EXTRACTION OF OPEN SURFACE WATER BODIES IN INDIA USING REMOTE SENSING AND GIS TECHNIQUES: A REVIEW

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Abstract - Water is vital for the existence of life on Earth. Nature has always made sure that the cycle of water never ends. Therefore, it becomes immensely necessary to maintain and manage our water resources. Over the recent past, population explosion has led to rapid urbanization. The increasing demand for water is imposing huge pressure on the existing natural resources. On the other hand, concrete jungles are interfering with the natural cycle of rejuvenating the water resources leading to water-logging and droughts. Thus, there arises an urgent need to monitor and map the existing water bodies. This can be achieved by using the techniques of remote sensing coupled with GIS. The present study provides a comprehensive review of the various remote sensing techniques that are being used in India for mapping the spatial extent and changes in water bodies. It is found that microwave remote sensing has not been explored much in this field for mapping Indian water resources. Also, no study contained the exploitation of hyperspectral satellite images. Moreover, a very recent technique of object-based classification too has not been used in this field by researchers in India. Thus, there arises a need to upgrade our existing techniques.

Keywords - Feature Extraction, Hyperspectral, Image Classification, Microwave Remote Sensing, Object-based Classification, Spectral Indices.

I. INTRODUCTION

Study of water bodies has become an exciting area of research owing to the direct and indirect connection of these with the environment, livelihood and prosperity of mankind. Researchers like Du et al. (2010) and many others are trying to quantify the impact of climate change, urbanization, population explosion, pollution, global warming and other such phenomena on water bodies which give an indirect insight into the impact of these on environment, flora and fauna. Hazard zonation mapping for floods and droughts is another area where monitoring and mapping of water bodies (area, volume and water level changes) is essential. Government agencies and policy-makers study the distribution of water bodies for better management of clean drinking water, water for domestic and agricultural purposes, transportation facilities and recreational programs. Therefore, this paper primarily targets students, new researchers and decision-makers amongst others.

India is a vast country inhabiting 1.324 billion people (2016, Office of the Registrar General & Census Commissioner, India; “World Population Prospects: The 2017 Revision”). The water resources within India are unevenly distributed and therefore frequent cases of droughts and floods are reported in various parts of the country (Kirby, 1999; Mahapatra, 2012; Nambiar, 2016). In such cases, conservation andclose monitoring of these water resources becomes unavoidable. Due to the country’s diverse geographical characteristics, sometimes field survey becomes difficult in remote areas like parts of the Himalayas and thus remote sensing techniques have been frequently used (Philip and Mazari, 2000; Jain et al., 2012; Hakeem & Sankar, 2013). Remote sensing has provided a cost-effective and an efficient way of studying land covers like water bodies over large areas across the globe without the need for any physical contact with the target object (Xu, H. 2006; Verpoorter et al., 2012; Abd - Almajied, 2015; Acharya et al., 2016; Cre´taux et al., 2016; Gao et al., 2016(a,b)).

In Optical Remote Sensing, sensors sense the amount of radiance, i.e., the amount of light the sensor sees from the object being observed and measures the reflection of sunlight. Sunlight is the portion of the electromagnetic spectrum which constitutes of the visible, infra-red regions and ultra violet regions. Optical remote sensors mounted on earth observation satellites are designed and constructed to measure sunlight in visible and infra-red regions. Images obtained from the visible region (Red, Green, Blue) resemble those seen by our naked eyes. This means, the vegetation appears to be green and the water appears to be blue in color. Such an image is technically known as a true color composite (Lillesand & Kiefer, 2002). The information obtained from these images can sometimes be misguiding, for example, the snow and clouds both appear to be white and therefore cannot be distinguished without prior knowledge (Bian et al., 2016), similarly ponds and lakes with impurities and algal growth appear green in color just like vegetation (Ji et al., 2015). Thus, infrared radiations were also used. Water absorbs most of the infrared radiations (mostly near and mid infrared) and therefore appears dark in images obtained in this region while vegetation appears bright (Palmer & Williams, 1974; Xu, 2006). Therefore, distinguishing one from the other becomes easier. Yet, there are instances when shadows of trees, buildings, clouds, mountains, hills, etc. are mistaken to be parts of water bodies or small water bodies altogether (Verpoorter et al., 2012; Acharya et al., 2016; Cre´taux et al., 2016; Gao et al., 2016(a,b)). Apart from the visible and infrared regions of the electromagnetic spectrum, the microwave region is also exploited for monitoring water bodies (Kuang et al., 2011; Kaplan & Avdan, 2017). This paper attempts at reviewing remote sensing and GIS (Geographical Information System) techniques which have been used in India by various researchers to calculate the numbers and areas of water bodies. It tries to identify the gaps by comparing these with the state of the art technologies highlighted by (Thiruvengadachari et al., 1980; Navatha et al., 2011; Jawak et al., 2015; Karpatne et al., 2016). Finally, this review paper attempts to discuss the reasons behind such gaps and the challenges that may have to be faced in bridging these.

