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Agricultural Water Management

Assessment of surface and sub-surface waterlogged areas in irrigation command areas of Bihar state using remote sensing and GIS

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ABSTRACT

Satellite remote sensing coupled with Geographical Information Systems (GIS) offers an excellent alternative to conventional mapping techniques in monitoring and mapping of surface and sub-surface waterlogged areas. In the present study, pre-monsoon and post-monsoon surface waterlogged areas were delineated in all the 132 irrigation command areas of the Bihar State, India using Indian Remote Sensing (IRS-1D) Linear Imaging Self Scanning Sensor (LISS-III) data acquired during the period 2002–2003. Normalized Difference Water Index (NDWI) was used primarily to delineate surface waterlogged areas. Perennial waterlogged and seasonal waterlogged areas were identified for the study area by integrating the waterlogged areas derived for both the pre- and post-monsoon seasons under GIS environment. Results show that the total surface waterlogged area in Bihar is 628 $\times$ 10^3 ha, which is 10.57% of command area (5939 $\times$ 10^3 ha) and spread over 132 command areas. Perennial surface inundation covers 2.95% of the waterlogged area in all the command areas. Maximum waterlogged area is observed in Gandak command (212 $\times$ 10^3 ha) followed by Eastern Kosi irrigation scheme (116 $\times$ 10^3 ha) and Sone modernization scheme (82 $\times$ 10^3 ha), respectively. Further, waterlogged areas induced by rise in groundwater level were also assessed spatially under GIS environment using the ground water level data pertaining to pre- and post-monsoon seasons of the year 2002–2003 which were spread all over the study area. The analysis of pre- and post-monsoon groundwater levels indicates that the area under non-critical category during pre-monsoon period was reduced from 4287 $\times$ 10^3 ha (72.72% of command) to 1391 $\times$ 10^3 ha (23.42%) in the post-monsoon. Area under most critical category during post-monsoon period increased from 0.083 $\times$ 10^3 ha of command area in pre-monsoon period to 50 $\times$ 10^3 ha. The study demonstrates utility of integration of remote sensing and GIS techniques for assessment of waterlogged areas particularly in regions where waterlogging conditions occur both due to excessive irrigation and accumulation of rain and floodwaters.

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1. Introduction

The introduction of canal irrigation in India has resulted in almost 7×10^6 ha of cultivated land becoming affected by soil salinity and waterlogging (Joshi and Tyagi, 1994). In India, the National Commission for Irrigation (1972), National Commission on Agriculture (1976), and the Ministry of water resources (1991) have estimated the extent of waterlogged area as 4.84, 6.00 and 2.46×10^6 ha, respectively. Bhattacharya, 1992 reported that the total area suffering from waterlogging in India is estimated to be about 3.3×10^6 ha and the state of Bihar alone constitutes an area of nearly 0.9×10^6 ha. In Bihar, waterlogging problem is stated to be serious in the Gandak and Kosi command areas lying in the lower reaches of the Gandak basin (Second Bihar State Irrigation Commission, 1994). Particularly, large parts of the Indo-Gangetic Plain (IGP) in India and Pakistan and to some extent in Bangladesh were already affected by soil salinity and waterlogging (Joshi et al., 2002). Hoffman and Durnford (1999) reported how soil salinity and waterlogging problems have developed worldwide, and the speed with which they are advancing at present. Plants that are waterlogged are very susceptible to salinity, especially in their early growth stages (Barrett-Lennard, 2002). The development of extensive areas of secondary salinisation and waterlogging has been a feature of agricultural parts of southwest western Australia for over 100 years (Bennett and Macpherson, 1983; McFarlane and Williamson, 2002). Thus, waterlogging and salinity problems pose a serious threat to the world's productive agricultural land.

Disturbance of the natural balance by introducing irrigation causes a rising water table, where natural drainage sinks cannot cope with the increase in ground water recharge (Gowing and Wyseure, 1992). Recharge to deep aquifers is closely linked to the incidence of waterlogging (Moore and McFarlane, 1998) and to the development of land salinisation. The major artificial causes of waterlogging in the command areas are seepage from water conveyance systems (Brahmabhatt et al., 2000), breakages of regulatory structure, silting and weed growth in canals (Dutta et al., 2004). Lack of surface and sub-surface drainage, poor maintenance of drainage system, over irrigation and growing water intensive crops are some of major causes of poor realization of benefits from the irrigation systems (Choubey, 1997). Wildman (1982) indicated that due to the accumulation of organic matter, soil color is generally darker in poorly drained areas than well drained soils. Thus, a proper assessment of these waterlogged areas is a prerequisite for finding a solution to the problem.

In general, for mapping of waterlogged areas, conventional technique such as ground survey is used. For regional studies, these techniques are neither cost effective nor time effective. Satellite remote sensing coupled with Geographical Information Systems (GIS) offer an excellent alternative to conventional techniques in monitoring and assessing the extent of waterlogged areas in real time. The integration of remotely sensed data and the use of GIS can serve as a useful guide for the selection of training areas for classification, and to update a database for the assessment of spatially and temporally dynamic phenomena. In the past, several studies have demonstrated the usefulness of remote sensing and GIS techniques in detecting and monitoring waterlogged and saline/alkaline soils (Bouwer et al., 1990; Choubey, 1996; Lohani et al., 1999; Dwivedi et al., 2001; Dwivedi and Sreenivas, 2002; Chatterjee et al., 2003). Passive optical remote sensing is a valuable tool in providing synoptic information on a number of water parameters as surface water absorbs a major part of the electromagnetic radiation in the visible range and almost all of it in near infrared range (Claassen, 1990; Van Stokkom et al., 1993). In visual interpretation of satellite data, high soil moisture and surface waterlogged areas are identified as deep dark grey to light black in color (Brahmabhatt et al., 2000; Mandal and Sharma, 2001).

There is growing concern about the decline in soil fertility, changes in water table depth, deterioration in the quality of irrigation water and rising salinity in the Bihar state. During monsoon period, nearly 74% of the total geographical area of the state is affected by the flood hazards (NBSS and LUP, 1997). The waterlogging and drainage problem over vast agricultural lands of this eastern region of India is of a magnitude that requires immediate attention. Hence, in the present study, a systematic attempt has been made for rapid, reliable assessment and delineation of the surface and sub-surface waterlogged areas in all the irrigation command areas of Bihar state using remote sensing and GIS techniques for both monsoon (*kharif*) and non-monsoon (*rabi*) seasons.

