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IDENTIFICATION OF WATERLOGGED AND SALINE SOILS WITH THE HELP OF REMOTE SENSING APPLICATIONS AND OTHER MODERN TECHNIQUES

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PREFACE

Irrigation projects involving interbasin transfer of water without adequate drainage has disrupted the equilibrium between the ground water recharage and discharges resulting in accretions to the ground water table. This is the major cause for waterlogging and secondary salinisation in various irrigation commands.

Although precise estimation on the magnitude of the problem are not known but the available information projects heavy socio-economic losses. Several thousand hectare areas need adequate drainage to prevent or reclaim degraded saline soils in different irrigation command areas in India. AT least 20 to 30 thousand hectare of irrigated land is lost every year due to waterlogging and salinisation.

There has been no systematic survey so far in order to firm up the total area affected by waterlogging and salinity . Future soil survey in different states, if properly organised may bring out more waterlogged and salt affected areas. A rapid and accurate assessment of the extent of affected areas can be made from using remotely sensed data. Results of the studies undertaken in the country so far clearly demonstrate the usefulness of remote sensing techniques in detecting and monitoring waterlogged and saline/alkaline soils.

This report has been prepared by Dr V K Choubey, Scientist C in connection with on-going UNDP project IND/90/003 entitled "Developing Capabilities in Hydrological Studies".

(S M SETH)
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ABSTRACT

The nature, characteristics and the extent of area covered under waterlogging and salt affected soils vary depending upon the climate, topography, surface hydrology, irrigation and cropping practices, geohydrology etc.

Irrigation projects involving interbasin transfer of water without adequate drainage has disrupted the equilibrium between the ground water recharge and discharge resulting in accretions to the ground water table. This is the major cause for waterlogging and secondary salinisation in various irrigation commands.

Although precise estimation on the magnitude of the problem are not known but the available information projects heavy socio-economic losses. Several thousand hectare areas need adequate drainage to prevent or reclaim degraded saline soils in different irrigation commond areas in India. At least 20 to 30 thousand hectare of irrigated land is lost every year due to waterlogging and salinisation.

The National Commission for Irrigation (1972) and National Commission on Agriculture (1976), Ministry of Agriculture (1985) reported waterlogged area in India is 4.84, 6.00 and 8.53 m.ha respectively. However Ministry of Water Resources (1991) has estimated 2.46 m.ha waterlogged area. NCA (1976) has estimated 7 m.ha salt affected area, out of which 2.5 m.ha is under alkali soil and 4.5 m.ha under saline soil. Ministry of Agricultute (1985) estimated this area to the extent of 9.08 m.ha, which include 3.58 m.ha alkaline and 5.50 m.ha under saline soils including coastal areas. The recent estimate (MOWR 1991) indicates 3.06 m.ha and 0.24 m.ha under saline and alkali soil respectively in command areas.

There has been no systematic survey so far in order to firm up the total area affected by waterlogging and salinity. Future soil survey in different states, if properly organised may bring out more waterlogged and salt affected areas. A rapid and accurate assessment of the extent of affected areas can be made from using remotely sensed data. Results of the studies undertaken in the country so far, clearly demonstrate the usefulness of remote sensing techniques in detecting and monitoring waterlogged and saline/alkaline soils.

1.0 INTRODUCTION

Water being the vital requirement for the successful raising of the crops, its availability in optimum quantity in the root zone, particularly at the critical stages of the crop growth is essential. Such moisture requirement of crops can either be met from precipitation through surface flow or from ground water. For the kharif crops though most of the moisture is met through rainfall, it being erratic both in time and space and confined in most part of the country to four rainy months i.e from June to September, requires some support. To raise the crops in the non-rainy months and to meet the moisture requirement when rains have failed, the necessity of irrigation has been felt. Moreover consequent upon the spurt of country's population, there was an urgent need for increasing the agricultural production from the available land resources. This has necessitated the development of adequate irrigation facilities in the country.

In India, rainfall is generally confined to 3-4 months in a year. Its distribution over the country is highly skew viz. 100 mm in West Rajasthan to over 11000 mm at Cherapunji in Meghalaya. On the top of all these unfavourable features, annual variation of rainfall is also highly uneven. The areas receiving less rainfall is also highly uneven. Various attempts have been made since the First Irrigation Commission (1901-03) to assess the water resources of India. The average annual natural run-off available in India is estimated to be 1880 cubic km. for the main land. Out of this, the utilisable water from surface structures is about 690 cubic km. Similarly, the Central Ground Water Board has estimated the possible utilisation from ground water as 418 cubic km. Thus, the assessed surface water resources of India are about 3 per cent of the world's surface water resources, whereas the country's population is about 16 per cent of world population. As such, the water resources in India are limited and for the ever growing population and increased number of industrial centres, unless a systematic attempt is made for the proper planning and management of water resources, the country will have serious problems in water availability to various sectors by the early 21st century, as can be seen from the table given below.

(All figures in M.Ha. Metres)

S.No.	Water Use	Present utilisation	Future projected requirements	
		1985 AD	2000 AD	2025 AD
1.	Irrigation	47.00	63.00	77.00
2.	Drinking & Domestic	1.67	2.42	4.00
3.	Industries	1.00	3.00	12.00
4.	Thermal power	0.43	0.58	1.50
5.	Miscellaneous	3.90	6.00	6.00
	Total	54.00	75.00	105.00

India has very large and ambitious plans for the development of irrigation and, which are indeed very essential for diversifying agriculture as also for increasing and stabilizing crop production. According to the Planning Commission (1974), the actual utilization of the irrigation potential was 22.6 million hectares in 1950-51 at the beginning of the era of planned development which rose to 36.0 million hectares in 1968-69 and 43.1 million hectares in 1973-74 against the ultimate irrigation potential of 107 million hectares from both surface and ground water. The Irrigation Commission in 1972 estimated the utilisable surface and ground-water resources as 8,70,000 million cubic metres; whereas, the actual utilisation was about 1,72,500 million cubic metres in 1950-51, which had risen to about 3,37,000 million cubic metres by March,1974. The utilisable surface water of the country is estimated as 66.6 million hectare meters and groundwater as 20.4 million hectare metres per year. It is expected that when the various irrigation projects are completed, irrigation will be practised over at least double the present area. This is what it should be if the country has to make economic progress quickly. But if the intelligent use of water is not pre-planned, the dreadful history may repeat itself with all its attendant havocs of seepage, rise in water-table, widespread water-logging and salinity. Irrigated agriculture instead of ensuring prosperity and economic stability may threaten the very security of the land. Salinity throws a challenge to irrigated agriculture. The success depends how we take up that challenge and save our national heritage, the soil, from deterioration.

Under irrigated conditions, farmers do uncontrol irrigation thereby the excess water is added to the ground water table. With subsequent irrigation done injudiciously, the excess water induces the raising of ground water table. Some times water logging in the low lying areas are also created due to seepage from irrigated upland and seepage from canal system. Over irrigation by canal water with inadequate water management practices further aggravates the situation which culminates into water logging and increase in salinity. Also the obstruction of natural drainage by way of construction of roads, railways, aerodrams, various structures, etc., causes the ponding of monsoon run off on the upstream of the structures. This has happened at many places which in turn has disturbed the surface hydrology of the areas. The cultivation of intensive irrigation without adequate drainage facilities contributes substantially to ground water table. Although irrigation and drainage both should go hand in hand, the drainage aspect has not been given much attention that it deserve even in the major and medium irrigation projects. In absence of such drainage system, the problem of water logging is created. Another adverse impact of irrigation management is the creation of soil salinity and alkalinity which adversely affects the soil productivity.

Although a large volume of data on the characteristics of saline, saline-alkali and alkali soils of this country is currently available, our knowledge on the nature and properties of this group of soils is still far from being complete. Because of the enormity of the problem and existence of salts in soils formed under diverse pedological conditions, the problem gets further aggravated. Except the early work in Uttar Pradesh, there are very few soil studies in this subject where nature and properties of Indian saline-alkali soils might have been correlated with pedogenic, hydrological or geomorphological characters. It is for this reason that in spite of the large volume of data in the principal regions where this soil problem exists, generalized knowledge has not yet been possible. Only in the alluvial region of Uttar Pradesh, Haryana and Punjab and in black cotton soil region of south some advance has been made in this direction. The problem is almost obscure in the vast coastal region and in the desert and semi-desert tracts where at least 40 per cent of the salt-affected area is known to exist. A clear understanding of the problem of soil salinity as related to pedological processes, and modified by hydrological and orographical factors, would certainly provide powerful tools for understanding the problem in its wider perspective.

Physical characterization of such soils in spite of its over riding importance has been rather ignored. There is urgent need to extend studies on mechanical impedence or barrier, aeration and moisture movement in alkali soils and such measurements as infiltration capacity; permeability, bulk and apparent density; pore size distribution, aggregation and modulus of rupture are properties that could profitably by investigated and the emerging data utilized to draw improvement plans. Clay and kankar pans with different degrees of induration or cementation, are known to occur throughout the country in alkali soils, which limit drainage, hinder root penetration and offer obstacles to techniques for reclaiming such soils. The subsoil or substrata characteristics in general nature and variability of such pans in particular have been little understood. Meaningful physical parameters and their field and laboratory techniques for determination are to be evolved to adequately define and characterize them for economic utilisation of the regions in which these occur. Geomorphological investigation on land forms and subsoil stratigraphy and mapping of ground-waters for their movement and changes in composition which would determine drainage requirements are additional fields that are still largely unexplored in this country.

Intensive research is required to be systematically organised on physico-chemical and chemical characterization of saline and alkali soils than mere routine soil analysis, to understand the intricate interrelationship existingt between the soil, soil solution and plant growth. A control over the dynamics of cation exchange is of utmost importance in irrigated agriculture, and this is hardly possible unless soil-water-plant relationship under diverse conditions is precisely known. The study of nutrient availability in saline-alkali soils at successive stages of their improvement and reclamation has not been given due emphasis. In many instances, the poor yield and retarded crop growth on such soils can be attributed largely to nutrient imbalance. Saline-alkali soils are significantly low in certain plant nutrients and toxically high in certain other constituents. How far these soils are potentially fertile will have to be thoroughly investigated. Reliable soil testing methodology to measure correctly the nutrient availability in saline-alkali soils is, in fact, lacking. The common tests meant for normal soils, at any rate, cannot measure correctly the nutrient; but the technique has to be evolved and suitably standardised. Furthermore, still lesser attention has been paid to the micronutrients in such soils.

There are two other equally important aspects of soil characterization which are linked with soil fertility, viz., the nature and composition of soil organic matter, and the microbiological properties of saline-alkali soils. The instability of humus under alkali conditions poses a serious conservation problem. Increase in the proportion of exchangeable calcium increases humus stability and promotes the establishment of a graminaceous vegetation.The deteriorating effect of exchangeable sodium on soil microbiological properties and plant growth requires better appraisal under varying soil and climatic conditions of this country. The interaction of various groups of algae and freshly decomposing organic matter with exchangeable sodium and consequent effect on pH, soil aggregation and nutrient availability are still the virgin and interesting fields of study, which may have far reaching effect on building up the fertility of otherwise barren soils.

For any large-scale economic utilisation of saline and alkali lands, it is essential that such soils, occurring in large blocks, are surveyed and mapped and their potentialities assessed through rapid diagnostic techniques in each of the principal soil tracts in the country. Early work done in Uttar Pradesh, by Agarwal and Yadav, can provide the necessary guide-lines for other potential areas. Needless to say that aerial surveys will be of great aid in locating and mapping these soils. In recent years, use of satellite imagery for the survey of salt-affected areas has been made successfully at the Central Soil Salinity Research Institute, Karnal.

1.1 OBJECTIVES: The main aims of this study is to make an assessment of the waterlogged and salinized area of the country.

STATUS OF WATER LOGGING, SOIL SALINITY & ALKALINITY IN INDIA

2.0 REVIEW

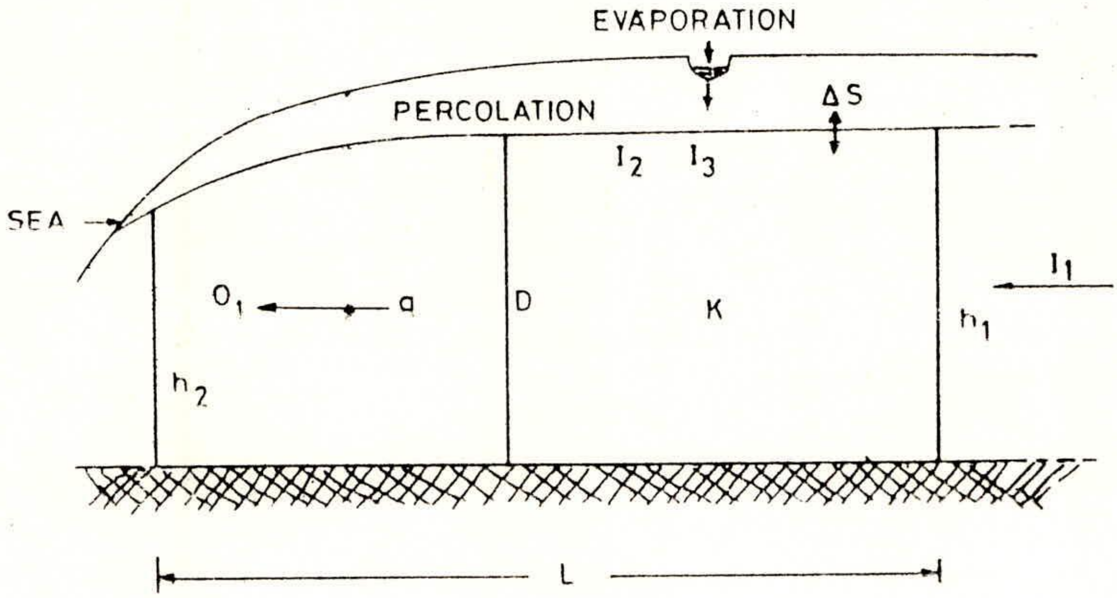
Waterlogging and salinization are interlinked and movement of water in soil influences both the phenomena. While water in unsaturated zone usually moves in a vertical direction; downwards as water drops and upward as capillary water and as water vapour, and in the saturated zone more or less horizontally from areas with high hydraulic head to areas with a low one. It can be explained by Darcy's law (fig 1).

