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Mapping of Salt Affected and Waterlogged Areas using Geospatial Technique

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Abstract—Integration of remote sensing and geographical information system (GIS) technique for the delineation of salt affected and waterlogged areas has become an innovation in the field of ground water research. The main objective of the present investigation is to identify and map the surface extent of salt affected and waterlogged areas during pre-monsoon and post-monsoon season using multi-temporal satellite images and its relationship with soil, rainfall, seasonal groundwater fluctuation and canal command areas. For this purpose, Satellite images from IRS P6, LISS-III sensor, on a scale of 1:50,000 have been used for delineation of thematic layers such as salt affected and waterlogged areas. The area covered under post monsoon waterlogging (seasonal) comprised of as 114.79 sq km area which is 3.60% of the study area whereas post monsoon waterlogging (permanent) comprised of 89.37 sq km area, which is 2.80% of the study area. The map depicting salt affected soils in the area indicates calcareous fine loamy, coarse-loamy, fine loamy and very fine soil comprising 2799.43 sq km, 9.26 sq km 363.73 sq km and 2.80 sq km area respectively. The monthly TRMM 3B43 rainfall data for the period of 1998-2009 covering the month of June to September shows rainfall varies from less than 965 mm to 1165 mm in the entire state. Depth to groundwater level recorded at select locations by Central Ground Water Board (CGWB), Government of India, for the period 2004-2005 during pre and post monsoon period indicated that a large portion of the area is under groundwater induced waterlogging conditions where groundwater occurs at a depth of 0-3 m below ground surface. The soil and rainfall map clearly specifies that salinity are pre dominant in areas with shallow groundwater levels and high rainfall. Canal command areas comprised the highest waterlogging and salt affected areas in their vicinity as a result of seepage and over irrigation.

Keywords*-Remote sensing; waterlogging; salt affected; GIS; Canal*

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I. INTRODUCTION*(HEADING 1)*

In India, an estimated 2.46 million hactares of land is reported to have suffered from waterlogging [1], and the area containing salt-affected soils has been estimated to be 7.0 million hactares [2]. Waterlogging, closely associated with salinization and/alkalinization, continues to be a threat to sustained irrigated agriculture, affecting an estimated 6 million hactares of fertile land in India [3]. About 4.5 million hectares of land have already become barren [4] and more lands are being encroached upon by these problems every year, depending on the climate, topographic, geohydrologic and groundwater conditions. India is estimated to have about 58.2 million hectares of wetlands [5], majority of which are distributed within the Indo-Gangetic plain. Generally regarded as ‘‘a water-surplus area’’ [6] the entire region is characterized by palaeo levees, swamps, relict palaeo channels, meander belts, ox-bow lakes, and cut-off loops [7-9].

Spaceborne multispectral data, by virtue of providing synoptic views of fairly large area at regular intervals, have been found to be very effective in providing the necessary information on salt-affected soils and waterlogged area in a timely and cost-effective manner [10-12]. Visual interpretation of the IRS data was used to delineate salt affected and waterlogged soils [13-15]. Permanently and seasonally waterlogged area was successfully mapped with remote sensing data [16-18]. On a global scale, irrigation induced salinity and waterlogging severely affects about 30 million ha [19].Waterlogging and salinity are the potentially serious problems for the agricultural industry and can reduce the potential yield by as much as 30-80% for many crops [20, 21]. In India, the total area suffering from waterlogging is estimated to be about 33000 sq km [22, 23], in which the state of Bihar constitutes an area of nearly 9000 sq km. LANDSAT and IRS satellite images have been successfully used for the assessment of waterlogging in different irrigated command area in India [24-28]. Waterlogging in low lying area is created by seepage of water from irrigated uplands and from canal systems. Continued irrigation with excess water induces rising of the groundwater table [29]. Drainage congestion causing surface waterlogging and flooding in area suitable for Kharif crops (monsoon season) and Rabi crops (winter season) are a common problem during monsoon season in most of the downstream stretches of river basins in India [30].

Examination of the historical pattern of land cover/use change in an area provides the necessary context for framing modern ecological studies and designing conservation efforts [31]. The salinity problem in irrigated agriculture is frequently associated with groundwater table within one to two meters below the ground surface [32]. Area with saline soils associated with a high water table conditions promote unfavourable growth conditions for green vegetation [33]. Hachicha et al.[34] assessed the impact of irrigation on changes of the groundwater level and soil salinity in Northern Tunisia and evaluated the future salinization risk. Irrigation development brings about large scale changes in the local geohydrological regime which often result in mobilization of salts stored in the underlying substrata [35].