2. Study area description

The study area, i.e. Bihar state is a part of Eastern Gangetic Plain which is now considered as the bread basket for much of South Asia (Aggarwal et al., 2004). Geographically, study area is situated in the eastern part of India and is a land-locked state with Nepal in the north, West Bengal in the east, Uttar Pradesh in the west and Jharkhand in the south. It is situated between 21°30′–27°31′N latitude and 82°19′–88°17′E longitude covering an area of about 94,800 km^2 (Fig. 1). The overall climate of the study area can be classified as tropical to sub-humid tropical. The average annual rainfall in the study area is around 1200 mm and 85% of the rainfall occurs during 4 months spanning from June to October. Often, rainfall exceeds 1800 mm in the northern and north-western fringes of the study area. The mean relative humidity varies from a minimum of 40% in April to a maximum of 85% in the month of July. The mean minimum temperature is generally of the order of 10.6 °C though some places record much lower temperature. The highest temperature is often registered in May, which is the hottest month in the state and the mean maximum temperature is around 41 °C.

The major cropping pattern in the study area is cereal based and rice, maize and wheat are the dominant crops. Besides this, some cash crops such as sugarcane and tobacco are also grown in the area. Under irrigated situations, rice–wheat or rice–rice constitutes the most important crop rotation practice. The major land use/cover statistics of the study area are presented in Table 1. The study area is endowed with rich water resources from monsoon and snow fed rivers and canals. In general, irrigation is provided through extensive canal networks which are fed through diversion of river flows. To supplement the uncertainties in surface water supplies

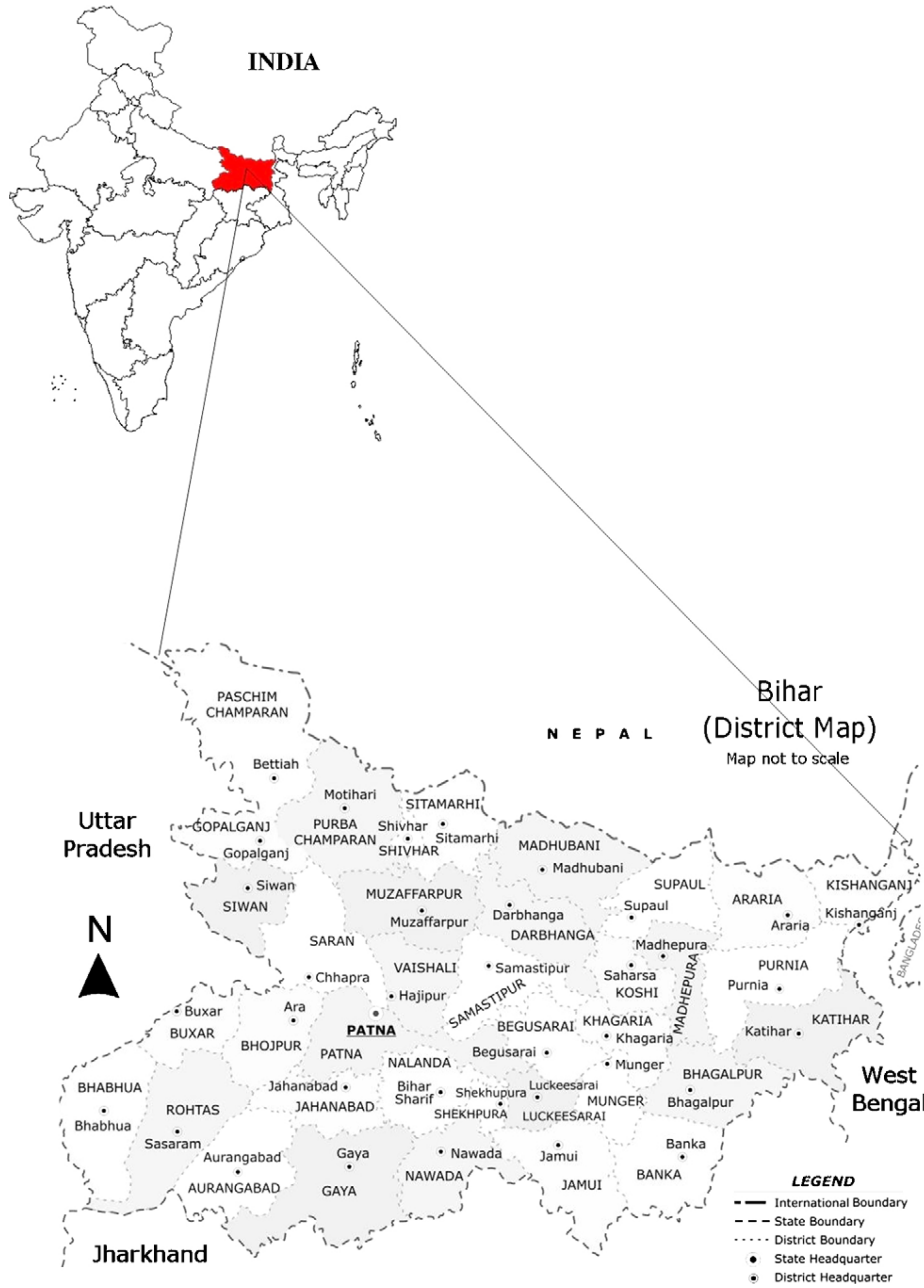

Fig. 1 – Location map of study area.

farmers use groundwater to meet irrigation requirements during the *rabi* season.

Hydro-geologically, the various litho-units of the study area can be grouped as unconsolidated/alluvial formation; semi-consolidated formations and consolidated/fissured formations. The main alluvial tract covers entire north Bihar and a sizeable area south of the Ganga river. These alluvial formations constitute prolific aquifers where the tube well can yield between 120 and 247 m^3/h. The potentiality of these aquifers decreases due south in the marginal tract. Auto flow conditions occur in the sub-Tarai region of Madhubani, Sitamarhi and west Champaran districts. In these areas, bore wells located near lineaments/fractures can yield between 10 and 50 m^3/h. The annual groundwater draft of Bihar state is around 10.77×10^9 m^3/year (http://cgwb.gov.in/gw_profiles/st_Bihar.htm). The over utilization of groundwater and the vast canal network has led to waterlogging and soil salinity in many parts of the study area. The major soil types in the study area are; (i) soils of piedmont plains, (ii) soils of active alluvial plains, (iii) soils of recent alluvial plains, (iv) soils of old alluvial plain, (v) soils of alluvial cone (NBSS and LUP, 1997). The alluvium plain was formed by the deposition of alluvium brought from the southern hills by the rivers viz., Sone, Punpun, Paimar, Phalgu and Chandan. More than 90% area of

Table 1 – Major land use/land cover statistics of the study area

S. no.	Category	Area (ha)	Area (%)
1	Forest land	676400	7.18
2	Land under misc. tree, groves	211709	2.25
3	(a) Current fallow	256783	2.73
	(b) Other fallow	687570	7.30
	(c) Cultivable waste	179319	0.84
4	Net area under cultivation	5570425	59.53
5	Barren land and permanent pasture	503381	5.35
6	Area under non agricultural use	1395340	14.82
Total		9480927	100

(Source: http://bihar.bih.nic.in/biharweb/WRD/land_use.html, State irrigation department)

study area is characterized by level to very gently sloping soils (0–3%) (NBSS and LUP, 1997). The detailed description of the study area about soils and geology of the study area is presented in NBSS and LUP, 1997.