II. PROBLEMS AND CHALLENGES BEING FACED GLOBALLY

Several algorithms and methodologies have been developed to extract rivers, lakes, ponds and other water bodies from the remote sensing data so obtained. It can thus be concluded that each method and each algorithm have its own advantages and disadvantages which are dynamic in nature. It is not necessary that one method which has been successfully applied in a region could be reproduced in another region for the same type of study. This uncertainty is due to the variability in environmental and geological characteristics, complex topographies, availability of data and its quality (existence of noise and cloud cover). It is also worth noting that no single method can yield the desired results. Many new techniques incorporate more than one method in different sequences to increase the spatial and spectral resolutions of data and to overcome the drawbacks of misclassification due to mixing of water pixels with that of snow, barren land, vegetation, built-up, shadows, and noise. The existence of shadows and noise makes it difficult to extract water bodies less than 1 hectare (Verpooter et al., 2012). This has created a gap in the database of ponds and lakes as the importance of small water bodies has been realized. Moreover, lack of a reliable global mapping and monitoring of water bodies has also posed as a major challenge. Karpatne et al. (2016) have identified this challenge by demonstrating the difficulties faced in applying a classification model that has been trained in distinguishing between a lake and its surrounding land, to another lake having different land and water characteristics. They selected 180 lakes from across the globe having different characteristic features of land and water (like different soils, moisture contents, quality of water, impurities in lakes, vegetation type, different elevations and terrains, etc.). They, then, compared the heterogeneity in space and time for a lake by using, on one hand, local training sets for the classification model, local to the lake and on the other training sets from all the diverse 180 lakes. The latter resulted in better distinction between water and land and one was able to observe the change (reduction, in this case) in the lake over a period which was otherwise not detected by the local model.

III. REVIEW OF EXISTING REMOTE SENSING AND GIS TECHNIQUES USED IN INDIA FOR MAPPING WATER BODIES

The mapping of Indian water bodies has been carried out by ISRO, NRSC along with other research institutes (Suresh et al., 2013). The advantages of optical remote sensing as well as microwave remote sensing have been exploited to monitor and map wetlands, urban and rural ponds and lakes, glacial lakes, etc. across the country. Existing approaches have been categorized based on the following (adopted fromKarpatneet al., 2016):

1) Based on type of input data

The very first mapping of wetlands in India was carried out by ISRO using LISS I and LISS II sensors which were mounted on IRS 1A and 1B satellites (Thiruvengadachari et al, 1980). To detect a water body reliably, its dimensions should be twice the dimensions of a pixel (Singh et al, 2014). Thus, sensors with finer spatial, spectral and radiometric, and temporal resolutions like LISS III (mounted on IRS 1C, 1D), MSS, TM, ETM, ETM+, OLI (mounted on Landsat series of satellites), ASTER (TERRA), AWiFS (on ResourceSat 1), OCEANSAT 1 (IRS P4), etc. have been utilized (Table 1). Coarser datasets of MODIS have even been fused with IR Band 3 of finer spatial resolution IRS LISS III using RGB-HIS algorithm to map wetlands of Greater Bangalore (Ramachandra & Kumar, 2008). Such data fusion provides a resultant image with high spatial resolution of one component image while keeping the spectral and radiometric resolutions of the other component image intact. However, optical remote sensing datasets meet with drawbacks such as cloud cover, only day-time images, and inability to distinguish between water, snow and ice. Such limitations are overcome by radar datasets (Srivastava et al., 2007). The synthetic aperture radar datasets obtained from MRS sensor on RISAT-1 have been used successfully to delineate water bodies (Suresh et al, 2013). From Table 1.a and 1.b, one can conclude that optical remote sensors have been used more extensively than microwave remote sensors because of their low costs (Karpatne et al., 2016).

2) Based on type of application

Many remote sensing techniques have been applied in mapping and monitoring surface water bodies like ponds, lakes, reservoirs, glacial lakes, watersheds, wetlands, etc. Table 2 categorizes the existing water monitoring approaches in India based on the type of water body they attempt at monitoring.

