

Spatio-temporal changes associated with natural and anthropogenic factors in wetlands of Great Rann of Kachchh, India

C. Sudhakar Reddy¹ · S. Vazeed Pasha¹ · C. S. Jha¹

Received: 13 December 2014 / Revised: 21 December 2015 / Accepted: 25 January 2016 / Published online: 1 March 2016
© Springer Science+Business Media Dordrecht 2016

Abstract Studies about wetlands have been identified as a key component of environmental change. The present study assesses the spatio-temporal changes in the wetlands of the Great Rann of Kachchh, in the Kachchh Biosphere Reserve, India, using remote sensing and GIS techniques. Satellite time-series data from Landsat (1977, 1990 and 1999) and IRS P6 (2006, 2008–2012) were used. The Normalised Difference Water Index (NDWI) was derived for each year and the layers were manually edited to obtain a high classification accuracy. The analysis found that the area has undergone considerable change from 1977 to 2011. The natural wetland area of 30.6 km² was converted to salt pans. An area of about 255 km² (41.6 %) of natural grassland was invaded by *Prosopis juliflora*, which raises further conservation concerns and emphasises the importance of having intervention plans to manage this ecosystem. The highest water spread of 1171 km² was observed in September 2011, followed by 2010, 2009 and 2008 in the same month. The present study is useful in planning the long-term management and conservation of the Great Rann of Kachchh wetland.

Keywords Spatial · Remote Sensing · GIS · Temporal Change · Natural · Anthropogenic · Wetlands · Kachchh

✉ C. Sudhakar Reddy
drsudhakarreddy@gmail.com

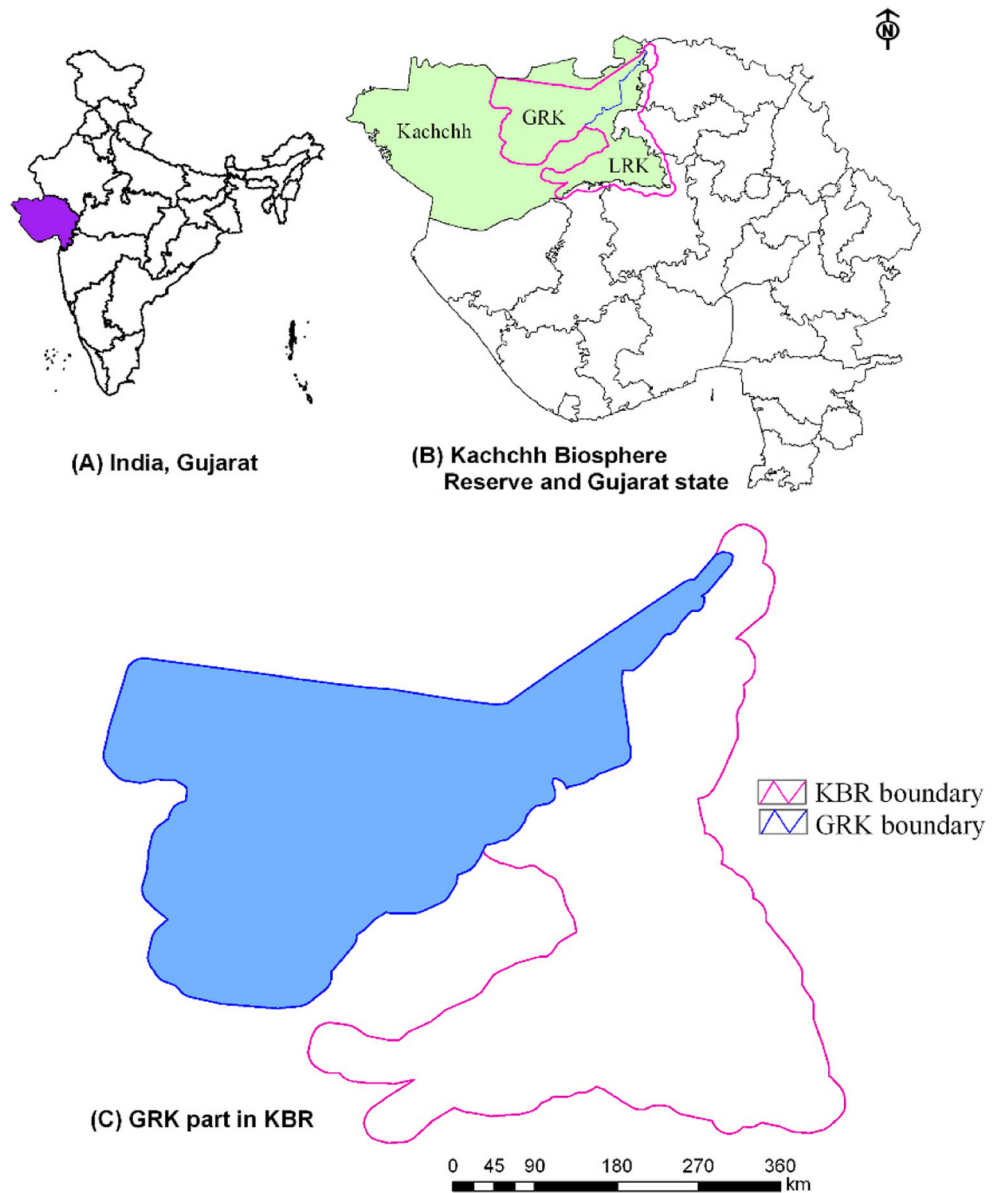
¹ Forestry & Ecology Group, National Remote Sensing Centre, ISRO, Balanagar, Hyderabad 500 037, India

Introduction

Throughout the world, wetlands are facing immense anthropogenic pressures. In fact, the major drivers implicated for the loss and degradation of wetlands include: expanding agriculture and aquaculture, pollution, biological invasion, desertification and more recently climate change (Chen 2002). Given these threats to wetlands and the concerns thereof, the assessment and monitoring of spatio-temporal changes in the wetlands have received increased research attention (Xie et al. 2010). Essentially, the drivers of change in the world's wetlands are driven by a combination of natural and anthropogenic factors, which can be scientifically studied by quantifying the spatio-temporal changes in the biotic and abiotic components of these prized ecosystems. Therefore, for change analysis studies, it becomes crucial to distinguish between the contributions from the drivers of change in terms of the biotic and abiotic components, which in turn will provide a basis for understanding the spatial and temporal dynamics of wetlands (Zhao and Lai 2007).