3. Data used

3.1. *Remote sensing data*

Digital data from Indian Remote Sensing (IRS-1D) Linear Imaging Self Scanning Sensor (LISS-III) sensor for the year 2002–2003 are used for delineation of pre- and post-monsoon surface waterlogged areas in the study area (Table 2). Each satellite data scene has information of four spectral bands which correspond to green (G) (0.52–0.59 μ), red (R) (0.62–0.68 μ), near infrared (NIR) (0.77–0.86 μ) and middle infrared (MIR) (1.55–1.70 μ). The spatial resolution for the G, R and NIR bands is 23.5 m, while the spatial resolution of MIR band is 70.9 m. In the present study, false color composite (FCC) constituted by three bands NIR, R and G bands corresponding to both pre- and post-monsoon seasons were used for delineation of surface waterlogged areas in all the irrigation command areas of study area.

Table 2 – List of IRS-1D LISS-III satellite data used in the present study

S. no.	Path	Row	Satellite data acquisition date	
			Kharif season	*Rabi* season
1.	103	52	27.10.2002	20.04.2003
2.	103	53, 54, 55	21.11.2002	20.04.2003
3.	104	53, 54, 55	18.11.2002	17.04.2003
4.	105	53	15.11.2002	04.05.2003
5.	105	54	15.11.2002	25.01.2000
6.	106	53, 54, 55	07.12.2002	06.05.2003
7.	107	53	09.11.2002	16.01.2000
8.	107	54	09.11.2002	04.05.2002

3.2. *Groundwater data*

To assess the waterlogged areas induced by rise in the ground water level near to the surface in the study area, ground water table data pertaining to pre- and post-monsoon seasons of the year 2002–2003 were collected for all the observation wells monitored by State Ground Water Department (SGWD) and Central Ground Water Board (CGWB) which are spread all over the study area (Fig. 2).

3.3. *Collateral data*

Survey of India toposheets at 1:50000 scale was used for preparation of the base maps and for remote sensing data interpretation. Further, irrigation command area maps around 132 were collected from Water Resources Department, Government of Bihar (Second Bihar State Irrigation Commission, 1994) and these command areas were grouped under 74 groups for generation of waterlogging statistics. The list of command area names in the study area along with their area statistics is given in Table 3.

4. Methodology

4.1. *Image geo-referencing*

Pre-monsoon season satellite data were geo-referenced with respect to the control points taken from Survey of India map on 1:50000 scale. Distinct control points such as sharp road intersections, canal–road intersections were taken as ground control points, as they appear clearly both on the map and satellite image, respectively. Efforts were made to ensure that the ground control points are uniformly distributed on the image. A second order polynomial model was generated with root mean square error less than a half pixel. Subsequently, post-monsoon season satellite data were geo-referenced with respect to the pre-monsoon season data. Lambert Conformal Conic (LCC) projection with spheroid and datum as modified Everest was considered in the present study.

4.2. *Mapping of surface waterlogged areas*

The digital data of IRS-1D LISS-III sensor for the year 2002–2003 are processed and analyzed for delineation of the surface waterlogged area using the ERDAS Imagine 8.7 digital image processing software (ERDAS, 1997). FCC images constituted by NIR, R and G bands were analyzed visually for probable areas of waterlogging from image tone, texture and association for both the seasons. In general, the waterlogged areas exhibit sharp contrast with the adjacent areas on the satellite data and these spectral properties of waterlogged areas can be easily picked by visible and infrared domain of optical sensors. The standing water areas appear as dark blue to black depending upon the depth of water, while the wet areas appear as dark grey to light grey in color/tone on the imagery. Spatial and temporal variability in the ground water levels were studied by integrating the ground water level data with satellite data observation under GIS environment.

Table 3 – List of command area names in the study area

CNC	Command name	Area (10^3 ha)	CNC	Command name	Area (10^3 ha)
1	Adhwara barrage scheme	51.19	38	Kaurinar[d]	22.97
2	Ausane weir scheme	0.99	39	Khalkhala Irrigation scheme	2.26
3	Azan	6.68	40	Khandbihari weir scheme	1.65
4	Baghel weir	0.17	41	Kulthi weir and Sakari irrigation scheme	21.23
5	Baghmati irrigation project	170.83	42	Lokain weir	3.13
6	Baglati pyne weir	0.66	43	Lower Kiul weir	36.99
7	Bagmati barrage scheme	79.25	44	Lower Lilajan and Golari weir	5.72
8	Bajan weir	3.52	45	Lower Morhar irrigation scheme[e]	36.22
9	Balan weir scheme	3.09	46	Mahabodhi weir	1.24
10	Barnar reservoir	18.62	47	Mahadeopur pump canal	13.00
11	Belharna, Badua, Mohane link and Bagra	60.8	48	Mahmuda weir scheme and Gebua	1.76
12	Bersoi and Phulhar lift irrigation scheme	35.56	49	Mahmuda weir-I	4.86
13	Bhena weir	1.19	50	Mahugain weir and Kadhar weir	2.31
14	Bhutanda reservoir scheme	0.46	51	Manindra weir	0.93
15	Bilasi reservoir scheme	13.38	52	Mechi weir scheme	11.79
16	Bunduni reservoir	2.23	53	Mohane weir scheme	0.6
17	Chandan weir scheme[a]	88.41	54	Morhar barrage	68.74
18	Dakra pump canal I&II	13.34	55	Morwe weir, Baskund, Jalkund	3.9
19	Dakra reservoir scheme	3.98	56	Nagi reservoir	1.9
20	Dhanarji reservoir	5.82	57	Nakati reservoir	1.08
21	Durgawati weir[b]	990.53	58	Natane weir	0.9
22	Eastern Kosi irrigation scheme[c]	950.94	59	Nischalganj, Sansi, Paimer weir	31.98
23	Firangi bigha weir	1.78	60	Orni reservoir scheme	3.5
24	Gandak, Tribeni, Dhaka canals	1631.83	61	Panchane phase-I	9.54
25	Ganga pump canal and Bateshwaran pump scheme	290.08	62	Panchane weir phase-II	3.72
26	Ghora katora reservoir	8.69	63	Paura weir	5.57
27	Gogha weir scheme	10.73	64	Phulwaria reservoir	16.45
28	Gokhula weir	7.76	65	Punasi reservoir scheme	5.9
29	Gothwa Weir	11.03	66	Punpun barrage[f]	322
30	Gulsakari weir	1.17	67	Sindhwarni reservoir scheme and Kharagpur lake	1.21
31	Job, Purain and Kolmahadeo reservoir	5.12	68	Sirkhindi[g]	1.34
32	Kailash weir and Tarkol weir	1.18	69	Sirnawa weir	3.22
33	Kamla irrigation scheme	121.35	70	Tati weir	2.57
34	Kankai and Mahananda	389.73	71	Tilaiya dhadhar diversion scheme, Sohjana	67.4
35	Kao reservoir scheme	0.83	72	Trisula weir scheme	2.95
36	Kapasi weir	2.97	73	Udrasthan, Bharthuanandan weir	8.71
37	Kararua weir	1.92	74	Western Kosi Irrigation scheme	222.21