Pearce and Warford [36] stated that irrigation-induced salinity was reckoned as a pervasive threat to agricultural production and to the environment due to its adverse effects on the sustainable use of land and water resources. Srivastava et al.[37] established remote sensing and GIS techniques for regional investigations of groundwater zones in Indo-Gangetic plains and stated that high salinity correspond to depressions in the bedrock. High relief, steep slopes and high drainage density impart higher runoff causing less infiltration, while low relief, gentle slope and low drainage density result in low runoff and comparatively high infiltration [38].

II. STUDY AREA

The district lies between 25º 53’ to 26º 23' north latitudes and 84º 52’ to 85º 45' east longitudes with a total area of 3123 sq. km. It is surrounded by Sitamarhi and East Champaran in North and Vaishali and Saran in south whereas in east by Darbhanga and Samastipur and in west by Saran and Gopalganj district. The district is mainly drained by river Burhi Gandak, Baghmati, Baya which generally flow in south easterly direction. The three rivers and their tributaries are perennial but these rivers are very devastating in nature during rainy season causing flooding in the area. Construction of Gandak Canal has totally changed the scenario for irrigation in the district and has led to increase in agricultural production. The district receives an average rainfall of 1280 mm during monsoon period from June to September with 85% of rainfall concentrated during monsoon period. Waterlogging and flood therefore constitutes the main hazards in the northern Bihar plains resulting due to surplus water availability in the region. The severity of these hazards turns into a disaster due to existence of high population density with low socioeconomic status.

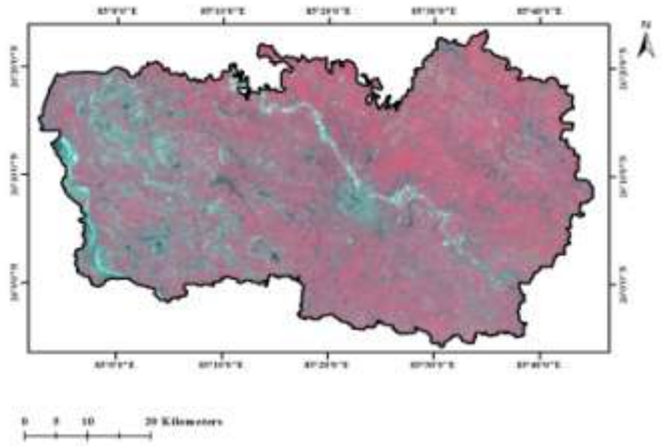

Figure.1 Satellite image of Muzaffarpur district of Bihar State (India) acquired in the month February, 2006 showing distribution of vegetated and settlement areas in shades of red and cyan colour respectively.

III. METHODOLOGY

The methodology adopted for the present study is shown in Fig. 2. The base map of Muzaffarpur district was prepared based on Survey of India topographic maps on a 1:50,000 scale. When utilizing spatial data from diverse sources, it is required that all dataset should accurately spatially overlap with each other. This requires georeferencing of all the maps to a common projection system. Satellite images from IRS P6, LISS-III sensor, on a scale of 1:50,000 (geo-coded, with UTM projection, spheroid and datum WGS 84, Zone 44 North) have been used for delineation of thematic layers such as salt affected and waterlogged areas. Georeferencing is a process of transforming an uncorrected raw image from an arbitrary coordinate system into a map projection coordinate system. Image pixels are positioned and rectified to align and fit into real world-map coordinates. Georeferening was done using image-to-map registration process by identifying common ground control points with rms error (RMSE) of less than a half pixel. The standard false colour composite (FCC) images created using selected bands (321) of satellite data were used for onscreen visual interpretation to delineate waterlogged area and salt affected areas. Field checks were carried out to acquire field characteristics of waterlogged and salt affected area and to relate them with corresponding image characteristics (figure 3.3 a, b). Finally visually interpreted waterlogged area were digitized using GIS. The canal network for the study area was mapped from Survey of India (SOI) toposheets and digitized in ArcGIS 9.3 platform and was updated with LISS III satellite data to correct for recent changes in the plain area. The rainfall map was prepared using the data obtained from the TRMM Multi-satellite Precipitation Analysis (TMPA) product. The monthly TRMM 3B43 data for the period of 1998-2009 covering the month of June to September was downloaded in ASCII format. The data was registered to real world coordinates in GIS to obtain variability of rainfall intensity with reference to geographic location. These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. This interpolation method combines the concepts of proximity to follow Thiessen polygons with gradual change of the trend surface. The map depicting salt affected soils in the area was prepared based on soil map (1:250,000 scale) published by NBSS and LUP (1997), Government of India. Depth to groundwater level recorded at select locations by Central Ground Water Board (CGWB), Government of India, for the period 2004-2005. Depth to groundwater level map of the study area were prepared using Inverse Distance Weighted interpolation (IDW) technique in GIS platform. All the thematic layers prepared viz., Depth to groundwater level, rainfall and canal command area etc. were related to mapped surface waterlogging and salt affected area through spatial integration in GIS to evaluate their interrelationship.