In retrospect, the conventional methods of data collection on natural resources are too costly and time intensive. However, in recent times, the potential applications of environmental remote sensing have revolutionized the way we monitor changes occurring in surface conditions of land-cover. Satellite-based remote sensing with a synoptic view collects large amount of spatial data with sufficient accuracy. Remote sensing data together with Geographic Information Systems (GIS) have been found to be suitable tools for the assessment and monitoring of the spatial-temporal dynamics of wetlands (Emadi et al. 2010; Ghobadi et al. 2012). Use of such tools to quantify the attributes of conservation value for these ecosystems could prove to be valuable in their sustainable management (Salari et al. 2014). Ozesmi and Baue (2002) provided a detailed review on the applications of remote

Fig. 1 Location map of Great Rann of Kachchh (GRK), Kachchh Biosphere Reserve (KBR), Gujarat, India



sensing for wetlands mapping and monitoring. For instance, using remote sensing tools, Xie et al. (2010) found that natural wetlands continue to decrease due to the expansion of cropland and aquaculture during 1987 to 2006 in the Tianjin part of China (Xie et al. 2010). In another study, urban expansion was believed to be the main reason for the loss of 60 % of wetlands in Dhaka metropolitan area in Bangladesh (Mahmud

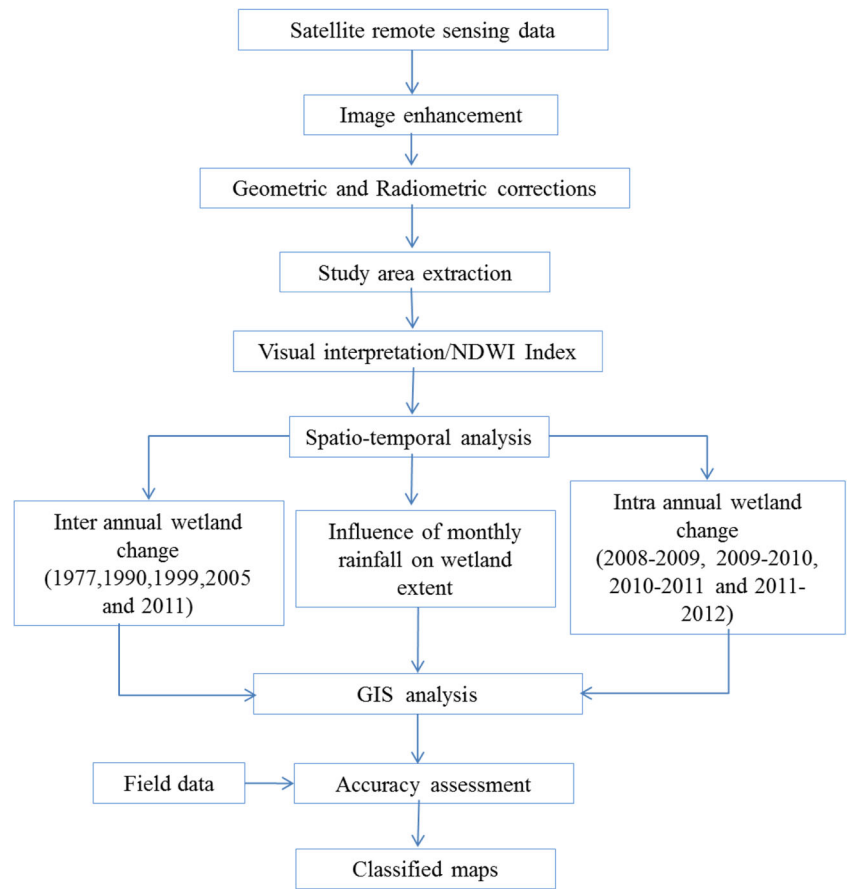
et al. 2011). Bayley et al. (2013) revealed that the conversion of native landscapes for croplands has resulted extensive loss of wetlands in Canada and was responsible for the increased runoff of nutrients affecting existing wetlands.

The Space Application Centre prepared a wetlands map of India at 1:50,000 scale (SAC 2011). However, there are only few studies on the temporal monitoring of wetlands using

Table 1 Annual rainfall (mm) in study area

Period	June	July	August	September	October	November	December	January	February	March	April	May	Total
2008–2009	63.2	38	84	113.2	0.1	1.1	14.6	0.1	0.1	0	0	0	314.4
2009–2010	42.4	324	125	6.4	0.9	0.1	0	0	0	0	0	0	497.9
2010–2011	52.7	344	283	153.3	0	54.2	0	0.3	0	0	0	0	887.8
2011–2012	1.2	77.3	313	244	2.3	0.2	0	0	4.5	0	0	0	642

Fig. 2 Flow chart of the overall methodology



satellite remote sensing in India. These include studies on wetlands such as Harike (Chopra et al. 2001), Ansupa

(Pattanaik and Reddy 2007), Keoladeo (Reddy et al. 2010) and Hokersar (Romshoo and Rashid 2012). The biological

Fig. 3 IRS P6 LISS III FCC image (18th December 2011) of GRK

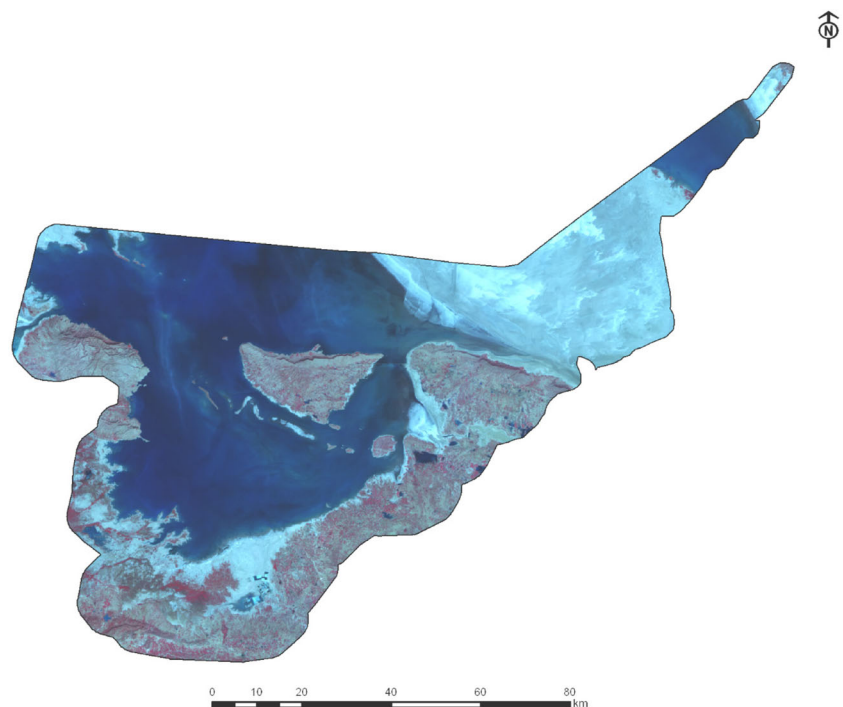


Table 2 Composition of land-use/land-cover classes in GRK (area in km²)