Input Dataset	Sensor	Operational Time	Spatial Resolution	Spectral Bands	Spectral Domain	References
Landsat-1,2,3	MSS	1972-1983	80m	4	VNIR	Ramachandra & Kumar (2008), M.V. & Ramachandra (2012), Reddy et al., (2016)
Landsat-4,5	TM	1982-1999	30m 120m	6 1	VNIR, SWIR TIR	Sharma et al. (1989), Ramachandra & Kumar (2008), Navatha et al.(2011), M.V. & Ramachandra (2012), Balasaheb Jamadar (2013), Kavyashree & Ramesh (2016)
IRS-1A,1B	LISS-I LISS-II	1988--1999	72.5m 36.25m	4 4	VNIR VNIR	Radhakrishnan & L. Elango (1996), Chopra, Verma and Sharma (2001), Sarkar & Sanjay(2008)
IRS-1C,1D	PAN LISS III	1995-present	5.8m 23.5m 70m	1 3 1	VNIR VNIR SWIR	Philip & Mazari (2000), Pattanaik & Reddy (2007), Humayun & Gowhar (2008), Jain et al. (2012), Kumar et al. (n.d.)
Landsat-7	ETM+	1999-present	15m 30m 60m	1 6 1	VNIR VNIR TIR	Balasaheb Jamadar (2013), Mishra & Rama Chandra Prasad (2015)
Terra	ASTER MODIS	1999-present 1999-present	15m 30m 90m 250m 500m 1000m	3 6 5 2 5 29	VNIR SWIR TIR VIS NIR SWIR/ MWIR LWIR	Ramachandra & Kumar (2008), Jain et al. (2012), Kumar et al. (n.d.)
Resourcesat-1	LISS III LISS IV AWiFS	2003- 2008	5.8m 23.5m 56m	4	VNIR, SWIR	Navatha et al. (2011), Jain et al. (2012), Hakeem & Sankar (2013), Sharma et al. (2014), Singh et al. (2014), Reddy et al. (2016), Ganesh et al. (2017),
Resourcesat-2	LISS III AWiFS		23m 56m			Ganesh et al. (2017), Hakeem & Sankar (2013)
Landsat-8	OLI	2013-present	15m 30m 100m	1 8 2	VNIR VNIR, SWIR TIR	Hari & N Bidyarani (2017)

Table 1.a
Table of references categorizing the existing water monitoring/mapping approaches in India based on type of input data used.

Microwave Remote Sensing Satellites &Sensors	
Multiparametric SAR sensors (ERS ½, Multi-incidence angle RADARSAT-1, Multi-incidence & Multi- polarized ENVISAT-1 ASAR)	Srivastava et al. (2001)
OCEANSAT-1/IRS-P4	Balasaheb Jamadar (2013)
RISAT-1 (MRS dual polarized H-H, H-V) 18m spatial resolution	Mishra et al. (2014), Ganesh et al. (2017)

Table 1.b
Table of references categorizing the existing water monitoring/mapping approaches in India based on type of input data used.

Waterbody Type	References
Lakes & Reservoirs	Radhakrishnan & Elango (1996), Sharma et al. (1989), Philip & Mazari (2000), Chopra et al. (2001), Pattanaik & Reddy (2007), Subramaniam et al. (2011), M.V. & Ramachandra (2012), Balasaheb Jamadar (2013), Sharma et al. (2014), Singh et al. (2014), Mishra and Prasad (2015), Ganesh et al. (2017), Hari & N Bidyarani (2017), Imdad & Agha (2017)
Ponds & Watersheds	Manju et al. (2005), Ramachandra & Kumar (2008), Ray et al. (2012), M.V. & Ramachandra (2012), Mishra et al. (2014), Sharma et al. (2014), Ganesh et al. (2017), Hari & N Bidyarani (2017), Imdad & Agha (2017)
Glacial Lakes	Jain et al.(2012), Hakeem & Sankar (2013)
Rivers and river basins	Hazra & Bhattacharya (1999), Hakeem & Sankar (2013), Mishra et al. (2014),Sharma et al. (2014), Mishra and Prasad (2015), Imdad & Agha (2017),
Wetlands	Srivastava et al. (2001), Manju et al. (2005), Pattanaik & Reddy (2007), Ramachandra & Kumar (2008), Sarkar & Sanjay (2008), Subramaniam et al. (2011), Navatha et al. (2011), Ray et al. (2012), Mishra et al. (2014), Sharma et al. (2014), Singh et al.(2014), Reddy et al.(2016), Imdad & Agha (2017)

Table 2
Categorizing existing water monitoring approaches in India based on the type of water body they attempt at monitoring

3) Based on type of algorithm

Based on the type of algorithm used for mapping land and water bodies using remote sensing datasets, the existing approaches for extracting water bodies can be categorized as follows (Karpatne et al., 2016):

1. Manual Annotation Based

Manual approaches like manual digitizing (Pattanaik & Reddy, 2007; Hakeem et al., 2013), visual interpretation of False Color composites of images using visual interpretation keys like tone, shape, size, pattern, texture, shadow, and association were the earliest methods used to extract water bodies from satellite images (Sharma et al., 1989; Hazra & Bhattacharya,1999; Chopra et al., 2001; Navatha et al., 2011). Infact, photo-interpretation was preferred over digital analysis back in India in the late 1980's because digital analysis was expensive and available at a few places (Sharma et al., 1989). Advantages include high estimation accuracy and low costs, while disadvantages are time-consuming, laborious, lack of reproducibility (Nath & Deb, 2010; Subramaniam et al., 2011; Jawak et al., 2015; Karpatne et al., 2016). Thus, manual methods would be less time-consuming and efficient if applied to single water body studies (Pattanaik & Reddy, 2007) or local-scale areas (Table 3).

