भारत की सभी वृहद् एवं मध्यम सिंचाई परियोजनाओं के कमान क्षेत्रों में उपग्रह सुदूर संवेदन द्वारा जलग्रसनता एवं लवणीय / क्षारीय मृदा का आँकलन

Assessment of Waterlogging and Salt and / or Alkaline affected Soils in the Commands of all Major and Medium Irrigation Projects in the Country using Satellite Remote Sensing

Country Report

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PREFACE

Several irrigation projects have been commissioned in India in the post-independence era for improving food production and economic development. In the last 50 years, Govt. of India has spent Rs. 2569720 million on development of irrigation projects throughout the country. Of this, a sum of Rs. 1553340 million or 60% is spent only on major and medium irrigation system. On an average, the government has spent Rs. 3086.77 billion per year on major and medium irrigation projects (Govt. of India, Tenth Five Year Plan 2002-07). These irrigated croplands, though limited to about 30 percent of the gross cropped area, contribute more than 50 percent of the total agricultural production. This means, scientific management of irrigation water and irrigated croplands is the only way to make our agriculture productive and competitive. It is realized, however, that the irrigation potential created is not being fully utilized and gap exists between the potential created and potential utilized. The centrally sponsored Command Area Development (CAD) programme was initiated in 1974-'75 with the objective of bridging the gap between the creation and utilisation of irrigation potential and for optimizing production and productivity from irrigated lands on sustainable basis. The programme mainly involves on-farm developmental works like construction of field channels and field drains, land leveling and shaping and introduction of conjunctive use of canal and tube well irrigation. During the 8th Five Year Plan Period, performance evaluation studies of irrigation projects were taken up. One of the major constraints of such evaluation studies is the absence of baseline inventory of irrigation projects on spatial scale with the Command Area Development Authority (CADA). The lacunae was felt most when the Ministry of Water Resources (MoWR), Govt. of India launched the National Water Management Project (NWMP) with the World Bank's assistance in early nineties in some of the irrigation projects. Since then, MoWR is pursuing evaluation studies with several alternatives including application of satellite remote sensing. The importance of satellite remote sensing due to its multi-spectral and multi-temporal capability in providing information on bio-physical and hydro-physical components of irrigation commands and Geographic Information System (GIS) for Spatial Decision Support is well acknowledged by number of studies globally. The project entitled "Assessment of waterlogging and salt and / or alkaline affected soils in the commands of all major and medium irrigation projects in the country using satellite remote sensing" has been entrusted by Central Water Commission to RRSSC, ISRO, Department of Space, Jodhpur.

The present study focuses on existing status of the irrigation commands in terms of i) surface waterlogging and salinity/alkalinity and ii) spatial correlation between ground water fluctuation and surface waterlogging. The waterlogging refers to both surface impounding (excluding ponds, lakes, reservoirs, canals and river) and saturated surface soil. The seasonal waterlogged areas are those which exhibits waterlogging only in one season i.e. April or November and perennial waterlogging, indicates where it persists in both the seasons. Likewise the salt affected areas include those, visible on satellite images, confirmed after soil analysis, and further characterized for its types and severity based upon pH, EC and ESP values. However, the salinity, which is not manifested on satellite data and remains under vegetation cover has been taken care by soil analysis. A menu driven Information System has also been developed for extraction of detailed information about the commands as ready reference and management alternatives. All the thematic layers of the commands and state per se have been organized in GIS database. Menu driven information retrieval and data input function both in tabular and spatial form are the major components of this Information System.

This consolidated report will be useful as baseline information for the irrigation officials, hydrologists, agriculturalists, conservationists and many research organizations.

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PROJECT TEAM

Diagnosis and mapping of waterlogged and salt affected soils in irrigation command areas is a pre-requisite for management of valuable land resources. Since independence the area under irrigation through major and medium commands has been increased from 9.70 m ha to 55 m ha during 10th Five Year Plan. There is simultaneous increase in cropping intensity and production also.

But there are some negative consequences of irrigation also. As per published reports considerable areas in Uttar Pradesh, Rajasthan, Gujarat Haryana and few other states, twin problems of waterlogging and salinity is alarming. If this remains unnoticed over the years a large area will be turned into barren areas. Hence it is worth to have a detailed inventory about the spatial extent and severity of waterlogging and salinity/alkalinity problem so that preventive and ameliorative measures can be taken to arrest degradation of productive agricultural lands.

Remote sensing is a pragmatic tool to identify and map waterlogging and soil salinity/ alkalinity when supported by ground observation and laboratory based soil analysis data. It is not only physically possible to go for soil sampling for the whole country but also the time taken and cost of collection and analysis will be prohibitive. From this perspective remote sensing is an excellent trade off for targeting the locations and strategic sampling. Satellite derived information synergistically combined with soil analysis data and ground intelligence is capable of provide near real time estimate of waterlogging and salinity/alkalinity at a cheaper cost and timely manner. Moreover the spatial extent and their dynamic nature could also be monitored.

Total 1701 irrigation commands (major and medium) covering 88895.620 Th ha (27.04% of the geographical area of the country) have been studied under this project. Number of major and medium irrigation commands are 429 and 1272, respectively. Total waterlogged areas based on remote sensing techniques for the year 2003-2005 within major and medium irrigation commands in the country is 1719.279 Th ha which is 1.93% of the command area. Perennial waterlogging covers 173.145 Th ha where as seasonal waterlogging covers 1546.134 Th ha. On the other hand, salt affected area occupies 1034.541 Th ha which is 1.16% of major and medium command areas studied. Total 16558 soil samples were collected and analysed to identify salinity/alkalinity along with severity classes. From ground water table rise point of view, 0.14% of the area under major and medium irrigation commands occupies most critical (upto 1 m) category in pre monsoon season which increased to 1.95% in post monsoon season. The critical category (1-2 m) which occupies 2.75% of command area during pre monsoon increased to 12.35% in post monsoon. There was no significant correlation between surface waterlogged areas and ground water rise in most of the places.

The present document is a compilation work of the studies of all the states and UTs carried out and presented as a comprehensive database for assessment of waterlogging and salt affected soils in the commands of all major and medium irrigation projects in the country in the form of a consolidated report. It is hoped that available database will be of immense use to planners, administrator, agriculturists, researchers, academicians, engineers and other related agencies as baseline information about the status of the problem of the irrigation commands.

सारांश

सिंचित कमान क्षेत्रों में जलग्रसनता एवं लवणीयता / क्षारीयता की समस्याओं का पता लगाना एवं उससे प्रभावित क्षेत्रों का सीमांकन करना सफल भू-संसाधन के अच्छे प्रबन्धन की पहली शर्त है। देश के स्वाधीन होने से लेकर अब तक, सिंचित क्षेत्रों के विकास में वृह एवं मध्यम कमान क्षेत्र द्वारा, सिंचित क्षेत्र में 9.70 मिलियन हेक्टर से बढ़कर 55 मिलियन हेक्टर (10वीं पंचवर्षीय योजना के दौरान) क्षेत्र के क्षेत्रफल में वृ हुई है। सिंचित क्षेत्रों के विस्तार के साथ-साथ फसलों की सघनता एवं पैदावार में भी लगातार बढ़ोतरी हुई है।

सिंचित क्षेत्र में सिंचाई के विस्तार से कुछ नकारात्मक परिणाम भी दृष्टिगोचर होने लगे है। सिंचित कमान क्षेत्र से संबंधित प्रकाशित होने वाले प्रतिवेदनों के अध्ययन से एक तथ्य साफ पविलक्षित हुआ है कि उतरप्रदेश, राजस्थान, गुजरात, हरियाणा आदि राज्यों एवं अन्य राज्यों के काफी क्षेत्रों में जलग्रसनता व मृदा में लवणीयता / क्षारीयता की गंभीर समस्याएँ उत्पन्न हुई है। यदि समय रहते इन समस्याओं पर ध्यान नहीं दिया गया तो आने वाले वर्षो में एक बड़ा क्षेत्र बंजर भूमि में परिवर्तित हो जायेगा। अतः यह उचित होगा कि उपजाऊ कृषि भूमि को बंजर होने से रोकने हेतु जलग्रसनता एवं लवणीयता / क्षारीयता समस्याओं का आंकलन, संघनता एवं उनकी विस्तृता का एक विस्तृत सर्वेक्षण कर इन समस्याओं को सुधारने के उपाय व सुझावों पर ध्यान केन्द्रित कर इनका निवाकरण करना है।

सुदूर संवेदन एक व्यावहारिक तकनीक है जिसे जमीनी निरीक्षण एवं प्रयोगशाला आधारित विश्लेषित ऑकड़ों के समन्वय से सिंचित कमान क्षेत्र में जलग्रसनता व लवणीयता वाले प्रभावित क्षेत्रों का प्रभावी रूप से सीमांकन कार्य किया जा सकता है। चूँकि भौतिक रूप से पूरे देश में मृदा के विस्तृत नमूने एकत्रित करना कठिन कार्य के साथ ज्यादा समय एवं अधिक खर्च अव्यवहारिक प्रतीत होता है, इस दृष्टिकोण से सुदूर संवेदन व्युत्पित सूचनाओं का मृदा विश्लेषित ऑकड़ों एवं क्षेत्र विशेष के ज्ञान के समन्वय से कम समय में व कम खर्चे में जलग्रसनता एवं लवणीयता / क्षारीयता का ऑकलन एवं गणना की जा सकती है। इसके साथ ही यह तकनीक समस्याग्रस्त क्षेत्र की गतिशील व्यवस्था को भी नियंत्रित करती है, जिससे समस्याओं का समय-समय पर सही ऑकलन किया जा सके।