Class	1977		1990		1999		2005		2011	
	Area	% of area	Area	% of area	Area	% of area	Area	% of area	Area	% of area
Wetlands										
Water	4359.4	45.7	4538.5	47.6	468.0	4.9	1034.1	10.8	4646.7	48.7
Marshy land	2042.8	21.4	1908.4	20.0	5963.8	62.5	5423.0	56.8	1808.3	18.9
Salt pans	0.0	0.0	0.0	0.0	15.3	0.2	19.9	0.2	30.6	0.3
Sub total	6402.3	67.1	6446.9	67.6	6447.1	67.6	6477.1	67.9	6485.6	68.0
Non Wetlands										
Thorn scrub	159.7	1.7	157.2	1.6	157.7	1.7	157.9	1.7	158.6	1.7
<i>Prosopis</i> scrub	679.5	7.1	797.1	8.4	826.7	8.7	855.3	9.0	970.7	10.2
Grasslands	612.4	6.4	466.9	4.9	445.7	4.7	392.3	4.1	267.7	2.8
Agriculture/Fallow	1678.9	17.6	1664.6	17.4	1654.9	17.3	1649.4	17.3	1649.1	17.3
Settlements	10.1	0.1	10.2	0.1	10.7	0.1	10.8	0.1	10.8	0.1
Sub total	3140.6	32.9	3096.0	32.4	3095.7	32.4	3065.8	32.1	3057.0	32.0
Grand total	9543	100.0	9543	100.0	9543	100.0	9543	100.0	9543	100.0

invasion of alien species was found to be a major threat in the wetlands of the Samaspur bird sanctuary in India (Reddy 2007; Reddy et al. 2009). These studies observed an increase of 39 % in the spread of invasive plant species during 1990 to 2006 (Reddy 2007; Reddy et al. 2009). The main objective of the present study is to analyse the spatio-temporal changes in wetlands of Great Rann of Kachchh, Kachchh Biosphere Reserve, Gujarat, India during 1977, 1990, 1999, 2006 and in continuous four years cycle: 2008/2009, 2009/2010, 2010/2011 and 2011/2012. In this study, change

refers to an increase or decrease in the surface extent of the water spread of wetlands due to natural or anthropogenic factors.

Study area

Kachchh, located in the western part of the India, represents one of the most unique geological features called the ‘Rann’ of Kachchh (Gaur et al. 2013). The Rann of Kachchh is a vast area of marshy salt plain which intermittently becomes wet

Fig. 4 Classified Map of Land use/Land cover in GRK (December, 2011)

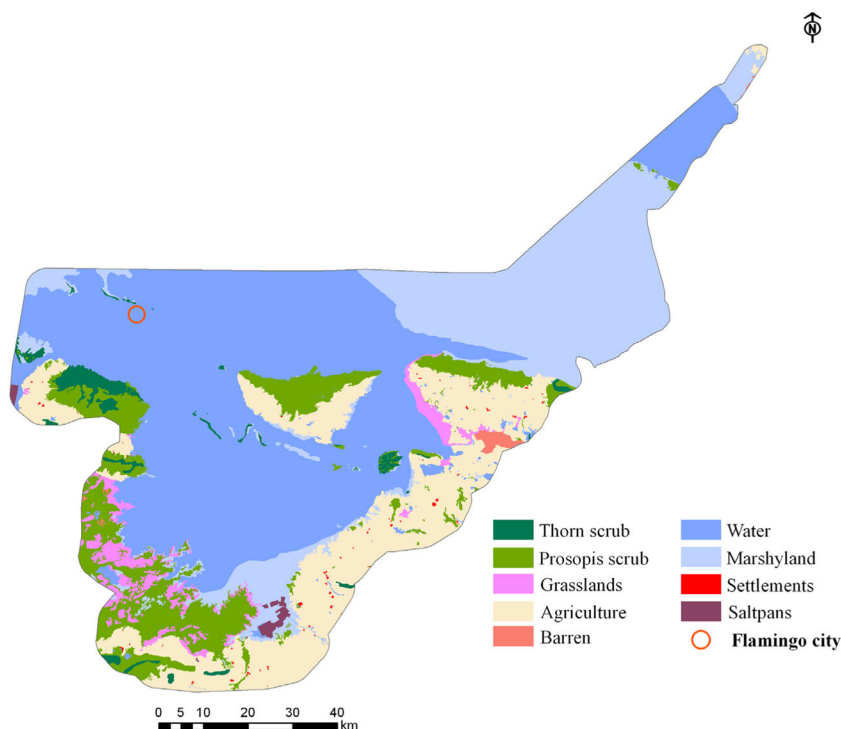


Table 3 Change area matrix of land-use/land-cover types of Great Rann of Kachchh: 1977 and 2011 (area in km²)

1977–2011	Thorn scrub	Prosopis scrub	Grasslands	Agriculture/Fallow	Marshy land	Water	Settlements	Salt pans	Grand Total
Thorn scrub	155.8	3.8	0.1	0.0	0.0	0.0	0.0	0.0	159.7
<i>Prosopis</i> scrub	1.0	666.4	3.9	1.5	5.0	1.8	0.0	0.0	679.5
Grasslands	0.1	254.8	258.6	1.0	70.9	27.1	0.0	0.0	612.4
Agriculture/Fallow	0.0	37.1	1.1	1630.6	3.1	6.3	0.7	0.0	1678.9
Marshy land	1.7	8.6	3.2	14.5	1880.0	110.4	0.0	24.5	2042.8
Water	0.0	0.0	0.9	1.6	197.3	4153.6	0.0	6.1	4359.4
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	10.1	0.0	10.1
Salt pans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grand Total	158.6	970.7	267.7	1649.1	2156.3	4299.1	10.8	30.6	9543

and dry and barely rises above sea level. The marshy salt flats become ‘snow white’ after the shallow water dries up every year before the monsoon season. The Government of Gujarat State (India) notified ‘the Great Rann of Kachchh’ as Kachchh desert wildlife sanctuary in 1986. The Great Rann of Kachchh’ (hereafter GRK) lies in the northern region of Kachchh district and covers a major part of the Kachchh biosphere reserve (Fig. 1) which was notified as a ‘Biosphere Reserve’ in the year 2008 (Palni et al. 2012). It is the fifteenth Biosphere Reserve designated by the Government of India and represents a unique combination of saline deserts and seasonal wetlands in the vast areas of the Great Rann of Kachchh. Topographically, the GRK is a bowl-shaped

depression, occurring adjacent to Pachchham, Khadir and Bela hill massifs (Gaur et al. 2013). It falls under a separate biotic province i.e. Kachchh desert and thus represents a distinct, typical gene pool of the Semi-Arid biogeographic zone in India (Rodgers and Panwar 1988). The internationally renowned and charismatic birding paradise ‘*Flamingo city*’ is situated in the mid-east of GRK. Flamingo city located in the GRK is Asia’s largest flamingo breeding ground. It is an Important Bird Area (IBA) declared by Bird Life International (Lee et al. 2011). The breeding period of Flamingo is mainly during September to November. This is an area of slightly raised ground where huge