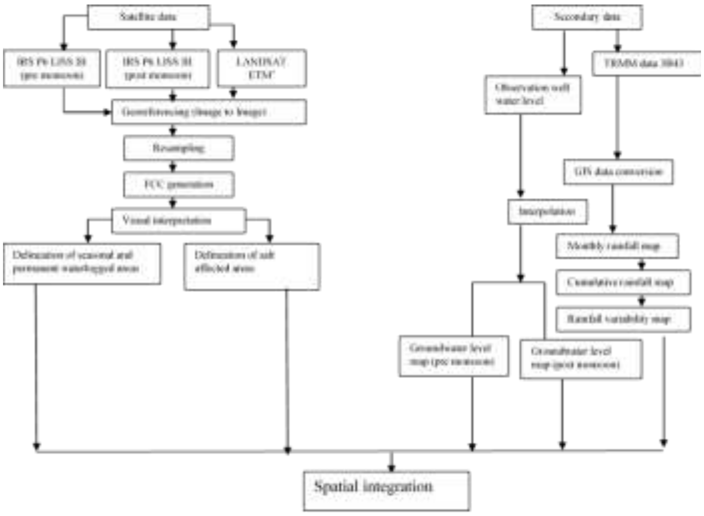

Figure. 2 Flow chart of the methodology

	
Figure. 3a Salt affected area	Figure. 3b Waterlogged area

IV. RESULTS

A. Waterlogging

In the present study visual interpretation of satellite images was done to delineate salt affected and waterlogged areas using a prior knowledge of the study area using multi-temporal satellite images. The term wasteland is a degraded land which can be brought under vegetative cover, with reasonable effort, and which is currently under-utilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes.To delineate salt affected and waterlogged areas we used bands 321 as RGB in case of IRS LISS III in multi-spectral mode (green, red and NIR) with 23.5 spatial resolution. The waterlogged areas appeared in tones of dark blue to black with a smooth texture on the FCC image. Additional pre- and post- monsoon images were used to permanently identify waterlogged area. To ascertain the inter seasonal waterlogging dynamics, the waterlogged area was categorized into seasonal waterlogged area and permanent waterlogged area. Permanent waterlogged land is that low lying land where the water is at/or near the surface and the water stands for most part of the year whereas seasonal waterlogged areas are those where the waterlogging condition prevails usually during the monsoon period. The three-season images (normally as FCC) were displayed and the waterlogged areas were delineated based on ground truth and legacy data. Resultant output was in vector format, which supports complex GIS analysis. Initially, the classification of Rabi season data was carried out using visual image interpretation technique on the basis of various image interpretation keys like: tone, texture, shape, size, pattern, texture, shadow, location and association. Resultant vector was overlaid onto Kharif and Zaid seasons satellite image to incorporate the features which were better delineated in Kharif as well as Zaid seasons image. The area covered under post monsoon waterlogging (seasonal) comprised of as 114.79 sq km area which is 3.60% of the study area whereas post monsoon waterlogging (permanent) comprised of 89.37 sq km area, which is 2.80% of the study area.