इस अध्ययन में सभी राज्यों के सभी वृहद एवं मध्यम सिंचित कमान क्षेत्रों में सुदूर संवेदन तकनीक द्वारा जलग्रसनता एवं लवणीयता / क्षारीयता से प्रभावित क्षेत्रों का पता लगाया गया है। कुल 1701 सिंचित कमान क्षेत्रों का अध्ययन किया गया, जिसमें 429 वृह व 1272 मध्यम कमान है। सिंचित कमान का कुल भौगोलिक क्षेत्रफल 88895.620 हजार हेक्टर है, जो देश के भौगोलिक क्षेत्रफल का 27.04 प्रतिशत है। सुदूर संवेदन ऑकड़े (2003-05) के आधार पर विश्लेषण करने पर जलग्रसनता का क्षेत्रफल वृह एवं मध्यम सिंचित कमान क्षेत्रों में लगभग 1719.279 हजार हेक्टर है, जो कमान क्षेत्र का 1.93 प्रतिशत है। वर्षा के बाद उत्पन्न जलग्रसनता 1546.134 हजार हेक्टर एवं चिरस्थायी जलग्रसनता 173.145 हजार हेक्टर है। देश के सिंचित कमान क्षेत्रों में लवणीयता / क्षारीयता की समस्या 1034.541 हजार हेक्टर में पायी गई, जो कमान क्षेत्र का 1.16 प्रतिशत है। मृदा के कुल 16558 नमूने लिये गये, जिसका विश्लेषण कर कमान क्षेत्र में लवणीयता/ क्षारीयता की सघनता को वर्गीकृत किया गया है। उपग्रह से चिन्हित जलग्रसन क्षेत्र तथा भू-जल स्तर पर आधारित मानसून पूर्व और मानसून पश्चात् क्षेत्रों की अत्यधिक गंभीर, गंभीर, एवं कम गंभीर श्रेणीयों में सह-संबंध निकाला गया। वृह एवं मध्यम कमान क्षेत्र का कुल 0.14 प्रतिशत क्षेत्र अत्यधिक गंभीर श्रेणी का क्षेत्र मानसून पूर्व, जो कि मानसून के पश्चात् बढ़कर 1.95 प्रतिशत हो गया। गंभीर श्रेणी का क्षेत्र, जो कुल कमान क्षेत्र का 2.75 प्रतिशत मानसून पूर्व है जो कि बढ़कर 12.35 प्रतिशत मानसून पश्चात् हो गया। अधिकतर राज्यों में उपग्रह से चिन्हित जलग्रसन क्षेत्र तथा भू-जल स्तर पर आधारित महत्वपूर्ण सह-संबंध नहीं निकाला गया है। प्रस्तावित दस्तावेज देश के सभी राज्यों के वृह एवं मध्यम कमान क्षेत्र में जलग्रसनता एवं लवणीयता / क्षारीयता के बारे में ऑकड़ों को संकलित कर एक प्रतिवेदन के रूप में प्रस्तुत किया गया।

आशा है कि प्रस्तुत प्रतिवेदन में संकलित किये गये राज्यवार ऑकड़ों का उपयोग योजनाकारों, प्रशासकों, कृषिशास्त्रों, अनुसंधानकर्ताओं, विद्वानों, अभियंताओं और सभी संबंधित संगठनों / संस्थानों को सिंचित कमान क्षेत्र की आधारभूत सूचनाओं के वस्तुस्थिति एवं समस्याओं के बारे में योजनाएँ बनाकर उन्हें क्रियान्वित करने में एक बहुउपयोगी सि होगा।

1. INTRODUCTION

Timely and accurate detection of waterlogged and saline / alkaline (sodic) soils and their spatial distribution along with severity information and seasonal dynamics are vital in determining the sustainability of any irrigated production system. A reliable, cost-effective and near real time approach is needed to determine the extent of twin problem of waterlogging and soil salinity / alkalinity and to monitor its change in spatial extent. Remote sensing offers several advantages over conventional ground methods used to map and monitor waterlogging and soil salinity / alkalinity. By virtue of synoptic viewing capability, repetitiveness and spectral sensitivity to water and salt, it is a valuable tool for obtaining dynamic information on waterlogging and soil salinity / alkalinity commonly associated with irrigated commands. An irrigation potential of 102.77 M ha has been created up to end of 10th five year plan (2007). Out of which 87.23 M ha (85%) could be utilized up to end of 10th five year plan. However the total ultimate irrigation potential of the country is estimated at 140.0 M ha (Major & medium - 58.5 M ha, and Minor - 81.5 M ha).

2. PROJECT OBJECTIVES

RRSSC Jodhpur, recently completed the study "Assessment of waterlogging and salt affected area in the major and medium irrigation projects in the country" entrusted by Central Water Commission, Ministry of Water Resources, New Delhi. The project aimed at fulfilling following objectives and deliverables:

- Assessment of waterlogged areas due to surface inundation using multi-temporal satellite data.
- Assessment of saline and /sodic lands using multi–temporal satellite data.
- Spatial correlation between critical ground water depth (from well observation data) and surface waterlogging manifested on satellite data.
- Development of information system by integrating all (collected/processed/developed) during the study for all the states and union territories.
- Preparation of state wise and consolidated report for the country as a whole.

3. IRRIGATION PROJECTS IN THE COUNTRY

3.1 Irrigation Projects

It was only after independence that planned development of irrigation was thought of as one of the priority requirements for the growth of India's economy, social well being and was undertaken on an extensive scale throughout India. After 1960 the concept of socio-economic benefits got formally associated with the planning and development of the irrigation systems.

The irrigation projects are classified into three categories viz. Major, Medium and Minor based on extent of Culturable Command area (CCA). Minor irrigation projects have both surface and ground water as their source, while major and medium projects exploit surface water resources.

Before the commencement of planned development in 1951, the irrigation potential created through the major and medium sector was only 9.70 M ha. In the 1st five year plan, the country launched a major irrigation programme to offset the loss in irrigation area due to partition and to solve the problem of perpetual food shortage necessitating large scale import. A number of major and multi purpose projects like Bhakra Nangal, Nargarjunasagar, Kosi, Chambal, Hira kund, Kakrapar and Tungabhadra were initiated. This trend continued till the 4th plan, when the emphasis shifted to the completion of ongoing projects, modernization and integrated use of surface and groundwater.

In 1951, during launching of the 1st five year plan, there were 74 major and 143 medium irrigation projects in the country. During the plan period since 1951 to end of 10th plan in 2007, as per available information, total number of projects taken up are 368 major, 1087 medium and 215 ERM (Extension, Renovation and Modernisation) schemes out of which 202 major, 865 medium and 126 ERM projects have been anticipated to be completed by end of 10th plan as given in Table 1.

Table 1: Number of major, medium and ERM projects taken up and completed upto 10th plan (2007)

Category	Projects taken up			Project likely to be completed			Spill over into XI plan
	Pre-plan	Plan	Total	Pre-plan	Plan	Total	
Major	74	368	442	74	202	276	166
Medium	143	1087	1230	143	865	1008	222
ERM	-	215	215	-	126	126	89
Total	**217**	**1670**	**1887**	**217**	**1193**	**1410**	**477**

Source : Report of the Working Group on Water Resources for 11th plan (2007-12)

3.2 Concept and Definition – Irrigation Projects

- **Culturable Command Area (CCA):** It is defined as the total cultivated and uncultivated area which can be irrigated economically from a canal scheme by flow or lift irrigation on the supposition that unlimited water supply is available.
- **Gross Command Area (GCA):** It is the total area which can be irrigated in a project command. It includes the area covered by roads, culverts, settlements, unculturable area etc.
- **Gross Irrigated Area:** The area irrigated under various crops during a year, counting the area irrigated under more than one crop during the same year as many times as the number of crops grown and irrigated.
- **Irrigation Potential Created:** It is the aggregate gross area that can be irrigated annually by the volume of water that could be made available by all the connected and completed works upto the last point for the water delivery system upto which the government is responsible for construction, management and operation.
- **Irrigation Potential Utilised:** The gross area actually irrigated during reference year out of the gross proposed area to be irrigated by the scheme during the year.
- **Major Irrigation Project:** It is the project with potential project area of more than 10000 ha.
- **Medium Irrigation Project:** It is the project with potential project area varying between 2000 ha and 10000 ha.
- **Minor Irrigation Project:** It is the project with potential project area upto 2000 ha. This includes both surface and groundwater as source.

4. WATERLOGGING

A soil / land is considered to be waterlogged when the water table rises to such an extent that the root zone becomes saturated, diffusion of air is curtailed and amount of oxygen is reduced with increase in CO_2 partial pressure. The water table, which is considered harmful, depends upon the type of crop, soil and quantity of water. Height of capillary fringe in soils varies from 0.9 to 1.5m, with extent more in fine soils than coarse soils. Hence the soils, where water table remains within 1.5m from the surface, are likely to be waterlogged during monsoon. As per Central Ground Water Board the areas with water table within 2m below ground level are considered as prone to waterlogging and 2-3m below ground is viewed as critical. Waterlogging causes shift in cropping pattern, ultimately leading to inefficient use of land. Land becomes partially unavailable for part of the year or fully unavailable throughout the year, leading to overall poor production performance of agricultural sector.