[a] Chandan weir scheme, Sukhnia weir scheme, Dakri weir, Tribeni weir, Chausa pump, Harna weir, Sonahula weir, Sundar weir and Kamarganj pump canal.
[b] Durgawati weir, Durgawati reservoir, Khoria reservoir, Zamania pump scheme (Larma), Surara weir, Sone canal modernization scheme, Sone high level canal, Kumber weir, Sone low level canal.
[c] Eastern Kosi irrigation scheme and Rajpur canals.
[d] Kaurinar, Nata and Chourdargha weir.
[e] Lower Morhar irrigation scheme, Lilajan weir, Chariari, Upper Jamuna, Kanak Bigha.
[f] Punpun barrage, Upper Morhar, Batane, Adri, Tekari, Mansare, Hilua, Madar, Dhawa, Sinane, Chotki, Chor Danda.
[g] Sirkhindi, Amrit, Kundgat reservoir scheme, CNC = Command area Name Code.

For delineation of water spread area, various digital image processing techniques such as thresholding, modeling techniques and classification techniques were used in the past (Nagarajan et al., 1993; Sharma et al., 1996; Manju et al., 2005). Goel et al., 2002 used multiband modeling criteria for identification of water spread areas, in order to avoid confusion between land and water boundary. Though, conventional maximum likelihood classification technique can be used for surface water mapping, but is not always appropriate as the identification of water pixels at the water/soil interface is difficult and depends on the interpretative ability of the analyst. Further, misclassification of shallow water as soil and saturated soil as water may induce classification errors in maximum likelihood classification technique. Often, the land/water demarcation is confusing in a single NIR band, and hence, two band data such as G and NIR bands can be used in such situations. Thus, ratioing of the two band data takes advantage of the difference in the

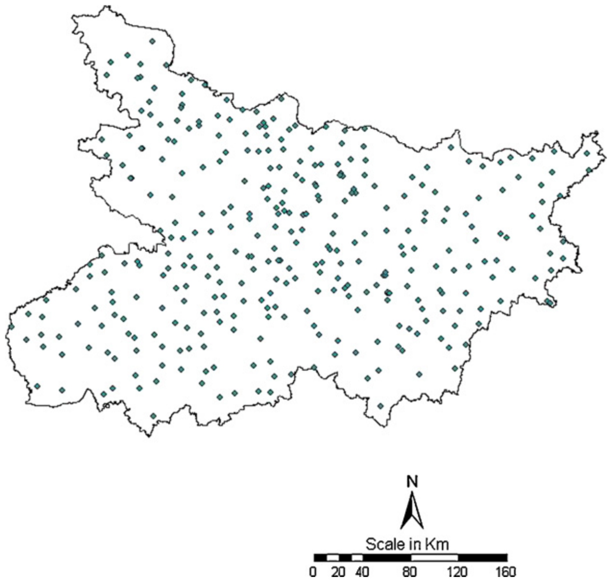

Fig. 2 – Location of observation wells in the study area.

reflectances of different wavelengths in enhancing a particular feature from the satellite data. Hence, in the present study, the Normalized Difference Water Index (NDWI) developed by McFeeters (1996) was used for delineation of waterlogged areas and to enhance their presence in remotely sensed digital imagery while simultaneously eliminating soil and terrestrial vegetation features. This index is calculated as follows:

$$\mathrm{NDWI} = \left(\frac{R_G - R_{NIR}}{R_G + R_{NIR}}\right) \quad (1)$$

where, R_G is spectral reflectance in G band and R_{NIR} is spectral reflectance in NIR band. The range of NDWI is from zero to one. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using G band; (2) minimize the low reflectance of NIR by water features and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features (McFeeters, 1996). Thus, positive and negative NDWI values indicate water features and vegetation features on the satellite data respectively due to higher reflectance of NIR band than G band (McFeeters, 1996). Subsequently, the resulting ratioed images were density sliced for delineation of waterlogged areas. Density slicing is a technique where the entire grey values of pixels occurring in the image are divided into a series of analyst specified intervals for segregating the image into waterlogged and saturated areas. For segregating the image, threshold NDWI value was fixed for each satellite image based on the visual interpretation of raw data. The threshold NDWI value is likely to change with different overpass dates, and needs to be fixed for each data independently. In the present study, it was found that the threshold limit of NDWI values varied 0.28–0.34. Chatterjee et al., 2005 found that the NDWI for water is either equal to or greater than 0.32. Further, on screen editing was done when water surface is covered with aquatic vegetation.

4.3. *Delineation of sub-surface waterlogged areas*

The collected ground water data pertaining to the year 2002–2003 was checked for anomaly/inconsistency (e.g. $\mathrm{depth}_{post} > \mathrm{depth}_{pre}$, abrupt changes in the depth, location, absence of location, etc.). Subsequently, sub-sets of the original data, which are consistent in all respects were used for generating point coverage in GIS and projected to desired projection. Point attributes such as pre-monsoon water table depth and post-monsoon water table depths were added to all the points. The water table depth values for both the pre- and post-monsoon seasons were extrapolated spatially using the point locations in Arc/info 7.4.1 GIS (using TOPOGRID function) to generate Digital Water Depth Grid (DWDG) at a grid/cell size of 100 m $\times$ 100 m. The TOPOGRID command is an interpolation method specifically designed for the creation of digital elevation models (DEMs) and is based upon the ANUDEM program developed by Hutchinson (1989). This method uses an iterative finite difference interpolation technique and is optimized to have the computational efficiency of local interpolation methods such as inverse distance weighted interpolation, without losing the surface continuity of global interpolation methods such as kriging and splines. The DWDG is seamless ground water table representation and was reclassified into four classes viz. most critical (GWT $<$ 1 m), critical (1 $<$ GWT $<$ 2), less critical (2 $<$ GWT $<$ 3) and not critical (GWT $>$ 3) (Dutta et al., 2004).

5. Results

The pre-monsoon and post-monsoon surface waterlogged areas in the study area for the year 2002–2003 are delineated for all the major and medium irrigation command areas of entire Bihar state and the integrated map is shown in Fig. 3. In the present study, four categories of waterlogging viz. surface inundation (seasonal), perennial waterlogging, saturated profile (seasonal), saturated profile (perennial) have been demarcated in the state. Surface inundation (seasonal) is the waterlogged area where land is not available for cultivation in *rabi* season, but by summer surface water is drained. Perennial waterlogged areas are those where land remains waterlogged throughout the year. Seasonal saturated profile is the land, which might be inundated in *kharif*, but water is drained during *rabi* leaving the soil moist. Perennial saturated profile is the land, which remains saturated all throughout the year but is used for agriculture with some constraints.