Waterlogging whether it is due to surface flooding or rise in ground water, inflow and outflow ratio plays an important role. The stagnation of surface water may be usually as a consequence of a low infiltration rate of the soil in combination with rainfall intensities and insufficient surface water drainage. It may also be on account of innundation of back flow or flood in rivers. However, high ground water levels are connected with high infiltration intensities and exfiltration of ground water as a result of restricted or stagnating subsurface flow.

The mineral and organic components of soil form a solid matrix consists of irregular shaped pores. Pore spaces filled with soil, air and liquid vapour or soil water. Thus soil serves as the storage reservoir of water and nutrients. Water present only in the rootzone of a crop can be utilised by it for its transpiration and other bio-chemical needs. Thus the proper proportion of water in the rootzone helps in providing the conductive environment to crop growth and excess dryness or wetness have the adverse effect on the plant growth. When water is received in dry soil either by rain or irrigation, it is distributed around the soil particles, where it is held by adhesive and cohesive forces; it displaces air from the pore spaces and thus increases water. Filling of water continues till it reaches to the maximum water holding capacity having 1/3 atmospheric pressure. This is called water at field capacity. The water layer betwen hydroscopic coefficient (held at 31 atmospheric pressure) and field capacity (1/3 atmospheric pressure) is theoretically available water (water at wilting point held by 15 atmospheric pressure is not available to most crop plants). Any addition of water beyond field capacity falls under the influence of gravitational force and this joins the ground water. The phenomenon is explained in fig.2 when the addition of water upto ground water continues, the water table keeps on rising and when it touches the rootzone, the adverse effect on crop are visible.

2.1 PREVIOUS ASSESSMENT OF WATERLOGGED AND SALINISED AREA

The post-independence period saw great progress in research on saline and alkali soils in India. By now the pioneering work done at the U.S. Salinity Laboratory on soil-plant-water relationship in saline soils was known; and these lines of investigations were critically put to test during 1950-1961 by Agarwal and Yadav (1954) in Uttar Pradesh for the diagnosis and characterization of saline and alkali soils of the Indo-Gangetic



$h_{1,2}$	=	HYDRAULIC
kD	=	TRANSMISSIVITY
$I_{1,2}$	=	INFLOW COMPONENTS (RECHARGE)
$O_{1,2}$	=	OUTFLOW COMPONENTS (DISCHARGE)
q	=	FLOW RATE PER UNIT WIDTH
S	=	CHANGE IN STORAGE

FIG. I PRINCIPLE OF GROUNDWATER FLOW. (KRUSEMEN 1976)

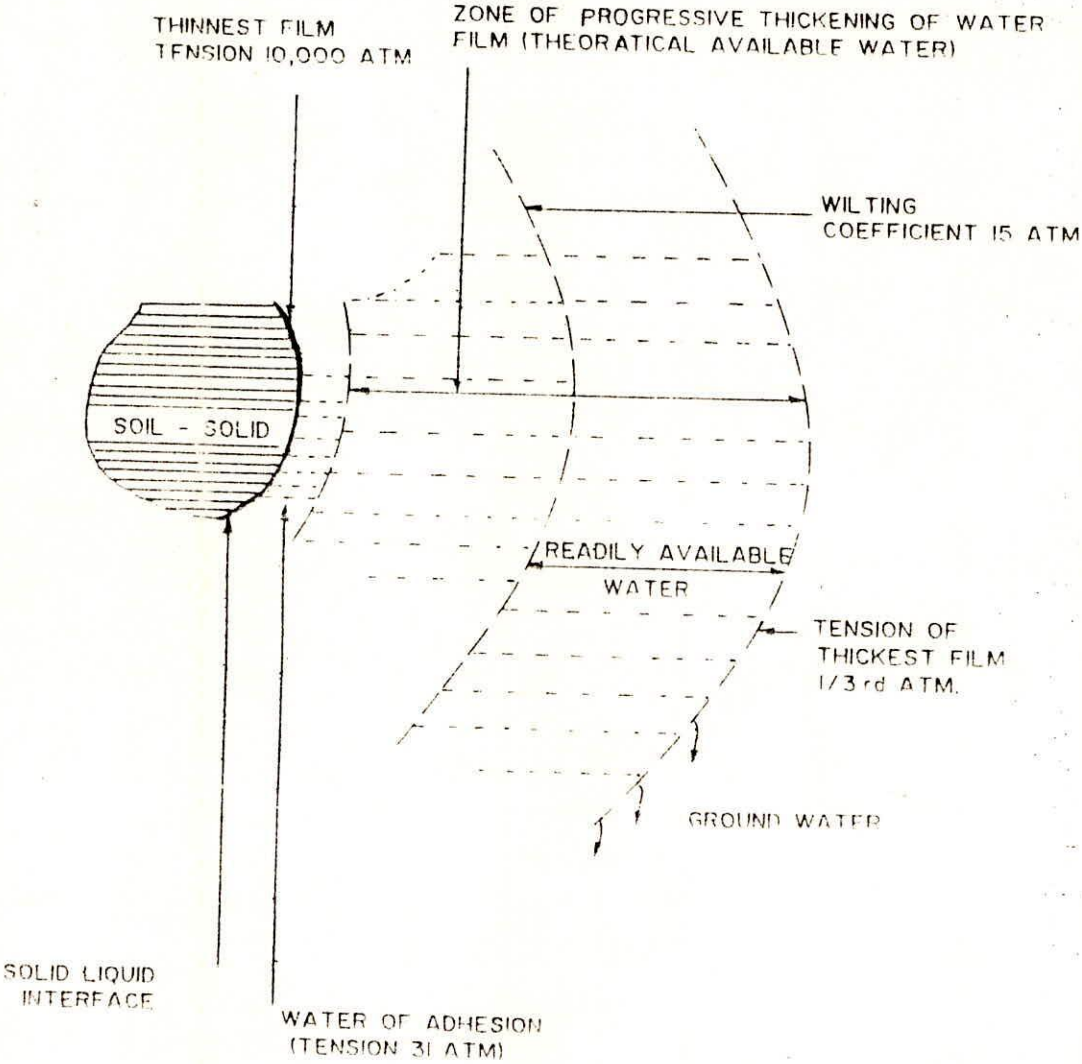


FIG. 2 SOIL WATER-SHOWING PROGRESSIVE THICKENING OF WATER

alluvium. A significant contribution was the salinity and alkali scale developed by these workers to evaluate saline and alkali soils for crop response. Work on similar lines during 1960-64 by Kanwar and Bhumbla brought forth useful information about Punjab and Haryana. Reconnaissance survey, particularly in Uttar Pradesh and Bhakra- Nangal Project of East Punjab, had revealed the occurrence of large blocks of saline and alkali soils which could profitable by exploited for agricultural purposes. Frantic efforts were made towards the development of suitable ameliorative and reclamation measures which could make large areas of saline and alkali soils produce crops very quickly. A number of schemes were initiated by the Indian Council of Agricultural Research both on fundamental and applied aspects of the salinity problem in India.

The first attempt to focus the attention on this vital problem was made by the Irrigation Commission (1972) which tried to collect the information on statewise areas affected by the waterlogging due to irrigation. The areas where the depth of water table varies from 0-1.5 metres were taken as waterlogged areas.It was reported that 4.84 million hectares were affected by waterlogging in the States of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Maharashtra, Rajasthan, Madhya Pradesh and Mysore. Whereas, it was considered that waterlogging was not a serious problem in the States of Assam, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Gujarat, Nagaland, Himachal Pradesh and Jammu & Kashmir.

The second attempt at national level was made by the National Commission on Agriculture (1976) which compiled the informations and put the figures at 5.986 (say 6) million ha. as the extent of waterlogged area in the country out of which 3.4 m. ha. are subject to surface flooding, mostly in the States of West Bengal, Orissa, Andhra Pradesh, Punjab, U.P., Gujarat, Tamil Nadu and Kerala and the remaining 2.6 m.ha as the area having high water table particularly in Punjab, Haryana, U.P., some parts of Rajasthan, Maharashtra, etc. The Commission also indicated that alkaline and saline soils, together, constitute an area of 7 m.ha. out of which 4.5 m.ha. under salinity and 2.5 m.ha. under alkalinity. Saline soils include 1 m.ha. in arid and semi-arid regions of Rajasthan and Gujarat and 1.5 m.ha.in black cotton soils. However, it is to point out that some researchers have put the total salt affected area and the area of saline soils at 9.826 m.ha. and 6.284 m.ha. respectively (Bhargava, 1989). Subsequently efforts were made but were not well coordinated. Thus, despite the development of such serious problems in the country, there has been no systematic/comprehensive survey so far in order to firm up the total areas affected by waterlogging, alkalinity and salinity. According to the recent estimate made by the Ministry of Agriculture (1990) about an area of 8.53 m.ha. is believed to have been subjected to waterlogging, whereas the extent of Alkali soils areas and saline (including coastal saline) areas are 3.581 m.ha and 5.50 m.ha respectively.

Recent studies (MOWR 1991) have indicated that there has been considerable rise in water table in number of irrigation commands in Madhya Pradesh, Haryana, Karnataka, Punjab, Uttar Pradesh, etc. where proper water management practises are lacking. In a few projects, where there has been conjunctive use of ground water fall in the water table. As far as unlined canals and distributaries are concerned a study undertaken in 1987 reveal that about 71% of the water is lost in transit from the reservoir to the field with the break up as under:

Canals	15%
Distributories	7%
Water courses	22%
Field losses	27%
Total losses	71%

SOURCE: Interim Report, National Committee on the Use of Plastics in Agriculture, 1987

The water table in the Bhakra canal area has been reported to be rising at the rate of about one meter per year. The rising water table adversely affects the production of many crops besides other adverse affects like causing floods even with slight rains due to loss of moisture storing capacity of the soil, maintenance of roads and buildings becoming difficult and increase in diseases in the waterlogged area. It is also reported that in Hissar in Haryana, the load-bearing strength of the soil in a waterlogged area became less than 50% in 15 years. During the drought of 1979-80, the farmers in the Sharda Sahayak Command Area in U.P. complained there was no water in canal but in the wet area of the canal water aggravated the flood problem created by excessive rain.

For evolving an effective and comprehensive strategy to arrest/remedy the waterlogging, it is required that following four aspects, in the given order, are dealt with.

a) Identification by proper definition
b) Quantification
c) Planned implementation
d) Evaluation

Wheat and Sugarcane are affected when the water table is within 0.6 metres; maize, bajra and cotton are sensitive to water table within 1.2 metres, and gram and barley within 0.9 meter.

According to Irrigation Commission (1972) all areas where the depth of water table varies from 0-1.5 metres are generally classified as waterlogged area. Also, this Commission's Report states that The behaviour of ground water levels after the introduction (of irrigation) has to be studied in selected open wells distributed over the ayacut, with a greater concentration in low lying areas generally twice in a year, once in June before a monsoon and a second time in October after the monsoon.

However, the Experts' Group, set up by the Ministry of Water Resources in October, 1986 to identify the extent of problems due to waterlogging/salinity/alkalinity in the existing irrigation projects in the country and to suggest the remedial measures, adopted the criteria for deciding the waterlogging conditions as the water table rising upto 2 meters depth from the ground surface observed in the month of November and April.

There is at present no uniformity in the definition of waterlogged areas and thereby the measurement of water table level to provide reliable data for the total area affected by the waterlogging in the country, is lacking the standardisation; although these variations are due to many variables like type of crop, type of soil, quality of water etc.

Due to such lack of uniformity of the criteria, for determining an area as waterlogged area in the particular agroclimatic conditions, the statistics paraded in this regard are of questionable magnitude and relevance. Secondly, quite often, the cited statistics are for the entire land area suffering from waterlogging and salinity, without any separation of the area affected due to canals and due to other causes like due to inundation of low lying area, encroachment/choking up of the natural drainage conditions etc. In flat areas, receiving high rainfall, lot of land is naturally waterlogged. The problem here is further aggravated when roads, railways and embankments are built with no/poor provision for cross drainage. Similarly, in highly arid regions of Western and Southern India, soil salinity is a natural occurrence which undoubtedly gets aggravated by the introduction of irrigation, particularly canal irrigation. Subject to this, the below given table 1 gives the extent of waterlogged area as estimated by various Agencies/Organisations.