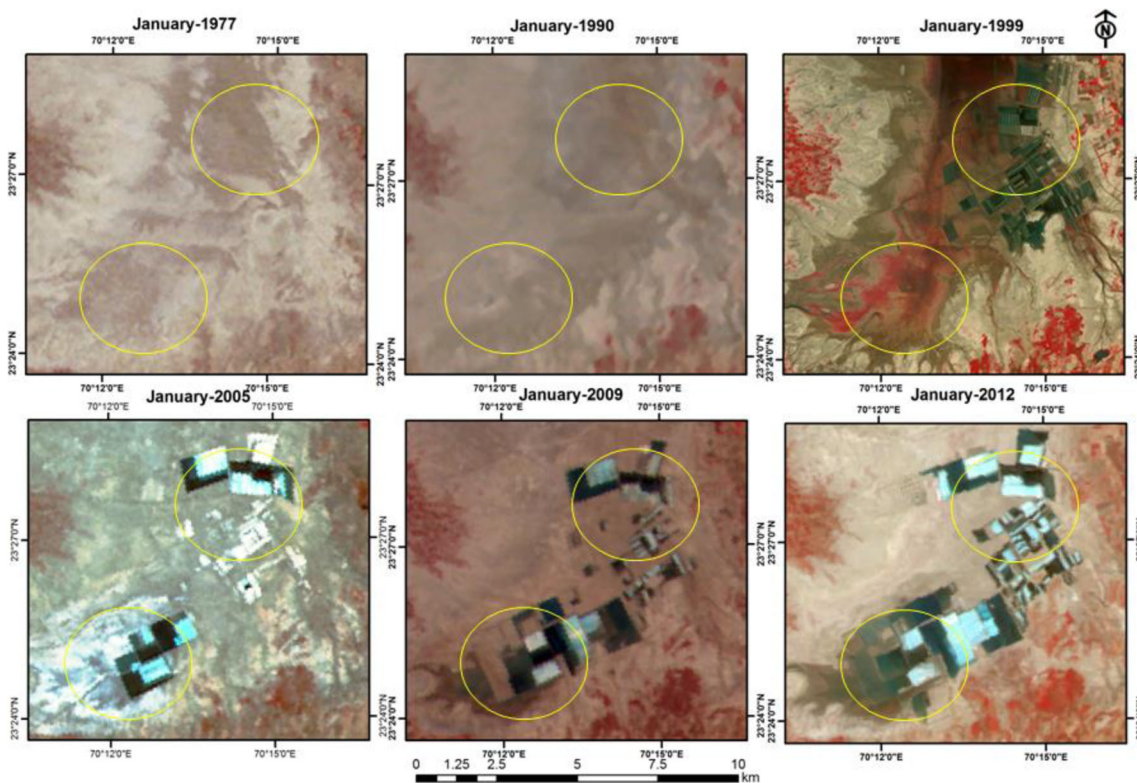
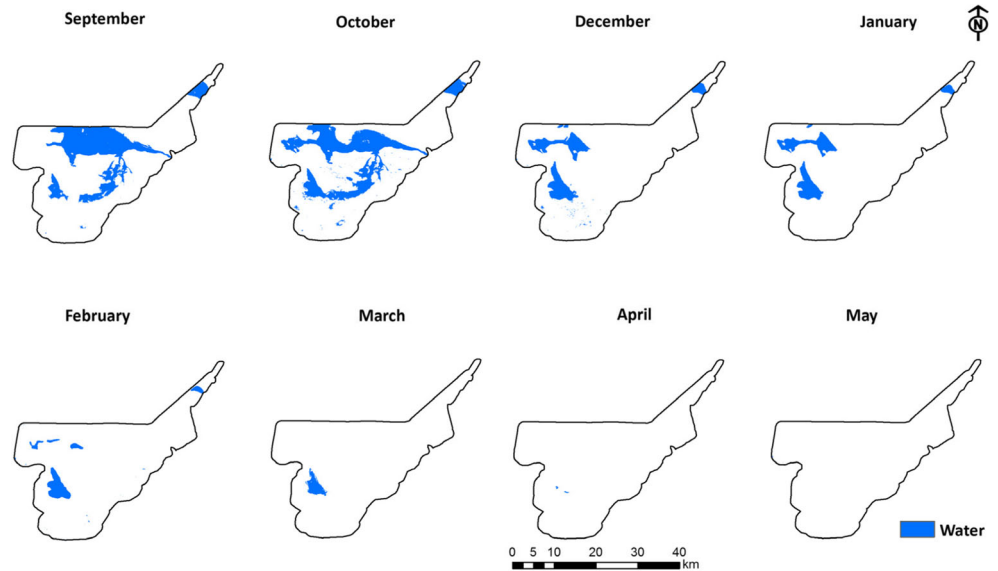


Fig. 5 The expansion of salt pans as evidenced by multi-temporal False Colour Composite satellite image data (Change areas highlighted in circles: No salt pans in 1977 and 1990)

Fig. 6 Map showing the spatio-temporal variations in the water bodies of GRK (2008–2009)



numbers of flamingos build their mud nests and it supports a large number of waterfowl. The Great White Pelican often breeds in the GRK (Grimmett et al. 1998). The mean minimum and maximum temperatures recorded during 2012 were 6 °C (February) and 42.2 °C (May) respectively. Climatically, the winter falls between November to February, the summer from March to May and rainy season from June to October. The period from 1932 to 1950 has received scanty rain. The period from 1951 to 1980 received considerable rainfall. A drastic decline in rainfall during the period 1981–1990 led to consecutive droughts. The rainfall again improved after 1990 (Gujarat Ecology Commission 2011). The highest rainfall in 2012 was recorded on 28th September as 75.6 mm. Annual rainfall (mm) patterns in study area have been shown in Table 1 (<http://www.imd.gov.in>).

