

# Assessment of the Temporal Variations of Surface Water Bodies in and around Chennai using Landsat Imagery

Nikita Roy Mukherjee<sup>1</sup> and Christopher Samuel<sup>2\*</sup>

<sup>1</sup>Remote Sensing and Geographic Information System, SRM University, Kattankulathur – 603 203, Kanchipuram District, Tamil Nadu, India

<sup>2</sup>Department of Civil Engineering, SRM University, Kattankulathur – 603 203, Kanchipuram District, Tamil Nadu, India; christophersamuel.g@ktr.srmuniv.ac.in

## Abstract

Urban India is witnessing a rapid growth that has an impact on the fate of water bodies. Chennai, one of the fastest growing metropolitan cities in India, is not an exception to this urbanization process. Chennai's precious water resources are under severe stress. Further, the recent, 100-year flood disaster that occurred in November–December 2015 over Chennai has had tragic consequences on its population and has brought back the focus on its water bodies. Remote sensing combined with GIS techniques enable accurate spatiotemporal change detection of natural resources. Landsat and multispectral imageries provide reliable and accurate data for the detection of changes in the areal extents of surface water bodies. Spatiotemporal change analyses on the surface water bodies in Chennai and its surrounding areas were conducted through water extraction techniques by using indexes, such as WRI, NDWI and MNDWI using GIS software. The changes in the surface water bodies were estimated by analyzing and using Landsat images for the pre- and post-monsoon periods of the years 1977–78, 1988–89, 1997–98, 2006–07 and 2015–16. The changes and their variations in the indexes and the interpretation of these changes are discussed. NDWI is most suitable for extracting surface water bodies. WRI and MNDWI can be used for the extraction of surface water bodies only from those satellite imageries that have the MIR band. However, MNDWI is suitable for inundated areas within a largely urban-covered region. Hence, urban planners can utilize these results for better urban planning and flood-disaster management.

**Keywords:** Change Detection, Chennai, Disaster Management, Landsat Imagery, MNDWI, NDWI, Remote Sensing and GIS, Surface Water Bodies, Urban Planning, Water Extraction Techniques, WRI

## 1. Introduction

Water resources are under stress globally and this stress has reached a stage of crisis in many developing countries. The surface water bodies are under severe stress caused by anthropogenic activities such as intensive urban growth and rapid industrialization. Physical changes in the urban environment degrade the quality of the water bodies.

The Chennai Metropolitan Area (CMA) is home to a network of rivers, ponds and lakes. These surface water bodies have since time immemorial served as sources for the irrigation and domestic needs of the population around them. Water resources management, land use

and hydrology are important for human beings and are critical for their survival<sup>1</sup>.

Remote sensing combined with GIS techniques enable accurate spatiotemporal change detection of natural resources. Landsat and multispectral imageries provide reliable and accurate data for the detection of changes in the areal extents of surface water bodies.

Spatiotemporal change analyses on the surface water bodies in Chennai and its surrounding areas were conducted through water extraction techniques by using indexes, such as WRI, NDWI and MNDWI by using GIS software. The changes in the surface water bodies were estimated by analyzing and using Landsat images for the

\* Author for correspondence

pre- and post-monsoon periods of the years 1977–78, 1988–89, 1997–98, 2006–07 and 2015–16. The changes and their variations in the indexes and the interpretation of these changes are discussed. Urban planners can utilize these results for better planning and disaster management.

## 2. Materials and Methods

### 2.1 Study Area

Chennai city is one of the largest urban agglomerations in India. The areal extent of Chennai Metropolitan Area (CMA) is 1189 km<sup>2</sup> (Figure 1)<sup>2</sup>. The CMA area has a longitudinal extension of 80° 1' 16" E to 80° 19' 18" E and a latitudinal extension of 12° 51' 41" N to 13° 15' 49" N approximately (Figure 1). It has an average elevation of around 6.7 m from the mean sea level and its highest elevation is 60 m. Chennai contains a diverse population of ethnoreligious communities. The CMA covers three districts of the state of Tamil Nadu: Chennai District, part of Tiruvallur District and part of Kanchipuram District. The district-wise details of the areal extents of the CMA is given in Table 1<sup>2</sup>.

Chennai city is drained by two meandering rivers, the Cooum River in the central region and the Adyar River in the southern region. Both the rivers are heavily polluted with effluents from commercial and domestic sources. The Buckingham canal travels parallel to the coast linking the two rivers, Adyar and Cooum. The OtteriNullah an east–west stream runs through Buckingham canal. The Red Hills, Cholavaram and Chembarambakkam lakes supply Chennai with potable water<sup>3</sup>.

There are 124 tanks spread throughout the CMA area

with a total water-spread area of 63.8 km<sup>2</sup> approximately 5.4% of the area of the CMA<sup>3</sup>. Many of these water bodies are a part of the system of tanks (Eri system) within the CMA. These are water harvesting systems that consist of a series of connected tanks that are situated within one of the basins of the rivers flowing through the area. They meet the needs of the people for both drinking and irrigation. They form the major aquifer recharge areas.

