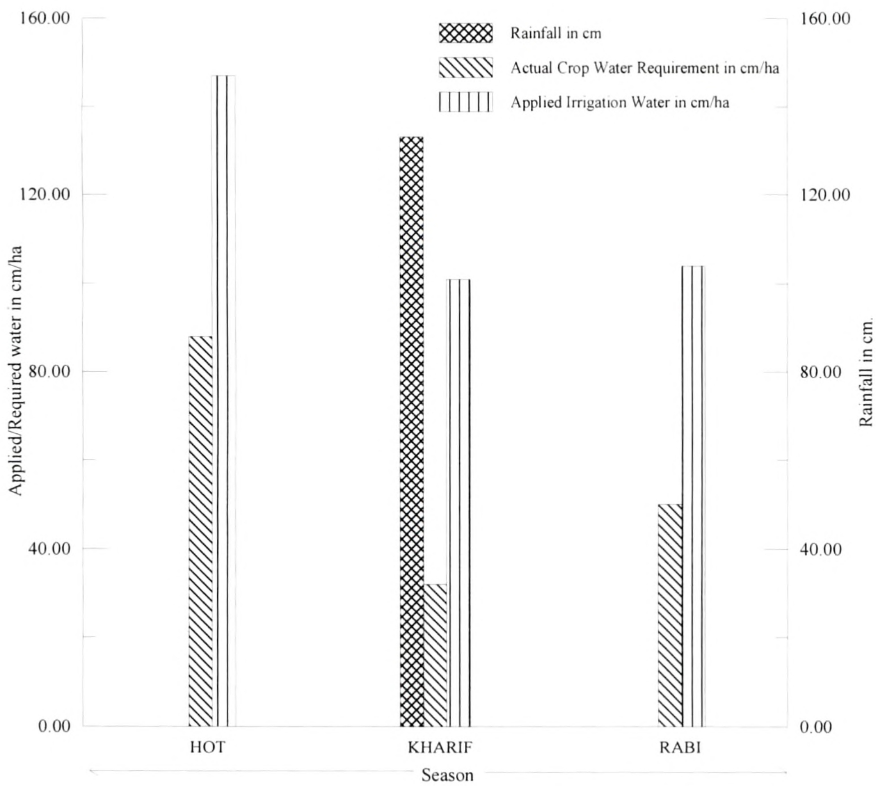

Fig. 9.9 Crop Water Requirement vis-à-vis Applied Irrigation Waters, Chalthan Branch Canal Command Area.

It can be seen from the Fig. 9.9 that the total input of water through canal irrigation including the precipitation is too high against the actual crop water requirement during various seasons of the year. Average irrigation water applied during the hot season is about 147 cm/ha, against the actual average crop water requirement of 88 cm/ha. Similarly, it is 104 cm/ha against the actual requirement of 50 cm/ha during the rabi season. During kharif season, average annual precipitation of 133 cm/ha is in addition to the irrigation waters applied at a rate of 101 cm/ha. Thereby the total water input stands at 234 cm/ha against the crop utilization of only 32 cm/ha. Therefore almost 200 cm/ha water is applied in excess, which ultimately goes to groundwater storage are of bound to create waterlogging hazards in the study area.

viii. Changes in Cropping Pattern

As envisaged and desired for increased production of the crops, there was sudden shift from the traditionally unirrigated crops to irrigated crops in the command area. Amongst the new introduced crops, sugarcane has gained a lot of momentum due to its high yield and more income. The sugarcane is grown in 60-70% of the Kakrapar Left Bank Canal Command area. In addition to this, the area under paddy and vegetable crops are also on the increase. Various cropping patterns as recommended by the project authority, since the inception of canal irrigation in Kakrapar Command Area by taking the basis of soil-water relationship and the actual practiced cropping pattern; adopted by the farmers in the command area (Table 9.4) shows manifold changes. The recommended cropping pattern in the year 1978 shows that perennial crops was earmarked for 21.3 % of total culturable command area; that has witnessed almost 03 fold increase i.e. 61.7 % in 1990-91.

Similarly the project authority by taking the basis of different land irrigability classes in the command area has recommended different cropping pattern. The suggested and actual cropping pattern based on the land irrigability classes are given in Table 9.5. From the Table it is evident that the sugarcane and paddy crops are grown in all the land irrigability classes except land irritability class V. Inspite of this very fact that land irrigability classes III and IV are suitable to only seasonal crops, the farmers have been growing sugarcane and paddy crops. The water requirement for seasonal crops is 5 MM^3 while the high water requirement crops like paddy and sugarcane varies between 50 and 200 MM^3. The land irrigability classes III and IV are characterized by poor internal drainage (Gajja et al, 1998). This drastic deviation from the recommended crop pattern has caused adverse soil-water relationship.

Table 9.4 Recommended and Adopted Crop Patterns of Kakrapar Left Bank Canal Command Area in the Year 1954 (area in Hectare).

Crops	Recommended Crop Pattern			Adopted by Farmers
	1954	1968	1978	1990-91
	CCA - 166190 ha	CCA - 173096 ha	CCA - 145335 ha	CCA - 142775 ha
	Area in percentage			
Perennials (sugarcane, banana)	-	10.45	21.3	61.7
Paddy	27.42	29.81	32.01	21.0
Cotton	14.22	11.21	3.33	1.3
Vegetables	16.75	6.0	10.03	2.0
Wheat	12.57	13.06	8.3	1.1
Juwar	12.30	12.42	14.33	0.4
Manure	16.74			12.4
Oil seeds and Pulses		6.11	10.7	
Maize		2.11		
Fodder		4.36		
Fruit trees		4.47		

(Source: S.I.C., Surat)

Table 9.5 Suggested and Adopted Cropping Patterns Based on Land Irrigability Classes in the Kakrapar Command Area.

Land Irrigability Class	Cropping Pattern	
	Suggested	Adopted by Farmers
I	High water requirement crops/perennial	Sugarcane, Banana, Paddy, Cotton
II	Light high water requirement crops/perennial	Sugarcane, Paddy, Banana, Cotton
III	Two season crops	Sugarcane, Paddy, Cotton
IV	One season crops	Sugarcane, Paddy, Cotton
V	Not suitable for irrigation	Cotton

In the Chalthan Branch Canal Command area Mota, Dastan, and Bagumara villages are considered to be the severely affected area by high water table i.e. waterlogging and that is attributed to change in cropping pattern. The statistical data plots on the aerial coverage of sugarcane crop with relation to time (Fig. 9.10) clearly points to this very fact. Sugarcane crops during 1987-88 was covering about 1650 ha of land which shows an increase to about 1875 ha in a span of 4 years i.e. 1991-92.