Waterlogging could be created not only due to excess water supply in the command areas but also due to landform pattern, surface topography, sub-surface barrier, heavy texture soils, poor soil drainage, inappropriate irrigation practice, unsuitable cropping pattern, insufficient natural drainage and proximity to river flood plain.

4.1 Surface Manifestation

Waterlogging is not manifested as surface standing water in first instance. The soil profile gets saturated due to upward capillary fringe from increasing ground water table and slowly blocks all the pore spaces in the soil. When all the soil pores get saturated then free water stands above the ground surface and appears as waterbody. Saturated soil appears darker than the surrounding and is characterized by hydrophytic or water loving plants and dominance of algal growth. Waterlogging and salinity is considered as twin problem as soil salinization normally follows waterlogging in arid/semi arid regions. Water carrying salts may be drained from upslope areas and left salts on the surface as water gets evaporated.

4.2 Severity Classes

Several agencies have given different criteria for severity of waterlogging. Table 2 shows the criteria given by National Commission on Agricultural (1976) and Ministry of Water Resources (1991). Apart from these, generally different states adopt their own criteria, which is slightly different than what is given by Ministry of Water Resources.

Table 2: Criteria adopted by different agencies to define waterlogging

Status of Waterlogging	National Commission on Agriculture (1976)	Ministry of Water Resources, GOI (1991)
Waterlogged / Critical	Water table <1.5m	Water table <2m
Potentially waterlogged	-	Water table <2-3m
Safe area	-	Water table >3m

4.3 Mapping Waterlogged Areas through Remote Sensing

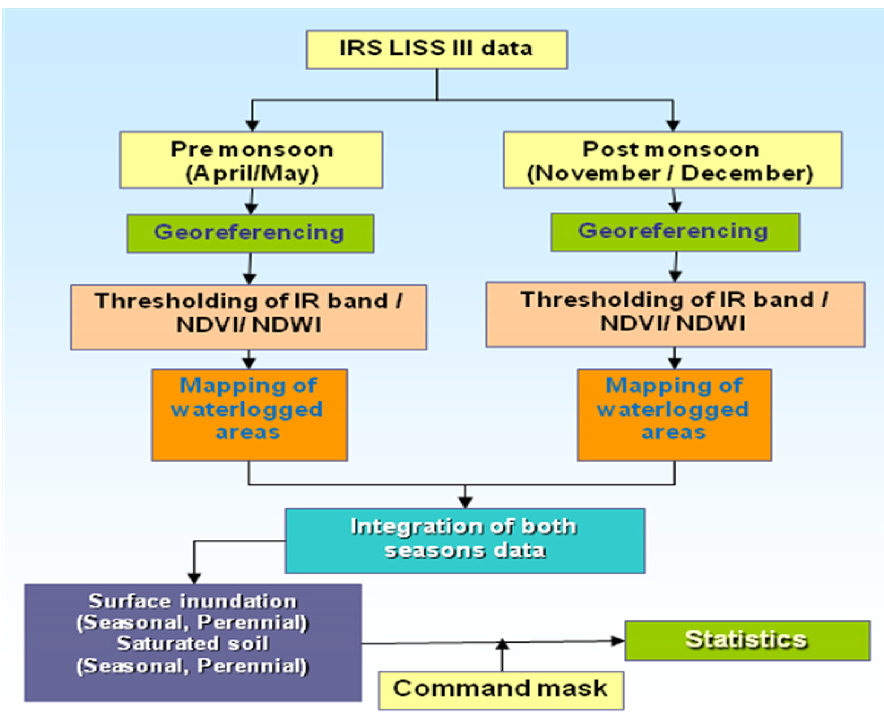
Algorithms developed for waterlogging take advantage of multi-spectral data acquired from space. Since the absorptance of electromagnetic radiation by water is at a maximum in the NIR spectral region, the DN value of water pixels is appreciably less than those of other land uses. Even if the water depth is very shallow, the increased absorptance in the NIR causes DN value to be less than red and green band. This condition differentiates the water pixels from the other pixels. One of the commonly used index is called NDWI (Normalized Difference Water Index) as is given below:

NDWI= (Green–NIR) / (Green+ NIR)

Waterlogged areas have been divided in two categories. Seasonal waterlogged areas are those where waterlogging exists in one season only. The areas where waterlogging occurs in two seasons are demarcated as perennial waterlogged area (Table 3).

Table 3: Classification scheme for waterlogged areas

Type of waterlogging	Pre-monsoon	Post monsoon	Remarks
Surface ponding	No	Yes	Surface ponding (seasonal)
Surface ponding	Yes	No	Surface ponding (seasonal)
Surface ponding	Yes	Yes	Surface ponding (perenniall)
Saturated soil surface	No	Yes	Saturated soil (seasonal)
Saturated soil surface	Yes	No	Saturated soil (seasonal)
Saturated soil surface	Yes	Yes	Saturated soil (perennial)



Methodology for mapping waterlogged areas

5. SOIL SALINITY / ALKLINITY

Soil salinization is far from being a uniform process. Salinity can develop both naturally and from interventions in the water cycle through irrigation. Salt only moves through the movement of soil moisture. Thus the time-depth behavior of salt is highly dynamic. Large number of measurements over a time period are necessary to diagnose salinity as a hazard to crop production.

Primary salinization occurs naturally where soil parent material is rich in soluble salts, or in the presence of a shallow saline groundwater table. In arid and semiarid regions, where rainfall is insufficient to leach soluble salts from the soil, or where drainage is restricted, soils with high concentrations of salts ("salt affected soils") may be formed. Several geochemical processes can also result in salt affected soil formation. When an excess of sodium is involved in the salinization process it is referred as sodification.
Secondary salinization occurs when significant amount of water is provided by irrigation, without adequate provision of drainage for the leaching and removal of salts, resulting in the soils becoming salty and unproductive. Salt-affected soils reduce the ability of crops to take up water and the availability of micronutrients. It also concentrates ions which are toxic to plants and may degrade the soil structure.

Excess salts in soil profile cause poor and spotty stands of crops, uneven and stunted growth, poor yields and presence of white crusts on the surface depending on the degree of salinity. When the salt problem is only mild, growing plants often have a blue/green tinge. Barren spots and stunted plants may appear in cereal or forage crops growing on saline areas. The extent and frequency of bare spots is often an indication of the concentration of salts in the soil. If the salinity level is not sufficiently high to cause barren spots, the crop appearance may be irregular in vegetative vigour. Moderate salinity, however, particularly if it tends to be uniform throughout the field, can often go undetected because it causes no apparent injuries other than restricted growth. Leaves of plants growing in salt infested areas may be smaller and darker blue-green in colour than the normal leaves. Increased succulence often results from salinity, particularly if the concentration of chloride ions in the soil solution is high. The primary effect of excess salinity is that it renders less water available to plants although it may still be present in the root zone.

Causes for development of soil salinity/alkalinity

- Presence of salt in the parent material, e.g. in salt layers accumulated in earlier times.
- Salt formation by weathering of the parent rock which is very slow process indeed. Some of the rocks have favourable chemical composition and porous texture so that under warmer / tropical climates relatively high proportions of salts are formed.
- Salt transported through the air by dust or by rainwater.
- Saline ground water, in this case, where the water table is near the surface, salt will accumulate in the top soils because of the upward evaporative flux.
- Small amount of salts in the irrigation water get gradually built up in the soil profile. Incorrect methods of irrigation may also lead to accumulation of these salts over time. Subsurface waterlogging also results in accumulation of salts in upper soil layer.

5.1 Surface Manifestation

Saline soils are recognized in the field by observing soil per se along with vegetation. Vegetation grown on salt affected soils are characterized by patchy growth of crops, tip burn and chlorosis (pale yellow colour) of leaves. These soils appear in whitish gray, milky white, dull white and light blue tones on imagery depending upon severity and other soil constituents present. In extremes salinity fluffy layer at the surface is formed. In crop land the salts accumulate at the top of the ridge as a result of evaporation and furrows remain relatively less saline where crops are generally sown.

5.2 Characterization and Severity Classes of Salt Affected Soils

Soil salinity /Alkalinity can technically be expressed in terms of pH, Electric Conductivity (EC), Exchangeable Sodium Percentage (ESP) and/ or Sodium Absorption Ratio (SAR). Table 4 and 5 show the characterization of salt affected soils and its severity classes, respectively.