B. Rainfall

Precipitation is a key parameter of the global water cycle and affects all aspects of human life and ecosystem processes [39]. However, due to its intense variability both on temporal and spatial dimensions, the reliable global precipitation measurement is a historically challenging task. The difficulty is further aggravated by the fact that the distribution of ground-based instruments throughout the globe is highly uneven, with very few measurements deployed over oceans and sparsely populated regions, the spatio temporal characteristics of rainfall can hardly be reproduced by point observations using rain gauges. Remote sensing techniques, the global precipitation measurements have been now largely dependent on various precipitation sensors aboard the satellite platforms, which supply areal-time precipitation survey on a global scale. The TRMM, [40] is a joint mission with Japan launched on November 27, 1997, aboard a Japanese H-II rocket. The TRMM orbit is non-sun-synchronous and initially was at an altitude of 350 km, until the satellite was boosted to

402 km on August 22, 2001. The spatial coverage is between 38 North and 38 South owing to the 35 inclination of the TRMM satellite [41, 42]. The TRMM offers a unique instrumental design with a 220-km-wide common swath for the TRMM microwave imager (TMI) and the PR.

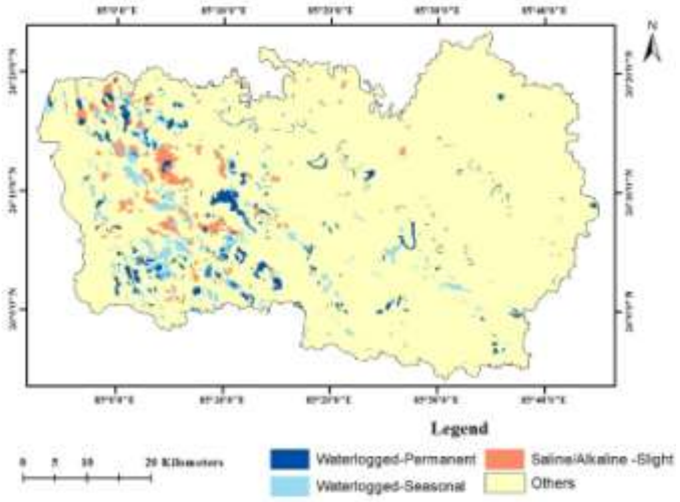

Figure.4 Salt affected and waterlogged area during pre and post monsoon

In the present study for the assessment of spatio-temporal variability of rainfall in the entire state, satellite based rainfall data using TRMM Multi-satellite Precipitation Analysis (TMPA) product was used. The TMPA provides a calibration-based sequential scheme for combining rainfall estimates from various satellites, at fine scales (0.25°x0.25° and 3-hourly) (Huffman et al., 2007). The monthly TRMM 3B43 accumulated rainfall (0.25°×0.25°) product which is the combination of TRMM Precipitation Radar (PR) and TRMM Microwave Imager (TMI) were acquired from TRMM Online Visualization and Analysis System (TOVAS), (http://disc2.nascom.nasa.gov/Giovanni/tovas/). Rainfall data were obtained for four monsoon months viz., June, July, August and September for the period from 1998 to 2009. The rainfall data were imported to Geographical Information System (GIS) and brought to real world coordinates. By using IDW spatial Interpolation technique, monthly and average rainfall maps showing the spatial variability in rainfall were prepared in GIS platform. The raster data pertaining to average rainfall during 1998-2009 period was further categorized into 3 classes which indicated rainfall variability from less than 965 mm to 1165 mm in the entire state (figure 5). The high runoff generated by monsoon rainfall, result in soil saturation and concomitant waterlogging and salt affected areas. The high incidence of waterlogging and salt affected areas delineated through satellite data and high average rainfall in the same area indicate a positive relationship between the two phenomenon. It also reflect that the rainfall induced runoff get concentrated in the localized depressions rather than carried downslope through river channels.