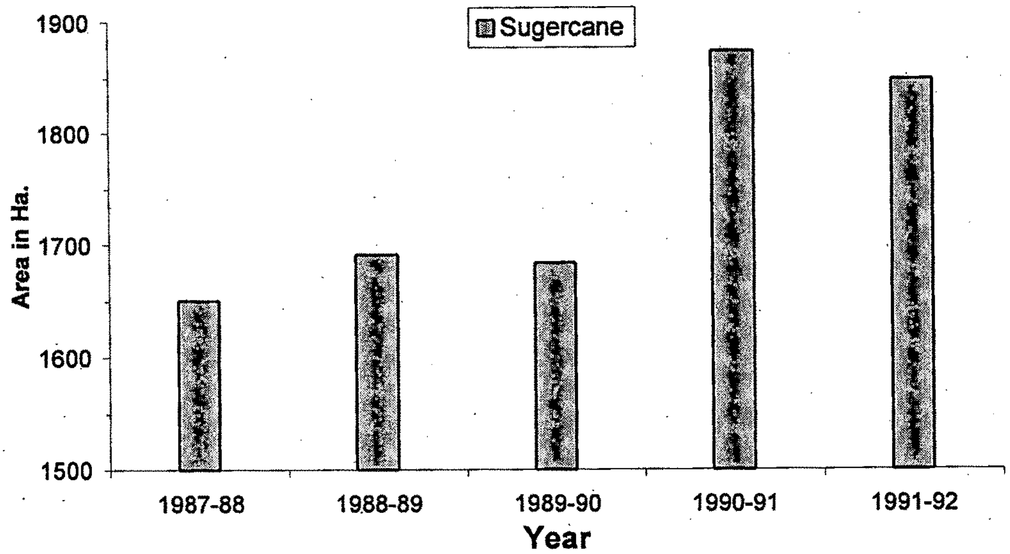

Fig. 9.10 Observed Annual Changes in Area Covered by Sugarcane in 03 villages of Chalthan Branch.

Effect of Waterlogging

Air and water in proper proportion in the root zone are essential for optimal growth of plants. Waterlogging effects are felt through the plant root system. The root system occupies a volume or soil roughly equivalent to the volume of the above ground plant parts. It serves to physically support the plant, and as an entry point for water, nutrients, and oxygen. The roots also release carbon dioxide, an end product of plant metabolism, into the soil (Svendsen, 1976). The presence of excess water in the root zone affects the plant in various ways; some of them are described as under:

- The plant needs oxygen for respiration but when the soil pores in the crop root zone become saturated, the plant roots do not receive the required quantity of air. The level of oxygen declines and that of carbondioxide increases with saturation of the soil with water (Wesseling, 1974). The cutting off or depletion of the oxygen supply to soil affects the root of the plant and aerobic microorganism looses almost entirely the capacity to product energy, hence plant stop growing and may even die.
- All soil supports populations of micro flora, which may exert both harmful and beneficial influences on plants. In well-drained soils this population is composed largely of aerobic organisms, which fix atmospheric nitrogen and mineralize organic material in the soil in the form of nitrogen, useable by

plants. Under conditions of prolonged waterlogging, these aerobic organisms are replaced by anaerobic forms with the result; nitrogen fixation and mineralization are greatly reduced. Additionally, nitrate and ammonium ions already present in the soil may be decomposed into forms, which are unavailable for plant use.

- Soil temperature is essential for many physical, chemical and biological activities in the soil. In regions having temperate climate the temperature plays still more important role. The well-drained soils warm up faster than waterlogged soils. The low soil temperature not only hampers the germination of seeds, but also restricts development of the root system and affects the rate of growth and final ripening. Furthermore, with low soil temperatures, accompanied by poor aeration, the plant root system does not develop properly and becomes susceptible to attack by number of pests and diseases.
- The physical conditions of the soil are affected adversely by water saturation and normal biotic activities of root development are disturbed. Low concentration of oxygen in waterlogged soils decreases nutrient uptake by slowing root growth, lowering the availability of some nutrients and reducing the energy available with the root for active uptake.
- Field operations become either impossible or difficult in such soils.
- The extent of damage becomes maximum when the capillary water brings up the salt from the lower horizon of the soils or those already present in the groundwater. Heavy concentration of salts thus accumulated for long renders the soil afflicted by salinity, non-conductive and rather injurious to the plant growth.

GROUNDWATER QUALITY

Water quality is governed by the extent and composition of the solids dissolved in it. Excessive concentration of dissolved ions, may make water injurious to irrigation and drinking use. Whenever water is diverted from a river for irrigation use, the quality of the return flow becomes degraded. The degraded return flow then mixes with the natural flows in the river systems and may deteriorate the river water too.

Also the water, which moves through soil profile, it may pick up additional salts by dissolution. In addition, some salt may be precipitated in the soil and there will be an exchange between salts present in water and soil. This water returns as return flow from field or through soil profile, expected to undergo variety of changes in quality (Skogerboe and Walker, 1981).

Drainage from surface sources consists mainly of surface runoff from irrigated land. Because of its limited contact and exposure to the soil surface, the following changes in quality of water might be expected (Skogerboe and Law, 1971):

i. Dissolved solids concentration only slightly increased,
ii. Addition of variable and fluctuating amounts of pesticides and fertilizer elements,
iii. An increase in sediments and other colloidal material,
iv. Crop residues and other debris floated from the soil surface and
v. Increased bacterial content.

Drainage water that has moved through the soil profile will experience different changes in quality from surface runoff. Because of its more intimate contact with the soil and the dynamic soil-plant-water relation, the following changes in quality are predictable (Skogerboe and Walker, 1981):

i. Dissolved solids concentration increased considerably,
ii. The distribution of various cations and anions may be quite different,
iii. Variation in total salt content,
iv. Increased in nitrate content
v. Reduction of oxidizable organic substances
vi. Reduction of pathogenic and colliform bacteria.

Groundwater Salinisation

The major problems resulting from irrigation are due to basic fact that plants are large consumers of water resources. Growing plants extract water from the supply and leave salts behind; resulting in a concentration of the dissolved mineral salts that are present in all natural water resources (Skogerboe and Walker, 1981). Salinity problems from irrigated agriculture are the result of subsurface return flows. Therefore, it becomes highly important to know the movement of groundwater flows.

Westcot (1979) has ideally depicted the mechanizing water and salts movement in an irrigated river basin (Fig. 9.11).