Table 4: Characterization of salt affected soils

Soil type	pH	EC (dS/m)	ESP
Saline	< 8.5	> 4.0	< 15
Sodic / Alkaline	> 8.5	< 4.0	> 15
Saline-Sodic	> 8.5	> 4.0	> 15

Source : US Salinity Laboratory Staff (1954)

Table 5: Characterization of salt severity classes

Type of salinity/alkalinity	Severity class	pH	EC (dS/m)	ESP
Saline	Medium High Very high	< 8.5 <8.5 <8.5	4-8 (2-4) 8-16 (4-8) >16 (>8)	<15 (<5) <15 (<5) <15 (<5)
Sodic / Alkaline	Medium High Very high	8.5-9.0 9.0-10.0 >10	<4 (<2) <4 (<2) <4 (<2)	15-40 (5-10) 40-60 (10-20) >60 (>20)
Saline-Sodic	Medium High Very high	8.5-9.0 9.0-10.0 >10	4-8 (2-4) 8-16 (4-8) >16 (>8)	15-40 (5-10) 40-60 (10-20) >60 (>20)

Figures in parenthesis represent the threshold values for Vertisols

5.3 Mapping Salt Affected Soils through Remote Sensing

Several algorithms were developed to quantify extreme salinization by computing salinity index or brightness index. Essentially, a brightness index is meant to detect high levels of brightness appearing with increasing levels of salinity within a finite limit. The unique patterns of geomorphologic shapes can also be very helpful in discriminating the salinization process from a physiographic perspective. The concept of salinity index emerged from the red edge concept for vegetation vigour mapping. In red edge concept, the spectral reflectance of infrared (IR) is divided with red band, which gives very high values for vegetation than other features on the earth. Here if the inverse is considered then for vegetation low values will be obtained thus suppressing the vegetation and highlight the soil. It is calculated as follows.

SI = (Red/IR) * 100

Another index viz., Normalized Difference Salinity Index (NDSI), is widely used:

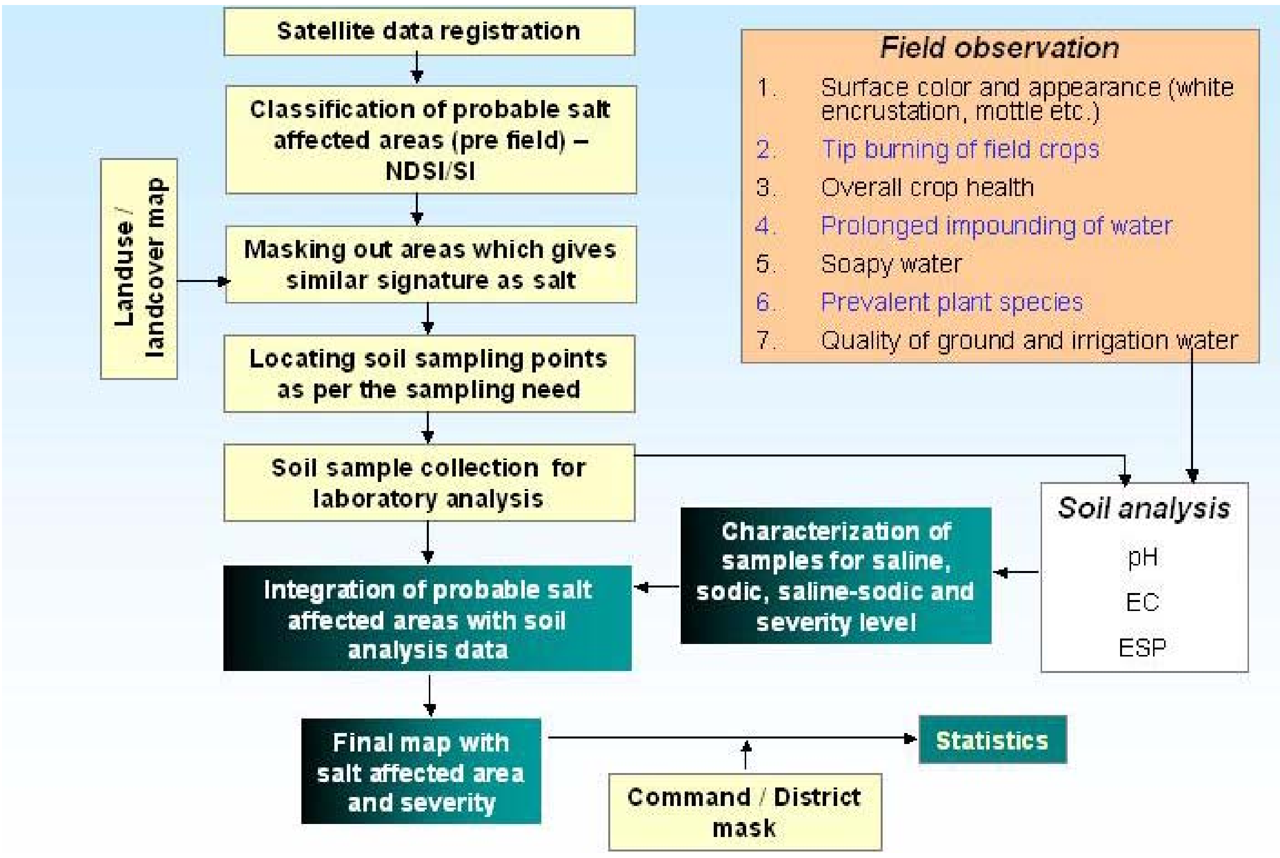
NDSI = [(Red - IR) / (Red + IR)]* 100

Salt affected soils could be identified on the optical image with more than 90% level of confidence due to their contrasting signature on the image. While assessing, it is necessary to have prior knowledge of landform and elevation of the area as there is some degree of spatial relationship of both with salinity/alkalinity. Hence all the areas apparently appear white or darker on the image has to be characterized in respect of contextual information and knowledge of soil properties variation in that area. Many a time bright tone of the image is confused with settlement and fine sandy area. In such cases care should be taken to mask out the settlement areas using ancillary information. Spectral characteristics of salt affected soils as appear in optical imagery are given below (Table 6).

Table 6: Spectral characteristics salt affected soils as appear in optical imagery

Sensor	Primary salt affected soils			Brackish water irrigated soils	
	Slight	Moderate	Severe	Saline	Sodic
IRS LISS I (May)	-	Light gray, regular wavy, smooth	Moderate white, regular, wavy, smooth	Light gray with white mottles	
IRS LISS II (May)	-	Light gray, regular, wavy	Moderate white, regular	Light gray mottles	White to bright white mottles
IRS LISS III (February)	Light gray, regular wavy, occasional, crop cover	Light gray to moderate white, regular, wavy, occasional crop cover	Moderate white to white regular, wavy	Light gray with red mottles	Moderate white to white red mottles, chess board pattern

Source : Adapted from Dwivedi and Sreenivas, 1998



Methodology for mapping salt affected soils

6. EXTENT OF WATERLOGGING AND SALINITY /ALKALINITY

Status of waterlogging varies in the country from place to place and time to time. Perennial waterlogged areas mostly remain same over the years but seasonal waterlogged areas vary with respect to rainfall. A good rainfall may bring large area under seasonal waterlogging. The nature, characteristics and extent of salt affected soils vary considerably from one region to another depending upon climate, topography, geology, soil texture, drainage, hydrology, ground water depth, salt content in ground water and management practices. The accumulation of salts in soil profile is attributed to natural processes and /or due to human intervention such as introduction of irrigation, use of saline water etc.

7. PROJECT RESULTS

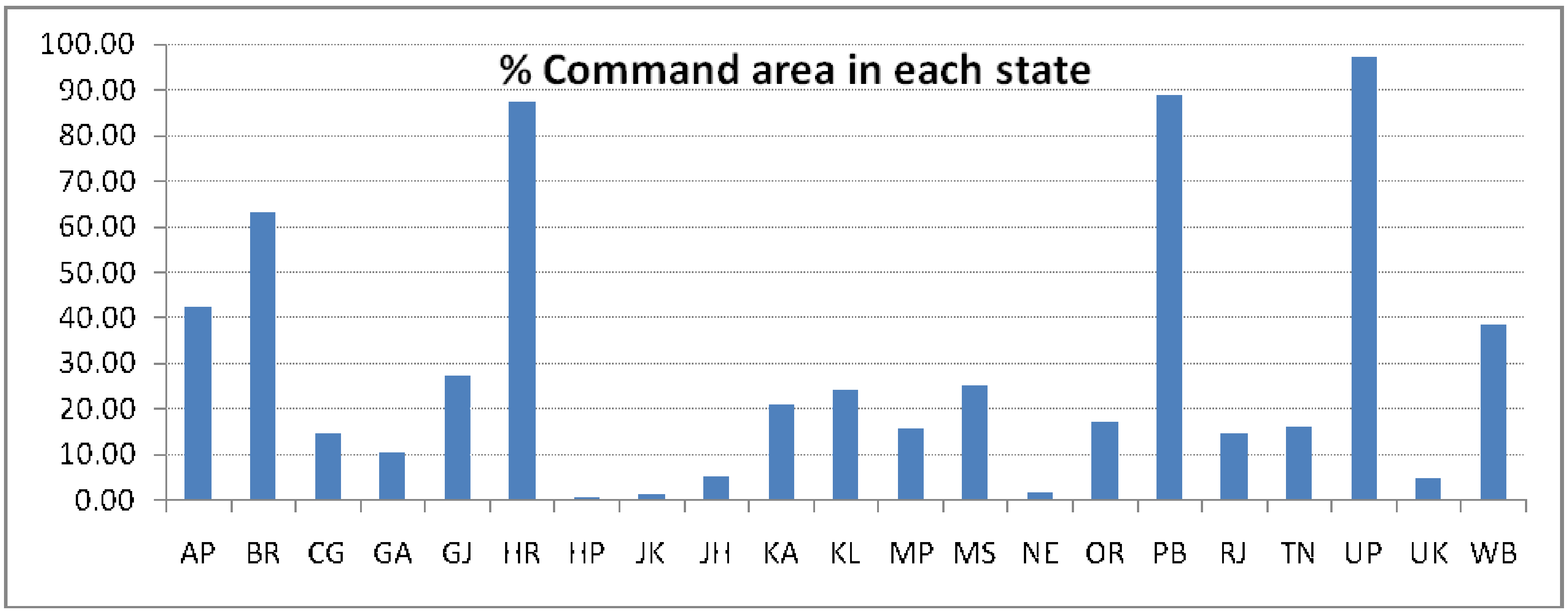
7.1 Irrigation Commands

Major and medium irrigation command boundary maps were obtained from concerned departments of different states. Table 7 shows the summary of major and medium irrigation commands studied in the country under this project. There are 1701 major and medium irrigation commands covering 88895.620 Th ha, which is 27.04% of the geographical area of the country. Number of major and medium irrigation commands are 429 and 1272, respectively.