Region of Study	References
Ansupa Lake, Orissa(now Odisha)	Pattanaik & Reddy (2007)
Delhi	M.V. & Ramachandra (2012)
Ganga-Padma River	Hazra & Bhattacharya (1999)
GreaterBangalore, Karnataka	Ramachandra & Kumar (2008)
Hydrabad city, Andhra Pradesh (but now in Telangana)	Mishra and Prasad (2015)
Keoladeo Ghana National Park, Bharatpur	Srivastava et al. (2001)
Mumbai, Maharashtra	M.V. & Ramachandra (2012)
Pulicat, Kalveli	Radhakrishnan & Elango (1996)
and lakes along the Vedaranniyam coast	
Srinagar, Jammu and Kashmir	Humayun & Gowhar (2008)
Tso Kar & Startsapuk Tso Lakes basins, Indus Suture of Northwestern Himalayas	Philip and Mazari (2000)
Tungbhadra Reservoir, Karnataka	Subramaniam et al. (2011)

Table 3
Summary of approaches that have been applied in different regions of India at a local scale arranged in alphabetical order of the name of the study region.

2. Unsupervised Learning

Image enhancement techniques of decorrelation stretching, spatial filtering and HIS transformations using FUSE and FUSEPCT have been applied on IRS 1C datasets to study shrinking of Tso Kar and Startsapuk Tso Lakes, situated in the proximity of Indus Suture zone of northwestern Himalayas (Philip and Mazari, 2000). Desirable features were extracted from the arid, inaccessible and complex terrain of this region of Northwestern Himalayas. Also, data fusion using PCA transformation and RGB-HIS algorithm was applied in the study of Ramachandra & Kumar (2008). Density slicing, and single-band thresholding have been applied in the earlier studies on water body mapping as these methods are quick and easy to perform and do not require any prior knowledge (Manju et al., 2005; Ray et al., 2012). However, these classification methods could not prevent mixing of pixels of water with those having similar spectral reflectance like saturated soil and shadows (Nath & Deb, 2010; Subramaniam et al., 2011; Jawak et al., 2015; Karpatne et al., 2016). Another problem is that while deep water bodies are clearly represented in imagery, shallow water bodies could be mistaken for soil thus making identification of water pixels at soil-water interface difficult (Sarkar & Sanjay, 2008). Thus, utilization of multiple bands was considered. Many studies have used non-linear transformation of multiple optical bands, called water indices, to enhance the water pixels and suppress the background. The most frequently used indices used are NDVI, NDWI, MNDWI, NDPI and NDTI (Sarkar & Sanjay, 2008; Jain et al., 2012; Ray et al., 2012; Sharma et al., 2014; Kavyashree & Ramesh, 2016; Reddy et al., 2016). Hari & N Bidyarani (2017) have performed NIR-RED model on Landsat 8 OLI image of Andhra Pradesh. NDWI performed quite well in delineating the water bodies in Harike Wetland, Punjab (Sarkar & Sanjay, 2008). However, the selection of threshold values is still based on visual interpretation and thus lacks robustness when applied to large regions (Nath & Deb, 2010; Subramaniam et al., 2011; Jawak et al., 2015; Karpatne et al., 2016). Other automatic unsupervised learning methods like k-means (Ramachandra & Kumar, 2008) and iso-data (Kavyashree & Ramesh, 2016) clustering algorithms have been applied.

3. Supervised learning

The potential of supervised learning depends upon the choice of algorithm and the adequacy of representative training data sets. Procuring authentic and adequate data sets at global level and frequent time intervals is time-consuming and expensive. Therefore, such approaches are generally suitable to local to regional scales and at infrequent time-steps (Karpatne et al., 2016). In the year 1980, an attempt was made to develop a regression model using Landsat datasets for estimating volume and areal extent of 17 reservoirs in Tamil Nadu (Radhakrishnan & Elango, 1996). Maximum Likelihood classifiers (Ramachandra & Kumar, 2008; Singh et al., 2014; Imdad & Agha, 2017; Kumar et al. (n.d.)), non-parametric classifier SVM (Support Vector Machine) (Dixit et al., 2017) to classify various land features like water bodies using Risat-1 dual polarimetric data (Mishra et al., 2014) and ANN (Artificial Neural Network) Perceptron Model (Mishra and Prasad, 2015) have been useful in water body mapping studies. These have performed better than the unsupervised methods. Table 4 enlists the different study areas of the above-mentioned studies at a regional scale.