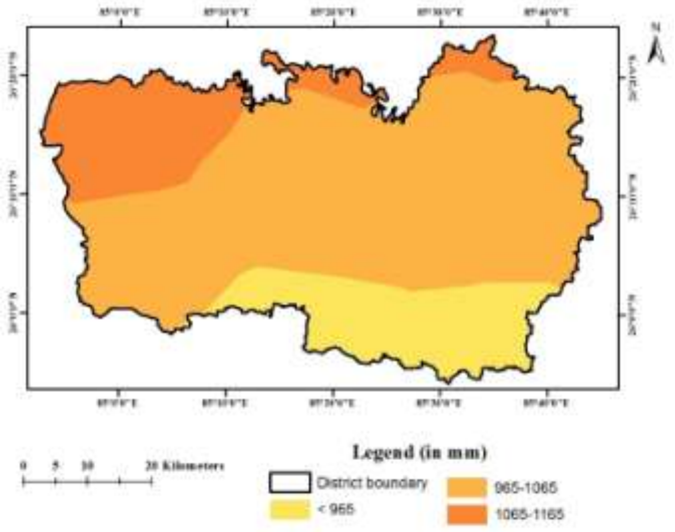

Figure.5 TRMM based rainfall map

C. Soil

In India, the problem of salinity and alkalinity increases every year as a result of secondary salinization. In India, about 8.6 million hectare of land area is affected by soil salinity. Almost 2.8 million hectares of salt-affected soil are present within the Indo-Gangetic alluvial plain occupying parts of Punjab, Haryana, Uttar Pradesh, Delhi, Bihar and Rajasthan [43]. The standard FCC was visually interpreted for salt affected soils and waterlogged areas with the help of image elements like tone, texture, shape, size, pattern and association, etc. The salt-affected soils were depicted in tones of bright white to dull white with medium to coarse texture on Standard FCC as per the presence of salts on soil surface [44-45].

Soil plays an important role in governing the subsurface flow of water due to variations in the porosity and permeability of soil layers. Land affected by salinity/alkalinity have excess soluble salts (saline) or high exchangeable sodium. Salinity is caused due to capillary movement of water, during extreme weather conditions leaving salt encrustation on the surface. Alkali soils have exchangeable sodium percentage (ESP) values of 15 or more, which is generally considered as the limit between normal and alkali soils. Saline soils cover an area of 76.19 sq km comprising (2.39 %) of the study area. The presence of excess salts on the surface of the soil and in the root zone characterizes all saline soils. Soil salinity and waterlogging are two main constraints present in irrigated agricultural lands. Soil map published by NBSS and LUP (1997) was used in delineating various soil and soil erosion classes in the area. These lands are mostly located in plain areas associated with the drainage congestion. In the present study calcareous fine loamy, coarse-loamy, fine loamy and very fine cracking soil comprises 2799.43 sq km, 9.26 sq km 363.73 sq km and 2.80 sq km respectively which indicates majority of the areas have low infiltration capacity due to presence of clay horizons near the surface where rain water stagnates on the soil and induces waterlogging conditions which generate highly reducing environment. The frequent occurrence of clay beds in subsurface act as impermeable layer preventing the infiltration and percolation of chemical constituents from shallow to deep aquifers. This is probably one of the major reasons for the continuous escalation of salinity in the shallow, intermediate and deep aquifers in the study area.

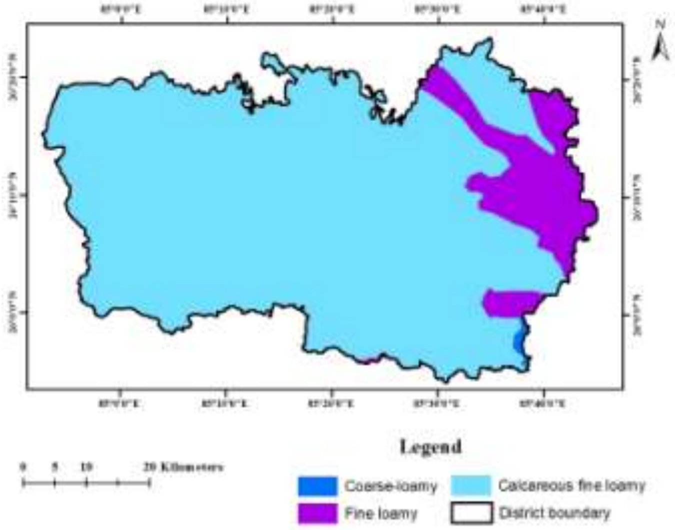

Figure. 6 showing distribution of various soil in the study area.