Spatially distributed surface waterlogged areas for both pre- and post-monsoon seasons are delineated using remote sensing data and overlaid with irrigation command area boundaries (Fig. 3). Further, command area wise surface waterlogged areas and saturated areas in the study area are estimated in GIS environment and are presented as Fig. 4a and b. From the Fig. 4a and b, it is observed that 20 command areas/command groups have waterlogged area less than 1% of command area, 16 have between 1 and 5%, 13 have between 5 and 10%, 14 have between 10 and 20% and 11 command areas/command groups have waterlogged area more than 20% of their respective command area. If we consider different stages of waterlogging, then 90.2% of the waterlogged area is under

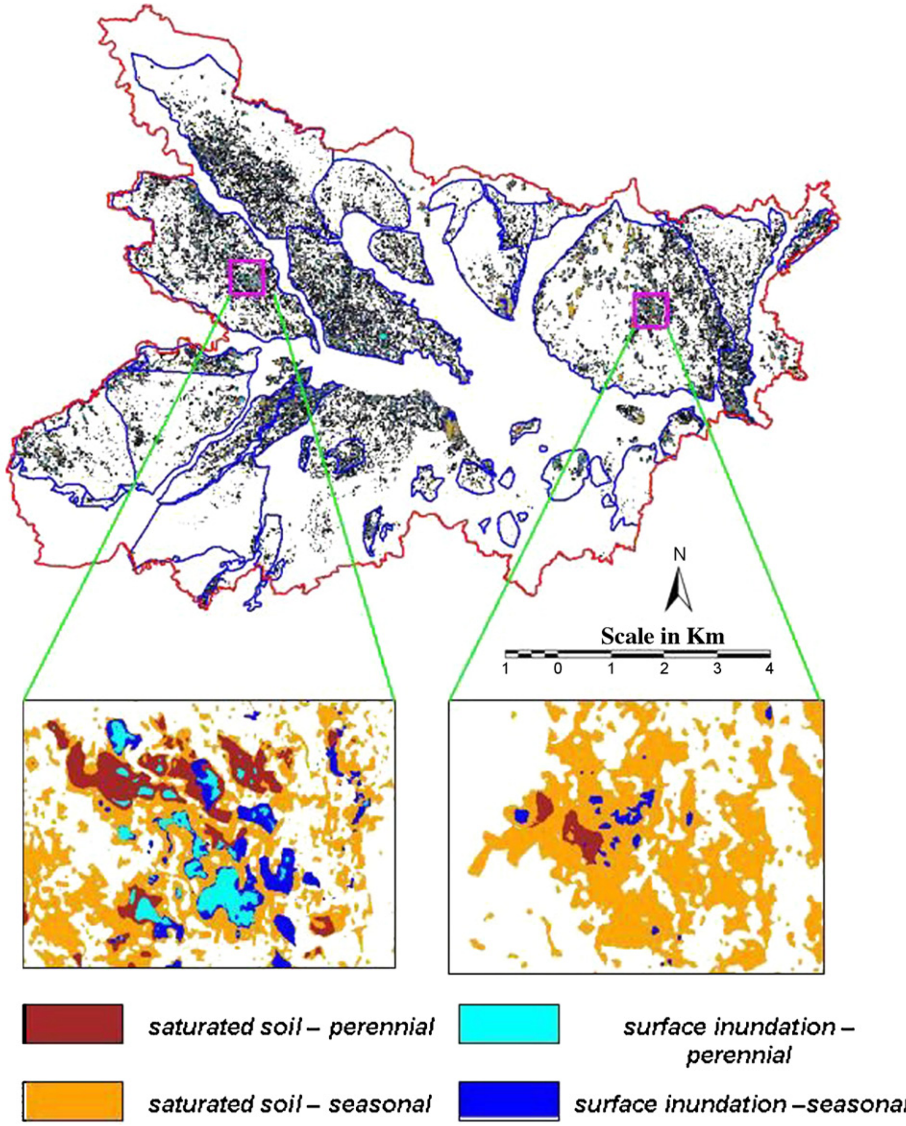

Fig. 3 – Integrated map overlaid with irrigation command area boundaries showing surface waterlogged areas for both pre- and post-monsoon seasons in the study area.

seasonal waterlogging, which includes surface inundation and saturated soil, mainly caused due to heavy floods in rainy season and poor drainage conditions. From the analysis, it was observed that the total waterlogged area in Bihar is 628×10^3 ha which is 10.57% of total command area (5939×10^3 ha) spread over all the irrigation command areas. Perennial surface inundation in the study area covers 2.95% of the waterlogged area in the command areas. Maximum waterlogged area is observed in Gandak command (212×10^3 ha) followed by Eastern Kosi irrigation scheme (116×10^3 ha) and Sone modernization scheme (82×10^3 ha), respectively.

Further, waterlogging areas due to rise in the groundwater level for both pre-monsoon and post-monsoon are also assessed and critical area map in terms of rise in ground water level are shown as Fig. 5a and b, respectively. Critical areas of depth of ground water for pre- (May 2003) and post- (November 2002) monsoon seasons for all the command areas are presented in Fig. 6a–d, respectively. From these figures, seasonal changes in the groundwater regime for all the command areas can be visualized. Analysis of pre- and post-monsoon groundwater regimes indicate that the area under non-critical category during pre-monsoon period was reduced from 4287×10^3 ha (72.72% of command) to 1391×10^3 ha (23.42%) in the post-monsoon. Area under most critical category during post-monsoon period increased from 0.083×10^3 ha of command area in pre-monsoon period to 50×10^3 ha.