Study Region	References
1:2,50,000	By ISRO in 1992-93 as cited in Suresh et al. (2013)
Alaknanda Valley, Himalayan Basin	Jain et al. (2012)
Central Uttar Pradesh (part of Lucknow, Raebarilly, Barabanki and Unnao district)	Singh et al. (2014)
East Champaran district, Bihar	Manju et al. (2005)
Great Rann of Kachchh wetland	Reddy et al. (2016)
Harike Wetland, Punjab	Hazra & Bhattacharya (1999),, Sarkar & Sanjay (2008)
Himachal Pradesh	Sharma et al. (2014)
Himalayan region of Indian river basins	Hakeem & Sankar (2013)
Indo-Gangetic Plains, Bihar	Subramaniam et al. (2011)
Jodhpur district, Rajasthan	Sharma et al. (1989)
Kolar district, Karnataka	Kumar et al. (n.d.)
Nadia District, West Bengal	Ray et al. (2012)
Prakasam District, Andhra Pradesh	Hari & N Bidyarani (2017)
Sirohi district, Rajasthan	Navatha et al. (2011)
Tamil Nadu	Radhakrishnan & Elango (1996)
Varanasi district, Uttar Pradesh	Mishra et al. (2014)
West coast of Karnataka from Nethravathi River mouth to Sharavathi River	Kavyashree & Ramesh (2016)
West Godavari District, Andhra Pradesh	Ganesh et al. (2017)

Table 4
Summary of approaches that have been applied in different regions of India at a local scale arranged in alphabetical order of the name of the study region.

4. Hybrid

The above mentioned supervised and unsupervised classification techniques have been found to be scene specific. These require some sort of manual intervention which is found to be highly subjective. Moreover, most of the spectral indices use only two spectral bands to extract features while contribution from other bands is left behind (Subramaniam et al., 2011). Therefore, Subramaniam et al. (2011) has attempted to develop an automated hierarchical multi-logic algorithm using all four bands of AWiFS sensors (mounted on Resourcesat-1) and proves its supremacy by comparing it with standard algorithm for temporal change monitoring of surface water area and volume of Tungabhadra Reservoir, India. The results show that the automated feature extraction algorithm was able to eliminate the cloud and cloud shadow pixels effectively. In case of NDWI (Normalized Difference Water Index) method, few cloud shadow pixels were identified as water pixels, while in the case of MNDWI (Modified Normalized Difference Water Index), few cloud pixels were included in the water pixels. Moreover, the results are comparable to those of hybrid digital-visual interpretation technique (Sharma et al., 1989; Hazra & Bhattacharya, 1999; Chopra et al., 2001; Navatha et al., 2011; Subramaniam et al., 2011). Many studies like have applied both supervised and unsupervised classifications (Ramachandra & Kumar, 2008; Jain et al., 2012; Sharma et al., 2014; Reddy et al., 2016; Ganesh et al., 2017; Kumar et al. (n.d)). Kumar et al. (n.d.) have assessed the suitability of constrained linear spectral unmixing technique for regional land cover mapping on MODIS data and has found that the method is successful in solving the problem of mixed pixels.

4) Software used

Various software packages have been utilized by the above-mentioned studies. Digital image processing has been mostly performed in ERDAS IMAGINE 2011 (Manju et al., 2005; Pattanaik & Reddy, 2007; Ray et al., 2012; Kavyashree & Ramesh, 2016) while GIS analysis has been conducted in either ILWIS (Sarkar & Sanjay, 2008) or ARCGIS 9.3 (Ray et al., 2012; Kavyashree & Ramesh, 2016; Ramachandra & Kumar, 2008).

DISCUSSIONS AND CONCLUSION

India is a developing country with a vast geographical area, second largest population and unevenly distributed natural resources. Therefore, seasonal mapping of land covered by water resources is prohibitive with data from commercial sensors with limited spatial coverage (Kumar et al. (n.d.)). For example, in Sarkar & Sanjay (2008)'s study on Harike Wetland, the satellite data used for 1990 was of post monsoon month while that used for 1993 and 2003 was of pre-monsoon month. This mismatch displayed confusing results of lesser area covered by water bodies in 1990 for Harike Wetland than that in 1993 and 2003. Thus, unavailability of adequate and appropriate data sets can pose problems despite the application of the most appropriate classification techniques. Moreover, microwave remote sensing for creating water bodies inventories has not been exploited much mainly because of the economic constraints (Suresh et al., 2013). The study of Keoladeo Ghana National park in Bharatpur has shown that radar data is 3 to 4 times better in delineating extent of open water (Srivastava et al., 2007). As such there is huge potential to explore and exploit the different capabilities of radar data for wetland research (Suresh et al., 2013). Out of all the Indian literatures cited in the review paper, none has explored the use of hyper spectral images for extracting surface water bodies in India. Also, a much recent technique of object-based classification (Baatz & Schäpe, 2010; Kaplan & Avdan, 2017), either supervised or unsupervised, too has not been used much in India for the sole purpose of water extraction. The reason behind this could be the limited access to commercially available high-resolution data like SPOT, QUICKBIRD, WORLDVIEW, etc because object-based classification works best with high resolution images (Baatz & Schäpe, 2010; Kaplan & Avdan, 2017). High resolution images provided by Google Earth (Tilahunl & Islam, 2015; Malarvizhi et al., 2016; Imdad & Agha, 2017) have not been utilized for mapping water bodies. Thus, for developing countries like India, it could prove to be an asset if object-based classification techniques could be applied on high resolution images freely accessible on Google Earth for spatial-temporal analysis of rivers, lakes, ponds, and reservoirs over large areas.