Table 1

Extent of Waterlogged Area as estimated by various Agencies (lakh.ha.)

State	As per National Commission for Irrigation (1972)	As per National Commission on Agriculture (1976)	As estimated by Min. of Agriculture (1990)
1	2	3	4
Andhra Pradesh	N.R	3.39	3.39
Assam	N.R	N.R	4.50
Bihar	N.R	1.17	7.07
Gujarat	N.R	4.84	4.84
Haryana	6.5	6.20	6.20
Jammu & Kashmir	N.R	0.10	0.10
Karnataka	0.07	0.10	0.10
Kerala	N.R	0.61	0.61
Madhya Pradesh	0.57	0.57	0.57
Maharashtra	0.28	1.11	1.11
Orissa	N.R	0.60	0.60
Punjab	10.9	10.90	10.90
Rajasthan	3.48	3.48	3.48
Tamil Nadu	N.R	0.18	0.18
Uttar Pradesh	8.10	8.10	19.80
West Bengal	18.5	18.50	21.80
Delhi	N.R	0.01	0.01
TOTAL	48.40	59.86	85.26

In such circumstances, it is rather absolutely urgent and essential to go for uniform criteria to determine the waterlogged area, if we want to avoid sharp as well as frequent variations in the extent of waterlogged area in the States. This can be done only if such definitions are developed on the basis of agro-climatic zones. The Planning Commission after examining the earlier studies at the regionalisation of the agricultural economy has recommended that agricultural planning be done on the basis of agro-climatic regions and, accordingly, the country has been broadly divided into 15 agricultural regions based on agro-climatic features, particularly soil type, climate including temperature and rainfall and its variation and water resources availability.

However, a fair judgement can be that canal induced area under waterlogging/salinity in the country may not be more than 1/3rd of the total national area under waterlogging/salinity. Still, there is no denying that our canal irrigation has significantly contributed to waterlogging and soil salinisation.

The problem of water logging is required to be tackled through two pronged strategy, namely one which is preventive type for new projects and the other of remedial nature for existing projects where water logging has already occurred. It is believed that spread of conjunctive use of ground water with that of surface water (especially in Punjab, Haryana and parts of UP) has substantially lowered the water table and helped contain water logging/salinity. The design for conjunctive use of surface and ground water has to be planned from the beginning. This requires emphasis on ground water investigation. Given the kinds of crop sets, the peak requirements of water can be worked out, for each crop set. Once the possibilities of safe withdrawal of ground water are known, the requirements of each crop set for the balanced surface water can be estimated. If this kind of planning is considered based on the below mentioned basic planning studies, from the beginning and institutionalized either by promoting use of tubewells by the farmers or by integrating ground water into the project, the possibilities of water logging would be eliminated from the beginning.

It would be pertinent to point out here that two further features, namely that systematic monitoring of ground water and construction of water balanced model at the level of an aquifer are in fact not very expensive propositions and can be followed through fairly easily with modern computers, once the basic data are available. Given preliminary estimates which can generally be built with easily available bore hole data, soil characteristics and land use information, more refined models can be developed as investigation of soil characteristics and the ground water regime proceeds at micro levels. At this stage of planning, the whole question of allocation of water to different regions become critical and would in turn determine the design of the conveyance system. The practice uptill now has been to consult agronomists and to fix the crop-pattern in to the design of irrigation project.

Soil conditions, temperature and its distribution, rainfall and its distribution, the ground water regime, existing forest cover and existing tanks and minor rivers and drains are all features which need to be paid very detailed attention while formulating an irrigation project. This will normally require that a command is regionalised into components. Even in the Indira Gandhi Nahar Project area in Rajasthan, where the initial feeling and intuitive sense was that of regional homogeneity of the proposed command in the Phase-II area. The available data showed that the average annual rainfall varied only by 40-42 per cent during 1930-60 but there were years when these variations could be in the range of 928.24 per cent. While a considerable part of the command had a depth to below ground water table of over 40 metres, area with levels below 20 metres was not unsubstantial. Also, there were pockets of critical hard pan area. With such conditions, regionalisation, aquifer and other studies have now been done for the IGNP Phase-II Commands.

Sardar Sarovar Project in Gujarat can be cited as a model for such kind of approach for conjunctive use of surface and ground water. In this project, it is planned to develop and utilise ground water in conjunction with canal water. Development of ground water will supplement surface water supply and will also help in controlling rise in sub soil water level. It is also proposed to provide drainage facilities for draining away excess surface flow in fields. Narmada Command Area has been divided into 13 regions on the basis of agro-climatic characteristics. A drainage study for Narmada-Mahi Doab area i.e. area comprising 4 regions was carried out with the objective to design a drainage system to minimise water logging problems. As per the study, drainage work is divided into (a) surface drainage to control inundation and (b) sub-surface drainage to control water table. A master plan is formulated both for surface and sub surface drainage showing drainage region, types of drains, etc. Similar drainage study for the remaining area is also planned. A scheme of conjunctive use of ground water with surface water has been integrated into the plan. Ground water assessed as per study carried out for command upto Mahi river and projected for the entire command works out to 2.7 MAF. Development of ground water will be left initially to farmers themselves. With the scheme of water allocations and incentive built in, it is expected that ground water development in the private sector will take place healthily. Where the ground water is saline or area is water logged needing drainage and not useful for irrigation, vertical drainage by pumping will be attended to by the Government. Such studies for areas beyond Mahi river have been recently entrusted to the Gujarat Water Resources Development Corporation and other private expert organisations.

It may be noted that at initial phases of an irrigation project, surplus water is available and its seepage through the soil to the aquifer is a sure-shot manner of augmenting the natural resource of ground water. In the new irrigation projects being planned, such models should be used to plan canal schemes. Irrigation projects have, therefore, now to be designed within the framework of very detailed understanding of the agro-climatic and agro-economic regime for which they are being designed. The association of the irrigation engineer with the wide disciplines of geography and land use, meteorology and ground water will from the beginning sensitise the irrigation planner to the diverse agro-climatic and agro-ecological environment in which the water system has to operate and this sensitivity is extremely important for planning the physical features of the irrigation structures so as to keep the adverse affects like water logging/salinity at the barest low level, if at all cannot be avoided all together. In sum and substance, the irrigation planning should reflect a close integration of water use and land use policies, as envisaged by the National Water Policy adopted in September, 1987.

The menace of water logging must no longer be ignored but tackled in right earnest. Lands which require drainage to maintain their productivity must be provided with it. Also there is an urgent need for establishing water table observation stations in adequate density for monitoring the rise in ground water table and the quality of water. This will provide excellent data for determining the ground water recharge and indicate the need for measures to keep the water tables low through more intensive ground water use or through more efficient surface and sub surface drainage systems. Particularly, from the Seventh Plan, all the approved new irrigation projects have the financial provision for carrying out necessary drainage works in the commands. Construction of field drains was not given due attention upto the Sixth Plan. However, with the increasing incidence of water logging and secondary salinisation noticed in different irrigated commands and consequent reduction in land productivity, due stress was laid in the Seventh Plan strategy for the drainage schemes for completed irrigation projects and by including drainage components in new projects. However, it is quite disturbing that the importance of drainage has not yet been perceived both by the Government departments and the beneficiaries and the tendency to over-irrigate as well as indifference to removal of excess water still persists. It should be made imperative to plan, design and execute drainage system simultaneously with the main project works since the projects approved particularly from the Seventh Plan contain the provision for drainage works as a part of the Project cost. For completed irrigation projects, the affected areas should be identified and remedial measures should be taken up effectively and timely as a special programme. During the Eighth Plan, we should, therefore, aim at improving the existing commands including drainage system for an area of about 10 million hectares.

Reclamation of saline alkaline lands is technically feasible, although availability of fresh water is a constraint in several cases. Nationwise review may be taken for identification of suitable areas which can be reclaimed and time bound programme prepared for implemention of reclamation schemes. Reclaimed land could be used for afforestation, growing fodder as well as for normal crops.

While formulating a comprehensive planning for tackling water logging problem through drainage works, it would rather be advisable to keep in view the certain special problems of drainage as under:

i) Unlike irrigation channels, drains carry a variable flow, when there are heavy rains they get flood: but normally they carry small flows. Because of very high fluctuations in capacity factors they are susceptible to erosion and silting and cannot maintain their initial sections for long.

ii) Repairs and the maintenance of drains are difficult because they are often located for away from roads and other means of communications. Work may have to be carried out under water, and in the case of deep drains and drains subject to tidal action, mechanical equipment such as dredgers is needed. Often these drains are moreover encroached upon.

iii) Normally drains do not receive as much attention from inspecting officers as canals, since they are situated away from irrigation canals and channels. They rarely carry inspection banks. Complaints about poor drainages come from only a section of farmers and only at certain periods of time. All these factors result in a lack of attention to drains.

iv) Roads, railroads and canals cause obstruction to surface sheet flow drainage in many places. Their structures are designed with an eye to economy, they cause an efflux in water levels and create drainage problems in the adjoining area. At road crossings most often only causeways are provided which cause considerable efflux at times of floods, just at the time when it is essential for drains to function efficiently.

v) Cross bunds are often put up across drains, sometimes with the permission of the authorities and sometimes without, to divert or pump out water for irrigation or to facilitate navigation of fishing. Generally, these bunds are not wholly removed after they have served their purpose. As the result, the drains deteriorate and their normal functioning is affected.

Although, every year we are spending several thousand crores of rupees on execution of irrigation projects, we have unfortunately inadequate data on the post-construction behaviour/ performance particularly with regard to water delivery capability, conveyance losses, actual crop pattern developed, incidence of waterlogging/salinity/alkalinity in case of completed projects. Also, no systematic/comprehensive plans to monitor the ground water table through well-designed and extensive network in the command on continuing basis after irrigation is started, are drawn up as a part of post-evaluation studies as well as an integral part of water use and management of the project. In fact, the data that would be available from such performance evaluation and ground water monitoring will help us to a great extent in tackling the planning problems of conjunctive use on the basis of its formulation as optimisation model of the water resources system as well as in making us sensitized to the incidence, if any in the course of time, of adverse effect like waterlogging etc., and thereby to plan and take up necessary remedial measures timely and effectively. The decision or control variables of the model are the ground water or surface water allocation. The optimal decision would maximise the objective of development while considering the hydraulic response equation of the surface and ground water system and any constraint limiting the head variation and the surface water availability.

Judging from the records it is apparent that considerable research work has been done on the subject of saline and alkali soils in India during the last 80 years. Although, the achievements in certain fields are quite impressive, in some states knowledge on the subject continues to be far from complete and very much unco-ordinated so that full benefit of the information available cannot be taken.

2.2 MONITORING OF WATERLOGGED AND SALINE SOILS WITH REMOTE SENSING TECHNIQUES

Waterlogging and Salinity are some of the major land degradation processes that restrict the economic and efficient utilisation of soil and land resources in command areas. Reliable and accurate mapping of areas affected by waterlogging and salinity with their location and extent can be extremely useful in chalking out suitable water management strategies and also to undertake remedial measures to prevent their advancement. Remote sensing techniques have shown great scope for providing a quick inventory of waterlogged, saline and alkaline soils and their monitoring. The areas that are not yet waterlogged but have an early potential for waterlogging could also be delineated through the use of remote sensing.

The experience at National Remote Sensing Agency Hydrabad, shows that the soils affected by salinity/alkalinity and waterlogging could be successfully mapped using Landsat data. It was observed that the highly saline soils with EC of 12 m mhos cm^{-1} and above showed higher spectral reflectance than the moderately saline soils because of the encrustation of soluble salts on the soil surface (Venkataratnam, 1980). The surface scrapping of such soils is white or light grey or pale yellowish depending on salt content and the salt affected soils appear white or grey in FCC. The normal soils give low spectral reflectance in the visible bands and high reflectance in the NIR bands due to presence of vegetation. Because of the difference in spectral reflectances in different bands atleast two degree of soil salinity apart from normal soils could be delineated.

Many crops growing in saline soils exhibit marked visual symptoms of moisture stress. Salinity may also influence leaf colour, physiological structure, leaf thickness and other properties. Black and white infrared film as well as multiband photography have been used in detecting salinity. The near infra-red (NIR) wavelength have been shown to exhibit best tonal contrasts for detecting the salinity as registered by plants. Also remote sensing of plant canopy temperatures is useful for salinity detection. Thermodynamic activity of water gets reduced if the soil solution is saline. As a result the rate of water uptake by plants decreases and hence reduction in stalk water content. Consequently, transpiration rate is reduced and the accompanying temperature decreases. In some cases based on the conditions of crop growth, saline and alkaline soils can be differentiated especially using multitemporal data. For example, wheat crop is not much affected by salinity, while sodicity affects the crop more resulting in sparse crop growth. After the harvest, the saline and alkaline soils are rendered grey in FCC. Healthy leaves record high IR reflectance while unhealthy ones have low reflectance.