It was observed that nearly 96% of the ground water critical zones match with the waterlogged area obtained through remote sensing in both the seasons. Some of the delineated surface waterlogged areas are verified during the field visits as well as using the ground truth information obtained from State Hydrology Cell and Water and Land Management Institute (WALMI), Patna, India. The estimated accuracy based on 645 random samples representing waterlogged categories

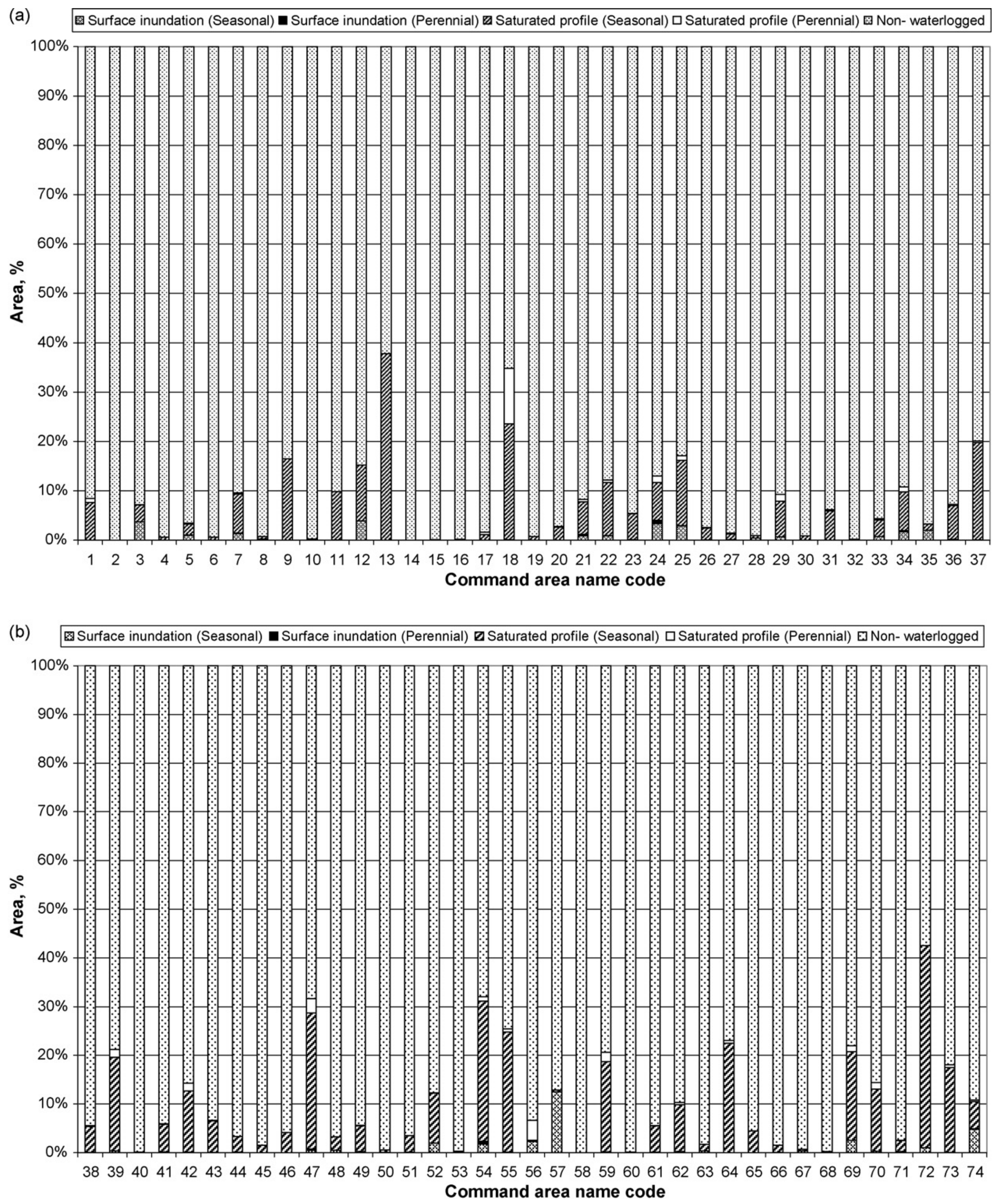

Fig. 4 – Surface waterlogged areas delineated using remote sensing for both pre- and post-monsoon seasons in the study area (a) for commands 1–37, (b) for commands 38–74.

shows an overall accuracy of 96%. The kappa coefficient ($\hat{k}$), originally developed to measure observer agreement for categorical data (Cohen, 1960), was estimated to be 0.92. A kappa coefficient value of $\hat{k} = 1$ indicates a perfect agreement between the categories while a value of $\hat{k} = 0$ indicates that the observed agreement equals the chance agreement (Cohen, 1960). A value greater than 0.75 indicates a very good to excellent agreement, while a value between 0.40 and 0.75 indicates a fair to good agreement. A value of less than or equal to 0.4 indicates a poor agreement between the classification categories (Manserud and Leemans, 1992). Based upon these criteria, the value of $\hat{k}$ in this case indicates a good to excellent agreement.

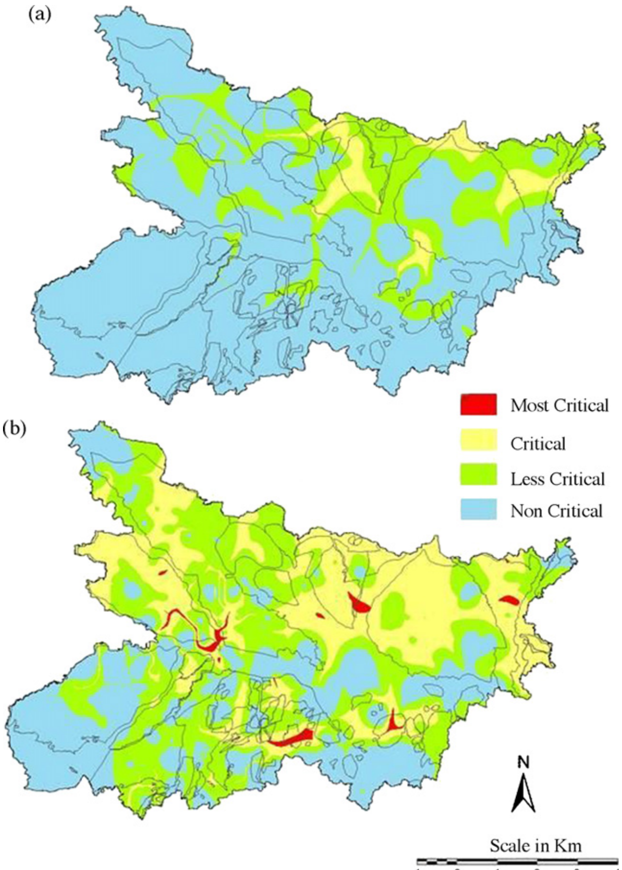

Fig. 5 – Critical areas for pre- and post-monsoon (in terms of depth of ground water) overlaid with irrigation command area boundaries: (a) pre-monsoon (May 2003), (b) post-monsoon (November 2002).