REFERENCES

[1] Du, N., Ottens, H., & Sliuzas, R, "Spatial impact of urban expansion on surface water bodies—A case study of Wuhan, China," Landscape and Urban Planning, 94(3-4), pp. 175-185, 2010. doi: 10.1016/j.landurbplan.2009.10.002.

[2] "World Population Prospects: The 2017 Revision". ESA.UN.org (custom data acquired via website). United Nations Department of Economic and Social Affairs, Population Division. Retrieved 10 September 2017.

[3] Kirby, Alex. "World Water Shortage Threatens Harvests." BBC World News. N.p., 7 February 1999.

[4] Mahapatra, Richard. "2012 a Drought Year, Accepts Government." N.p., 2012. Web. 30 Nov. 2017.

[5] Nambiar, Nisha. "Drought Years May Become More Frequent in India, Says Study." The Indian Express. N.p., 31 May 2016. Web. 30 Nov. 2017.

[6] Philip, G. and Mazari, R., "Shrinking lake basins in the proximity of the Indus Suture Zone of northwestern Himalaya: A case study of Tso Kar and Startsapuk Tso using 1RS-1C data," International Journal of Remote Sensing, 21(16), pp. 2973-2984, 2000.

[7] Jain, S., Lohani, A., Singh, R., Chaudhary, A. and Thakural, L, "Glacial lakes and glacial lake outburst flood in a Himalayan basin using remote sensing and GIS," Natural Hazards, 62(3), pp.887-899, 2012.

[8] Hakeem Abdul K. and Sankar Siva E, "Inventory and Monitoring of Glacial Lakes/Water Bodies in the Himalayan Region of Indian River Basins, "Technical Document. Water Resources Monitoring & Assessment Division, Water Resources Group, Remote Sensing Applications, Area National Remote Sensing Centre ISRO, Dept. of Space. Govt. of India, Hyderabad, 2013.

[9] Xu, H., "Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery," International Journal of Remote Sensing,27(14), pp. 3025-3033, 2006. doi:10.1080/01431160600589179

[10] Verpoorter, C., Kutser, T., and Tranvik, L., "Automated mapping of waterbodies using Landsat Multispectral," Data.Limnol. Oceanogr. Methods 10: pp. 1037–1050, 2012, 2012.

[11] Abd-Almajied, I. M., "Predicting water depth of lake using remote sensing," Iraqi Journal of Science, Vol 56, No.2A, pp.1208-1215, 2015.

[12] Acharya, T., Lee, D., Yang, I. and Lee, J., "Identification of Water Bodies in a Landsat 8 OLI Image Using a J48 Decision Tree," Sensors, 16(7), p.1075, 2016.

[13] Crétaux, J., Abarca-del-Río, R., Bergé-Nguyen, M., Arsen, A., Drolon, V., Clos, G. and Maisongrande, P, "Lake Volume Monitoring from Space," Surveys in Geophysics, 37(2), pp.269-305, 2016.

[14] Gao, H., Wang, L., Jing, L. and Xu, J., "An effective modified water extraction method for Landsat-8 OLI imagery of mountainous plateau regions," IOP Conference Series: Earth and Environmental Science, 34, p.012010, 2016a.

[15] Gao, H., Zhang, S., Durand, M. and Lee, H., "Satellite Remote Sensing of Lakes and Wetlands," Hydrologic Remote Sensing, pp.57-72, 2016b.

[16] Lillesand, T.M., and Kiefer, R., Remote sensing and image interpretation (4th ed.). New York: Wiley, 2002.

[17] Bian, J., Li, A., Liu, Q., & Huang, C., "Cloud and Snow Discrimination for CCD Images of HJ-1A/B Constellation Based on Spectral Signature and Spatio-Temporal Context," Remote Sensing,8(1), 31, 2016. doi:10.3390/rs8010031.

[18] Ji, L., Gong, P., Geng, X., & Zhao, Y., "Improving the Accuracy of the Water Surface Cover Type in the 30 m FROM-GLC Product," Remote Sensing,7(10), pp. 13507-13527, 2015. doi:10.3390/rs71013507.