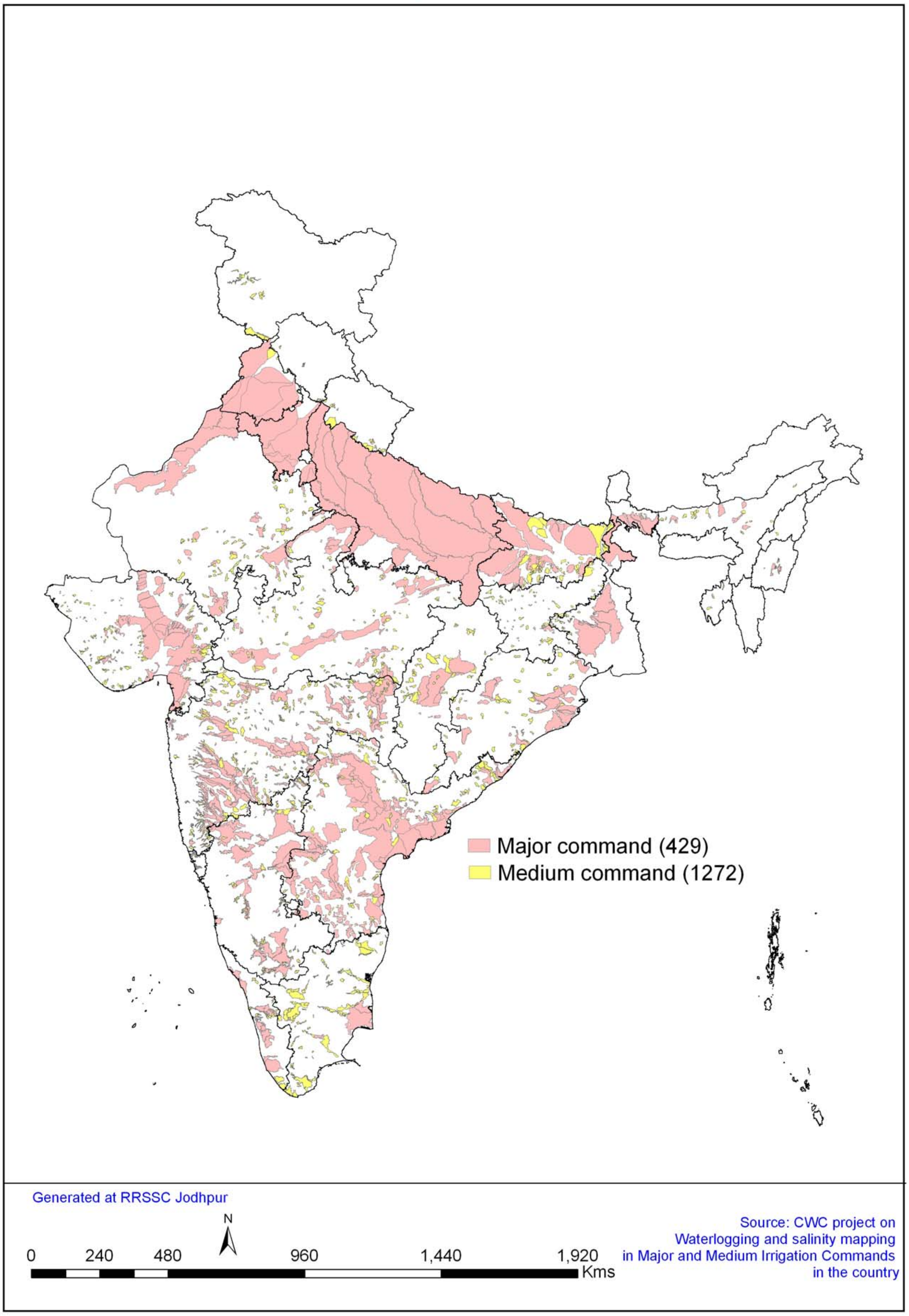
Table 7: Statistics of major and medium irrigation commands studied in the country

State	Geographical area (Th ha)	Number of irrigation commands			Command area (Th ha)	% of geographical area
		Major	Medium	Total		
Andhra Pradesh	27504.500	54	112	166	11631.410	42.29
Bihar	9416.300	22	110	132	5939.255	63.07
Chhattisgarh	13519.100	9	42	51	2009.823	14.87
Goa	370.200	2	3	5	38.120	10.30
Gujarat	19602.400	36	133	169	5334.172	27.21
Haryana	4421.200	9	0	9	3868.356	87.50
Himachal Pradesh	5567.300	1	6	7	35.830	0.64
J&K	22223.600	0	13	13	269.800	1.21
Jharkhand	7971.400	2	72	74	399.477	5.01
Karnataka	19179.100	26	59	85	4012.862	20.92
Kerala	3886.300	11	13	24	935.204	24.06
Madhya Pradesh	30824.500	30	114	144	4862.888	15.78
Maharashtra	30771.300	100	249	349	7696.820	25.01
States of North East region*	26217.900	9	26	35	429.762	1.69
Orissa	15570.700	17	50	67	2640.770	16.96
Punjab	5036.200	6	2	8	4471.190	88.78
Rajasthan	34223.900	23	68	91	5051.890	14.76
Tamil Nadu	13005.800	3	80	83	2171.885	16.70
Uttarakhand	5348.300	0	12	12	251.710	4.71
Uttar Pradesh	24092.800	62	78	140	23400.763	97.13
UTs**	1096.000	2	0	2	31.140	2.84
West Bengal	8875.200	5	30	35	3412.493	38.45
INDIA TOTAL	**328724.000**	**429**	**1272**	**1701**	**88895.620**	**27.04**

* All eight states namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim.
** Commands only in Pudducherry and Dadra & Nagar Haveli.