6. Discussion

The waterlogging problem is serious in the Gandak command lying in the lower reaches of the Gandak basin. The major causes of waterlogging in the Gandak command include superfluous irrigation supplies, seepage losses from canal, impeded sub-surface drainage and lack of proper land development (Chatterjee et al., 2005). Further, soils of recent alluvial plains which cover major portion of the Gandak command area are also responsible to waterlogging. These soils are very deep, imperfectly to poorly drained and fine loamy to fine in texture. However, some portion of the command area mainly located in west Champaran district (upper reaches) is covered by soils of piedment plains and is generally very deep, moderately well to well drained, fine loamy to coarse loamy in texture. In case of Kosi command area, dominant soils occurring in this landscape are very deep, imperfectly to moderately well drained, loamy to sandy in texture and are subjected to moderate to sever flooding. Old alluvial plains are mainly located in the Sone command area and these soils are very deep, imperfectly to poorly drained, fine loamy to fine in texture. Overall, waterlogging problems in most of irrigation command areas can also be attributed to the seepage losses from the extensive unlined or poorly canal network present in the study area. Further, the designed capacity of canals has been reduced considerably due to silt deposition in the canal. Although, soils are permeable in general but many places internal drainage is blocked causing rise in ground water table. Further, the accumulation of rain and floodwaters in depressions have aggravated the situation (Chatterjee et al., 2005). Some known as 'Chaurs', i.e. bottom lands created by seismic disturbance in the earthquake of 1934; others known as 'Mauns' were created due to shifting of river courses and consequent deposition of heavy sediment loads. During high floods these depressions having no drainage outlet to river form a sprawling sheet of water rendering *kharif* cultivation impossible. Formation of meanders, ox-bow lakes, abandoned channels and sand bars in the Ganges and its tributaries also cause waterlogging and saturation of soil.

In most of the command areas, river bank itself lies high, and the tributaries are flooded and pushed back at the high water level. Specifically, the Punpun valley, parallel to the stream Sone on the east, is thus annually flooded. The construction of railways across the drainage both in the north and south of Ganges, causes local but sometimes disastrous waterlogging and flooding. Specifically, seasonal surface inundation in the command areas located in the Baghmati river basin can be attributed to the differential drainage pattern on both sides of the Baghmati river, i.e. floodwater drained faster in the left bank than that of right bank. The flood prone right bank of the Baghmati river is a topographic low sandwiched between Kosi and Burhi Gandak and flows at higher elevation than the right bank area (Chandran et al., 2006). Further, the embankment constructed along the course (Baghmati and Burhi Gandak) is found to impede the recession of floodwater. Overall, the discharge from the tributaries is heavily silt-loaded during floods which when deposited in favourable environment, creates more problems of floods and the river channel oscillates between the two banks damaging the existing protective measures. It is reported that the Kosi river has progressively shifted westwards by a distance of 112 km in 225 years. However, after the construction of Kosi Barrage and the flood embankments, the flood problem has been minimized and westward swing has been checked. Thus, low topography, low carrying capacity and avulsive behavior of the river system are attributed herein to frequent and prolonged flooding in some of the irrigation commands.

Poor performance in the command areas can be attributed to the failure of public sector management, a significant factor being the inability to provide adequately for the cost of operation and maintenance. The problem is even more severe in public drainage schemes, as drainage does not generate more income, but simply aims to protect existing income, so farmers are reluctant to pay much to support such schemes (Gowing and Wyseure, 1992; Konukcu et al., 2006). Other major problems that play important role in waterlogging include (i) availability of main/public drains, (ii) high cost involved in connecting individual farm drainage systems to the public drain, (iii) resistance by neighbouring land owners to drainage effluent passing across their fields, (iv) environmental concerns, (v) salt loading of rivers and (vi) availability of drainage sinks in closed basins (Konukcu et al., 2006). Thus, the execution of irrigation projects with provision of adequate

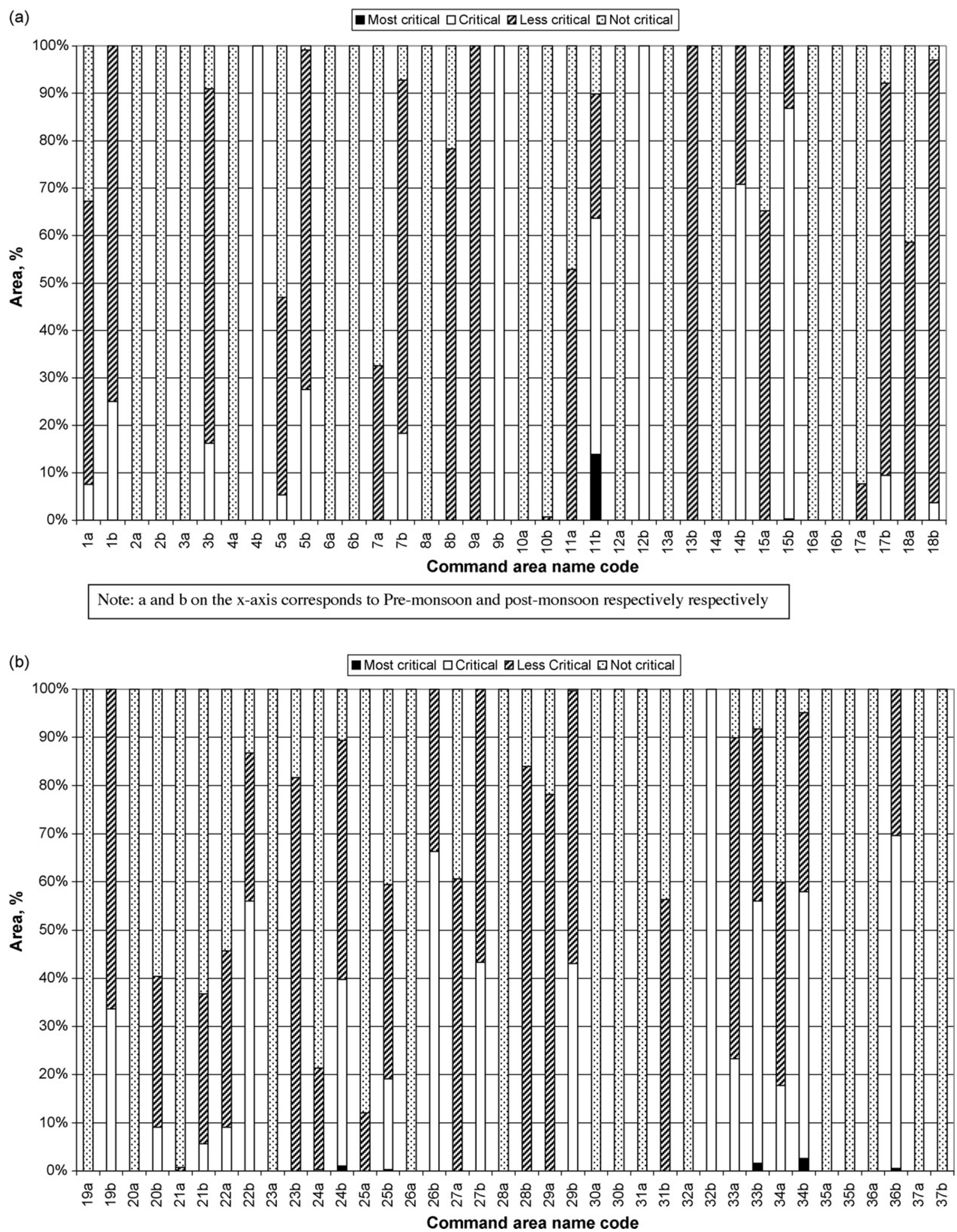

Fig. 6 – Status of groundwater levels in the study area during pre- and post-monsoon seasons (a) for commands 1–18, (b) for commands 19–37, (c) for commands 38–56, (d) for commands 57–74.

drainage system will certainly bring the equilibrium between the groundwater recharge and discharge resulting in the control of groundwater table in the command areas of Bihar state.