Results of the studies undertaken in the country so far, clearly demonstrate the usefulness of remote sensing techniques in detecting and monitoring waterlogged and saline/alkaline soils. Some of the studies are discussed below. Computer aided analysis of salt-affected lands helped delineating two categories of self-affected lands in the Indo-Gangetic Plains (Venkataratnam, 1977 and Singh and Dwivedi, 1982). Sahai et al.,

(1982) carried out a study in the Ukai Kakrapur command area using multidate, multi-season LANDSAT imagery to delineate water-logged and salt-affected areas. The study was continued to operationalise the technique and the changes which have taken place during 1972-1977 were observed (Kalubarme et al. 1983). Monitoring of soil salinity/alkalinity was attempted using multitemporal data for a part of north-western India (Venkataratnam, 1985). Manchanda et al. (1984) using Landsat imagery delineated two levels of salinity, whereas with aerial photographs, three levels were identified on part of Chambal command area, M.P.

One of the serious drawbacks that hamper the developmental progress of the command areas is the lack of drainage .Remotely sensed data can assist in detection of unfavourable drainage conditions and location of drainage channels particularly in waterlogged areas.Wherever open drainage ditches are present,they can be readily distinguished by dark tones reflecting the lower temperatures of the water surfaces in relation to the land.The lines of buried field drains can also be detected as a result of wetter soil conditions along these subsurface channels.Wet soils are dark in visible images and radar data at wavelength in excess of 20cm has some ability to integrate subsurface moisture level (Barret and Curtis,1982)

3.Ø STATUS OF WATERLOGGING, SALINITY AND ALKALINITY OF THE COUNTRY

3.1 WATERLOGGING

3.1.1 CAUSES OF WATERLOGGING

The obstruction of the natural drainage by way of construction of roads, railways, aerodromes, buildings etc. cause the ponding of monsoon run-off on the upstream of the structures. This has happened at many places which has disturbed the surface hydrology of the areas. The advent of canal irrigation has given a new dimension to the problem. The condition of waterlogging is caused due to seepage from canals, embankments of the main canals, branches and distributaries. The cultivation with intensive irrigation without optimum drainage facilities contributes substantially to water table.

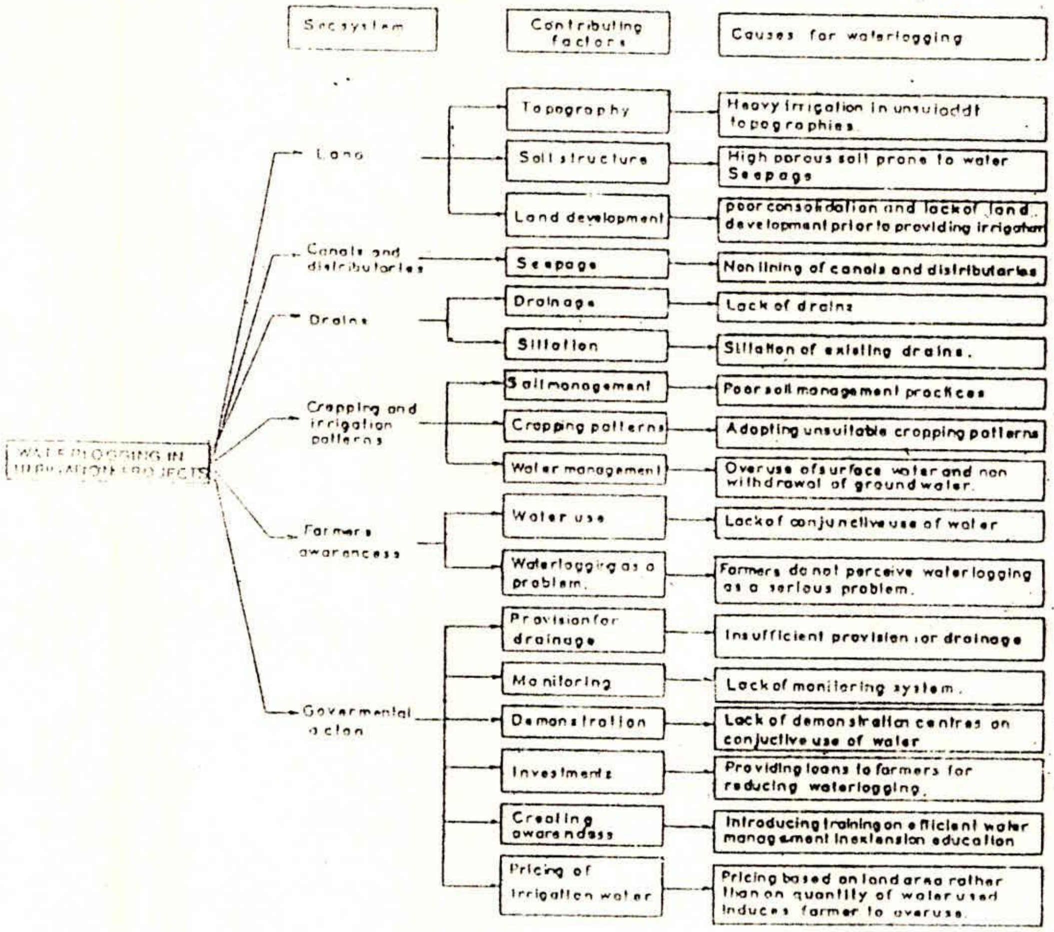
Heavy precipitation and floods resulting in prolonged inundation also cause a rise in the water table. Waterlogging depends also upon the nature of soil and subsoils. For example, black cotton soil is prone to waterlogging because of its low permeability. Even when there is a permeable layer at the top, an impermeable stratum below can cause waterlogging because it prevents the downwards movement of water. In the Deccan Canals tract, water percolating through a pervious layer often meets impervious 'chopan' soil and is forced to the surface at the junction with the impervious strata. In the Bhogavo Irrigation Scheme in Gujarat, it was found that an impermeable rock barrier was blocking the sub-soil drainage and causing waterlogging over an area of 81 hectares (MOWR 1991). Even masonry structures, like causeways with foundations that go into the impermeable soil can obstruct sub-soil drainage and cause a rise in the water table.

There is a tendency for waterlogging to occur, over most of the areas in the Indo-Gangetic Plains. Irrigation is perennial and consequently the inflow into the sub-soil is considerable. The corresponding outflow is poor, due to the flat nature of the country and bad outfalls. Consequently, waterlogging here is more extensive than elsewhere. The causes of waterlogging in a flow diagram is shown in fig 3.

Waterlogging as a result of surface water irrigation is seen in many perennial canal irrigated areas. The recharge component is further reinforced in canal irrigated areas by the percolation losses from the conveyance system and percolation losses due to the field application which may be excessive due to over irrigation or following intensive water use cropping thus exceeding the recharge to that of discharge.The subsurface outflow increase in the amount of water stored in the soil pores and it results in a rise of ground water table and ultimately cause the condition of water logging.

Use of local ground water has the reverse influence as described above. The increased discharge by pumping when exceeds the percolation rate,there is a loss in the stored water and that results in corresponding drop in the water table . However when irrigation is provided through imported ground water, there is a

FIG. 3



Causes of waterlogging in irrigation projects (MOWR 1991) water table rise.

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-di-oxide. The water table which is considered harmful would depend upon the type of crop, type of soil and the quantity of water, the actual depth of water table, when it starts affecting the yield of the crops adversely, may vary over a wide range from zero for the rice to about 1.5 metres for other crops.

The rooting zone of crops differ from crop to crop (Water Management manual, MOWR-1985). Shallow rooted crops (60 cm) are rice, potato, cauliflower, cabbage, lettuce, onion etc. Moderately deep rooted crops (90 cm) are wheat, tobacco, castor, groundnut, muskmelon, carrot, pea, bean, chilies etc. the deep rooted crops (120 cm) are maize cotton, sorghum, pearlmillet, soybean, sugarbeat, tomato etc. Very deep rooted ones (180 cm) are sugarcane, citrus, coffee, apple, grape wine, sunflower, locerne etc. The depth of water table which adversely affects the crops varies accordingly. However, the norms of water table below ground level (bgl) have been adopted by different States differently for defining waterlogged areas on the basis of soil types, crops being grown, etc. This aspect has been analysed by the Planning Commission during December 1990 as detailed in Table 2 below.

Table 2

Norms for Categorisation of waterlogged Areas in States

State	Water table depth below the ground level (metre)
Uttar Pradesh (Sharda Sahayak Project)	
i) Worst Zone	Less than 1
ii) Bad Zone	1-2
iii) Alarming Zone	2-3
iv) Safe Zone	More than 3
Punjab	
i) Very Critical	0-1.5
ii) Critical	0.2
Haryana	
i) Critically waterlogged	0-1.5
ii) Moderately waterlogged	1.5-3
Karnataka (Tungabhadra Command)	0-2
Himachal Pradesh	0-2
Maharashtra	
i) Fully waterlogged	Water at Surface
ii) Waterlogged	0-1.2

From the aforesaid information, it is observed that for monitoring the water table in the States, there is no uniformity in the definition of waterlogged areas and thereby the measurement of extent of water table to provide reliable data for the total area affected by the waterlogging problem in the country is lacking. According to the Central Ground Water Board, the areas where water depth of water table is within 2 to 3 metres of land surface are considered potential areas for the development of a similar problem.

3.1.2 EFFECT OF WATERLOGGING

Air and water in proper proportion in the root zone are essential for optimal growth of plants and any imbalance in them adversely affects the crop growth. Waterlogging conditions in the root zone disturbs plants functions and related aspects as described below:

i) 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 carbon dioxide increases with saturation of the soil with water.The cutting off or depletion of the oxygen supply to soil affects the root of the plant and aerobic micro-organism loose almost entirely the capacity to produce energy, hence they stop growing and may even die. Subsequently anaerobic bacteria, which do not need oxygen for their growth, proliferate, because they can still generate energy by consumption of organic compounds using substances other than oxygen in the soil, such as micro elements. Micro elements used by aerobic bacteria become many times more soluble and can increase to toxic levels in waterlogged but not in well-drained soil. When the soils become waterlogged,less gas diffuses, to and from the roots through the soil pores.There are changes in the concentration of mineral elements in soil solution and with toxic products of roots and soil micro organism begin to accumulate.These changes adversely affect the germination, growth,and development of plants.Gases diffuse through water about 10000 times more slowly than through air.So ultimately the concentration of gases such as oxygen decreases whereas that of gases which are so produced such as carbon dioxide, methane, hydrogen sulphide etc. increase.

ii) Soil temperature is essential for many physical, chemical and biological activites 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. Generally each 10 degree drop in temperature reduces the rate of change in gas concentrations by 2 to 3 times.

iii) The physical conditions of the soil is 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.

iv) Field operations become either impossible or difficult in such soils. The natural flora such as micro organism which are useful, get diminished and harmful pests like pathogens, insects and weeds come up which create problem for crop development.

v) 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 ground water. Heavy concentration of salts thus accumulated for long renders the soil afflicted by salinity, non-conducive and rather injurious to the plant growth.

vi) Waterlogging will encourage competititon for the available oxygen between micro organism (whether they cause plant disease or not) and roots. Thus the susceptibility of waterlogged plants to disease and particularly root fungal, will depend on relative abilities of the micro organism and plants to grow in anaerobic conditions.

3.2 SOIL SALINITY/ALKALINITY

3.2.2 CAUSES OF EXCESS SALT CONCENTRATION

Desruption of equilibrium between inflow (recharge) and outflow (discharge) mainly due to human interference causes the situation of waterlogging and when salts are in the soil layers or water coming with capilaris on soil layer does cause salinisation.If irrigation is given by saline water,it is also a reason of salinisation

Combination of factors which are mainly geological, climatic and hydrological in nature, are usually involved in the formation of saline and alkali soils (Agrawal,et al 1982). The intimate relationship of geology is often observed in the nature of soluble salts in the weathered crusts of rocks of the parent materials from which the soil originated. In view of this the products of weathering from acid rocks like granites and gneisses are least mineralised whereas those from basic rocks i.e. basalt, dibase etc. are highly mineralised.

The semi-arid and arid climates where the evaporation exceeds the rainfall, associated with certain elements of topography and ground water hydrology, are often responsible for the accumulation in-situ or transport and deposit at other places. The process of salinisation in arable land is much connected with the level of water table in the area. In case of canal irrigation tracts, the equilibrium between inflow and outflow is disturbed due to excessive seepage from canal network, contribution of excess water through indiscriminate and unscientific irrigation etc. without taking the measures of vertical/horizontal drainage systems. Horizontal drainage with adequate outfall is imperative for efficient disposal or accumulated salts and surplus water.

Salinity/alkalinity contents in soil depends on three factors namely

i) Total salt content (Salinity)
ii) Sodium carbonate and bicarbonate concentration in relation to calcium and magnesium concentration (sodicity), and
iii) Toxicity of specific ions of chlorides and boron.

Deposition of salts dissolved in water and the soil profile accounts for salt contents and may be expressed either in terms of electrical conductivity (EC) or in terms of concentrations in ppm or mg per litre. Most of the crop plants get affected by the concentration of ions in water. Irrigation with poor quality water, inadequacy of leaching, seepage from canals and high adjacent areas together with the presence of high water table and high evaporation rates account for secondary salinisation of irrigated soils.