Material and methods

Data used

Landsat MSS, Landsat TM, Landsat ETM+, IRS P6 LISS III and IRS P6 AWiFS remote sensing data were used to map land-use and land-cover, and to analyse changes in wetlands. The Landsat images were downloaded from the [Global Land Cover Facility](http://glcf.umd.edu) (<http://glcf.umd.edu>). IRS datasets were procured from the National Remote Sensing Centre, India. The Landsat MSS data of 17th January 1977, Landsat TM of 2nd November 1990, Landsat ETM+ of 18th October 1999, IRS P6 LISS-III of 9th October 2005, 18th December 2011 and IRS P6 AWiFS of September, 2008 to May 2012 were analysed. Meteorological data (2008–2012) were

Fig. 7 Map showing the spatio-temporal variations in the water bodies of GRK (2009–2010)

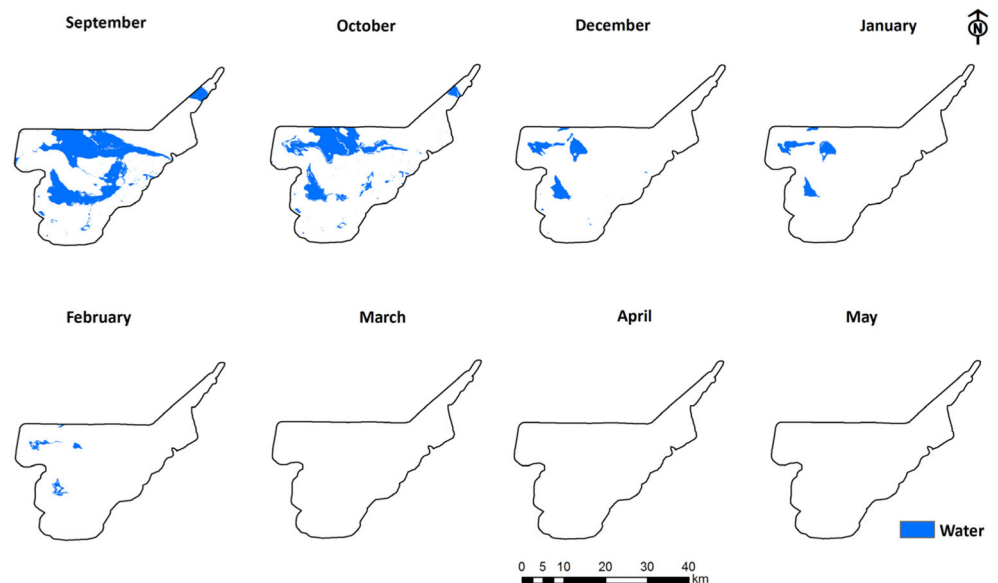
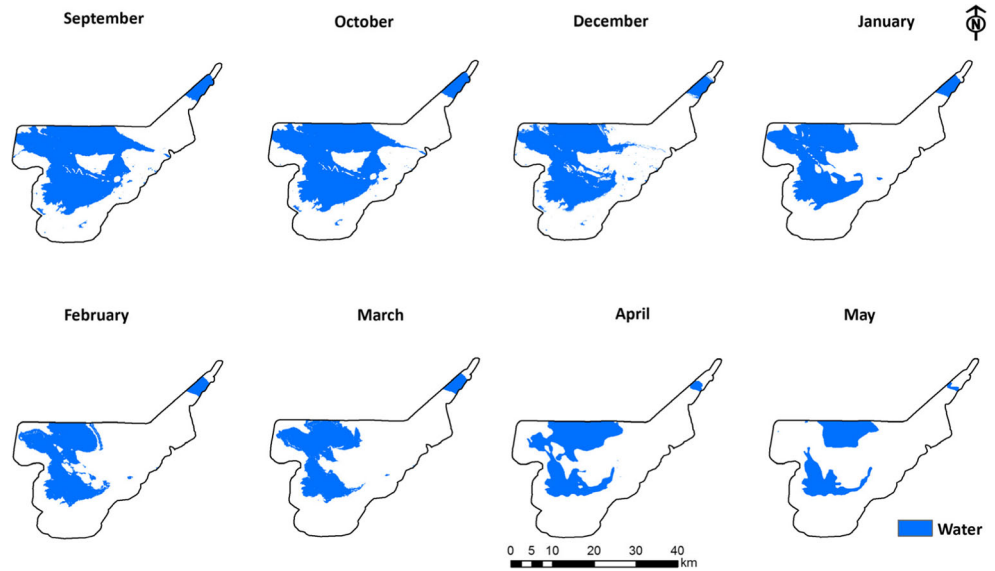


Fig. 8 Map showing the spatio-temporal variations in the water bodies of GRK (2010–2011)



collected from Indian Meteorological Department (<http://www.imd.gov.in>). The Survey of India topographical maps were used as ancillary data.

Methods

Ortho-rectified Landsat ETM+ data were used as a reference for the geo-rectification of IRS data. The images were georeferenced to the Universal Transverse Mercator (UTM) coordinate system and the WGS 84 datum. To calibrate reflectance, the Top-of-Atmosphere correction procedure was used (Chavez 1996).

Multispectral satellite remote sensing data (1977 to 2012) were used for mapping the various categories of land-use/land-cover. The study utilized 32 IRS P6 AWiFS images for

analysing the inter and intra-annual temporal changes in wetlands (2008–2009, 2009–2010, 2010–2011 and 2011–2012). In order to delineate the wetlands, the Normalized Difference Water Index (NDWI) was used. The NDWI was calculated using the following formula (McFeeters 1996):

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where green is in the spectral range of 0.52–0.59 μm and NIR is in 0.77–0.86 μm.

The application of this indicator for a multi-spectral satellite image results in positive values for water features and zero or negative values for soil and vegetation (Chatterjee et al. 2003).