Major and Medium Irrigation Commands in India



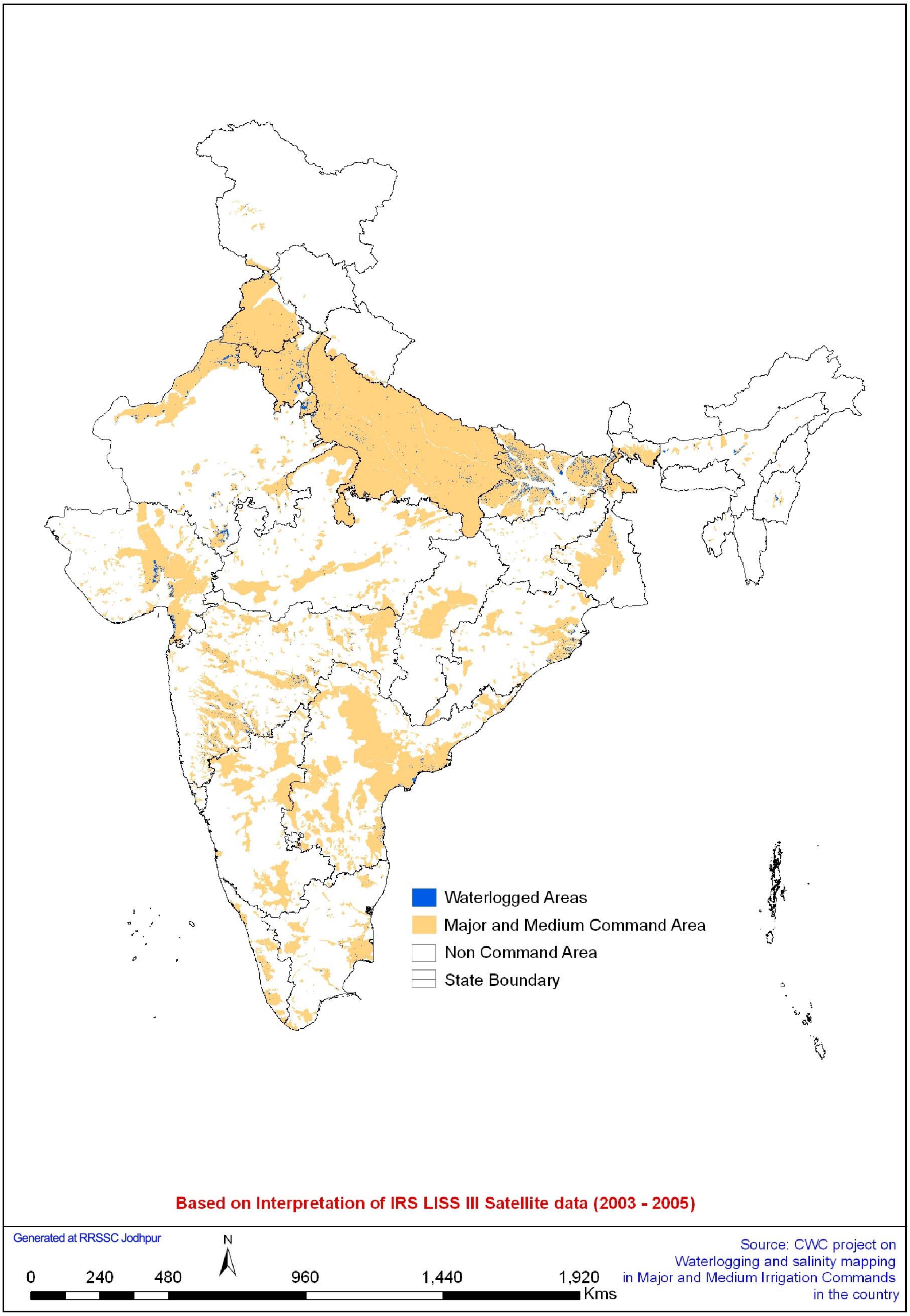
7.2 Waterlogged Areas

Table 8 shows the waterlogged area within major and medium irrigation commands in different states. Perennial and seasonal waterlogged areas have been mapped in this study. Total waterlogged areas or in other terms, the land not available for cultivation due to waterlogging within major and medium irrigation commands in the country is 1719.279 Th ha which is 1.93% of the command area. Perennial waterlogging covers 173.145 Th ha where as seasonal waterlogging covers 1546.134 Th ha. Total waterlogged area within major and medium irrigation commands is 0.52 % of the geographical area of the country.

Table 8: State wise waterlogged area within major and medium irrigation commands in the country

State	Geographical area (Th ha)	Command area (Th ha)	Waterlogged area (Th ha)			% command area
			Perennial	Seasonal	Total	
Andhra Pradesh	27504.500	11631.410	25.812	2.455	28.267	0.24
Bihar	9416.300	5939.255	61.666	566.222	627.888	10.57
Chhattisgarh	13519.100	2009.823	0.000	0.000	0.000	0.00
Goa	370.200	38.120	0.000	0.000	0.000	0.00
Gujarat	19602.400	5334.172	49.660	215.600	265.260	4.97
Haryana	4421.200	3868.356	3.287	13.172	16.459	0.43
Himachal Pradesh	5567.300	35.830	0.006	0.255	0.261	0.73
J&K	22223.600	269.800	0.380	3.590	3.970	1.47
Jharkhand	7971.400	399.477	0.000	0.000	0.000	0.00
Karnataka	19179.100	4012.862	0.000	0.000	0.000	0.00
Kerala	3886.300	935.204	2.436	9.894	12.330	1.32
Madhya Pradesh	30824.500	4862.888	0.543	0.000	0.543	0.01
Maharashtra	30771.300	7696.820	11.306	415.102	426.408	5.54
States of North East region	26217.900	429.762	0.093	2.564	2.657	0.62
Orissa	15570.700	2640.770	1.270	84.720	85.990	3.26
Punjab	5036.200	4471.190	1.623	33.347	34.970	0.78
Rajasthan	34223.900	5051.890	0.715	7.694	8.409	0.17
Tamil Nadu	13005.800	2171.885	1.290	31.228	32.518	1.50
Uttarakhand	5348.300	251.710	0.076	0.149	0.225	0.09
Uttar Pradesh	24092.800	23400.763	11.295	115.386	126.681	0.54
UTs	1096.000	31.140	0.012	0.034	0.046	0.15
West Bengal	8875.200	3412.493	1.675	44.722	46.397	1.36
INDIA TOTAL	**328724.000**	**88895.620**	**173.145**	**1546.134**	**1719.279**	**1.93**

Waterlogged Area within Major and Medium Irrigation Commands in India



7.3 Salt Affected Areas

Table 9 shows the number of soil samples collected from major and medium irrigation commands of each state. The soil samples were tested for EC, pH and ESP. Table 10 shows the salt affected areas in different states in the country within major and medium irrigation commands. Total salt affected area in the country as per the analysis is 1034.541 Th ha which is 1.16 % of the command area. It covers 0.31% of the geographical area of the country.

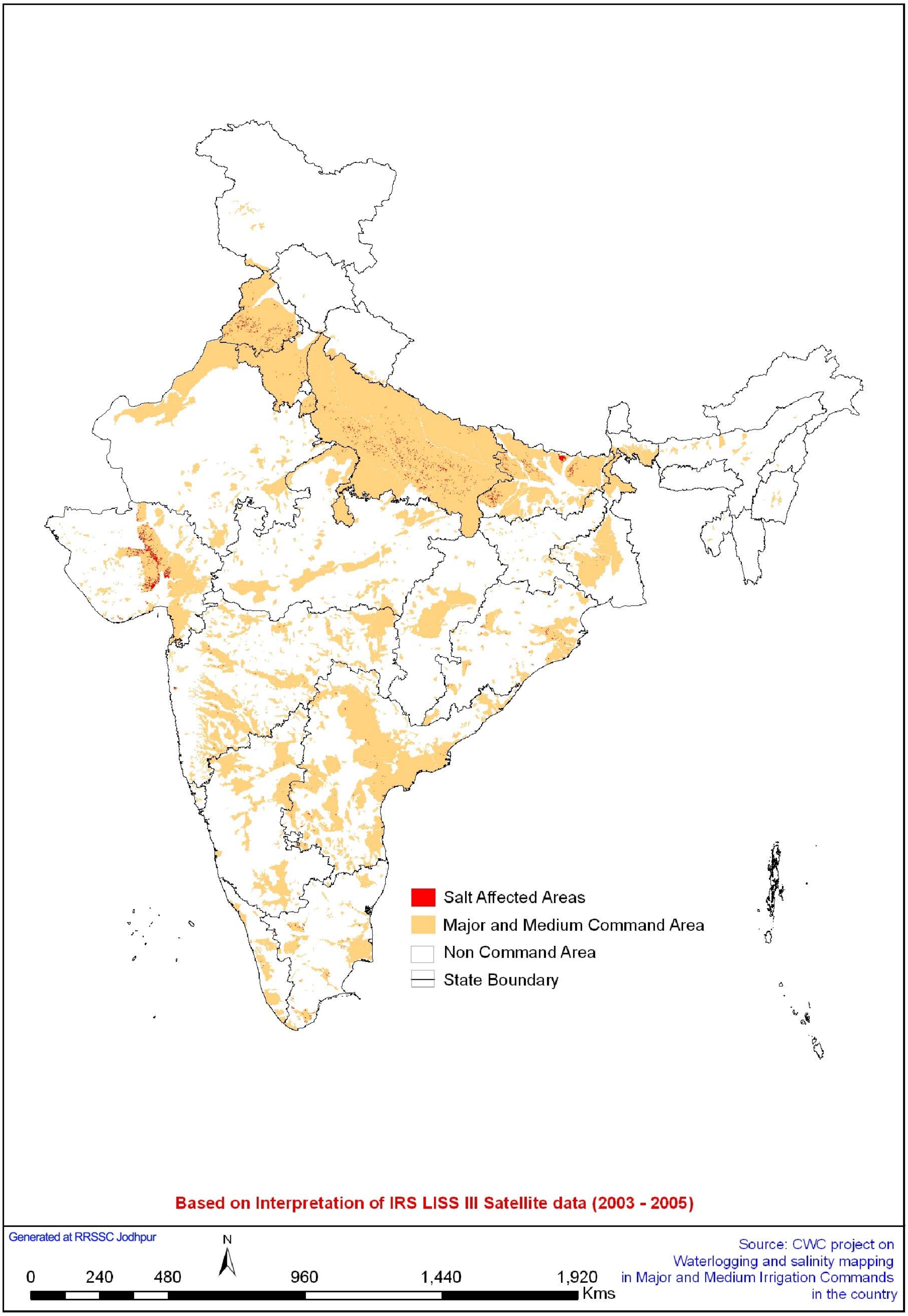
Table 9: State wise number of soil samples collected within major and medium irrigation commands

State	Number of soil samples	State	Number of soil samples
Andhra Pradesh	1397	Madhya Pradesh	840
Bihar	1252	Maharashtra	1308
Chhattisgarh	404	States of North East region	0
Goa	21	Orissa	909
Gujarat	1320	Punjab	965
Haryana	1149	Rajasthan	1748
Himachal Pradesh	28	Tamil Nadu	424
J&K	32	Uttarakhand	64
Jharkhand	223	Uttar Pradesh	1462
Karnataka	2081	West Bengal	800
Kerala	131	**TOTAL**	**16558**

Table 10: State wise salt affected areas within major and medium irrigation commands in the Country