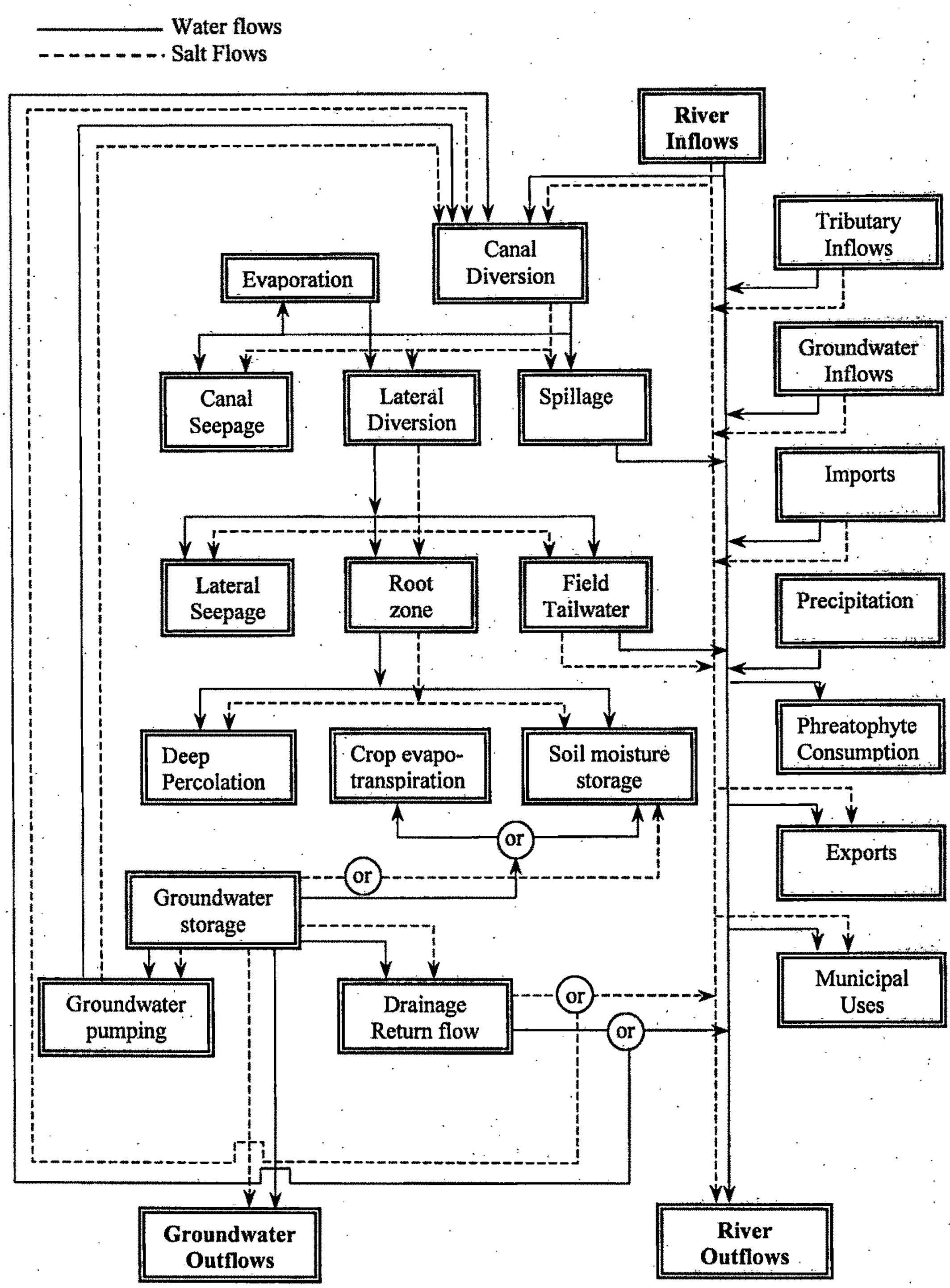

Fig. 9.11 Flow Sheet Diagram Depicting Water and Salt Circulation in an Irrigated River Basin (Westcot, 1979).

As it has already been discussed in the previous chapters that after the introduction of canal irrigation there has been considerable increase in the area covered under saline water, which is very well revealed from Table 9.6. 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.

It is an established fact that as the salinity of water increases, the proportions of sodium, magnesium and calcium salts also increases. At higher level of salinity, the proportion of magnesium salt increases over calcium salts (Skogerboe and Walker, 1981; Gupta and Gupta, 1997). Hence the groundwater salinisation adversely affect the physical properties of soil, reduction in crop yields etc (El-Ashry et. al., 1985).

Table 9.6 Temporal Aerial Distribution Pattern of Electrical Conductance in Chalthan Branch Canal Command Area.

Year	Pre-monsoon							
	< 1000 mmhos/cm		1000-2000 mmhos/cm		2000-3000 mmhos/cm		> 3000 mmhos/cm	
	Area in ha.	%	Area in ha.	%	Area in ha.	%	Area in ha.	%
1970	67.43	61.61	40.64	37.13	1.37	1.25	0.00	0.00
1980	1.78	1.63	85.93	78.51	11.15	10.19	10.58	9.67
1985	7.32	6.69	74.67	68.22	21.64	19.77	5.74	5.25
1990	4.34	3.96	63.63	58.14	32.52	29.71	8.96	8.18
1995	2.31	2.11	91.89	83.96	15.24	13.92	0.00	0.00
1999	7.07	6.46	61.66	56.34	32.56	29.75	8.15	7.45
	Post-monsoon							
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	10.48	9.57	61.51	56.20	30.62	27.97	6.84	6.25
1985	19.17	17.51	61.73	56.40	17.74	16.21	10.81	9.88
1990	11.54	10.55	77.36	70.68	20.54	18.77	0.00	0.00
1995	10.01	9.15	94.34	86.20	5.09	4.65	0.00	0.00
1999	3.88	3.54	42.88	39.17	46.57	42.55	16.12	14.73

Geochemical Diversity

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 (Mathess, 1982). Study of these ionic ratios is helpful in identifying the relative contribution of ions from natural and anthropogenic sources. A detailed quantitative data on various ionic ratios as Na/Ca, Ca/Mg and Na/Cl, obtained from groundwater from various locations and for different seasons are given in Table 9.7.

Table 9.7 Seasonal Ionic Ratios of Groundwater in Chalthan Branch Canal Command Area.

Sr. no.	Grid no	Location	Pre monsoon 1999			Post monsoon 1999		
			Na/Ca	Ca/Mg	Na/Cl	Na/Ca	Ca/Mg	Na/Cl
1	G-3	Warad	1.92	7.14	1.19	1.46	6.50	1.00
2	I-2	Kantali	5.39	0.56	2.94	3.51	0.72	1.65
3	H-2	Khoj-pardi	3.40	0.22	0.71	18.39	0.06	0.73
4	G-2	Motiphalod	5.76	0.81	0.83	16.83	0.38	1.08
5	F-1	Nagod	2.22	1.52	1.99	4.16	0.61	1.73
6	F-1	Vihan	1.99	1.44	1.41	3.71	1.26	1.50
7	F-1	Vihan	10.18	0.74	1.05	19.50	0.41	1.07
8	E-2	Sevni	9.05	1.22	2.25	9.57	1.12	2.26
9	E-2	Mota	9.11	0.51	1.02	22.53	0.17	0.97
10	D-4	Kareli	4.91	0.75	1.13	8.54	0.44	1.05
11	F-3	Rampura	1.50	1.08	1.06	2.13	0.88	1.40
12	F-3	Rampura	4.81	0.79	1.08	32.03	0.19	1.24
13	F-2	Mavachhi	6.59	0.89	0.93	4.18	2.47	1.09
14	G-3	Warad	2.70	0.37	1.31	5.87	0.14	0.84
15	C-5	Bhatpur	4.68	0.86	1.04	15.08	0.36	1.17
16	D-4	Tundi	17.50	0.13	1.35	13.90	0.13	1.10
17	D-4	Dastan	4.55	2.44	1.13	6.95	0.75	0.99
18	C-3	Haldharu	7.53	1.41	0.98	9.41	0.69	1.20
19	C-2	Parab	11.46	0.16	0.79	6.71	0.20	0.59
20	B-3	Umbhel	24.08	0.42	1.15	35.08	0.50	1.22
21	C-4	Bagumara	3.32	1.21	1.39	5.12	0.21	0.80
22	B-4	Sanki	13.42	0.60	1.10	9.47	0.45	1.12
23	A-4	Karan	3.71	1.20	0.87	8.17	0.39	0.85
24	A-5	Wadadla	10.63	0.16	0.72	6.74	0.30	0.77
25	A-4	Chalthan	4.88	0.49	1.20	5.02	0.75	1.14
Minimum			1.5	0.13	0.71	1.46	0.06	0.59
Maximum			24.08	7.14	2.94	35.08	6.5	2.26

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 (Chhabra, 1995). Based on the Ca/Mg ratio (Table 9.7) 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 (Astaraei and Chauhan, 1995). 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 (Astaraei and Chauhan, 1995) and also because of base exchange, whereby most calcium is displaced by sodium (Degens and Chilingar, 1967). 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 (Sarin et. al., 1992). The lower ratio i.e. < 1 indicate reverse ion exchange phenomenon where Ca and Mg replace Na from soil (Keerthisecl et al, 2001).