Among the soluble constituents in irrigation water, sodium is considered as the most hazardous. Sodium affects the permeability of the soil by causing swelling and dispersion of clay particles and clogging of soil pores and it may cause injury to crops. Effect of sodium depends not on its total concentration in the water but on its concentration relating to the concentration of other cations. The presence of high concentration of carbonates and bicarbonates results generally in an increase in the proportion of sodium because of precipitation of calcium and magnesium carbonates in contact with the soil. The classification of water according to the sodium content is based on the ratio of Na^+ to (Ca^+ Mg^{++}). In USA sodium absorption ratio (SAR) is used as a parameter for soil characteristics.

The SAR of water is related to exchangeable sodium ratio (ESR) of the soil and can be represented by the equation:-

$$ESR = K \times SAR \text{ where } ESR = \frac{ex(Na)^+}{ex\ (Ca^{++}Mg^{++})}$$

The effect of sodium on the soil permeability is inversely related to the total ion concentration. The higher the concentration, the lesser is the permeability. On the other hand, the rate of soil alkalisation is directly related to total electrolytic concentration. The higher the concentration the faster the rate of electrolysis. Consequently any classification system must take the two factor SAR and electrolyte concentration into account. In addition to the two factors, there are other modifying factors, such as soil mineralogy which needs to be taken into account while assessing the sodicity hazard.

3.2.3 CLASSIFICATION OF SALT AFFECTED SOILS

The classifications of these soils can be done taking into account the effect of salinity on crop production ability of the soil, as growth of most crops is restricted when the conductivity of the soil saturation extract reaches (ECE) the level of 4 mmhos/cm and exchangeable sodium percentage is more than 15. On the basis of the chemical characteristics four different classes of soil (US Salinity Laboratory) have been proposed as given in Table 3.

Table 3

Classification of salt affected soils on the basis of chemical characteristics (USSL)

S.No.	Class	Ece	ESP	PH	Indian Local Names
1.	Saline Soils	> 4	< 15	> 8.5	Thur, Vippu, Lona, Shora, Soula, Pokhali, Khar and Kari.
2.	Saline-alkali	> 4	> 15	Variable	Usar, Kallar, Kari, Chopan, Bari, Reh, Choudu, Kshar and Fougu
3.	Non-Saline or alkali	< 4	> 15	> 8.5	Usar, Rakkar, Bara soil chopan kari

According to the chemical characteristics of soils, salt affected soils have thus been defined as under:-

i) Saline Soils : are defined as those soils whose electric conductivity of the saturation extract (Ece) is more than 4m mhos/cm at 25 C and the exchangeable sodium percentage (ESP) is less than 15, the pH of such soils is usually below 8.5.

ii) Saline alkali soils: are those soils whose Ece is greater than 4m-mhos/cm at 25 C and ESP greater than 15, but pH is variable.

iii) Non-saline alkali Soils: have their Ece less than 4m mhos/cm at 25 C and ESP greater than 15. The pH readings of alkali soils usually range between 8.5 and 10, though in some cases pH value even exceeds 10.0.

Saline Soils contain excessive amount of soluble salts like sodium chloride, sodium sulphate, calcium chloride, calcium sulphate, magnesium chloride and magnesium sulphate. Such soils usually occur in the vicinity of rivers, streams or canals. Alkali soils refer to such soils which contain excess exchangeable sodium carbonates and sodium bicarbonates while saline-alkali soils are the soils in transition of conversion from saline to alkali soils or vice-versa and possess mixed conditions of both.

The FAO (1970) recommended the sodicity classification as given below.

Class	ESP	Description
0	10	Sodic free
I	10-20	Slightly sodic
II	20-30	Moderately sodic
III	30-50	Strongly sodic
IV	50	Very strongly sodic

Ece = Electric Conductivity of saturation extract
ESP = Exchangeable Sodium Percentage

3.2.4 ADVERSE EFFECT

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 them are as under:

i) The physical condition of the soil is deteriorated. The highly deteriorated alkali soils have very low water intake rate with the result that most of the rain falling on such soils goes out as run-off and causes floods and damages crops in adjoining areas.

ii) Yields of crops are reduced and in extreme cases, the crops fall either due to inadequate uptake of moisture and nutrients and injurious effect of salts or deteriorated soils conditions.

iii) Choice of the crops is limited because some crop are very sensitive to salinity.

iv) Fodders growing in alkali soils may contain high amounts of molybdenum and selenium and low amount of zinc. The nutritional may cause diseases in livestock.

3.2.5 NATURE AND PROPERTIES OF SALINE AND ALKALI SOILS

Salt affected soils categorised on the basis of total salt content, presence of sodium carbonate and carbonate concentration in relation to calcium and magnesium concentration (sodicity) and toxicity of specifications of chloride and boron. These aspects are expressed in terms of electrical conductivity (Ece) or in terms of concentration in ppm or milligram per litre, exchangeable sodium percentage and pH. Classification of salt affected soil is given in table 3.

3.2.5.1 SALINE AND ALKALI SOILS OF UTTAR PRADESH

These soils are locally termed as reh, rehala or namkin. The common outwardly feature of this type of soil is the presence of extensive white, greyish white or ash coloured fluffy deposit of salts on the surface of the land, either in patches scattered irregularly or otherwise in blocks. Inwardly, the soil possesses an open structure. The texture of the soil may vary from loamy sand to loam; but the soil and subsoil are not compact and dense or inherently impervious to water. There is usually no hard pan or kankar layer in the subsoil. Such soils usually occur in the vicinity of the rivers, streams or canals where obstruction to natural drainage has taken place and consequently ground water table remains near the surface for the major part of the year. When the rivers or streams are not in high floods, or when the canal is closed, the level of water table sinks down. Since the land is permeable, once the water level goes down there is free vertical percolation in the profile. The salt contents are usually high to inhibit plant growth and so vegetation exists on these soils only during the monsoon period when with increase in moisture content there is either dilution effect or some salt may leach down the profile. The pH of the soil usually remains below 8.5 (Agrawal et al 1982).

The total area of the typical saline soils in Uttar Pradesh is very much less than that of alkali soils. Zonally, they are confined to khadir (riverine) tracts of the major rivers. Secondary salinization has also occurred in some canal commanded areas of the state. Saline soils are more prominent in the district of Mathura where ground water table, with poor quality water, remains high for most of the time.

Yamuna 'khadir' saline soils are occasionally heavier in texture and darker in colour and do not possess such flat topography as their Ganga counterparts (Agrawal 1952). Salinity is high at the surface but decreases in the subsoil. Small amounts of soluble carbonates are also reported in the subsoil; otherwise sulphates and chlorides form the bulk of the anions with significant amounts bicarbonates. But for the riverine location and some reserve of lime this soil would rapidly undergo alkalization if freed from the effects of floods. Similar heavy saline soils with tendency towards alkalization in the subsoil are found in the low-lying situation in the basin of the right bank of the river Yamuna in Delhi (Raychaudhuri and Shankaran, 1952). The natural vegetation of these tracts consits of jhau, kans and jawasa.

Saline-alkali soils

In local parlance these soils are called, reh, kallar or usar, and are the most commonly occurring varieties among all the categories of salt affected soils in Uttar Pradesh. Topographically, these soils occur in low-lying pockets of the geological uplands in the Gangetic alluvium. Drainage is obstructed internally due to the presence of hard and indurated subsoils which are more or less impermeable to water. The water hard indurated layer is usually a clay pan or a kankar (calcium carbonate nodules) pan, varying in thickness from some centimeters to a metre. The texture of the soil may be loam to clay loam, but the subsoils are always heavier in texture although the surface may even be found to be sandy loam. Water table may or may not be high but surface water stagnation is very common Agrawal et al 1982).

Alkali soils

Alkali soils are the typical usar soils found in the state. The profile possesses a hard and compact structure with loam to clay-loam texture, the surface soil of which rests on heavier indurated and columnar subsoils. When wet, the soils are plastic and gummy. Physical deterioration of the soil is of an extreme degree. Usually, a thick and highly cemented bed of big-sized kankar is to be found in the subsoil which is occasionally so much cemented that it appears rock like and difficult to pierce. Water percolation is almost nil and surface water stagnation with high degree of turbidity is a common land feature. On evaporation and drying, such condition may leave flakes of clay and black reddish-brown residue on the surface (black alkali) caused by the dissolution of humus in the alkaline media. The soils are completely barren or else can support only salt-tolerant grasses during the rainy season.

Degraded alkali soils

Under this category may be included those saline-alkali soils with low lime content which have been partially reclaimed through paddy cultivation in eastern districts of Uttar Pradesh. The surface soil has undergone dealkalization with consequent development of moderate to slight acidity; but in the subsoil potential dangers of salinization or alkalization still persist or soluble sodium percentage is still high enough to inhibit root development of crops other than paddy.

3.2.5.2 SALINE AND ALKALI SOILS OF BIHAR

The Northern part of Bihar, comprising the north-western districts of Champaran, Muzaffarpur and Darbhanga, is reported to have saline and alkali patches (Raychaudhuri, 1953). These districts, along with Bhagalpur and southern part of Purnea, have been categorized as sandy alluvial soils, with scattered alkaline and saline deposits. There are two distinctive characters which distinguish these saline soils from similar other soils of the country: (i) highly calcareous nature of these soils, and (ii) silty nature of the parent material. This zone is actually the continuation of a similar tract in Gorakhpur district of Uttar Pradesh (Agarwal and Mukerji 1951). The climate is subhumid with an average annual rainfall of 112 & 125 cm. It may be observed that salinity is not a major problem in these areas, and, wherever such patches are found, reclamation can be possible through the mere process of leaching.

The alkalinity is only moderate at the surface but increases in the subsoil. The soil is saline and of the sulphate-bicarbonate type; but dangers of alkalization are present in the subsoil. Leaching with water alone was found to remove the adverse effects of salinity and alkali condition in the soil.

3.2.5.3 SALINE AND ALKALI SOILS OF DELHI

Saline and alkali soils found in Delhi occur in two distinct physiographic divisions, viz., khadir or recent alluvium and bangar or older alluvium; the two are separated by a ridge of geologically different origin. Saline soils of the recent alluvium of the River yamuna have been studied by Raychaudhuri et. al. (1952, 1953), where two texturally distinct types have been reported. Insoluble carbonates occur in the subsoil which is also comparatively lighter in texture. These soils are more or less similar to their counterparts on the opposite bank of the same river in Uttar Pradesh. In the southern part of the territory, the soils are lighter in texture being predominantly silt loam and rest on stratified beds of sand and silty material. Both these groups of soils suffer from high subsoil ground-water level.

Raychaudhuri et.al. (1955, 1957) studied some of the saline and alkali soils of the bangar (older alluvium) tract of Delhi. The soils are reported to be primarily solonchak but are at various stages of salinization and alkalization due to the leaching of saline constituents having not yet reached the typical solonetz stage. The soils are characterized by sandy loam texture at the surface and loamy subsoils with occasional deposits of kankar and cloddy structure. The pH is only moderately alkaline and exchangeable sodium percentage ranges between 15 and 35. These soils appear to merge gradually with the stronger alkali soils of the neighbouring state of Haryana.

3.2.5.4 SALINE AND ALKALI SOILS OF HARYANA AND PUNJAB

The soils of Haryana and Punjab plains consist of alluvium which, in some cases, is reported to be covered by aeolian deposits (Taylor and Mehta, 1941). They generally contain 10-15 per cent of clay with an average profile depth of 3.0 metres. The entire soil crust lies on a bed of sand in which the water table is located. There is also excessive amount of calcium carbonate present in the nodular form. Sodium salts are usually located in the soil crust and the control of their movement is one of the major problems in irrigated agriculture. The soil has an alkaline reaction due to varying amounts of sodium adsorbed on the clay complex. The thur soils are predominantly saline with low pH values and rich in sulphates. rakkar soils obviously contain some soluble carbonates to show a pH of 9.8 and have high exchangeable sodium and correspond to typical alkali soils.

Characteristics of thur lands:

All salt-encrusted soils in Haryana and Punjab are collectively designated as thur lands and the saline efforescence as thur. The concentration of thur at the surface is largely due to the spread of irrigation in large areas with the rapid opening of canals and headworks, constructed during the ealry part of the present century (Mehta, 1951). Such soils are predominantly saline but at places a very significant amount of sodium has entered the exchange complex to make them moderate to strongly alkaline. The salts in thur lands are composed of Na_2SO_4 and much less amounts NaCl.

The Hissar and Karnal districts of Haryana characterize two saline phases of thur lands, developed on low and high ground water tables. In the former case, which is either dry-farmed or well irrigated with low water table, the redistribution of salts did not occur while in the latter case, the high groundwater table contributed to the formation of typical thur.

Bari soils are typical saline and alkali soils and rakkar represents the non-saline alkali phase. A typical alkali profile in the alluvium of the Punjab, described by Puri et al. (1937), consists of three well-defined layers: (i) an upper highly alkaline layer, compact and impervious, (ii) a layer of medium alkalinity containing $CaCO_3$ nodules (kankar), and (iii) a layer with a lower alkalinity and higher permeability than the above two. Sand usually occurs below the third layer. In the lands under newer canal colonies, alkali soils with subsoil pan were of lesser occurrence than in those under the older canal system.

In Haryana saline-alkali and alkali soils are chiefly present in Karnal district, where the pan is more calcareous than in Punjab districts (Mehta, 1951). Studies by Kanwar et al (1961, 1962) revealed the occurrence of many types of saline-alkali soils in Haryana, which were chiefly differentiated on the basis of exchangeable sodium percentage and the nature of soluble anions. The ground-water level is incidentally deeper in saline soils than in saline-alkali and alkali soils.