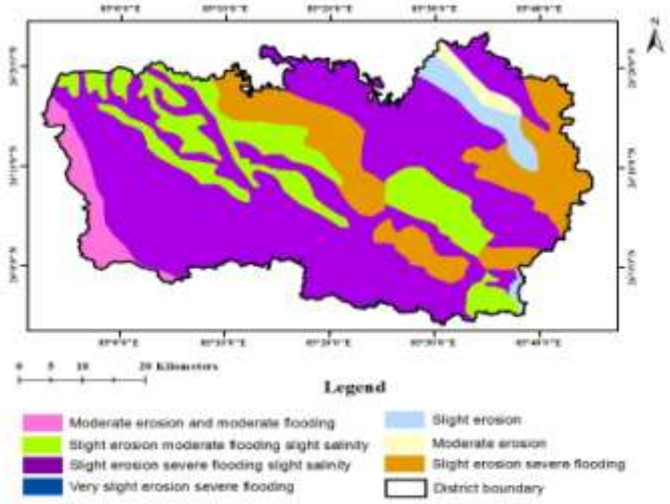

Figure. 7 Showing soil erodibility based on NBSS and LUP

D. Seasonal groundwater fluctuation

Ground water table is another influencing factor for waterlogged environment. The depth to water level data was examined for the assessment of seasonal fluctuation in groundwater level and to evaluate the relationship between salt affected and waterlogged areas. The pre (May) and post (January) monsoon groundwater level data recorded at select hydrological stations spread over the entire study area was acquired from Central Ground Water Board (CGWB) for the period of 2005 to 06. The observation wells water level data was converted into database files and were attached to their respective coordinates in GIS environment. Inverse Distance Weighted (IDW) interpolation technique was applied to analyze the spatial pattern and variability in groundwater levels. Interpolation permits representation of point data in a continuous spatial domain and therefore helps in understanding the spatial variability of the phenomenon [46]. The IDW method is selected in the present study as it is one of the standard spatial interpolation procedures in geographic information science [47]. Maps representing groundwater level during pre and post monsoon seasons were prepared based on observation wells data using IDW interpolation technique. Waterlogging due to rising groundwater level occurs when the root zone of crops generally extending from surface to a depth of 2 m is filled with water [48].

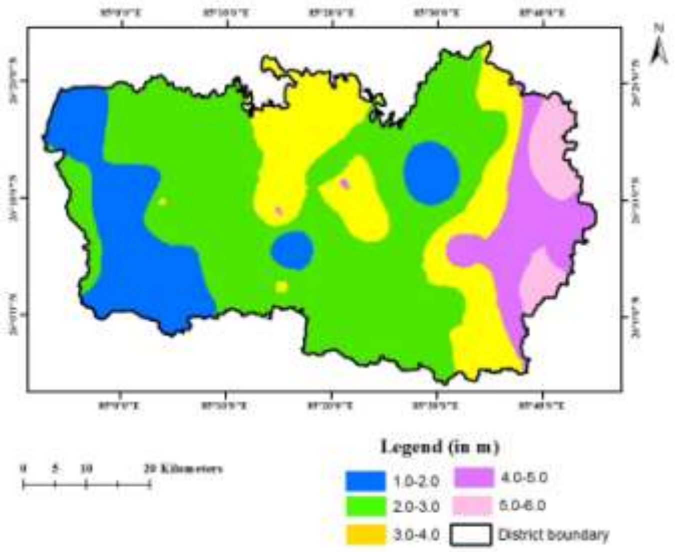

Figure. 8 Depth to water level (Pre-monsoon)

The groundwater level in the northern Bihar plains, can be classified as highly critical (<1 m), critical (1-2 m), moderately critical (2-3 m), less critical (3-4 m) and not critical (>4 m) with reference to subsurface waterlogging (Dutta et al., 2004) (figure 7.7). In the post-monsoon period average depth to groundwater level is <1 m below ground surface exists only at few places in the western parts, 1.0-1.5 m in majority areas in western parts, 1.5-2.0 m in the central parts, 2.0-2.5 m in the eastern parts whereas 2.5-3.5 m in the south eastern parts.

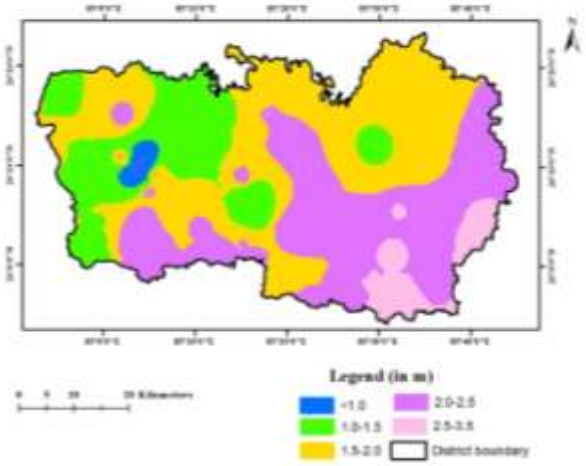

Figure.9 Depth to water level (Post-monsoon)