After the generation of classified maps from the individual remote sensing datasets, a post-classification comparison

Fig. 9 Map showing the spatio-temporal variations in the water bodies of GRK (2011–2012)

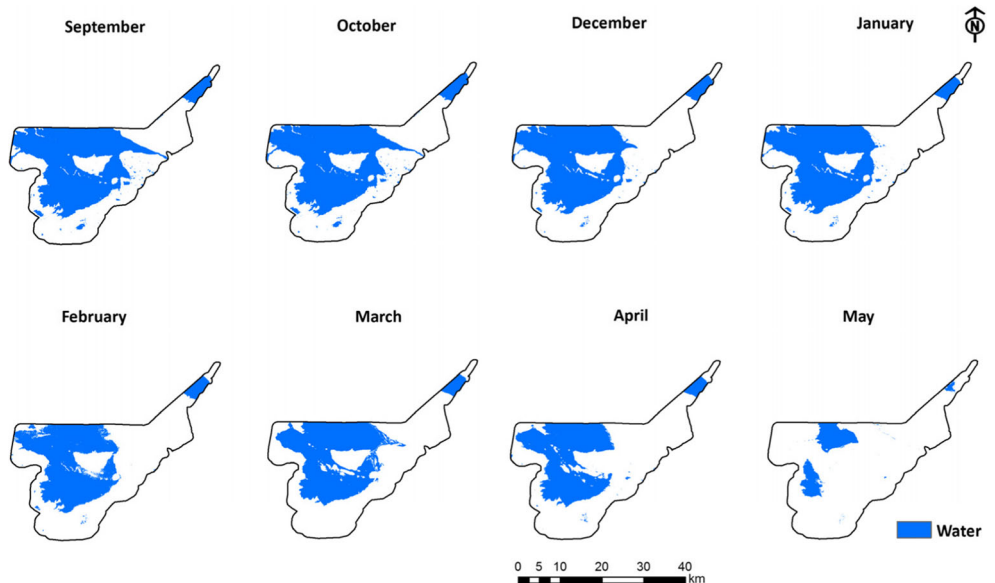
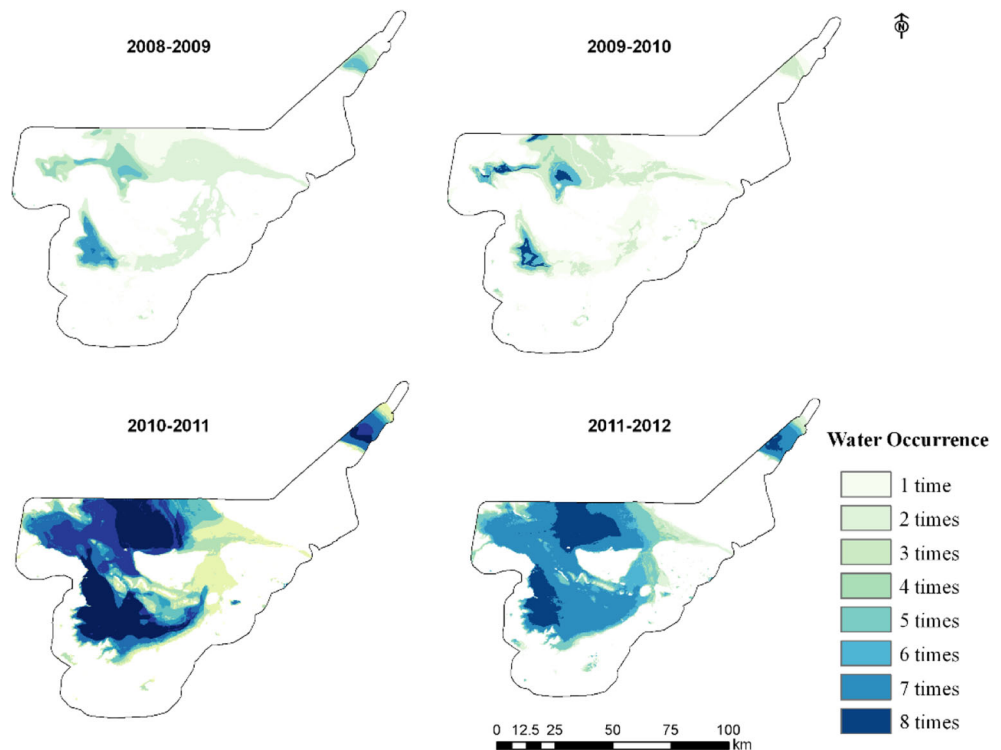


Table 4 Month wise water spread area during 2008–2012 (area in km²)

Year	September	October	December	January	February	March	April	May
2008–2009	2058.1	2119.9	820.1	702.6	369.2	159.3	5.6	1.3
2009–2010	2462.5	1500.3	473.2	355.3	139.2	0	0	0
2010–2011	4326.1	4296	3480.6	2508.1	2533.2	2362.1	2287.4	1546.8
2011–2012	4646.7	4594.4	4194.6	4137.1	3630.5	3728.9	3187.4	885

technique was used to determine changes in land-use/land-cover between 1977 and 2011. The post-classification comparison approach provides “from – to” change information and the type of land-cover transformations that have occurred can easily be calculated and mapped (Jensen 2004). Change-detection information with 64 combinations of “from –to” change information was derived for each of the eight classes mapped. Changes in the spatial distribution of land-use/land-cover classes can be summarised by overlaying maps of different dates and analysing their spatial coincidence (Weng 2002). In the present study, GIS overlay analysis technique was used for assessing the spatial and temporal consistency of area under water spread to identify the actual location and spatial extent of change.

An accuracy assessment was carried out to validate the classified map of 2011. Validation of classified maps for 1977, 1990, 1999, 2005 were undertaken based on the visual assessment of satellite images and the temporal consistency of ground control points. The overall methodology of the study area is presented in Fig. 2.

Fig. 10 GIS overlay analysis showing spatio-temporal variations in the water bodies of GRK (2008–2009, 2009–2010, 2010–2011 and 2011–2012)

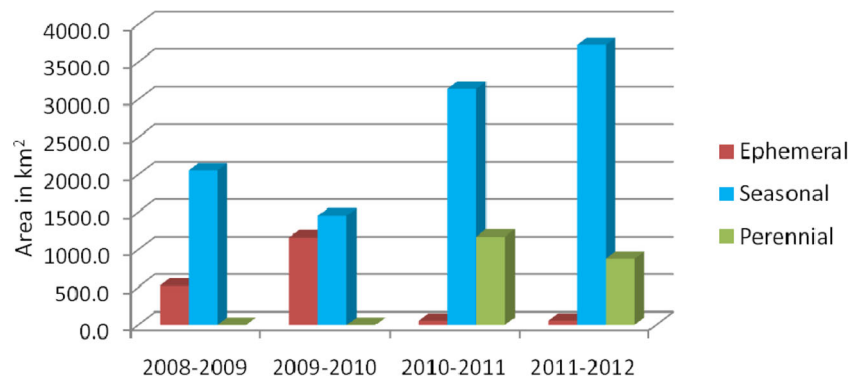
Results and discussion

The IRS P6 LISS III False Colour Composite (FCC) image of the study area is shown in Fig. 3. The analysis showed that the wetland ecosystem of GRK was undergoing drastic inter-annual and intra-annual changes during the study period. The overall accuracy of the land use/land cover maps derived for the years 1977, 1990, 1999, 2005 and 2011 was 89.2 %, 90.4 %, 92.8 %, 93.1 and 93.4 % respectively. All the kappa values were above 0.88. Although 85 % accuracy is a recommended target for land use/land cover classification in remote-sensing applications (Anderson et al. 1976), satellite data used in the present study has given 93.4 % accuracy in the LU/LC mapping of 2011/2012.