3.2.5.5 SALINE AND ALKALI SOILS OF ANDHRA PRADESH

The formation and characteristics of alkali soils and of bogs, locally known as phodus, in the Nizamsagar Project area of Andhra Pradesh, have been reported by Krishna and Perumal (1950) and later by Wali (1956). Quagimires are formed from hidden alkali soils (in the subsoil) which, on absorbing moisture swell and burst open, ejecting the alkaline fluid.

In the black as well as the red soil areas where rainfall is high, varying from 80 to 125 cm, soluble salts are washed to the lower levels tending to accumulate in depressions, mild slopes or valley basins. Hidden saline soils are thus first formed on impervious beds. With the progress of alkalization, the natural vegetation gradually disappears. In the alkali patches with bad drainage and damp subsoil, small, circular, fluffy saline spots are observed. On absorption of water the sodium clay swells exerting greater pressure on the surface soil. As a result, the surface is lifted into flat topped, cone shaped knolls which finally burst out ejecting the fluid. The soluble salt content of the fluid is composed predominantly of sodium salts in the form of carbonate and bicarbonate and the clay of the fluid is significantly sodium saturated (Krishna and Perumal, 1950). When wet, the quagmire is active and ejects fluid during the after the rainy season. In several years the activity ceases and the soil dries to a hard, crusty mass. The natural vegetation consists chiefly of kunda grass (Ischaemum pilosum) growing in clumps; and on the rest of the surface white or black efflorescence of salt or black alkali is left behind.

The quagmire is reported to be a type of solonetz formation under specific conditions of drainage and topography. It is not a recent formation although the introduction of canals during recent years has intensified the process. It is reported to be formed in all textural classes of soils from sandy loam to clay. The pre-requisite to the formation of such alkali bogs is some impediment to the flow of salt-laden underground seepage. Pocket-like depressions, junctions of different textured soils and mid-portion of vast slopes, favour their formation. Remedial measures suggested are the provision of adequate drainage and proper reclamation treatments almost similar to other alkali type soils.

3.2.5.6 SALINE AND ALKALI SOILS OF KARNATAKA

Salt-affected lands in Karnataka are known by the local names of soudu, karl and jougu. Whereas soudu and karl occur in the low lands with poor drainage, jougu stands on high water tables.

Soudu soil is highly saline with a puffed surface (0-5 cm). Karl soil has a saline surface efflorescence and has been regarded as an example of saline alkali soil. Jougu soil has also the characteristics of saline-alkali. The soils are rich in sulphates and chlorides and the major cationic content is of sodium, though calcium and magnesium are prominent in the lower horizons.

3.2.5.7 SALINE AND ALKALI SOILS OF RAJASTHAN

The semi-desert climate of Rajasthan in the arid zone greatly favours salt accumulation in soils and, if conditions happen to be such as to bring them up on the surface, widespread soil salinity can easily be encountered. Mehta et al.(1969) have described,the saline-alkali soils of Rajasthan in respect of their nature, extent and management. Similarly, Abichandani and Kolarkar (1967) and Roy and Kolarkar (1968) have drawn attention to the soil salinity problems in western Rajasthan. Zonally, saline soils can be met with in immature young soils, in riverine tracts (such as in the lower Luni basin) where sodium-rich saline soils containing sulphate and chlorides, as the main anions, are found in abundance (Sharma, 1963).

Salinity and alkali problems in the soils of the Pali district have been investigated by Sharma,(1968). Salt ridden soils were found both in the canal-irrigated and well-irrigated tracts. In the canal commanded areas, salinity has come up due to rise of ground-water levels; and in well-irrigated areas the main causative factor is considered to be the use of saline irrigation waters. A survey of the underground waters in this tract revealed them to be highly saline.

The above is a clear evidence of the fact that in Pali district, saline-alkali problem has developed in irrigated areas irrespective of its source. With canal irrigation, salinity of the sulphate and chloride type is observed, whereas, with well irrigation the soils tend to become saline-alkali. The well waters are highly saline and due to its poor supply only small quantities are applied with greater frequency, which does not give scope for vertical leaching of the residual salts. Greater evaporation rates actually accentuate the accumulation stage and salinity gets built up.

In 1967, a study was made of the development of salinity in the Chambal Command Area after irrigation was practised on the land for the first five years of its introduction. The investigation was done in the Matunda Region, in Bundi district, by Darra, Jain and Singh (1970). Morphological characters of the profiles, in the problem areas, showed them to be sandy-loam to clay-loam in texture. Calcium carbonate was present at varying depths and had a tendency to increase with depth of the profile. There was also a zone of clay accumulation in the sub-surface layer. The morphological characters were thus identical to those found in the Pali district. The water-table was high (above 1.5 metres) and was fluctuating with the closing and opening of the canal.

3.2.5.8 SALINE AND ALKALI SOILS OF THE CAUVERY DELTA IN TAMIL NADU

The saline-alkali soils of the Cauvery Delta have been classified into old and new deltas (Govind Iyer, 1957). The old deltaic soils, covering the entire northern part of the Tanjore district, are dark grey, clayey, low-lying and ill-drained with water-table within 1.5 metre of the surface. The contents of soluble salts are generally below 0.1 per cent; but the pH in the subsoil lies between 8.5 and 9.0. Dispersion coefficient is not very high. Subsoil shows restricted drainage. The geology of the new delta is reported to be Cuddalore sandstone, lying in the southern half of the district. The soils here are accordingly light textured. These are, more dispersed and water transmission rates are low. The soils are calcareous and moderatley to strongly alkaline in reaction, especially in the subsoil. Paddy yields are low.

3.2.5.9 SALT AFFECTED COASTAL LANDS

Thousands of square kilometres of land, along the coastal line of India, have been damaged by the action of sea water. The Great Rann and the Little Rann, as the very names signify, are salt-soaked lands and cover about two million hectares. Large areas of land around the mouths of the rivers and creeks in Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal are subjected to periodic tidal inundations and have been rendered infertile, due to impregnation of salt brought in by the sea water. They are locally known as khar lands, khajan or kchars. These khar lands are practically devoid of all vegetation, except small shrubs and patches of grass. In the Rann proper there is no vegetation and cultivation terminates after a few kilometers from its edge. On the border of the Rann, in dhoi or bet, and on transitional kallar, some scattered vegetation and grass may be found. In bani tract camel bush and groves of babul (Acacia spp.) are the characteristic vegetation.

3.2.5.10 SALINE AND ALKALI SOILS OF GUJRAT

The surface soil is generally black with clayey or silty clay texture which becomes somewhat lighter in lower horizons.

Gypsum is present in almost all the profiles. Gleying effect and rusty brown mottlings are common due to the nearness of subsoil water-table and flooding during rains. The pH values of the soils lie between 7.8 and 8.4. The desert saline area bordering the Rann towards the desert, consists of a number of islands called bets. Here the soil is sandy in texture and easy to leach (Shah and Trivedi, 1954). The salient features are the sandy nature and presence of a large amount of gravels in these soils. The soil has a reserve of lime and alkalinity is not high. Gypsum crystals are also recorded.

All classes of soils ranging from sandy to silty clay are met with along the coastal line, which in the interior of the creeks or estuaries may be heavier than at the mouths where the tides are turbulent. The khar lands in the vicinity of Dumas and Umrath, of which a large number of profiles were examined by Hoon (1955), are medium to heavy in texture and show characteristics distribution of salts in the profile. The soils are sandy clay loam in the top and bottom of the profile and light day in the centre. The salt content varied from 1.0 to 3.5 per cent and rose appreciably lower down the profile.

In cases where the soils are sandy, the contents of soluble salts are generally much less. Among the soluble salts, the chlorides preponderate over sulphates and the proportion of alkaline earth salts is very low. The pH is generally 8.0-8.5 at the surface and increases to about 9.5 in lower depths. This may further rise on leaching, if suitable ameliorating agents are not employed. Rice cultivation is recommended as an ameliorating management practice to prevent realkalization and further deterioration of soil condition.

3.2.5.11 EAST COAST OF ANDHRA PRADESH

Large areas on the East Coast lying in Andhra Pradesh which have been damaged due to salinity from sea-water, are light textured from the surface to a depth of 120 cm, where water table is located. The subsoil waters are highly saline. Krishna Rao and Raja Rao, (1960) reported that due to high water table, the concentration of soluble salts is generally more at the surface. Sodium salts, chiefly sodium chloride, account for more than 70 per cent of the dissolved solids; the quantity of alkaline earth salts, present chiefly as sulphates, is variable. The pH in a majority of the cases is below 8.5. The high salt conetent of the soil and subsoil waters, the dominance of neutral salts, the moderate range of pH and the light texture are conditions which indicate that the problem is one mainly of salinity and within easy means to be resolved, provided adequate drainage and protection from further damage from sea-water is taken care of.

3.2.5.12 SALINE COASTAL ALLUVIUM OF TAMIL NADU

The saline soils of the Cauvery delta in Tamil Nadu have been reported by Goving Iyer (1957). The soils of the tidal areas are, for the most part, dark grey clayey soils, underlaid with sandy horizons wherein the water table is occasionally met with. The pH of the soils is normally below 8.5, but the concentration of soluble salts is invariably high being mostly of chlorides and sulphates of sodium and calcium. Gypsum occurs in the subsoil. The exchangeable sodium percentage was found to have a mean value of 19, dispersion coefficient was low and water transmission rate was high. The soils are permeable.This means that the soluble salts are such that after being removed by leaching are not likely to leave abnormal exchangeable sodium to affect dispersion coefficient.

3.2.5.13 SALINE COASTAL ALLUVIUM OF WEST BENGAL

Banerjee (1959) reported some salt-affected soils of Canning which show characteristic differences from the coastal salt affected lands described above or those found inland in the arid region. To illustrate the point, the data of only two selected profiles have been presented. The soils are saline and show high exchangeable sodium percentage, but the pH in all such cases is not high and in a typical case is even moderately acidic. The salinity obviously must be due to neutral salts and the high acidity has been explained as coming from organic acids released from the large amounts of decaying organic matter present. This gives rise to degraded saline-alkali soils.

3.3 REGIONAL EXTENT OF SALT AFFECTED SOILS IN INDIA

The extent of area covered under salt affected soil very depending upon the climate topography, surface hydrology, irrigation and cropping practices, geohydrology, ground water conditions and quality etc.

The nature and intensity of salinity varies depending upon the causes responsible for the formation of saline soils in different regions. Where as in coastel belt,soil salinity is caused by sea water intrusion and inundation,the inland salinity is generally encountered in areas with high ground water tables.Here the salts move along with ground water to the soil surface by capillary action during dry spells.The water evaporates and leaves the salts in the surface soil layer which accumulate in amounts toxic for plant growth.In most irrigated areas,rise in the level of ground water table is the primary cause of root zone salinity.In the absence of adequate drainage,the faulty water management practices in irrigation commands may bring more and more areas under salinity problem every year.

In India it is estimated that nearly 8 m ha area is affected by salt affected soils. Most of these confine to the inland semi-arid and arid regions and also along the long coast line. Salient characteristics of salt affected soils with extensive areal coverage are discussed below.

3.3.1 ALKALI SOILS OF THE INDO-GANGETIC ALLUVIAL PLAIN

These occupy micro depressions within the composite upland plains in the states of Punjab, Haryana, Uttar Pradesh, Bihar and Rajasthan under semi-arid climate with mean annual rainfall varying from 550 to around 1000 mm. These have high pH of around 10 or even more, high degree of sodium saturation and predominance of sodium carbonate and bicarbonate. At around 1 m depth a calcic horizon signifying pedogenic accumulation of calcium carbonate occurs. The ground water quality in general is good with low salt concentration. Signs of clay alluviation and soil degradation are commonly encountered in these soils. Establishment of many plant species and their subsequent growth is limited due to prevailing hostile physical and chemical characteristics.

3.3.2 INLAND SALINE SOILS OF THE ARID AND SEMI-ARID REGION

Highly saline soils enriched with neutral salts are widespread in the arid to semi-arid parts of Haryana, Punjab and Rajasthan states. These occur in regions with less than 550 mm annual rainfall. Maximum salt accumulation under excessively dessicating conditions happens to be in the surface horizon of these soils. Such soils have a shallow saline water table and often remain submerged for some duration each year.

3.3.3 SALINE-ALKALI SOILS OF THE INDO-GANGETIC ALLUVIUM

These mostly confine to regions with around 550 mm annual rainfall in the form of a narrow band separating the alkali and saline soils. These have preponderance of neutral salts but contain sizeable quantities of sodium carbonates and bicarbonates. These generally have sandy to loam textural gradation and may have a calcic or petrocalcic horizon in the substratum.

3.3.4 INLAND SALINE SOILS OF THE SUB-HUMID REGION

Sizeable area in the sub-humid parts of north Bihar has undergone secondary salinisation. Widespread in the parts of East Champaran, West Champaran, Muzaffarpur, Saron and Saharsa districts these are unique in having developed on dolomitic alluvium containing 25 to 40 percent calcium and magnesium carbonates in fine powdery form. Although neutral salts predominate in these soils, some soils containing sizeable quantities of sodium carbonate and bicarbonate present saline-alkali nature.