This clearly indicates that a large portion of the area is under groundwater induced waterlogging conditions during the month of August where groundwater occurs at a depth of 0-3 m below ground surface (figure 4.5a). On the contrary during pre-monsoon period average depth to water level is 1-2 m in the western parts, 2-3 m in the central parts, 3-4 m in the north eastern parts and 4-6 at a few places in the eastern parts. This indicates substantial lowering of the water level generally by 1-2.5 m at various places in the month of May (figure 4.5b). The surface runoff is low due to the flat topographic terrain, high precipitation zone, low infiltration due to permanent saturation of soil condition as the pore spaces in the soil is filled by the groundwater which results in waterlogged and salt affected areas.

E. Canal Command Area

The introduction of canal irrigation in India has resulted in almost 7×106 ha of cultivated land becoming affected by soil salinity and waterlogging [49]. Disturbance of the natural balance by introducing irrigation causes a rise in water table, where natural drainage sinks cannot cope with the increase in ground water recharge [50].

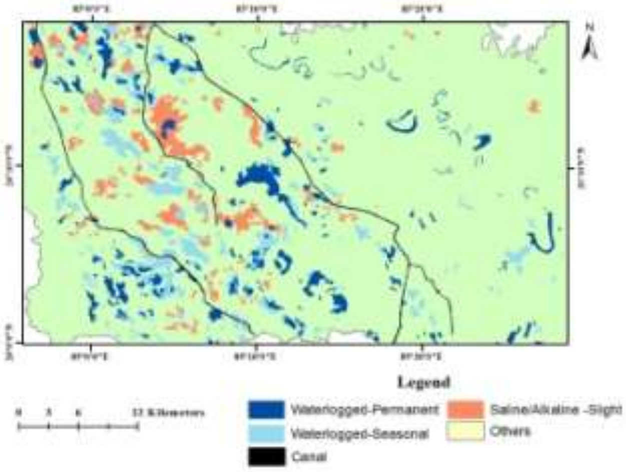

Fig. 10 showing canal command areas with salt affected and waterlogging.

Intensive irrigation without adequate drainage therefore contributes substantially to a rising ground water table [51]. The recharge of deep aquifers is closely linked to the incidence of waterlogging [52] and to the development of land salinisation. The major artificial causes of waterlogging in the command area are seepage from water conveyance systems [53], breakages of regulatory structure, silting and weed growth in canals [54]. Lack of surface and sub-surface drainage, poor maintenance of drainage system, over irrigation and growing water intensive crops are some of the major causes of poor realization of benefits from the irrigation systems. Generally, saline soils were formed due to the buildup of soluble salts in the soil. This is because of the low precipitation during the summer months at a time of high evaporation and crop growth, which might lead to increased water movement to the surface. The plants use the water and the salts are left behind in the soil, which eventually begin to accumulate. Thus, the canal network is also responsible for increase in the salinity and waterlogging in the study area.

V. CONCLUSIONS

In this study we attempted to identify waterlogged and salt affected areas using remote sensing and geographic information system techniques in the Muzaffarpur district of Bihar state (India). Therefore for this purpose various thematic layers such as, base map, rainfall map, soil map, depth to water level map and canal command areas were prepared from satellite images and secondary data using Arc GIS and ERDAS software and these maps were integrated to infer the relationship of salt and waterlogged areas with various factors for groundwater research. The high incidence of waterlogging and salt affected areas and high average rainfall in the same area indicate a positive relationship between the two phenomenon. The frequent occurrence of clay beds in subsurface act as impermeable layer preventing the infiltration and percolation of chemical constituents from shallow to deep aquifers. This is probably one of the major reasons for the continuous escalation of salinity in the shallow, intermediate and deep aquifers in the study area. Such studies based on Remote Sensing and Geographical Information system (GIS) can provide a better platform for developing insight into the intricate relations of various hydro-geological parameters influencing waterlogging and salt affected severity in the area. Remote sensing and GIS techniques have emerged as very effective and reliable tools in the assessment, monitoring and preservation of groundwater resources. The overall results establish that geospatial technology provide possibly influential tools for studying groundwater resources and planning a suitable exploration plan. The integrated map could be useful for various purposes such as sustainable development of groundwater as well as identification of priority areas for implementation of water conservation projects and programmes in the area.

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