Area change in wetlands

In the present spatial analysis, land-cover has been divided into two categories, i.e. wetlands and non-wetland. Marshy lands and water body classes were combined into one ‘wetland category’ for long term multi-temporal analysis. This

Fig. 11 Inter and Intra annual cyclic changes in water spread area of GRK (area in km²)



reduced the effect of seasonality on surface water area and provided an opportunity to compare the total wetland cover available across the time periods studied. Wetlands represented 68 % of the total geographical area of GRK in 2011 (Table 2).

The non-wetland category includes thorn scrub, *Prosopis* scrub, grasslands, agriculture/fallow and settlements (Fig. 4). Among the natural vegetation cover classes, grasslands and *Prosopis* scrub shown large spatial changes; the former is decreasing and the latter is increasing. Among the cultural land-use classes, agriculture occupies 17.3 % of the total geographical area, followed by salt pans (0.3 %) during 2011.

Abrupt long term changes

The area change matrix analysis showed that land-cover in the GRK has changed significantly since 1977 with wetlands being converted to other land-uses (Table 3). Due to invasion, the wetland area of 8.6 km² was changed into *Prosopis juliflora* scrub. The natural wetland area of 30.6 km² was converted into salt pans. The area under salt pans increased twofold due to this conversion during the study period. The expansion of salt pans is illustrated in Fig. 5. The change in grassland area to *Prosopis* scrub (254.8 km²) can be considered as compounding threat to natural ecosystem of GRK. The grassland area of about 98 km² was inundated due to seasonal changes.

Short-term seasonal changes: 2008–2012

The spatio-temporal changes in wetlands are shown in Figs. 6, 7, 8 and 9. The extent of wetland was significantly decreased from September to May (Table 4). The maximum waterbody area mapped was in the months of September and October. The highest water spread was recorded in September 2011 (4646.7 km²) followed by the same months in 2010 (4326.1 km²), 2009 (2462.5 km²) and 2008 (2058.1 km²). GIS overlay analysis showed that the persistent surface water (for the full year) was not found in 2008–2009 and 2009–2010 due to prolonged drought in 2009. 2009 is marked as the warmest year since 1901 (IMD 2009).

The areas that hold water throughout the year are referred to here as ‘perennial’, based on the presence of surface water in all the seasons. The areas that hold water only during and immediately after rain events are referred to as ‘Ephemeral’. Seasonal or intermittent water bodies hold water in the rainy and winter seasons (Fig. 10, 11). The perennial water body area was estimated as 1171 km² in 2010–2011. This was the highest among all years i.e., 2008–2009, 2009–2010 and 2011–2012 (Table 5).

Studies on wetlands have developed into a priority research subject of global environmental change (Liu et al. 2004). The Government of India has initiated integrated coastal and marine area management programmes to plan industrial developments in an ecofriendly manner and to maintain productivity

Table 5 GIS overlay analysis for temporal change of water spread (2008–2012) (area in km²)

No. of months in annual cycle	2008–2009	2009–2010	2010–2011	2011–2012
1	520.3	1161.9	55.8	58.0
2	1351.0	996.4	679.6	305.0
3	197.6	149.2	440.4	132.9
4	254.9	216.0	415.1	207.2
5	126.8	92.9	300.0	507.4
6	121.9	0.0	610.6	438.5
7	5.1	0.0	698.8	2136.5
8	0.0	0.0	1171.0	873.2
Total	2577.6	2616.3	4371.4	4658.7

and biodiversity (Saravanakumar et al. 2009). The State Government of Gujarat is actively involved in the development of integrated coastal zone management with the support of the people's participation to promote the livelihood security of the coastal communities and to protect the ecosystems whilst promoting sustainable development. The study of Agoramoorthy et al. (2014) has reviewed the problems and prospects associated with coastal zone management policies of Gujarat in relation to industrial and allied developmental activities. Presently, Rann of Kachchh is a storehouse of a thick layer of salt. Geological studies have indicated that different environmental conditions prevailed in the past (Gaur et al. 2013). The analysis of the past 100 years (1891 to 1996) data on annual mean maximum and minimum temperatures showed that the mean maximum temperature increased by 0.5 °C (Gujarat Ecology Commission 2011). The time series wetland mapping demonstrated the existence of intra-seasonal spatial dynamics in GRK. Wetlands of GRK are highly variable in space and time. The study on wetlands investigated long-term and seasonal changes that have occurred in the study area for the periods between 1977 and 2012. This study will prove to be a benchmark for the future research to quantify dynamics of wetlands of GRK. Although Rann of Kachchh is known to be a dynamic wetland ecosystem, there are significant seasonal variations under different precipitation regimes which have been addressed in the present study. There was a correlation between water level and pattern of rainfall. During 1932–2010 there was 11 years severe drought conditions and 12 years of excess rains (Gujarat Ecology Commission 2011). The incidence of severe drought during the period 2001–2010 has occurred only once and there were fairly good number of rainy years with 2 years of excessive (relatively for the arid area) rain (Gujarat Ecology Commission 2011). Hence, Rann of Kachchh will be an important case to understand the impact of climate change in all its social and ecological dimensions. Land-cover area comparisons between 2008 and 2012 indicated that the changes in overall wetland areas were significant over the four year cycle.

Conclusions

GIS techniques such as overlay and post-classification comparisons contributed to reduce the complexity associated with change detection. This study quantifies seasonality using a suite of multi-temporal and multi-sensor satellite datasets. The high fluctuations in wetland areas may affect both flora and fauna. Natural factors especially climate can also affect the wetland. However, in recent times (after 1990s), the human-induced activities are becoming a critical threat, especially in the fringes of the wetlands of Kachchh. The study identified anthropogenic threats due to the expansion of salt pans and biological invasion of *Prosopis juliflora* (Mesquite).

In view of ecological significance, monitoring of wetlands is needed for sustainable management and conservation of GRK.