Schoeller Index (SI) is used to determine the possibilities of ion exchange reaction taking place in groundwater. This index results due to changes in the chemical composition of groundwater (Schoeller, 1959). The positive value of the SI is indicative of base exchange reaction i.e. Na+K in water being exchanged with Mg and Ca, whereas negative value of the SI is considered, indicative of cation-anion exchange reaction i.e. chloro-alkaline dis-equilibrium (Schoeller, 1962). 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 (Fig. 7.36). 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.

Statistical Treatment

The statistical analysis of geochemical data is given in Table 9.8, which shows general distribution of the various ions in the study area and their tends of fluctuation from pre to post monsoon season.

Table 9.8 Statistical Data on Ionic Content of Groundwater in Chalthan Command Area.

Parameter	Pre monsoon 1999			Post monsoon 1999		
	Range	Avg.	Std. dev.	Range	Avg.	Std. Dev.
PH	7.32 - 8.80	8.09	0.35	7.90 - 8.50	8.19	0.15
EC mmhos/cm	0.38 - 4.60	1.65	0.85	0.46 - 4.43	1.72	0.81
TDS ppm	243.2 - 2944.0	1053.87	543.66	294.4 - 2835.2	1103.64	519.75
Hardness meq/l	85.46 - 702.11	247.87	160.13	72.20 - 699.88	250.01	152.95
Ca meq/l	0.50 - 4.12	1.84	0.85	0.32 - 3.20	1.41	0.76
Mg meq/l	0.21 - 11.51	3.11	2.86	0.20 - 10.75	3.57	2.81
Na meq/l	0.21 - 37.55	10.44	7.08	1.90 - 32.90	11.71	6.66
K meq/l	0.00 - 0.63	0.08	0.16	0.00 - 0.26	0.05	0.08
CO_3 meq/l	0.00 - 0.60	0.14	0.19	0.00 - 1.40	0.27	0.36
HCO_3 meq/l	0.96 - 4.58	2.16	0.68	0.84 - 3.60	2.22	0.72
Cl meq/l	1.83 - 36.88	9.98	7.90	1.90 - 34.00	11.37	7.73
SO_4 meq/l	0.18 - 8.93	2.82	2.09	0.40 - 6.20	2.88	1.46
SAR %	0.15 - 15.21	6.92	3.81	2.19 - 19.85	7.93	4.30

The systematic calculation of correlation coefficient between water quality variables and regression analysis provides an indirect means of rapid monitoring of water quality (Tiwari and Ali, 1988; Jain and Sharma, 2000). The correlation coefficient is calculated with the following equation

$$\mathrm{P}xy = \frac{Cov(X,Y)}{\sigma x.\sigma y}$$

where $-1 \leq \mathrm{P}xy \leq 1$ and $Cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_x)\times(y_i - \mu_y)$

The correlation matrix for different groundwater quality variables of the Chalthan Branch Canal Command area is given in Table 9.9 & 9.10 for pre and post monsoon 1999.

It is evident from Table 9.9 that distribution of hardness, sodium, chloride, magnesium, sulphate and calcium were significantly correlated (r > 0.5) with electrical conductivity in almost all the study area. While the data of post monsoon 1999 (Table 9.10) shows that the distribution of hardness, chloride, sodium, magnesium, calcium and bicarbonate were significantly correlated (r > 0.5) with electrical conductivity. In these the potassium does not show significant correlation with electrical conductivity.

Table 9.9 Correlation Matrix Among Different Water Quality Variables (pre monsoon 1999).

	EC	Hardness	HCO_3	Cl	SO_4	Ca	Mg	Na	K
EC	1.00								
Hardness	0.69	1.00							
HCO_3	0.28	0.46	1.00						
Cl	0.95	0.67	0.15	1.00					
SO_4	0.55	0.52	0.22	0.67	1.00				
Ca	0.53	0.51	-0.06	0.46	0.46	1.00			
Mg	0.61	0.97	0.53	0.61	0.44	0.27	1.00		
Na	0.94	0.50	0.11	0.94	0.51	0.44	0.43	1.00	
Kankra	0.22	0.00	0.00	0.17	-0.01	0.17	-0.05	0.17	1.00

(Level of significance 5%)

Table 9.10 Correlation Matrix Among Different Water Quality Variables (post monsoon 1999).

	EC	Hardness	HCO_3	Cl	SO_4	Ca	Mg	Na	K
EC	1.00								
Hardness	0.73	1.00							
HCO_3	0.56	0.33	1.00						
Cl	0.94	0.72	0.36	1.00					
SO_4	0.41	0.25	0.54	0.10	1.00				
Ca	0.54	0.42	0.18	0.26	0.26	1.00			
Mg	0.70	0.97	0.31	0.71	0.20	0.19	1.00		
Na	0.92	0.48	0.48	0.92	0.27	0.21	0.46	1.00	
Kankra	0.50	0.32	0.12	0.43	0.43	0.11	0.32	0.46	1.00

(Level of significance 5%)

A positive high correlation between sodium and chloride is an indicative of sodium chloride in these waters. A good relation of hardness exists with the magnesium (r = 0.97) and chloride (r = 0.67), indicates that hardness groundwater is mainly due to the salts of magnesium and chloride ($MgCl_2$). The presence of magnesium chloride may be due to its inherent property, high degree of solubility and low degree of precipitation properties of the magnesium ion (Matthes, 1982).

Empirical Modelling

The above discussed correlation coefficient is suggestive of the ionic concentrations of groundwater are highly correlated to electrical conductivity. Precise and accurate means of estimating ionic concentration from easily measured electrical conduction are of great value and time saving. In a view of this author has made an attempt to work out empirical relationship between electrical conductivity and different ionic concentration of groundwater. Four different empirical models were examined for predicting the ionic concentrations are given below.

I. $y = c \times (ec) + b$ ....Linear

II. $y = c \times \mathrm{In}(ec) + b$ ....Logarithmic

III. $y = c \times (ec)^b$ ....Power

IV. $y = c \times e^{b \times (ec)}$ ....Exponential

where, y = total ionic concentration of particular ion, ec = Electrical Conductivity, c and b are empirical constants. Based on coefficient of determination (R^2) best suitable model is predicted. A computing formula for R^2 is

$$R^2 = 1 - \frac{SSE}{SS_y} = \frac{SSR}{SS_y}$$

$$\text{with } SS_y = \sum (Y_i - \overline{Y}_i)^2; SSE = \sum (\hat{Y}_i - Y_i)^2; SSR = \sum (\hat{Y}_i - \overline{Y}_i)^2$$

where $\overline{Y}$ is the average value of dependent variable and $\hat{Y}_i$ are the model computed values of the dependent variable. A strong linear association between Y_i and $\hat{Y}_i$ yields a large value of R^2 and vice versa (Bhatia et al, 1997). The values of different parameters and coefficient of determination (R^2) for different models using pre monsoon 1999 data are presented in Table 9.11. The relationship between EC and various ions are discussed below.