3.3.5 INLAND SALT AFFECTED MEDIUM AND DEEP BLACK SOILS (VERTISOLS)

The medium and deep black soils (vertisols) are extensive in parts of Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Gujarat and Karnataka states. All vertisols have the potentials to turn saline, alkali or saline-alkali and all the three situation may exist within a small geographical area. Salinisation/alkalisation processes are associated with rising water table subsequent to introduction of canal irrigation on vertisols. Alkali vertisols have an opposite trend of pH and ESP variation as compared to alkali soils of Indo-Gangetic alluvial plain. Soil pH and ESP are highest in the profile substratum and tend to decrease towards surface horizons in recently degraded soils. Soils degraded over past few decades have a uniform degraded soil profile with high pH and ESP throughout. These contain montmorillonitic clay in the range of 40 to 80 percent. High swell-shrink potential and high clay content impart low hydraulic conductivity to these soils. These are underlain with saline ground water. Their reclamation through drainage is extremely difficult proposition due to scarcity of water and limiting soil characteristics.

3.3.6 MEDIUM TO DEEP BLACK SALINE SOILS OF THE DELTAIC AND COASTAL SEMI-ARID REGIONS

In the deltas of the Godavari and Krishna and along the Saurashtra coast in the Gujarat state saline vertisols with shallow water table prevailing mostly within 1 metre depth occur. These generally contain only neutral salts with traces of bicarbonates. The operating marine and delta cycles cause salinisation.

3.3.7 SALINE DELTAIC ALLUVIUM OF THE HUMID REGION

The deep, micaceous, fine textured soils of the Ganges delta in the humid subtropical climatic region are saline with a perpetual shallow saline water table. These have neutral salts which owe their origin to saline sub-stratum and saline water inundations during marine cycles and also during the origin of the delta. Salt accumulation happens to be maximum in the surface.

3.3.8 SALINE ACID-SULPHATE SOILS

These occur along the Malabar coast and in some places in the Sundarvan delta. These usually occur in marshy depressions in humid to sub-humid and tropical to sub tropical climate. Sea water inundation is or had been a common feature of these soils.

Some of these soils have a humid horizon in the substratum usually within 1 m depth. These have high salt content throughout wherein neutral salts abound. Soil pH happens to be as low as 3 in the horizon where free acid generation takes place. These are improvised in almost all major and several micronutrients. Drainage of these soils particularly those with humic horizon is not suggested because oxidizing conditions facilitate free acid generation, causing irreversible soil degradation.

3.3.9 SALINE MARSH OF THE RANN OF KUTCHCHH

The great Rann of Kutchchh constitutes the vast saline marsh. The textural stratification are interspread with bands of gypsum, calcium carbonate and hydrated iron oxide accumulation thus facilitating identification of separate texonomic units.

4.0 STATEWISE/PROJECTWISE STATUS OF WATERLOGGING/SALINITY/ALKALINITY

4.1 ANDHARA PRADESH

The State of Andhra Pradesh has encountered waterlogging situation in the command areas of three projects, namely the Sriramsagar Project, Nagarjunasagar Project Left and Right Canals and Tungabhadra Project. The areas affected during 1988-89 were 75.60 th.ha. (28% of the avacut) and 57.0 th.ha (17% of the avacut) respectively.The area affected by salinity in Nagarjunasagar Left Canal is 3.00 th.ha and Tungabhadra Project 2.00 th.ha. The Sriramsagar Project Command has not experienced salinity problem.The areas affected by alkalinity are 10.00 th.ha and 12.04 th.ha. in the case of Nagarjunasagar Left Canal and Tungabhadra Project respectively. No areas in the Sriramsagar Project command are having alkalinity problem (MOWR 1991).

Over use of irrigation water in many fields,constant seepage from the canal system and absence of adequate drainage system are the main causes.

4.2 BIHAR

An area of 1.99 lakh ha under Tirhut Canal System and 33 lakh ha under Saran Canal System is affected by waterlogging in several districts of Gandak Command Area, namely the Muzaffarpur, Vaishali, Samastipur, East and West Champaran, Saran, Sivan and Gopalganj. The extent of areas affected by salinity in these districts is 2.24 lakh ha.

The main causes of waterlogging and salinity in East and West Champaran, Muzaffarpur, Vaishali and Samastipur districts has been stated to be shifting of river course of Gandak, whereas the districts of Saran, Sivan and Gopalganj have numerous low lying areas commonly known as 'Chaurs' formed due to meandering course of Jharshi, Daha and Gandak rivers.

4.3 GUJRAT

An area of about 11.46 th.ha, 2.15 th.ha, 2.04 th.ha, 3.94 th.ha, 0.80 th.ha, 69.00 th.ha, and 0.02 th.ha were affected by waterlogging in the Kakrapar, Ukai RBC, Ukai LBC, Mahi RBC, Kadana LBC, Ghed area and Shetrunji LBC respectively in 1989. The areas affected by salinity i.e. having more than 4 m mhos per cm are mentioned as 0.789 lakh ha (27% of GCA) and 0.751 lakh ha (18.5% of GCA) respectively under the Mahi Right Bank Canal Command and Kakrapar RBC and LBC commands (MOWR 1991).

4.4 HARYANA

Haryana has peculiar water condition. In the fresh ground water areas, water table is declining constantly while in saline or brackish area, water table is rising at an alarming rate. The State Government has considered critically waterlogged areas where the water table lies 3m bgl. Details of such areas, under several command areas, as reported during June '86 are given in Table 5.

Table 4

S.No.	Name of the Command Area	District	Waterlogged Area (Th.ha.)
1.	Bhakra Command Area	Kurukshetra	9.218
		Hissar	19.00
		Sirsa	20.350
		Ambala	0.600
			49.168
2.	W.J.C. Command Area	Karnal	2.637
		Jind	36.209
		Sonepat	44.686
		Rohtak	61.289
			144.821
3.	Gurgaon Canal Command Area	Faridabad	21.481
		Gurgaon	14.373
			35.854
		Grand Total:	229.843

The area affected by salinity and alkalinity are 275 th.ha and 180 th.ha respectively.

The reason for the waterlogging has been stated to be the absence of both surface as well as sub-surface drainage and continuous heavy seepage from its canal system. The state Govt. has undertaken various measures to reduce the extent of waterlogged areas as follows:

i) Lining of Canal System: Under the assistance of World Bank, Phase 1 of the modernization of canal system has been completed and phase II of this project is under execution. The period envisages lining of entire canal system and water courses in particular. Thus, 3,876 km of canal and distributaries and 16,101 km of water courses have been lined by the end of 1986.

ii) Conjunctive use of surface and ground water: The State Government is encouraging the farmers for installation of shallow tubewells/and use the underground water in conjunction with canal waters. Since 1966-67 to 1983-84, the number of shallow tubewells has been increased from 25,311 to 3,88,201 and deep tubewells, including both direct irrigation tubewells and augmentation tubewells, have been increased from 901 to 3,089.

iii) Improvement of Drainage System: At present, the state does not have satisfactory drainage system, except in eastern parts. The State has planned to construct a good number of surface and sub-surface drains. Some pilot schemes covering area of 10 to 60 hectares have already been taken up on sub-surface drainage and vertical drainage at HAD in Hissar district, Deuana in Jind district, Mudlong in Sonepat district and Sampla in Rohtak district.

iv) Improvement in Water Management Practices: The Government has initiated better water management practices to reduce the recharge of surface water to the underground water through introduction of sprinkler system. Upto 1986-87, about 20,000 sprinkler sets have been installed in the State. Another scheme for installation of drip irrigation system is also being introduced.

4.5 KARNATAKA

An area of 24.543 th.ha was waterlogged under nine projects, namely the Bhadra, the Upper Krishna, the Malaprabha, the Ghataprabha, the Tungabhadra, the Kabani, the Harangi, the Hemavathy and the Krishna Rajasagar. The area affected by salinity is reported as 34.24 th.ha under the above mentioned projects, excluding Hemavathy project. The area affected by alkalinity is 17.12 th.ha under the Bhadra, the Malaprabha, the Ghataprabha and the Tungabhadra projects.

As a remedial measure open field drains are constructed to drive away excess water and to lower the water table. These field drains are linked to the main drain directly wherever possible.

4.6 KERALA

The State Government has identified about 11.60 th.ha under waterlogging in the following eight irrigation projects of the State:-

i)	Pamba	0.42 th.ha
ii)	Periyar Vagai	0.08 "
iii)	Pazhassi	0.57 "
iv)	Kuttiyadi	0.76 "
v)	Moovattu Puzha	2.82 "
vi)	Idamalayer	2.84 "
vii)	Peechi	1.50 "
viii)	Kanakkan Kadavu	2.61 "
	Total	11.60 th.ha

The area affected by salinity in Peechi is 8.00 th.ha in Kanakkan Kadavu is 2.61 th.ha the Pazhassi is 0.57 th.ha and in Kuttiyadi is 0.75 th.ha.

The Command Area Development Authority of Kerala State reveal that no area under the ten completed irrigation projects of the State covered by command Area Development Programme is affected by waterlogging, soil salinity and alkalinity.

4.7 MADHYA PRADESH

The development of irrigation in Chambal Command without proper drainage system, gradually raised water table and created waterlogging conditions. A study done during October, 1969 in Chambal Command (Madhya Pradesh) revealed that an area of about 28.029 thousand ha was having water table between 0 to 1.5 m below ground level and 38.838 th.ha was having water Table between 1.5 to 3 m below ground level.

As a remedial measure the waterlogged area under the Chambal Command has been divided into 18 pilot project schemes. Initially the work was started in 14 such pilot schemes covering an area of about 5.332 th.ha and an area of 2.325 th.ha was reclaimed and made fit for cultivation. Upto June 1975 an area of 8.610 th.ha was reclaimed. An area of about 54.900 th.ha has been reclaimed upto the end of Dec. '86 against the total waterlogged area of 58.870 th.ha.

The study conducted in Tawa irrigation projects shows that 25 villages. have water logging conditions in an area of 335 ha for which a number of preventive and curative measures have been taken up.

4.8 MAHARASHTRA

The Directorate of Irrigation Research and Development under the State Irrigation Department is continuously monitoring the water table over last many years. As a result of such monitoring and implementation of number of drainage schemes, the extent of waterlogged area is kept as low as 1 percent. The extent of fully damaged area in the State is 6.028 th.ha in an Irrigated Command Area of 822 th.ha as per 1984-85 data.

The CAD authorities are continuously trying to adopt modern techniques of irrigation for economic use of water so as to prevent any rise of ground water. Because of overall shortage of water in Maharashtra, well construction activity is extremely popular and it is helping to a great extent in lowering down the ground water. Upto 1984-85, 138 drainage schemes have been constructed and additional 635 drainage schmes have been proposed in about 23 canal command areas having 8.22 lakh ha. Fifteen more new canal commands are likely to be included in near future covering CCA of 10.39 lakh ha.

4.9 ORISSA

The State is suffering from drainage congestion and waterlogging in an area of about 196.26 th.ha in the Mahanadi basin, including districts of Cuttack, Puri, Balasore and Sambalpur. The main area where this problem is prevalent is the Mahanadi Delta system in Cuttack and Puri, districts where the area affected is 114.2 th.ha. The area affected is estimated to be 58.5 th.ha in Cuttack district and 55.9 th.ha in Puri district. In addition to this an area of about 82.00 th.ha in Balasore district and 0.06 th.ha in Sambalpur district is affected by drainage congestion.

The main reason for this malady are as follows:

i) The canal system is old and the seepage losses are very high.

ii) The command area development works have not been systematically taken up.

iii) In the course of formation of delta, where the waterlogging is mainly confined, the river beds have gradually risen higher than the adjoining lands.

iv) Flood embankments, provided along the rivers often breach causing inundation to the adjacent lands.

In order to alleviate these maladies an integrated comprehensive development plan, namely the Delta Development Plan, envisaging several remedial measures such as :

(i) Development of catchment areas and improvement of drainage in basins and deltas: The project envisages improvement of surface drains to retrieve about 110.6 ha. of ill-drained area. The project estimate includes suitable provisions for construction of link drains, improvement of secondary and outfall drains and provision for tidal control structures in order to check tidal ingress.

ii) Modernisation of old canal system: The modernisation of existing old canal system and thereby providing control to every 5 ha patch against the present system of nearly 40 ha., lining of canal system in the highly porous reaches and control of tidal ingress.

iii) Conjunctive use of surface and ground water: A large number of tubewells are proposed to be bored throughout the delta command to utilise the ground water for (i) the nurseries for early transplantation, (ii) augmenting irrigation supplies during high demand period, and (iii) lowering water table.

4.10 PUNJAB

The State of Punjab is experiencing very serious problem of waterlogging in the south - western districts the Faridkot, Ferozpur and Bhatinda, over the past few years. The water table has been continuously rising and after construction of Indira Gandhi Canal and Sirhind Feeder, the rate of rise has further increased. Vast areas of this tract have been waterlogged with the result that thousands of hectares of land have gone out of cultivation, buildings have started crumbling down and roads have been badly damaged. It has been reported that the water logged areas i.e. where the water table is within 1.5 m below ground level is of the order of about 2.0 lakh hectares as detailed in table 5 below.