State	Geographical area (Th ha)	Command area (Th ha)	Salt affected area (Th ha)	% of command area
Andhra Pradesh	27504.500	11631.410	12.933	0.11
Bihar	9416.300	5939.255	156.887	2.64
Chhattisgarh	13519.100	2009.823	0.000	0.00
Goa	370.200	38.120	0.000	0.00
Gujarat	19602.400	5334.172	307.320	5.76
Haryana	4421.200	3868.356	19.393	0.50
Himachal Pradesh	5567.300	35.830	0.000	0.00
J&K	22223.600	269.800	0.075	0.03
Jharkhand	7971.400	399.477	0.000	0.00
Karnataka	19179.100	4012.862	5.781	0.14
Kerala	3886.300	935.204	3.997	0.43
Madhya Pradesh	30824.500	4862.888	4.410	0.09
Maharashtra	30771.300	7696.820	34.541	0.45
States of North East region	26217.900	429.762	0.000	0.00
Orissa	15570.700	2640.770	34.780	1.32
Punjab	5036.200	4471.190	131.998	2.95
Rajasthan	34223.900	5051.890	2.053	0.04
Tamil Nadu	13005.800	2171.885	30.696	1.41
Uttarakhand	5348.300	251.710	0.013	0.01
Uttar Pradesh	24092.800	23400.763	283.146	1.21
UTs	1096.000	31.140	0.053	0.17
West Bengal	8875.200	3412.493	6.465	0.19
INDIA TOTAL	**328724.000**	**88895.620**	**1034.541**	**1.16**

Salt Affected Areas within Major and Medium Irrigation Commands in India



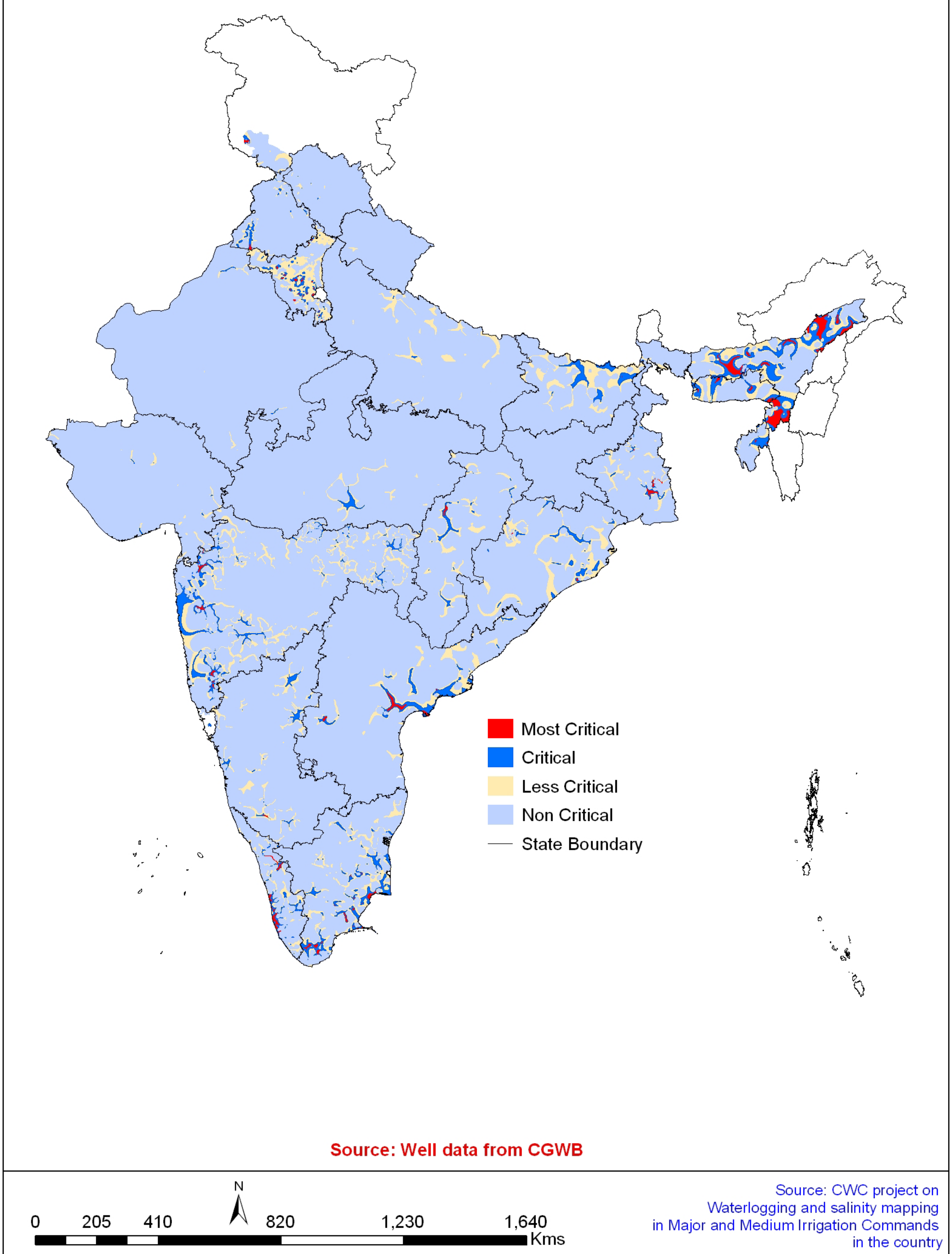
7.4 Ground Water Criticality Map

To know the depth of ground water towards identification of critical areas leading to waterlogging, water table data from observation wells of Central Ground Water Board (CGWB) and State Ground Water Department were used. Table 11 and 12 show the critical area of depth of ground water for pre and post monsoon, respectively.

Table 11 : Critical areas of depth of ground water for pre monsoon (within commands) during 2003 – 05

State	Most critical (<1m)		Critical (1–2m)		Less critical (2–3 m)		Non critical (>3 m)	
	(Th ha)	(% of command area)	(Th ha)	(% of command area)	(Th ha)	(% of command area)	(Th ha)	(% of command area)
Andhra Pradesh	63.320	0.54	485.390	4.17	830.890	7.14	10251.800	88.15
Bihar	0.083	0.00	309.035	5.20	1343.400	22.62	4286.737	72.18
Chhattisgarh	0.145	0.01	57.017	2.84	217.738	10.83	1734.923	86.32
Goa	0.428	1.12	3.922	10.29	0.986	2.59	32.784	86.00
Gujarat	1.460	0.03	520.700	9.76	2080.010	38.99	2732.002	51.22
Haryana	20.430	0.53	205.900	5.32	1925.740	49.78	1716.286	44.37
Himachal Pradesh	0.000	0.00	0.386	1.08	0.620	1.73	34.824	97.19
J&K	0.000	0.00	1.155	0.43	21.049	7.80	247.596	91.77
Jharkhand	0.000	0.00	0.000	0.00	0.000	0.00	399.477	100.00
Karnataka	1.471	0.04	111.166	2.77	257.271	6.41	3642.954	90.78
Kerala	5.159	0.55	38.093	4.07	73.121	7.82	818.831	87.56
Madhya Pradesh	0.000	0.00	0.875	0.02	36.211	0.74	4825.802	99.24
Maharashtra	4.690	0.06	167.810	2.18	758.690	9.86	6765.630	87.90
States of North East region	0.398	0.09	58.360	13.58	158.126	36.79	212.878	49.54
Orissa	2.060	0.08	118.790	4.50	633.840	24.00	1886.080	71.42
Punjab	7.388	0.17	90.772	2.03	197.184	4.41	4175.847	93.39
Rajasthan	0.000	0.00	5.312	0.11	34.148	0.68	5012.430	99.21
Tamil Nadu	17.970	0.83	254.180	11.70	432.507	19.91	1467.228	67.56
Uttarakhand	0.000	0.00	0.000	0.00	0.000	0.00	251.706	100
Uttar Pradesh	0.000	0.00	5.847	0.02	608.136	2.60	22786.770	97.38
UTs	0.000	0.00	0.000	0.00	0.000	0.00	31.140	100.00
West Bengal	0.028	0.00	10.899	0.32	140.749	4.12	3260.817	95.56
INDIA TOTAL	**125.030**	**0.14**	**2445.609**	**2.75**	**9750.416**	**10.97**	**76574.565**	**86.14**

