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Delineation of waterlogged areas in Vaishali district (Bihar) using normalized difference water index

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ABSTRACT

Surface waterlogged areas were delineated using satellite remote sensing data for Vaishali district of North Bihar. Digital data of LANDSAT thematic Mapper sensor acquired on 1998 and 2006 were analyzed using spectral analysis using software-ERDAS Imagine. The surface waterlogged areas were delineated using normalized difference water index (NDWI) technique, the result indicates that waterlogged areas ranges from zero to +1. The positive values +1 signifies the occurrence of waterlogged areas whereas the negative values -1 is for vegetation cover. Areas of 190 sq. km and 60 sq. km were found to be affected by surface waterlogging during 1988 and 2006 respectively. A considerable reduction in waterlogging during 2006 is credited to the operation of government wasteland reclamation events in the areas affected by waterlogging. The spatio-temporal waterlogging dynamics tried in this study would be beneficial for organizers to implement protective actions for waterlogging and best use of available land and water resources for sustainable growth of flooded lands.

Keywords: Satellite images; NDWI; Waterlogged area; Geospatial

INTRODUCTION

An estimated area of 6.73 M ha salt-affected soils are in India, of which 2.5 M ha is in the Indo-Gangetic plain (Mandal *et al*., 2011; Mandal and Sharma, 2005; Saxena *et al.,* 2004). Interpretation of Landsat images showed old levees, relict flood plain and poorly drained low-lying flats are common topographic zones with salt infestation along the Gangetic alluvial plain (Manchanda and Iyer, 1983). Due to the over use of irrigation water in poorly drained areas, waterlogging and secondary salinization appeared and caused losses in productivity for rice (42%), wheat (38%) and sugarcane (61%) crops (Samra *et al*., 2006). Because of the large spectral coverage and discreet bands, remote sensing data have been used for mapping and monitoring salt-affected and waterlogged soils in a time and cost-effective manner (Dwivedi, 2006; Mandal and Sharma, 2013; Rao *et al*., 1998; Saxena, 2003; Shrestha, 2006).

India has lost nearly 20,000 and 30,000 ha of irrigated land each and every year owing to water logging due to the barrier of natural drainage, construction of settlements, roads, railways and various structural activities (Pandey *et al*., 2015, Pandey *et al*., 2012). 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 socio-economic status (Singh *et al*., 2014c, Singh *et al*., 2014d). Periodic monitoring of waterlogged area in the basin through the multi-temporal satellite imagery to help analysing the waterlogged situation and taking appropriate corrective measures (Pandey *et al*., 2013). Pandey *et al*., (2010) examined the impact of natural and anthropogenic features on flood induced waterlogging in parts of Bihar plains, and revealed that canals and railway line induced highest waterlogging conditions.

Van der Walt and Van Rooyen (1995) definition of waterlogging is: “Soil or land saturated with water, it may result from excessive rain, irrigation or seepage, coupled with inadequate drainage, and is detrimental to the growth of most crop plants”. Salinity problems encountered in irrigated agriculture are very frequently associated with an uncontrolled water table, within 1-2 m of the ground surface (FAO, 2005). Over-irrigation and leaking water supply canals that result in water seepage which promote water table formation and subsequent salinization, occur in many irrigation projects (Rhoades and Loveday, 1990; Singh *et al*., 2011). The introduction of irrigation in arid and semi-arid environments inevitably leads to watertable rise and often to problems of waterlogging and salinization (Hoffman and Durnford, 1999). Pandey *et al*., (2010) described that areas with high waterlogging risk in northern Bihar plains corresponds to high flood hazards and vulnerability due to poor socio-economic conditions in these areas. Remotely sensed data and the potential to distinguish between different characteristics of land features from this data provides great potential for rapidly creating accurate LULC maps (Singh, 2016; Yadav *et al*., 2015, Singh *et al*., 2014a, Singh *et al*., 2014b; Kanga *et al*., 2013; Kanga *et al*., 2011; Kanga *et al*., 2015, Kanga *et al*., 2014, (Nathawat *et al*., 2010).

The NDWI was first proposed by McFeeters in 1996 to identify non-urban surface water associated with wetlands. McFeeters (1996) proposed the Normalized Difference Water Index (NDWI), using the green and Near Infrared (NIR) bands of remote sensing images based on the phenomenon that the water body has strong absorbability and low radiation in the range from visible to infrared wavelengths. NDWI can enhance the water information effectively in most cases, but it is sensitive to built-up land and often results in over-estimated water bodies. Remote sensing techniques provide important capabilities to map surface water features and monitor the dynamics of surface water. The NDWI data derived from Landsat MSS, TM, and ETM+ have been successfully used in delineating water bodies and monitoring the water area changes (Jain *et al*., 2005). Among all prevailing water body mapping methods, the spectral water index-based method is a type of reliable method, because it is user friendly, efficient and has low computational cost.