Acknowledgments The work has been carried out as part of the national project on 'Inventorisation and Monitoring of Biosphere Reserves in India using remote sensing and GIS technology', supported by Ministry of Environment and Forests, Government of India. Authors are thankful to Dr. V.K. Dadhwal, Director, NRSC, Dr. P.G. Diwakar, Deputy Director, NRSC for encouragement and technical support. We are grateful to Shri D.K. Sharma, Field Director, Kachchh Biosphere Reserve, Bhuj and State Forest Department, Gujarat for permission and facilities to carry out the field work. We thank the editor and anonymous reviewer for their valuable comments and suggestions, which helped us to improve the manuscript.

References

- Agoramoorthy G, Patel P, Basu SK, Chakraborty C, Hsu MJ (2014) India's coastal zone management with an emphasis on rapidly developing Gujarat state. *J Coast Conserv* 18(6):683–690
- Anderson JR, Hardy EE, Roach JT, Witmer RE (1976) A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U. S. Geological Survey, Professional Paper 964, Reston, VA
- Bayley SE, Wong AS, Thompson JE (2013) Effects of agricultural encroachment and drought on wetlands and shallow lakes in the boreal transition zone of Canada. *Wetlands* 33(1):17–28
- Chatterjee C, Kumar R, Mani P (2003) Delineation of surface water-logged areas in parts of Bihar using IRS-1C LISS III data. *J Indian Soc Remote Sens* 31:57–65
- Chavez PS (1996) Image-based atmospheric corrections – revisited and improved photogram. *Eng Rem S* 62:1025–1036
- Chen X (2002) Using remote sensing and GIS to analyze land cover change and its impacts on regional sustainable development. *Int J Remote Sens* 23:107–124
- Chopra R, Verma VK, Sharma PK (2001) Mapping, monitoring and conservation of harike wetland ecosystem, Punjab, India, through remote sensing. *Int J Remote Sens* 22(1):89–98
- Emadi M, Baghernejad M, Pakparvar M, Kowsar SA (2010) An approach for land suitability evaluation using geostatistics, remote sensing, and geographic information system in arid and semiarid ecosystems. *Environ Monit Assess* 164:501–511
- Gaur AS, Vora KH, Murali RM, Jayakumar S (2013) Was the rann of Kachchh navigable during the harappan times (mid-Holocene)? An archaeological perspective. *Curr Sci* 105(11):1485–1491
- Ghobadi Y, Pradhan B, Kabiri K, Pirasteh SH, Shafri ZM, Sayyad GA (2012) Use of multi-temporal remote sensing data and GIS for wetland change monitoring and degradation IEEE colloquium on humanities, Science & Engineering Research (CHUSER 2012), December 3–4, 2012. Kota Kinabalu, Sabah, Malaysia
- Grimmett R, Inskipp C, Inskipp T (1998) Birds of the Indian Subcontinent London: Christopher Helm, A & C Black
- Gujarat Ecology Commission (2011) Trends of changing climate and effects on eco-Environment of Kachchh District, Gujarat. Government of Gujarat, India
<http://glcf.umiacs.umd.edu/>
<http://www.imd.gov.in>
 IMD (2008–2012) <http://www.imd.gov.in>
- Jensen JR (2004) Digital change detection introductory digital image processing: A remote sensing perspective. New Jersey' Prentice-Hall Pp 467–494

- Lee R, Arengo F, Bechet A (eds) (2011) Flamingo, Bulletin of the IUCN-SSC/Wetlands. International Flamingo Specialist Group, No 18 Wildfowl & Wetlands Trust, Slimbridge, UK
- Liu H, Zhang S, Li Z, Lu X, Yang Q (2004) Impacts on wetlands of large-scale land-use changes by agricultural development: the small sanjiang plain, China. *Ambio* 33:306–310
- Mahmud MS, Masrur A, Ishtiaque A, Haider F, Habiba U (2011) Remote sensing & GIS based spatio-temporal change analysis of wetland in Dhaka city, Bangladesh. *J Water Resource Prot* 3:781–787
- McFeeters SK (1996) The use of normalized difference water index (NDWI) in the delineation of open water features. *Int J Remote Sens* 17:1425–1432
- Ozesm SL, Baue ME (2002) Satellite remote sensing of wetlands. *Wetl Ecol Manag* 10:381–402
- Palni LMS, Rawal RS, Rai RK, Reddy SV (2012) Compendium on Indian Biosphere Reserves- Progression during two decades of conservation Uttarakhand: GB Pant Institute of Himalayan Environment & Development Ministry of Environment and Forests, India, Government of
- Pattanaik C, Reddy CS (2007) Need for the conservation of wetland ecosystems: A case study of ansupa lake (Orissa, India) using remote sensing based data. *Natl Acad Sci Lett* 30:161–164
- Reddy CS (2007) Conservation status and monitoring of wetlands of samaspur bird sanctuary and environs, Uttar Pradesh. *Sarovar Saurabh* 3(3):4–5
- Reddy CS, Harikrishna P, Swetha V, Shivakala T, Prabhu DC (2010) Assessment and monitoring of spatiotemporal changes in Keoladeo Ghana National Park, Rajasthan using Geoinformatics. *Jour Wetland Ecol* 4:33–42
- Reddy CS, Rangaswamy M, Pattanaik C, Jha CS (2009) Invasion of alien species in wetlands of samaspur bird sanctuary, Uttar Pradesh, India. *Asian Jour Water, Environ Pollution* 6(3):43–50
- Rodgers WA, Panwar HS (1988) Planning a wildlife protected area network in India. Wildlife Institute of India, Dehradun
- SAC (2011) National wetland inventory and assessment. MoEF, Government of India
- Salari A, Zakaria A, Nielsen CC, Boyce MS (2014) Quantifying tropical wetlands using field surveys, spatial statistics and remote sensing. *Wetlands*. doi:10.1007/s13157-014-0524-3
- Saravanakumar A, Rajkumar M, Sun J, Serebiah JS, Thivakaran GA (2009) Forest structure of arid zone mangroves in relation to their physical and chemical environment in the Western Gulf of Kachchh, Gujarat, northwest coast of India. *J Coast Conserv* 13(4):217–234
- Weng Q (2002) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. *J Environ Manag* 64:273–284
- Xie Z, Xu X, Yan L (2010) Analyzing qualitative and quantitative changes in coastal wetland associated to the effects of natural and anthropogenic factors in a part of Tianjin, China. *Estuar Coastal Shelf Sci* 86:379–386
- Zhao S, Lai P (2007) Millennium ecosystem assessment. China Environmental Science Press