EC versus Sodium: In the present study EC of groundwater varies from 0.38 to 4.6 mmhos/cm and sodium content varies from 0.21 to 37.55 meq/l (Table 9.8). These ions have linear relationship with EC and the best fit line for EC versus sodium fall under model I is

$$Na = 7.8344 \times EC - 2.4565 \quad (R^2 = 0.8825)$$

Table 9.11 Empirical Constants and Coefficients of Determination (R^2) for Different Models for Groundwater in Chalthan Branch Canal Command Area (premonsoon 1999).

Model No.	Model Parameter c	b	R^2	Model Parameter C	b	R^2
	EC and Na			EC and HCO_3		
I	7.8344	-2.4565	0.8825	0.2271	1.7852	0.0803
II	11.074	6.3187	0.7001	0.5132	1.9680	0.1628
III	4.5079	1.5306	0.7723	1.8771	0.2012	0.2239
IV	2.0749	0.8175	0.5548	1.7299	0.1087	0.0977
	EC and Mg			EC and SO_4		
I	2.0670	-0.2984	0.3780	1.3491	0.5994	0.2997
II	2.7554	2.0787	0.2667	1.8791	2.1209	0.2309
III	1.6397	0.8690	0.3273	1.3886	1.0075	0.3304
IV	0.8989	0.5616	0.3443	0.8355	.5364	0.2859
	EC and Ca			EC and CO_3		
I	0.5292	0.9682	0.2819	0.0730	0.0218	0.1077
II	0.6466	1.5968	0.1671	0.0944	0.1070	0.0713
III	1.4794	0.2865	0.0934			
IV	1.1113	0.2386	0.1631			
	EC and Cl			EC and SAR		
I	8.8376	-4.5705	0.9030	3.0316	1.9310	0.4563
II	12.2300	5.4260	0.6867	5.0563	5.0394	0.5039
III	4.5069	1.3463	0.7975	3.4423	1.2465	0.5540
IV	1.9045	0.8277	0.7591	1.9946	0.6134	0.3379

EC versus Chloride: In the study area groundwater EC varies from 0.38 to 4.6 mmhos/cm and chloride content varied from 1.83 to 36.88 meq/l (Table 9.8). These ions have linear relationship with EC and the best fit line for EC versus chloride fall under model I is

$$Cl = 8.8376 \times EC - 4.5705 \quad \left(R^2 = 0.9030\right)$$

EC versus Calcium and Magnesium: In the study area groundwater EC varies from 0.38 to 4.6 mmhos/cm and calcium content varied from 0.50 to 4.12 meq/l and magnesium varies from 0.21 to 11.51 meq/l. These ions have linear relationship with EC and the best fit line for EC versus calcium and magnesium is fall under model I is

$$Ca = 0.5292 \times EC + 0.9682 \quad \left(R^2 = 0.2819\right) \ \&$$

$$Mg = 2.0670 \times EC - 0.2984 \quad \left(R^2 = 0.3780\right)$$

EC versus Bicarbonate and Sulphate: In the study area groundwater EC varies from 0.38 to 4.6 mmhos/cm and bicarbonate content varied from 0.96 to 4.58 meq/l and sulphate varies from 0.18 to 8.93 meq/l. The best-fit line is obtained with model No. III, which shows the highest coefficient of determination (R^2=0.2239 for bicarbonate and R^2=0.3304 for sulphate). The form of relationship is

$$HCO_3 = 1.8771 \times EC^{0.2012} \quad (R^2 = 0.2239) \ \&$$

$$SO_4 = 1.3886 \times EC^{1.0075} \quad (R^2 = 0.3304)$$

EC versus SAR: In the study area groundwater EC varies from 0.38 to 4.6 mmhos/cm and SAR varies from 0.15 to 15.21% (Table 9.8). The best-fit line is obtained with model No. III, which shows the highest coefficient of determination (R^2=0.5540). The form of relationship is

$$SAR = 3.4423 \times EC^{1.2465} \quad (R^2 = 0.5540)$$

Based on the above derived correlation of EC with coefficients of various ions, it can be inferred that sodium and chloride shows very high positive linear correlation with electrical conductivity, this indicate that as EC increases sodium and chloride also increases in groundwater. This observation also indicate that mineralisation is more in the form of sodium chloride which can be responsible for the soil salinity in the study area.

SOIL DEGRADATION

Groundwater rising under capillary action will evaporate, leaving salts in the soil. The problem is of particular concern in arid and semi-arid areas are of soil salinity. Talati (1941) had identified four types of damaged soils in basaltic terrain excluding waterlogged areas viz. (i) mixed saline soils, (ii) saline soils, (iii) alkali soils and (iv) strong alkali soils.

Important causative factors for an increase in soil salinity (Dougherty and Hall, 1995) on an irrigation scheme may be listed as under

i. Salts carried in the irrigation water are liable to build up in the soil profile, as water is removed by plants and the atmosphere at a much faster rate than salts. The salts concentration of incoming flows may increase in time with development activities upstream and if rising demand leads to drain water reuse.

ii. Solutes applied to the soil in the form of artificial and natural fertilizers as well as some pesticides will not be utilized by the crops completely.

iii. Salts, which occur naturally in soil, may move into solution or may already be in solution in the form of saline groundwater.

iv. Where the groundwater level is both high and saline, water will rise by capillary action and then evaporate, leaving salts on the surface and in the upper layers of the soil.

v. The transfer from rainfed to irrigation of a single crop, or the transfer from single to double irrigation may create a "humidity/salinity bridge" in the soil, between a deep saline groundwater and the (so far) salt-free surface layers of the soil.

Whereas the implications of land salinisation (Tyagi, 1982) includes

- low economic returns due to high cost of cultivation, decreased yields, and poor quality
- loss of habitat and biodiversity
- the salinisation of rivers and wetlands and altered surface water levels and flow regimes
- low groundwater recharge
- soil erosion and sedimentation
- waterlogging of soils, including the impact on health of rivers and wetlands as a result of contaminated surface runoff.

Some of the important works illustrating the process of soil and water salinization and referred by the author for understanding the aspects of soil degradation of his study area are Agrawal and Gupta, 1968; Abrol and Bhumbla, 1971; Paliwal and Gandhi, 1973; Gupta and Pandey, 1979; Garg and Singhal, 1982; Tyagi, 1982; Edmond et. al. 1985; Gupta, 1985; Hem, 1991; Gupta and Gupta, 1997, Tickell 1997; Hopkins and Richardson, 1999; Salama et. al., 1999; Cruz and Silva, 2000; Mehta et. al., 2000; Singh, 2000; Valenza, et. al., 2000; Wang and Cheng, 2000; Babu Rao, et. al., 2001; and Pariente, 2001.

As it has already been discussed in the preceding chapter on soil and sub-soil characteristics of saturation extract, through the soils of Kakrapar Left Bank Canal Command Area can be classified in to normal, saline, sodic and saline-sodic soils; but as far as Chalthan Branch Canal Command Area is concern 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 (Plate 11 and 12). 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 (Richards, 1954).

Plate 11 Saline Soils in Chalthan Branch Canal Command Area (Location: South of Bagumara village).