Pre Monsoon Ground Water Criticality Map in India



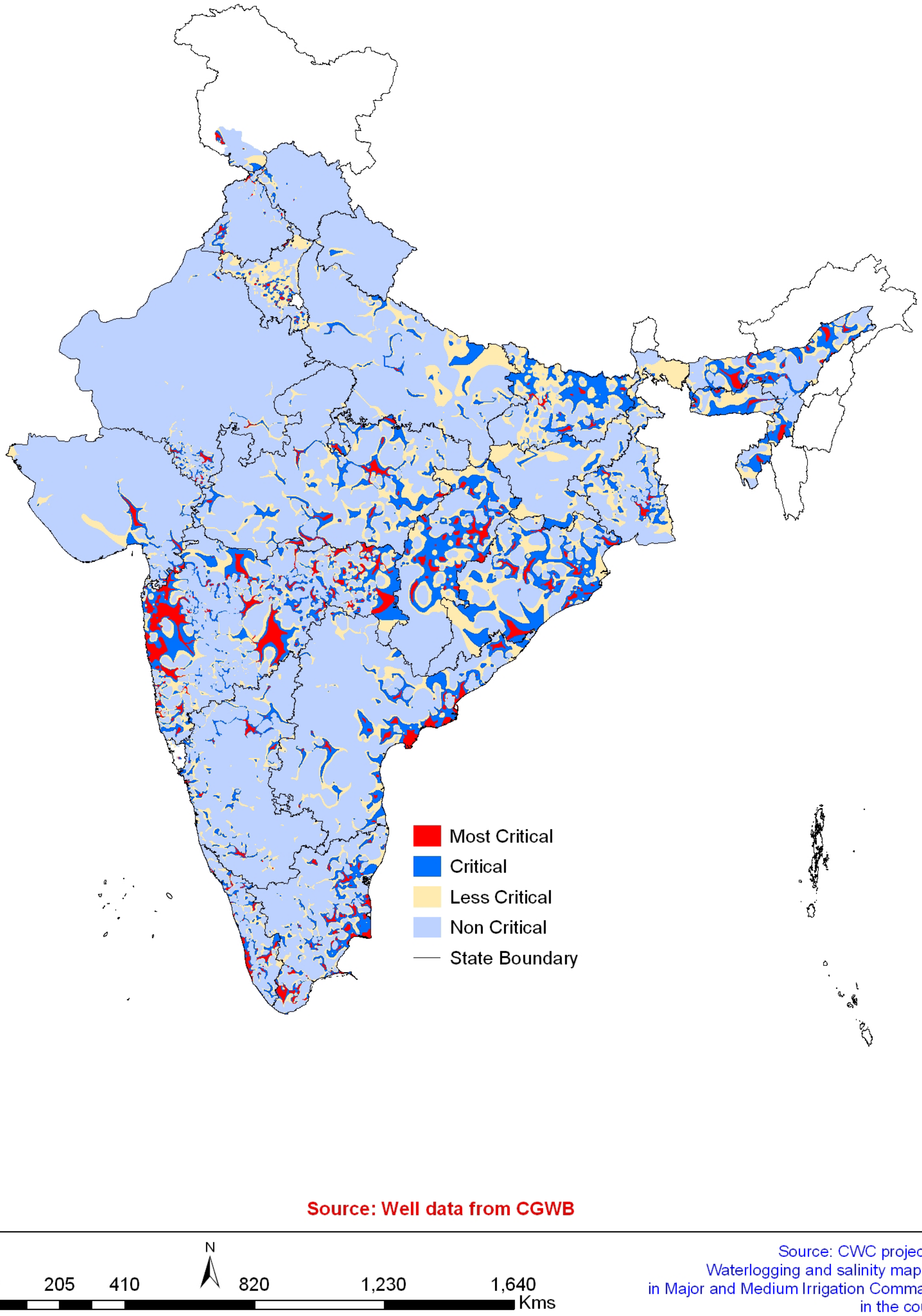
Source: Well data from CGWB

Source: CWC project on Waterlogging and salinity mapping in Major and Medium Irrigation Commands in the country

Table 12: Critical areas of depth of ground water for post monsoon (within commands) during 2003 - 05

State	Most critical (<1m)		Critical (1–2m)		Less critical (2–3 m)		Non critical (>3 m)	
	(Th ha)	(% of command area)	(Th ha)	(% of command area)	(Th ha)	(% of command area)	(Th ha)	(% of command area)
Andhra Pradesh	428.530	3.68	1478.440	12.71	1581.740	13.60	8142.700	70.01
Bihar	49.988	0.84	1996.870	33.62	2501.310	42.11	1391.090	23.43
Chhattisgarh	228.089	11.35	1062.680	52.87	403.793	20.09	315.262	15.69
Goa	0.425	1.11	3.592	9.42	4.379	11.48	29.724	77.99
Gujarat	154.790	2.90	845.680	15.85	1702.300	31.91	2631.400	49.34
Haryana	35.840	0.93	240.150	6.21	1826.660	47.22	1765.706	45.64
Himachal Pradesh	0.014	0.04	0.291	0.81	4.246	11.85	31.279	87.30
J&K	0.000	0.00	15.902	5.89	26.792	9.93	227.106	84.18
Jharkhand	0.000	0.00	27.504	6.89	110.723	27.72	261.250	65.39
Karnataka	43.368	1.08	273.481	6.82	458.139	11.42	3237.872	80.68
Kerala	16.179	1.73	116.347	12.44	174.338	18.64	628.340	67.19
Madhya Pradesh	15.031	0.31	154.101	3.17	588.038	12.09	4105.718	84.43
Maharashtra	415.940	5.40	1701.640	22.11	1693.040	22.00	3886.210	50.49
States of North East region	3.975	0.92	71.955	16.74	158.346	36.85	195.486	45.49
Orissa	137.460	5.21	1127.060	42.68	769.610	29.14	606.640	22.97
Punjab	28.545	0.64	155.860	3.49	210.635	4.71	4076.150	91.16
Rajasthan	13.484	0.27	50.817	1.01	119.083	2.36	4868.506	96.36
Tamil Nadu	132.540	6.10	536.168	24.69	380.915	17.54	1122.263	51.67
Uttarakhand	0.000	0.00	0.000	0.00	1.691	0.67	250.015	99.33
Uttar Pradesh	29.592	0.13	919.346	3.93	4092.568	17.49	18359.250	78.45
UTS	0.000	0.00	0.000	0.00	0.000	0.00	31.140	100.00
West Bengal	3.005	0.09	201.540	5.91	1377.850	40.38	1830.100	53.62
INDIA TOTAL	**1736.795**	**1.95**	**10979.424**	**12.35**	**18186.196**	**20.46**	**57993.207**	**65.24**

Post Monsoon Ground Water Criticality Map in India



Source: Well data from CGWB

Source: CWC project on Waterlogging and salinity mapping in Major and Medium Irrigation Commands in the country

8. CORRELATION BETWEEN WATERLOGGING AND GROUND WATER RISE

To find out the waterlogged areas due to rise in ground water level, waterlogged map prepared from satellite data and the critical area map in terms of rise in ground water level for pre and post monsoon seasons were overlaid in GIS environment. Command map was superimposed with the above map and command wise correlation was found out. Most of the states did not show any significant correlation between surface waterlogged area and rise in ground water table. The waterlogging is caused by external factors like lower topographic position, heavy texture soils, poor drainage, non judicious use of irrigation water, seepage from unlined canal etc. rather than rise in ground water table.

9. LIMITATIONS

The limitations of the study could be divided into three heads for all the states viz. problems related to precise command boundary & detailed information, field data collection and analysis of satellite data.

9.1 Command Boundary Related

The command boundaries maps received from concerned state departments were at different scales and accuracy. Some of the boundaries were adjusted after geo-referencing and considerable improvement has been made in logical extension of the boundaries based on crop extent on satellite data. The entire statistics is calculated based on the actual command boundary drawn in GIS environment. Some states where all boundaries could not be obtained, groups of commands were made.

9.2 Field Data Collection

Ideally the field data collection should commensurate with the image acquisition date, but there is time gap between satellite data acquisition, field survey and soil sample collection. Salinity manifestation at the soil surface is a dynamic process and with rainfall it leaches down the profile and will not be seen in the field although it may be apparent on the image.

9.3 Analysis of Satellite Data

Mapping of salt affected areas is generally hindered by the white signature on the image depicting various features like sand, eroded areas, scrub land, stony waste and areas of shunted growth of crop and vegetation. The remote sensing data is generally being supplemented by field verifications, collateral data and soil analysis. The satellite data can only pick up extreme salinity when it appears on the surface but the dissolved salts in the profile are not manifested on the surface.

10. CONCLUSIONS

Timely and accurate detection of waterlogged and saline / alkaline (sodic) soils and their spatial distribution along with severity and seasonal dynamics are vital in determining the sustainability of any irrigated production system. Soil salinity/alkalinity significantly limits crop production and consequently has negative effects on it. Prevention and reclamation of salt affected soils require an integrated management approach, including consideration of socioeconomic aspects, monitoring and maintenance of irrigation scheme and reuse and /or safe disposal of drainage water. Implementation of efficient irrigation and drainage systems and good farming practices including proper crop selection and rotation can prevent and, in some cases, reverse salinisation/alkalinisation. If appropriate management practices are not applied in time, it may result in the land out of production altogether.

The analysis of waterlogging and soil salinity based on remote sensing techniques for the year 2003-2005 for all the states indicates that waterlogged area mapped in present analysis falls under two categories viz., perennial waterlogged and seasonal waterlogged areas. Total waterlogged area in the country occupies 1719.279 Th ha which is 1.93% of the major and medium irrigation command areas (88895.620 Th ha) studied.

Total salt affected area occupies 1034.541 Th ha which is 1.16% of major and medium command areas studied. Total 16558 soil samples were collected and analysed in the country to identify salinity/alkalinity along with severity classes.

From ground water table rise point of view, 1.95% of the area under major and medium irrigation commands occupies most critical category in post monsoon season which reduces to 0.14% in pre monsoon season. The critical category (1-2m) which occupies 2.75% of command area during pre monsoon increased to 12.35% in post monsoon. There was no significant correlation between surface waterlogged areas and ground water rise in most of the places.