[19] Palmer, K. F., & Williams, D., "Optical properties of water in the near infrared. Journal of the Optical Society of America," 64(8), p.1107, 1974. doi:10.1364/josa.64.001107

[20] Kuang, G., He, Z. and Li, J., "Detecting Water Bodies on RADARSAT Imagery," GEOMATICA, 65(1), pp.15-25, 2011.

[21] Kaplan, G., and Avdan, U., "Object-based water body extraction model using Sentinel-2 satellite imagery," European Journal of Remote Sensing, 50:1:143-150, 2017. doi: 10.1080/22797254.2017.1297540.

[22] Thiruvengadachari, S., Rao, K.R., and Rao, P.S., "Surface water inventory through satellite sensing," Journal of the Water Resources Planning and Management Division, ASCE Volume 106, Issue WR2, Proc. Paper, 15563, pp. 493-502, 1980.

[23] Navatha, K., Pattanaik, C. and Reddy, C., "Assessment of wetland dynamics in Sirohi district of Rajasthan, India using remote sensing and GIS techniques," Journal of Wetlands Ecology, 5(0), 2011.

[24] Jawak, S., Kulkarni, K. and Luis, A., "A Review on Extraction of Lakes from Remotely Sensed Optical Satellite Data with a Special Focus on Cryospheric Lakes," Advances in Remote Sensing, 04(03), pp.196-213, 2015.

[25] Karpatne, A., Khandelwal, A., Chen, X., Mithal, V., Faghmous, J. and Kumar, V., "Global Monitoring of Inland Water Dynamics: State-of-the-Art, Challenges, and Opportunities," Computational Sustainability, pp.121-147, 2016.

[26] Suresh, B., Muthyam, S., and Rao, V., "Inventory, mapping and monitoring of Surface water bodies," NNRMS Bulletin, 2013.

[27] Singh, A., Kunwar, P., and Naithani, S., "Identification of Wetlands in Parts of Central Uttar Pradesh Using Geo-informatics," In book: Current Trends in Environmental Resource Management, Chapter: Identification of Wetlands in Parts of Central Uttar Pradesh Using Geo-informatics, Publisher: Gaura Books India Pvt. Ltd, New Delhi, Editors: Suneet Naithani, Girdhar Joshi and Siba Sankar Mohanti, 2014.

[28] Ramachandra, T.V., and Kumar, U., "Wetlands of Greater Bangalore, India: Automatic Delineation through Pattern Classifiers," Electronic Green Journal, Issue 26, Spring 2008 ISSN: 1076-7975, 2008.

[29] Srivastava,H.S., Patel,P.,Prasad,S.N., and Sharma Y., "Potential applications of multi-parametric synthetic aperture radar (SAR) data in wetland inventory: a case study of keoladeo national park (a world heritage and Ramsar Site)," Proceedings: Taal 2007: the 12Th World Lake Conference, pp. 1862-1879, 2007, Bharatpur, India.

[30] M V, Sowmyashree, and T V Ramachandra, "Temporal Analysis of Water Bodies in Mega Cities of India," LAKE 2012: National Conference on Conservation and Management of Wetland Ecosystems, 2012.

[31] Reddy, C., Pasha, S. and Jha, C., "Spatio-temporal changes associated with natural and anthropogenic factors in wetlands of Great Rann of Kachchh, India.," Journal of Coastal Conservation, 20(2), pp.145-155, 2016.

[32] Sharma, K., Singh, S., Singh, N. and Kalla, A., "Role of satellite remote sensing for monitoring of surface water resources in an arid environment," Hydrological Sciences Journal, 34(5), pp.531-537, 1989.

[33] Balasaheb Jamadar, B., "Review on Study of Lake Water Using Multi Sensor Remote Sensing Data," IOSR Journal of Mechanical and Civil Engineering, 6(5), pp.50-52, 2013.

[34] Kavyashree, M., and Ramesh, H., "Wetland mapping and change detection using remote sensing and GIS," International Journal of Engineering Science, 6(8), 2356, 2016.

[35] Radhakrishnan, N. and Elango, L., "Lake environments along the coast of Tamilnadu, India, delineated by IRS-IA satellite data," Lakes and Reservoirs: Research and Management, 2(3-4), pp.163-167, 1996.

[36] Chopra, R., Verma, V. and Sharma, P., "Mapping, monitoring and conservation of Harike wetland ecosystem, Punjab, India, through remote sensing," International Journal of Remote Sensing, 22(1), pp.89-98, 2001.

[37] Sarkar, A., and Sanjay K. J., "Using Remote Sensing Data to Study Wetland Dynamics–A Case Study of Harike Wetland," Proceedings of Taal2007: The 12th World Lake Conference, pp. 680-684, 2008. Edited by M. Sengupta and R. Dalwani.