STUDY AREA

The district lies between latitude 25°28' to 26°00' N and longitude 85°5' to 85° 40'E with geographical area of 2015 sq km. The district is surrounded by Muzaffarpur (North), Patna (South), Samastipur (East) and Saran (West). The climate of the district is sub-tropical to sub-humid (figure 1). The average annual rainfall in the district is 1154 mm and receives about 85% of the total rainfall from south-west monsoon during monsoon months. Vaishali district is characterized by quaternary alluvial deposit consisting of alternate layers of sand, silt, clay and gravel forms prolific unconfined and confined aquifer system. The Vaishali district constitutes a part of Ganga river basin with two sub-basins, namely Gandak and Burhi Gandak sub-basin among which the majority part of the district falls under Burhi Gandak sub-basin. The district comprises widespread plain formed by the alluvium transported by the Ganga, Gandak and Burhi Gandak.

METHODOLOGY

When applying spatial data from varied origins, it is essential that all datasets should precisely spatially overlay each other. This needs georeferencing of all the maps to a common approximation system. Georeferencing is a procedure of converting an uncorrected raw image from an arbitrary coordinate system into a map projection coordinate system. Image pixels are located and corrected to align and fit into real world map coordinates. The root mean square error (RMSE) in all the image-to-image registration processes was less than 0.05. The resampling process

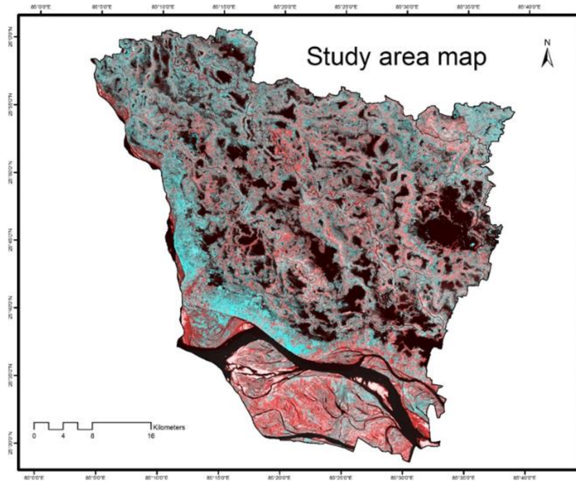


Figure. 1 Study area map

was performed using the nearest neighbourhood technique. The commencement of satellite imaging with the Landsat series of satellites in 1972 started an era of space imaging-based mapping of the earth's resources. In this study, the satellite data in were used to obtain the past perception of waterlogging in the area (figure 2).

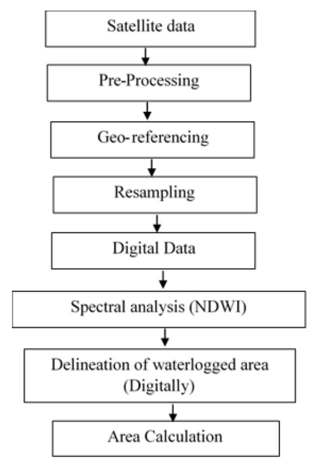


Figure.2 Methodology adopted for mapping

Repeatedly, the land/water parting is unclear in a single NIR band, and hence, two band data such as G and NIR bands can be used in such conditions. Chowdary (2008) stated that waterlogged areas ranges from zero to +1. Now, +1 indicates the occurrence of extensive deep water bodies and -1 is for vegetation cover. From the LANDSAT imagery, following McFeeters (1996), NDWI can also be calculated using the formula as follows:

NDWI = (Band 2 – Band 4) / (Band 2 + Band 4)

Where, Band 2 is spectral reflectance in G band and Band 4 is spectral reflectance in NIR band. Hence, in the present study, the Normalized Difference Water Index (NDWI) developed by McFeeters (1996) was used for demarcation of waterlogged areas and to increase their manifestation in remotely sensed digital imagery while concurrently removing soil and terrestrial vegetation features.

RESULTS AND DISCUSSION

The collection of these wavelengths was done to maximize the characteristic reflectance of water features by using G band and minimize the low reflectance of NIR by water features and thereafter 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 ratio images were density sliced for delineation of waterlogged areas. NDWI takes advantage of the fact that water has a high reflectance in the green band while it has strong absorptions in the Near Infra-Red bands.