Plate 12 Saline Soils in Chalthan Branch Canal Command Area (Location: South of Mota village).

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 (Szabolcs, 1989).

Causes of Soil Salinity

Theoretically there are numerous factors influencing soil salinisation. However primarily it is irrigation, which leads to the formation of saline lands. In Chalthan Branch Canal Command Area various factors have contributed to the soil salinisation. A few important and identified factors are discussed below:

i. Climate

The study area constitutes a part of tropical terrain and characterised by sub-humid climatic conditions. Monsoon being the major and only source of water, the non-monsoon months faces net saturation deficit where in evaporation exceeds rainfall. This loss of water from subsoil horizon under the influence of capillary rise and plants' transpiration; mobilize the soluble salts upward and deposit within the soils. The rate of salt build up is invariably high in those areas, which are characterised by shallow water table and fine textured (clayey) soils, which is very well applicable in this present case

ii. Groundwater Table Conditions

Excessive application of canal irrigation has enhanced the groundwater recharge through the returned irrigation seepage, thereby rise in water table. As the rising groundwater always transfer salts from the deeper layers to the surface the soils become saline. The saline soil areas having higher water table, this factor has played a major role in the process of soil salinisation (Plate 13).

iii. Soil Properties

Basic soil properties like texture, structure, hydraulic conductivity, soluble salts content, and exchangeable cations, greatly influence the salinisation/alkalization processes (Szabolcs, 1989). The medium textured soils are more prone to salinasation as compared to fine texture soils as the later has a very slow saturated conductivity. But in the study area the occurrence of the fine textured soils are very widely distributed and availability of shallow saline water for a prolonged duration has facilitated the widespread salinisation. Further presence of compact duricrust layers normally obstructs the leaching of salts, which in turn gets deposited on the surface.

Plate 13 High Water Level in Agricultural Field (Location: West of Rampura Village).

iv. Over Irrigation

As a result of over irrigation there will be more recharge to the groundwater storage; even due to unlined and poorly maintained canal system the roadside ditches and drains remain full (Plate 14) with irrigation water; thereby rise in salt laden water table causing soil salinisation.

In the command area the sugarcane is a major crop. For a crop like sugarcane an average 20-22 irrigations of (8 cm) is applied by the farmers, amounting to total 160 cm of water. Whereas considering the soil types and groundwater conditions of the command area, only 10-15 irrigations can suffice the crop water demand. Therefore on an average 60 cm (40%) more water is applied that becomes additional contribution to groundwater regime.

Plate 14 A view of Kankra Khadi Showing Water Discharge Gathered from Over Irrigation & Canal Seepage (Location: East of Kadodara Village).

v. Irrigation Practices

Under irrigated conditions, the salt regime of the soils also depends on the method and technical standard of irrigation management (Szabolcs, 1989). The distribution of water and salts in soils vary with the method of irrigation. Therefore, the methods followed should create and maintain favourable salt and water regimes in the root zone in such a way that water is made readily available to plants for their growth without causing any damage to crop and its yield (Minhas and Singh, 1996). In the study area farmers mainly applying surface irrigation by water spreading methods. In case of surface irrigation, as a function of the amount of irrigation water applied, excessive leaching may result during the rise in water table, a reduction in the possibility for leaching soluble salts, and even in an increase in the salt balance of the soils. This is particularly true when the drainage condition of the irrigated area is very poor (Szabolcs, 1989).

Effect of Salinity on Soil Properties

The accumulation of salts in soils can lead to irreversible damage to soil structure, which is essential for irrigation and crop production. Soils containing significant clay fractions can be affected severely by particular mixtures and concentrations of salts. This leads to a loss of soil structure and impairment of water movement, makes growing conditions very poor, makes soils very difficult to work and prevents reclamation by leaching using standard techniques (Svendsen, 1976). The transfer from rainfed to irrigated agriculture, or intensification of existing irrigated crop production requires a higher level of nutrient availability in the soil profile. If this aspect is not given adequate attention, the irrigation efficiency remains low. High water losses through the profile will result into wash out of useful cations from the soil-complex.

A general lowering of pH may decrease the plants capability to take up nutrients, as well as an increased availability/release of heavy metals in the soil profile. in that case rectifying soil acidification problems can be very costly. For similar reasons the content of organic material in the soil may decrease. Such decrease leads to a degradation of soil structure and to a general decrease of soil fertility (Skogerboe and Walker, 1981).

Effect of Salinity on Agriculture

Suitable soil environment free from excess harmful salts is a pre-requisite for the proper plant development. Salts whether soluble or otherwise disturb the whole eco-system and cause adverse effect by way of innumerable factors, a few of important one listed as under:

- The most serious and common problem associated with agricultural salinity is the result of dissolved solids occurring in soil water. The quantity of such dissolved solids determines the osmotic potential of the soil water, which is the key determinant of plant response to salinity (Bernstein, 1974).
- The physical condition of the soil gets deteriorated. Highly deteriorated saline soils have very low water intake rate resultantly most of the rain falling on such soils goes out as run-off and cause floods and damages crops in adjoining areas (Svendsen, 1976).
- Almost any salt present in excess quantities may be termed toxic and can cause acute injury to a plant. The most common occurrence of this effect is the sensitivity of many woody plants, including fruit crops, to sodium and chloride ions (Bernstein, 1974).

- Plants require a balanced diet of nutrients to maintain optimal growth. That balance may be disturbed by the influx and root zone storage of salts carried by irrigation water. Thus, for example, a high concentration of calcium ions in the soil solution may prevent the plant from absorbing enough potassium to meet plant requirements even though sufficient potassium may be present in soil solution. (Bernstein, 1974).
- Fodders grown in alkali soils may contain high amounts molybdenum and selenium and low amount of zinc. Such nutritional imbalances may cause diseases in livestock (Svendsen, 1976).

Empirical Modeling

Author has made an attempt to work out empirical relationship between electrical conductivity and different ionic concentration of soil saturation extract. Four different empirical models were examined for predicting the ionic concentrations are given below.

I. $y = c \times (ec) + b$ ....Linear

II. $y = c \times \text{In}(ec) + b$ ....Logarithmic

III. $y = c \times (ec)^b$ ....Power

IV. $y = c \times e^{b \times (ec)}$ ....Exponential

where, y = total ionic concentration of particular ion, ec = Electrical Conductivity, c and b are empirical constants. Based on coefficient of determination (R^2) best suitable model is predicted. The values of different parameters and coefficient of determination (R^2) for different models using pre monsoon 1999 data are presented in Table 9.12. The relationship between EC and various ions of soil saturation extract i.e. soluble cation and anion are discussed below.

EC versus Sodium: In the present study EC of soil saturation varies from 0.23 to 2.9 mmhos/cm and sodium content varies from 1.24 to 16.20 meq/l. These ions have linear relationship with EC and the best fit line for EC versus sodium fall under model I is

$$Na = 5.5184 \times EC - 0.5756 \qquad (R^2 = 0.9127)$$

Table 9.12 Empirical Constants and Coefficients of Determination (R^2) for Different Models for Soil Soluble Ions in Chalthan Branch Canal Command Area (premonsoon 1999).