[38] Pattanaik C, and Reddy CS., "Need for the conservation of wetland ecosystems: A case study of Ansupa lake (Orissa, India) using remote sensing-based data." Natl AcadSci Lett 30(5&6), pp. 161-164, 2007.

[39] Humayun, Rashid, and Gowhar, Naseem., "Quantification of loss in spatial extent of lakes and wetlands in the suburbs of Srinagar City using geospatial approach," Proceedings of Taal2007: The 12th World Lake Conference, 2008: 653-658, 2008.

[40] Kumar, U., Kerle, N. and Ramachandra, T., "Constrained Linear Spectral Unmixing Technique for Regional Land Cover Mapping Using MODIS Data," Innovations and Advanced Techniques in Systems, Computing Sciences and Software Engineering, pp.416-423, (n.d.).

[41] Mishra, K. and Prasad, P., "Automatic Extraction of Water Bodies from Landsat Imagery Using Perceptron Model," Journal of Computational Environmental Sciences, 2015, pp.1-9, 2015.

[42] Sharma, A. Panigrahy S., Singh T. S, Patel J. G. and Tanwar H., "Wetland information system using remote sensing and GIS in Himachal Pradesh," India. Asian J. Geoinform., 14 (4), pp. 13-22, 2014.

[43] Ganesh, K.M., Rao, R.S., Muthy, Y.S.S.R, and Raju, P.A.R.K., "Assessment of surface water bodies using automated algorithm, West Godavari district, Andhra

Pradesh, India," IJCSEIERD, ISSN (P): 2249-6866; ISSN (E): 2249-7978 Vol. 7, Issue 5, pp. 89-94, 2017.

[44] Hari N & N Bidyarani Chanu, "Extraction of Surface Water Bodies from Landsat 8 of Prakasam district of Andhra Pradesh," International Journal of Agricultural Science and Research (IJASR), ISSN(P): 2250-0057; ISSN(E): 2321-0087, Vol. 7, Issue 3, pp. 149-154, 2017.

[45] Mishra, V.N., Kumar, P., Gupta, D.K., and Prasad, R., "Classification of various land features using RISAT-1 dual polarimetric data," Int Arch Photogramm Remote Sens Spat Inf Sci XL-8, pp. 833–837, 2014.

[46] Subramaniam, S., Suresh Babu, A. and Roy, P., "Automated Water Spread Mapping Using ResourceSat-1 AWiFS Data for Water Bodies," Information System. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 4(1), pp.205-215, 2011.

[47] Imdad, Kashif, and Agha Mansoor Khan., "Impact of Global Warming on Wetlands: A Case Study of Lucknow District," SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, vol. 9, no. 01, 2017. doi:10.18090/samriddhi.v9i01.8334.

[48] Manju, G., Chowdary, V., Srivastava, Y., Selvamani, S., Jeyaram, A. and Adiga, S., "Mapping and characterization of inland wetlands using remote sensing and GIS," Journal of the Indian Society of Remote Sensing, 33(1), pp.51-61, 2005.

[49] Ray, R., Mandal, S., Dhara, A., "Characterization and mapping of inland wetland: A case study on selected bils on nadia district," Int. J. Sci. Res. Pub., 2012.

[50] Hazra, P.B. & B. Bhattacharya., "River shifting and bank failure problem of Ganga- Padma in West Bengal," As cited in: Prasad S. N., et al. "Conservation of wetlands of India – a review", Tropical Ecology, 43 (1), pp. 173-186, 1999.

[51] Nath, R.K., and Deb, S., "Water-body area extraction from high resolution satellite images-an introduction, review, and comparison." Int. J. Image Process. (IJIP), 3, pp. 265-384, 2010.

[52] Dixit, A., Hedge, N., and Reddy, B. Eswar, "Texture Feature Based Satellite Image Classification Scheme Using SVM," International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 12, Number 13, pp. 3996-4003, 2017.

[53] Baatz, M., and Schäpe, A.," Multiresolution segmentation: An optimization approach for high quality multiscale image segmentation,"AGIT-Symposium Salzburg 2000: 12–23, 2010.

[54] Tilahunl, A., and Islam, Z.., "Google Earth for land use land cover change detection in the case of Gish Abbay Sekela, West Gojjam, Amhara state, Ethiopia," International Journal of Advancement in Remote Sensing, GIS and Geography, IJARSGG Vol.3, No.2: 80-87, 2015.

[55] Malarvizhi, K., Vasantha Kumar, S., and Porchelvan, P., "Use of High Resolution Google Earth Satellite Imagery in Landuse Map Preparation for Urban Related Applications," International Conference on Emerging Trends in Engineering, Science and Technology (ICETEST- 2015), Procedia Technology 24: 1835 – 1842, 2016.

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