In recent years, there have been attempts to identify solutions, which will work within environmental constraints and will also be economically viable (Hanson, 1989; Gowing and Wyseure, 1992; Sharma and Tyagi, 2004). Practical

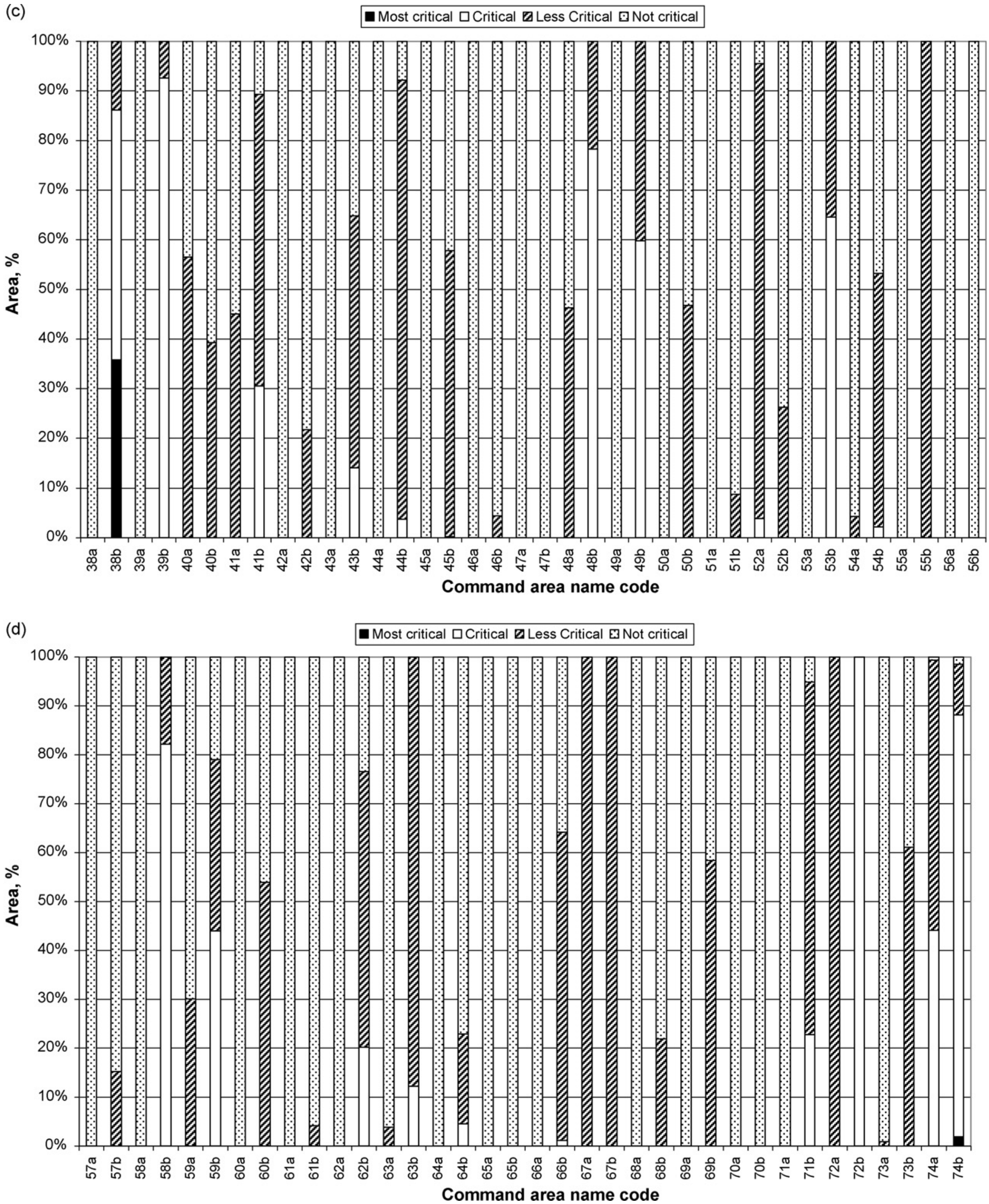

Fig. 6. (Continued).

significance of dry-drainage systems which means that part of the available land is set-aside as a sink for excess groundwater and for salt transported with the groundwater has been recognized for some time and it has also received some attention in field studies in Australia and Africa (Greenwood et al., 1992, 1994; WARDA, 1997; Konukcu et al., 2006). Though, management practices and technologies are available in the irrigation command areas where these problems are more common, their adoption is constrained due to lack of appropriate institutional arrangements. Another major problem in the assessment of waterlogging areas in the command areas is the discrepancy in the extent of waterlogging areas reported by different agencies. The differences are due to evaluation criteria, time of observation and methods used for delineation of waterlogging. These surveys do not allow a clear identification of the waterlogged areas at higher scale which usually serve as guiding tool to the planners/decision makers on the functioning of an irrigation system and on its agricultural productivity. Normally, the conventional technique of surface waterlogged area mapping uses ground survey data. This technique not only is time consuming and requires much more labour, but is not accurate as well. Satellite remote sensing coupled with geographical systems becomes a great promise in monitoring and mapping of surface waterlogged areas. Advantages of the spectral measurements made by sensors onboard satellite are synoptic coverage and repetivity which allows the comparison and assessment of changes in dynamic phenomena like surface waterlogging before, and after monsoons.

7. Conclusion

Reliable assessment of waterlogged areas forms a crucial element in the irrigation command area development program. In the present study space borne multispectral satellite data was successfully employed for assessment of spatially and temporally distributed waterlogged areas in order to evaluate the impact of canal irrigation. However, this analysis can be carried out at frequent intervals to study the dynamics of these phenomena and to evaluate the impact of irrigated agriculture. Further, such analysis facilitates the administrators and planners in planning and implementing corrective and preventive measures for optimal utilization of available land and water resources for sustainable development of irrigated lands. Hyperspectral data from the Earth Observation System (EOS) in the optical region of the spectrum and microwave data may further improve assessment of the hydrological condition of irrigated lands. The study demonstrates utility of integration of remote sensing and GIS techniques for assessment of waterlogged areas particularly in regions where waterlogging conditions occur both due to excessive irrigation and accumulation of rain and floodwaters.

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