Model No.	Model Parameter		R^2	Model Parameter		R^2
	C	b		C	b	
	EC and Na			EC and Cl		
I	5.5184	0.5756	0.9127	5.1007	0.6774	0.9251
II	4.4040	6.5851	0.8194	3.9963	6.2018	0.8004
III	6.0964	0.8962	0.8755	5.7815	0.8442	0.0705
IV	1.9706	1.0005	0.7740	1.9899	0.9461	0.7826
	EC and Mg			EC and HCO_3		
I	1.8160	-0.2655	0.6794	3.6337	-0.4057	0.9289
II	1.3119	1.6562	0.4997	2.8229	3.5201	0.7902
III	1.3037	0.9776	0.5560	3.0789	1.1275	0.9032
IV	0.3596	1.1646	0.5597	0.7345	1.2749	0.8192
	EC and Ca			EC and SO_4		
I	1.0989	-0.0040	0.5639	1.1820	0.1840	0.1257
II	0.8558	1.1840	0.4821	0.09821	0.3143	0.1223
III	0.9605	0.9136	0.4966			
IV	0.2819	1.1080	0.4984			
	EC and Ca+Mg			EC and SAR		
I	2.9149	-0.2695	0.8111	1.9340	3.5660	0.2385
II	2.1677	2.8402	0.6322	1.8405	5.7930	0.3045
III	2.3822	0.9768	0.6690	5.5860	0.4079	0.3323
IV	0.6581	1.1632	0.6730	3.4354	0.4189	0.2487

EC versus Chloride: In the present study EC of soil saturation varies from 0.23 to 2.9 mmhos/cm and chloride content varies from 1.24 to 16.8 meq/l. These ions have linear relationship with EC and the best fit line for EC versus chloride is fall under model I is

$$Cl = 5.1007 \times EC - 0.6774 \quad \left(R^2 = 0.9251\right)$$

EC versus Calcium and Magnesium: In the present study EC of soil saturation varies from 0.23 to 2.9 mmhos/cm and calcium content varies from 0.17 to 3.5 meq/l and magnesium varied from 0.19 to 7.10 meq/l. These ions have linear relationship with EC and the best fit line for EC versus calcium and magnesium is fall under model I is

$$Ca = 1.0989 \times EC - 0.0040 \quad \left(R^2 = 0.5639\right) \ \&$$

$$Mg = 1.8160 \times EC - 0.2655 \quad \left(R^2 = 0.6794\right)$$

EC versus Bicarbonate and Sulphate: In the present study EC of groundwater varies from 0.23 to 2.9 mmhos/cm and bicarbonate content varies from 0.67 to 9.6 meq/l and sulphate varies from 0.00 to 0.87 meq/l. The best-fit line is obtained with linear relation model No. I, which shows the highest coefficient of determination (R^2=0.9289 for bicarbonate and R^2=0.1257 for sulphate). The obtained form of relationship is

$$HCO_3 = 3.6337 \times EC - 0.4057 \quad (R^2 = 0.9289) \ \&$$

$$SO_4 = 0.1182 \times EC - 0.1840 \quad (R^2 = 0.1257)$$

EC versus SAR: In the present study EC of groundwater varies from 0.38 to 4.6 mmhos/cm and SAR varies from 1.81 to 8.49%. The best-fit line was obtained with model No. III, which shows the highest coefficient of determination (R^2=0.3323). The form of relationship is

$$SAR = 5.5860 \times EC^{0.4079} \quad (R^2 = 0.3323)$$

Based on obtained empirical models of EC and various ions, it can be inferred that sodium and chloride shows very high positive linear correlation with electrical conductivity, this indicate that as EC increases sodium and chloride also increases both as soil soluble (Table 9.12) as well as groundwater ions (Table 9.11). Thus it is inferred that soil salinisation has dominantly resulted from groundwater. The groundwater therefore constitutes a potential source of soil salinisation.

LAND IRRIGABILITY CLASSIFICATION

The interpretation of soil and land conditions for irrigation is concerned primarily with predicting the behaviour of soils under an altered water regime after introduction of irrigation. Thus land irrigability interpretations are required to indicate the areas suitable for irrigation, crop type and the yield that may be expected, water delivery requirements, problems in drainage and special reclamation practices (USDA, 1970).

The classification of land for irrigation is an assessment of the physical and chemical factors of soil and topography that affect irrigation potential. Land selected for irrigation should remain permanently productive under the changes in the physical and chemical regime anticipated after the application of water. The suitability of land for irrigation depends on physical and socio-economic factors in addition to the soil irrigability class (Table 5.25). Among the more important considerations in addition to soil suitability in deciding upon suitability of land for irrigation are (i) Quality and quantity of water, (ii) Drainage requirement and (iii) Economic considerations.

In the Chalthan Branch Canal Command Area the irrigation was introduced in early Sixties. Prior to introduction of canal irrigation, 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 and hence there has been observed noticeable change in land irrigability classes (LIC) of the command area.

Fig. 9.12 shows that 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 LIC - II area was restricted to south of Sanki, Haldharu, Jolwa, Rampura and east of Kantali villages. While the area around Isanpur, Mavachhi, south of Chalthan, south of Mota, and east of Vansda Rundhi villages were under LIC - IV.

The data analyzed for 1991 shows some alarming changes in land irrigability classes (Table 9.13). 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. The LIC scenarios for the year 1970 and 1991 are given in Fig. 9.12 and 9.13.

Table 9.13 Land Irrigability Classification in Chalthan Branch Canal Command Area.

Land Irrigability Class	Year of observation			
	1970's		1991	
	Area in ha	%	Area in ha.	%
II	1435	13.11	1315	12.20
III	8924	81.50	7971	72.80
IV	590	5.39	1663	15

The deterioration in Land Irrigability Classes may be attributed to (i) Very unfavourable soil conditions, (ii) high water table, and (iii) unfavourable topography & drainage conditions.

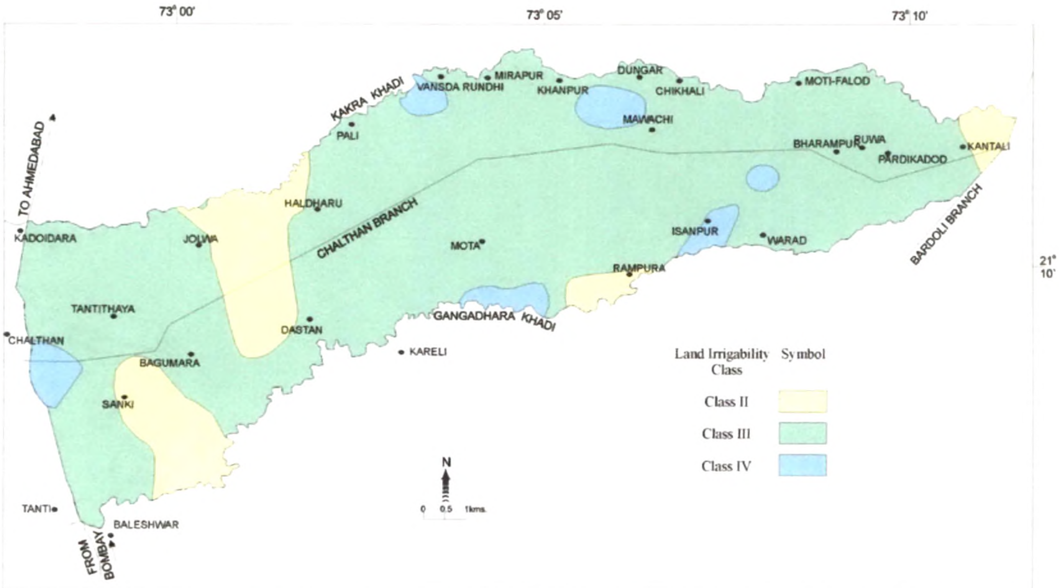

Fig. 9.12 Land Irrigability Classification During Initial Phase of Canal Irrigation (1970) in Chalthan Branch Canal Command Area.