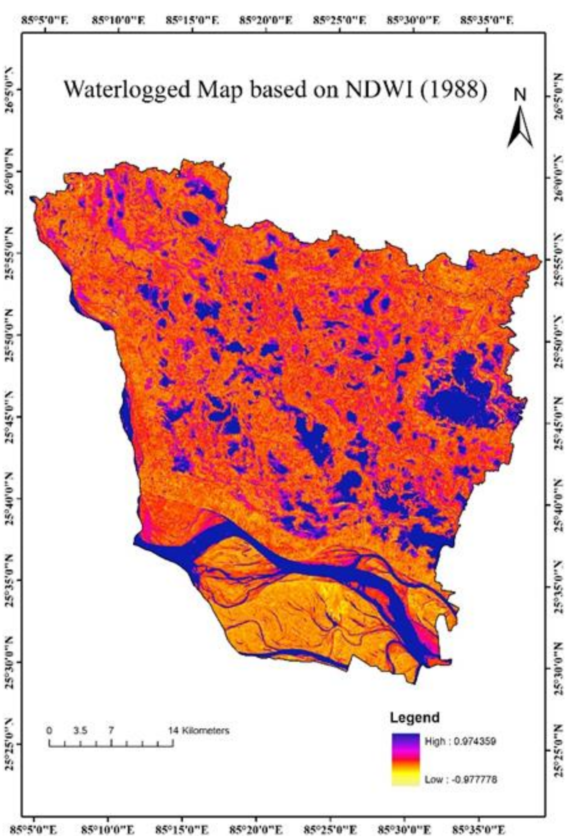
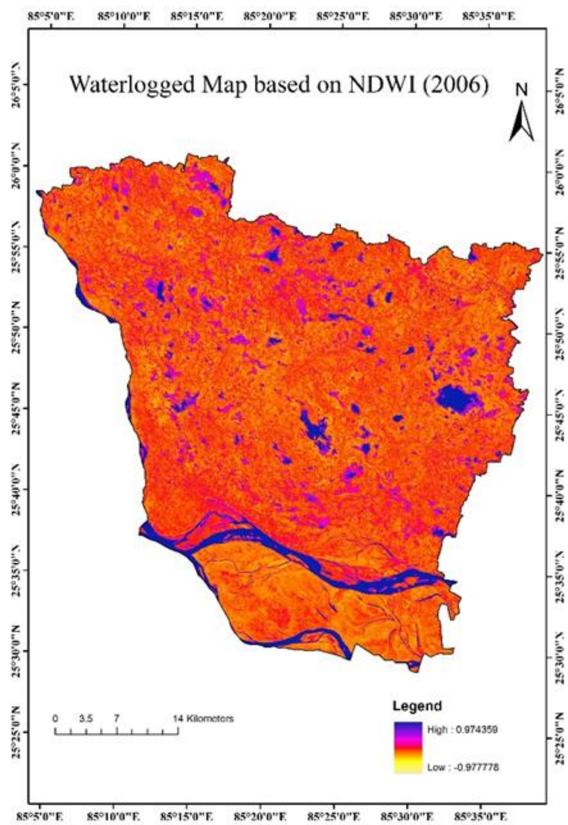


Figure 3 (a) NDWI image of waterlogged area in 1988



3 (b) image of waterlogged area in 2006

The spectral water index is a single number derived from an arithmetic operation of two or more spectral bands. An appropriate threshold of the index is then established to separate water bodies from other land-cover features based on the spectral characteristics. The design of a spectral water index was based on the fact that water absorbs energy at near-infrared (NIR) and shortwave-infrared (SWIR) wavelengths. The arithmetic operation not only enhances the spectral signals by contrasting the reflectance between different wavelengths, but also cancels out a large portion of the noise components that are common in different wavelength regions (i.e., sensor calibration and changing radiation conditions caused by illumination, soil, topography, and atmospheric conditions, etc.). The reason for using the green band instead of the red band is that soil and vegetation have a similar reflectance in the green band. However, vegetation has a much lower reflectance in the red band than soil due to the chlorophyll absorption in green vegetation. Therefore, the green band is relatively insensitive to the background components.

Satellite images of LANDSAT TM were used to delineate areas affected by waterlogging during 1988 and 2006 respectively. The result indicates that the positive values +1 signifies the occurrence of widespread deep water bodies, rivers and waterlogged areas whereas the negative values -1 is for vegetation cover (figure 3a and 3b). Thereafter the classified map was vectorised for area analysis using raster to vector conversion option in Arc GIS. The river and waterbody area were deleted while area calculation to avoid ambiguity in classified area of waterlogging. The result indicated that the areas of 190 sq km and 60 sq km were affected by surface waterlogging in the years 1988 and 2006 respectively. The area statistics computed for waterlogged lands in different period images clearly indicate a substantial decrease in the surface waterlogging condition. Remote sensing techniques provide important capabilities to map surface water features and monitor the dynamics of surface water. Monitoring water resource changes is essential in water resources management and in flood or drought prevention.

CONCLUSIONS

Consistent valuation of waterlogged areas methods a vital element in the irrigation command area development program. In the present study space borne multispectral satellite data was effectively employed for valuation of spatially and temporally distributed waterlogged areas in order to assess the impact of canal irrigation. Though, this analysis can be carried out at recurrent intermissions to study the dynamics of these phenomena and to evaluate the impact of irrigated agriculture. Further, such study enables the managers and organisers in development and realizing remedial and protective procedures for optimal application of accessible land and water resources for sustainable development of irrigated lands. The NDWI value ranges between -1 to +1, depending on the leaf water content but also on the vegetation type and cover. High values of NDWI (in blue) correspond to high water content and Low NDWI values (in red) correspond to low vegetation. In period of water stress, NDWI will decrease. 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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