Table 5

S.No.	Name of District	Area waterlogged (th.ha)
1.	Faridkot	161.975
2.	Ferozepur	14.850
3.	Bhatinda	21.750
	Total	198.575
	Say	200.00

4.11 RAJASTHAN

Water table in Ghaggar bed and command of Indira Gandhi Nahar Pariyojana State-II in Sriganganagar district during the period from 1981-84 revealed that the water table is continuously rising, with the rate varying from 0.20 m to more than 2.0m with an average rate of 0.80 m per annum. In some areas, water table has risen to depth less than 6.0 m from land surface. Two such areas have been reported in Tibi Sector, east of Hanumangarh district and Baropal Sector, east of Suratgarh district having waterlogged area of 57.200 th.ha and 56.700 th.ha respectively in 1984.rendering 8.700 th.ha of land out of cultivation.

The Tibi Sector includes parts of Indira Gandhi Canal, Bhadra Canal and Ghaggar Canal Commands and Baropol Sector falls under the command of Indira Gandhi Canal. But the southern part of this sector is surrounded by line of depression which are filled up with flood waters from Ghaggar river through Ghaggar diversion Channel. The main causes of waterlogging are deep percolation of canal water and seepage from Ghaggar depressions.

High water-table and over irrigation have created the problem of salinity and alkalinity in Chambal command area. The water-table, in most of the sites, varied from 0 to 90 cm, within 2 to 3 days after the opening of the canal, whereas it stood generally at 120 to 180 cm when the canal is closed. This level is considered to be much above the critical level.

Hydrogeological studies were carried out by the State Ground Water Department for examining the feasibility of lowering water table by vertical drainage system. The studies revealed that vertical drainage system can be effective for lowering the water table in Tibi and Baropal sectors by way of constructing battery of tubewells at 1000m apart. The saline drained water in major part of the area has to be blended in pre-determined ratio with the canal water at selected points in such a way that the water after blending is suitable for irrigation. The operation of these tubewells is proposed to be synchronised with the flow of canals. Consequently the Government of Rajasthan formulated a proposal for vertical drainage pilot project for anti-waterlogging measure in IGNP Stage-I in the district of Sri Ganganagar, during October, 1986.,covering an effective area of 1.125 th.ha.

4.12 TAMIL NADU

In Thanjavur district, where the majority of the lands are irrigated by Cauvery System, the extent of waterlogged area is about 18.00 th.ha. The areas affected by the salinity and alkalinity in the canal system are indicated as 20.12 th.ha and 27.48 th.ha.The cause for the malady is mainly due to the depressions found in the flat topography coupled with lack of drainage facilities.

The Irrigation Department has already taken up some improvements to irrigation and drainage channels in Thanjavur delta. In the delta there are 519 major and 177 minor drains. Out of these as many as 343 drains have been completed by the end of March, 1988 by way of widening and deepening. The remaining drains are planned to be taken up in a phased manner.

4.13 URRAR PRADESH

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The information available from the Sarda Sahayak Command Area Development Authority gives some generalised idea on the problem in the command area of Sarda Sahayak Project. It is mentioned that an area of 35,2000 ha is facing waterlogging problem-water table being within 1.5 metres below the ground surface. However, during the past years of 1982, 1983 and 1984, the area gone under waterlogging was 238 th.ha, 148 th.ha and 62 th.ha respectively, indicating a positive decline in the affected area. The districts affected as per 1984 study were Barabanki, Rai Bareilly, Sultanpur, Allahabad, Jaunpur, Azamgarh and Varanasi. An area of about 4.83 lakh ha is stated to be affected by salinity and alkalinity.

The main cause of the problem was commissioning of Sarda Sahayak Canal system prior to the completion of lining and consequent seepage from feeder canal.

The lining of Sarda Sahayak Canal system has been taken up which has arrested rising trend of water table.An area of 2.12 th.ha has so far been covered with surface drainage and 0.96 th.ha with sub-surface vertical drainage. There is a further plan to cover 177 th.ha under drainage plan. The saline and alkaline areas reclaimed so far are 10.8 th.ha and 16.4 th.ha respectively.

Table 6 shows the area affected by waterlogging, salinity and alkalinity in the various States.

Table 6

Statewise/projectwise area under waterlogging,salinity/alkalinity

(Area in th.ha)

S.No.	Name of State	No. of projects affected	Water-logging	Area under Salinity	Alkality	Remarks
1	2	3	4	5	6	7
1.	Andhra Pradesh	4	266.400	5.000	22.040	
2.	Bihar	3	362.670	224.300	-	
3.	Gujarat	7	89.408	1214.165	-	
4.	Haryana	3	229.840	-	-	
5.	Jammu & Kashmir		1.500			
6.	Karnataka	9	24.543	344.244	17.170	Upated on March 1991
7.	Kerala	8	11.600	10.610	-	
8.	Madhya Pradesh	1	4.260	-	-	
9.	Maharashtra	2	6.000	-	-	

10.	Orissa	1	196.260	-	-	
11.	Punjab	1	200.000	1008.00	1211.300	
12.	Rajasthan	1	179.500	70.000	-	
13.	Tamil Nadu	1	18.000	20.120	27.480	
14.	Uttar Pradesh	1	35.200	483.000		Total salinity alkalinity
		42	1625.181	3069.439	1277.990	
		m.ha	1.62	3.07	1.28	

(Source: MOWR,1991 report on waterlogging,salinity and alkalinity)

4.14 OTHER STATES/UNION TERRITORIES

The following States/UTs have reported that there is no waterlogging problem experienced by them:

STATE	UNION TERRITORY
Assam	Andaman & Nicobar
Arunachal Pradesh	Chandigarh
Goa	Delhi
Himachal Pradesh	Dadra & Nagar Haveli
Manipur	Lakshdweep
Mizoram	Pondicherry
Nagaland	
Tripura	
West Bengal	

Besides the detailed information gives in the proceeding paragraphs on waterlogged, soil salinity and alkalinity areas in irrigation project commands (as obtained from CWC,MOWR,MOA), the author has also collected information direct from the various Central/States Government offices and project authorities for the assessment of affected areas in the country.

The collected data were examined and compiled Statewise. The details of statewise waterlogged and salinised area in irrigation projects is given in annexure 1 . The consolidated information is given as under:

i) Waterlogged areas — 2.46 m.ha

ii) Area affected by excess salt concentration
 a) Saline soils — 3.06 m.ha
 b) Alkali soils — 0.24 m.ha

iii) Total — 3.30 m.ha

5.Ø CONCLUSIONS:

The waterlogging could be caused either due to surface flooding or as a result of rise in ground water table.The problem of surface flooding is common in the states of Assam,Bihar,Kerala,Punjab ,Haryana ,Uttar Pradesh,Tamil Nadu and West Bengal,while the problem on account of rise of water table has been reported in the state of Punjab,Haryana and Uttar Pradesh. As far as high concentration is concerned, the saline soils are mostly found in Uttar Predesh, Gujrat, West Bengal, Rajasthan, Punjab,Haryana,Maharastra,Karnataka and Andra Pradesh. Existence of alkali soils is mostly limited to the states of Haryana,Punjab and Uttar Pradesh.

So far as the data on waterlogged areas are concerned , the National commission for irrigation (1972) and NCA (1976),Ministry of Agriculture (1984-85) reported 4.84,6.ØØ and 8.53 m.ha respectively.This data is for both irrigated commands as well as of the areas outside the irrigation commands. An area of 2.46 m.ha is suffering from waterlogging in irrigation commands.

Since the saline soils vary considerably in their nature and characteristics,it is imperative that only location specific agronomic and cultural practices are developed. The adoption of a package of scientifically developed agronomic and cultural practices can ensure successful crop production in saline soils.

In most irrigated areas,rise in the level of ground water table is the primary cause of root zone salinity.In the absence of adequate drainage,the faulty water management practices in irrigation commands may bring more and more areas under salinity problem every year. It is suggested to give due priority to drainage schemes of completed irrigation projects and to include the drainage component in new projects.

So far as the area affected by excess salt concentration is concerned,National commission on agriculture (1976) has estimated to the extent of 7 m.ha out of which 2.5 m.ha is under alkali soils and 4.5 m ha under saline soils,but later Ministry of Agriculture estimated this area to the extent of 9.Ø8 m.ha which include 3.58 m.ha under alkali soils and 5.5Ø m.ha under saline soils,including coastal sandy areas. An area under irrigated commands as 3.3Ø m.ha i.e.3.Ø6 m.ha under saline soil conditions and Ø.24 under alkali soils.

The waterlogging and salinity/alkalinity of soils make the fertile soils unproductive or sometimes even barren.An area of 5.8 m.ha is suffering from both waterlogging,salinity/ alkalinity in the command of major/medium irrigation projects in the country.

There has been no systematic survey so far in order to firm up the total area affected by alkalinity and salinity. Future soil survey in different states,if properly organised ,may bring out many more areas of salt affected soils.

6.0 RECOMMENDATION

The irrigation projects could be grouped into three broad categories namely (1) projects which are at scrutiny level,(2) projects which are under execution and (3) projects under operation.In the projects which are under scrutiny/formulation,in depth study should be made on the likely behaviour of the sub-soil water level after introduction of irrigation and necessary preventive and remedial measures included in the project proposals itself.In the case of projects,which are under execution and those in operation proper water management practices may be undertaken.In the project under operation proper monitoring of water table be done so that the drainage network could be provided as and when required.Wherever the water table risen to the alarming level and high salt concentration has appeared,such projects be taken care of by taking remedial measures through drainage work either by open drain and or by sub surface drains and ameliorative measures.

The preventive measures should be initiated in all the major and medium irrigation projects at the very beginning of the commissioning of the project. Command area development approach (water management) efforts like construction of field channels, field drains,land levelling and shapping,providing proper irrigation structure,growing low water intensive and high water use efficiency crops,judicious use of irrigation water by way of ensuring proper quantity and interval,enforcement of proper warabandi system in the farmers fields,properly managed night irrigation using sprinkler and drip irrigation wherever feasible,conjuctive use of surface and ground water etc.,are the measures to keep the water table down for avoiding the condition of waterlogging and soil salinity.

Results of the studies undertaken in the country so far, clearly demonstrate the usefulness of remote sensing techniques in detecting and monitoring waterlogged and saline/alkaline soils.A rapid and accurate assessment of the waterlogged and salt affected area can be made by the use of remotely sensed data.

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Annexure I

Statement showing the statewise area waterlogged in irrigation projects

Sl.No.	Name of State	Name of Project	Area waterlogged (th.ha)	CCA (th.ha)	Percentage area waterlogged to CCA (col 4×100) / col 5
1	2	3	4	5	6
1	Andhra Pradesh	Sriram Sagar	75.60	270	
		Nagarjuna Sagar LBC	19.80	430	
		Nagarjuna Sagar RBC	114.00	475	
		Tungabhadra	57.00	300	
		Sub-total	266.40	1475	18%
2	Bihar	Tirhut canal	199.60	960	
		Saran canal	132.80		
		Kosi command	30.27	440	
		Sub-total	362.67	1400	26%
3	Gujrat	Kakrapar	11.46		
		Ukai RBC	2.15		
		Ukai LBC	2.04		
		Mahi RBC	3.94	348	
		Kadana LBC	0.80		
		Shetrunji LBC	0.02	30	
		Ghed area	69.00		
		Sub-total	89.41	378	4%
4	Haryana	Bhakra command	49.17	1166	
		W.J.C command	144.82	1084	
		Gurgaon canal	35.85	138	
		Sub-total	229.84	2388	9.6%
5	Kerala	Pamba	0.42	49.0	
		Periyar Vagai	0.08	36.5	
		Pashassi	0.57	22.3	
		Kuttiyadi	0.76	25.4	
		Moovattu Puzha	2.82	18.6	
		Idamalayer	2.84	19.4	
		Peechi	1.50	17.6	
		Kanakkan Kadavu	2.61		
		Sub-total	11.60	189.7	6%

6	Karnataka	Bhadra	3.93	125	
		Upper Krishna	0.65	70	
		Malaprabha	1.15	215	
		Ghataprabha	1.22	317	
		Kabini	3.04	154	
		Harangi	0.43	55	
		Hemavathy	1.88	289	
		K.R.Sagar	4.19	113	
		Tungabhadra	8.05	529	
		Sub-total	24.54	1867	1%
7	Maharashtra	Krishna & Godavari	6.03	1250.6	
		Sub-total	6.03	1250.6	0.5%
8	Madhya Pradesh	Chambal	3.93	220	
		Tawa	0.33	247	
		Sub-total	4.26	467	0.9%
9	Orissa	Mahanadi St.I & II	196.26	336	
		Sub-total	196.26	336	58%
10	Punjab	Integrated project in south-west Distt. of Punjab	200.00	3072	
		Sub-total	200.00	3072	7%
11	Rajasthan	IGNP St.I	179.50	540	
		Sub-total	179.50	540	33%
12	Tamil Nadu	Cauvery Delta	18.00	378	
		Sub-total	18.00	378	5%
13	Uttar Pradesh	Sharda Sahayak	35.20	2000	
		Sub-total	35.20	2000	7%
		Grand total	1593.45 or 1.6 m.ha	14030.7	11%

(Source: MOWR 1991)