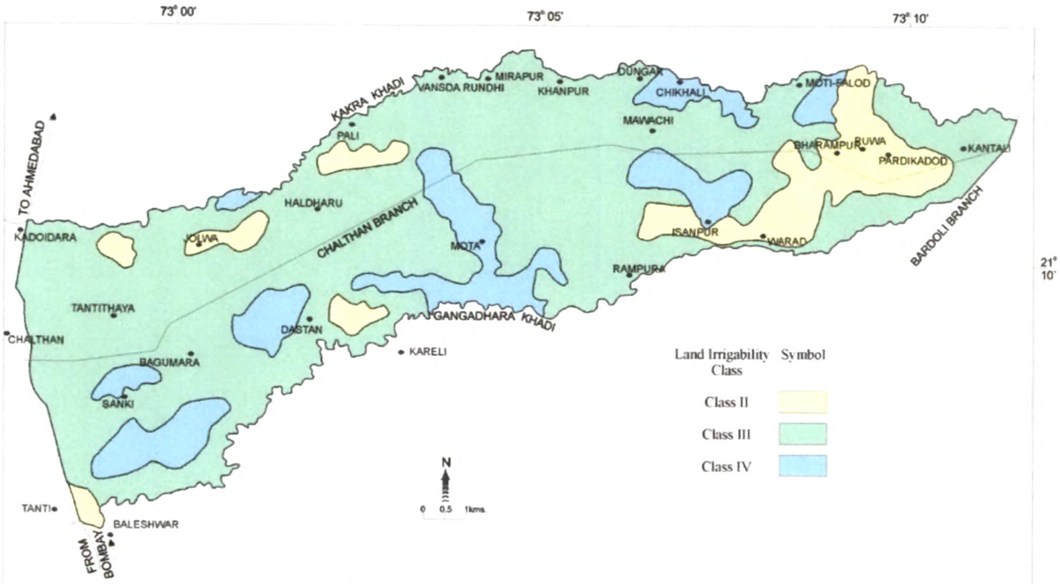

Fig. 9.13 Present (1991) Land Irrigability Classification in Chalthan Branch Canal Command Area.

LANDUSE PATTERN

Landuse planning is often perceived with four basic objectives: (i) to protect current land use, (ii) to guide future developments, (iii) to reduce present and future conflicts, and (iv) to avoid pollution (Gold et al., 1989). Land use can be broadly classified into irrigated land, forestland, culturable wasteland, unirrigated land etc.

The land use pattern scenarios for the year 1971, 1981 and 1991 (Table 9.14) shows considerable shift in its various categories viz.

Table 9.14 Statistical Data on Shift in Landuse Pattern of Chalthan Branch Command Area.

Year	Irrigated land (ha)	Unirrigated land (ha)	Culturable waste land (ha)	Waste land (ha)
1971	5276.8 (39.38)	6451.83 (48.15)	560.08 (4.18)	1111.76 (8.30)
1981	8475 (63.27)	2969.1 (22.16)	661.1 (4.94)	1290.62 (9.63)
1991	9613.33 (73.52)	829.51 (6.34)	1396.22 (10.68)	1236.44 (9.46)

Figure in bracket indicate percentage of the total area (Source: District census, Gujarat)

i. Cultivable land: Cultivable or agricultural land may be defined as land used primarily for production of food and fibber. This includes irrigated as well as unirrigated land. Cultivable land covers about 79.87% of the total area out of which 73.52% area is irrigated while 6.34% area falls under unirrigated category. Twenty years land use data under this category clearly suggests that the unirrigated area has reduced from 48.15% to the 6.34% while, irrigated area shows considerable increase from 39.38% to 73.52% (Table 9.14). These changes in irrigated and unirrigated area may be attributed to the positive impact of irrigation.

ii. Culturable wasteland: These are the lands, which are neither productive nor useful for growing food, and fibber. Land belonging to this category may be made useful only after giving primary and secondary treatments. This category also shows significant increase from 4.18% in 1971 to 10.68% in 1991 (Table 9.14). This increase may be attributed to the waterlogging and increase in soil salinity due to excess irrigation.

iii. Area not available for cultivation: Land which is not available for the cultivation and being utilized as residential area, lakes, ponds, roads etc fall under this category. The data shows almost 1.16% increase in this category. This may be attributed to growing urbanization at the cost of encroaching the land used under other categories.

A time progression bar graph showing change in land use pattern for all the categories in Chalthan Branch Canal Command Area is given in Fig 9.14.

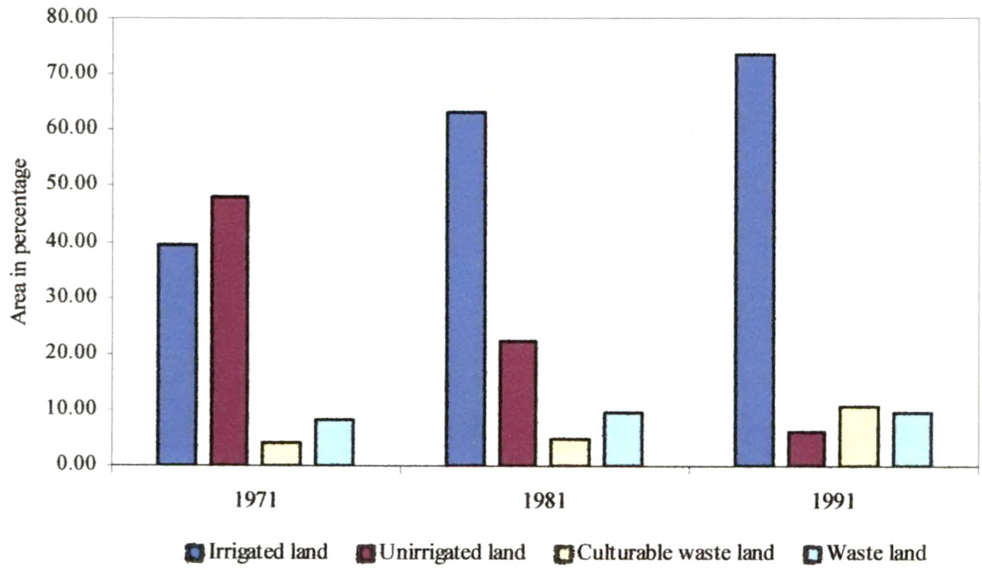

Fig. 9.14 Long term Landuse Pattern Changes in Chalthan Branch Canal Command Area.

The derived irrigation impacts on soil and water regimes in Chalthan Branch Command Area have clearly established the degenerating state of soil and water resources. If proper measures are not taken to remediate these problems; a time may come that a significant chunk of land will be rendered barren. There exist innumerable techniques and management practices to mitigate the adverse effects in the Chalthan Command's soil and water regimes. The various details on management and mitigating aspects of such geo-environmental problems are provided in the next chapter.