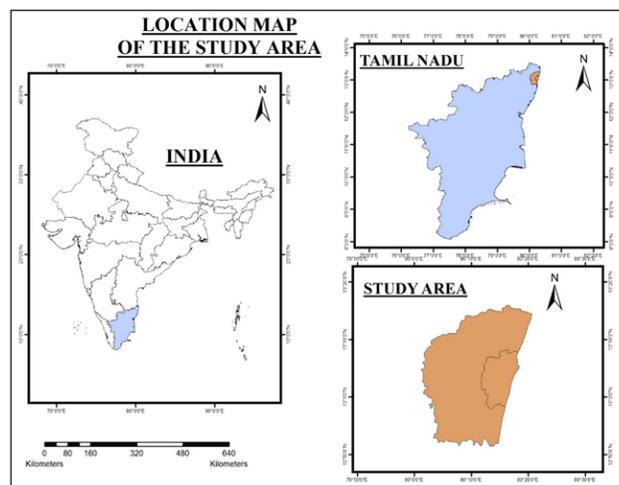


Figure 1. Map of the Chennai Metropolitan Area (CMA).

### 2.2 Materials

The analyses in this study were conducted by using Landsat satellite images. Five sets of satellite images were acquired for the years 1977 to 2016<sup>4</sup>. The imageries for the pre-monsoon seasons are for the years 1977, 1988, 1997, 2006 and 2015. The corresponding post-monsoon imageries are for the years 1978, 1989, 1998, 2007 and 2016. The details of the imageries are provided in Table 2.

Table 1. Areal extent of CMA

DISTRICT	TALUK	AREA in km <sup>2</sup>
Chennai	Fort-Tondiarpet, Perambur-Purasawalkam, Egmore-Nungambakkam, Mambalam-Guindy, Mylapore-Triplicane	176 (total area)
Kanchipuram	Tambaram, Sriperumbudur, Chengalpattu	376 (part of the district)
Tiruvallur	Ambattur, Tiruvallur, Ponneri, Poonamallee	637 (part of the district)

Table 2. Details of satellite imageries

Satellite	Sensor	Bands (number)	Spectral Range (µm)	Scene Size (km)	Pixel Resolution (m)	Year
Landsat 1–4 <sup>5</sup>	Multi-Spectral Sensor (MSS)	1, 2, 3, 4	0.5–1.1	170 × 185	79	1977, 1978 and 1989
Landsat 4–5 <sup>5</sup>	Thematic Mapper - TM	1, 2, 3, 4, 5, and 7	0.45–2.35	170 × 183	30	1988, 1997 1998, 2006, and 2007
Landsat 8 <sup>6</sup>	Operational Land Imager (OLI)	1–11	0.43–12.51	170 × 183	30	2015 and 2016

### 2.3 Methodology

The Landsat satellite images were processed using GIS software, ERDAS Imagine and ArcGIS. The satellite images were converted to the Universal Transverse Mercator (UTM) projection prior to processing. The surface water bodies were analyzed by using the Water Ratio Index (WRI), Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI). These indices provide a quantification of the temporal changes in the surface water bodies.

## 3. Results

### 3.1 Water Extraction Techniques

#### 3.1.1 Water Ratio Index (WRI)

The Water Ratio Index as highlighted by Shen and Li<sup>2</sup>:

$$WRI = (GREEN + RED) / (NIR + MIR)$$

WRI is the ratio between the total of the spectral reflectances in the RED and GREEN bands to that of the total of the Near Infra-Red (NIR) and Middle Infra-Red (MIR) bands. In this study, this technique was applied over the L 4-5TM and L 8 images as only these have the required band characteristics. Therefore, WRI was not calculated for the years 1977, 1978 and 1989 because of the limitations in the number of bands provided by Landsat MSS. The WRI indexes that were computed for the pre-monsoon seasons of the years 1988, 1997, 2006 and 2015 and the identified water bodies are shown in

Figure 2. The computed corresponding WRI values for these years are presented in Table 3. The WRI indexes that were computed for the post-monsoon seasons of the years 1998, 2007 and 2016 and the identified water bodies are shown in Figure 3. The computed WRI values for these years are presented in Table 4.

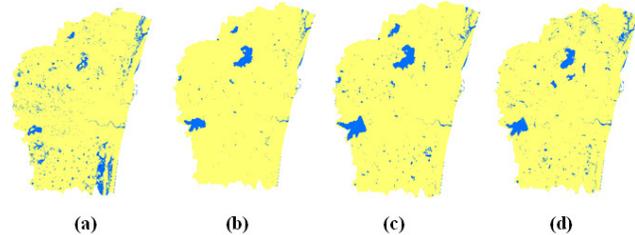


Figure 2. WRI images showing extracted surface water bodies for the pre-monsoon years (a) 1988, (b) 1997, (c) 2006 and (d) 2015.

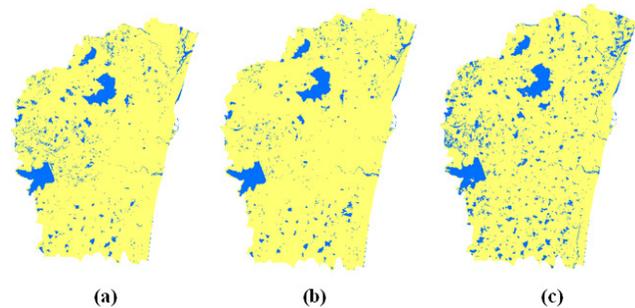


Figure 3. WRI images showing extracted surface water bodies for the post-monsoon years (a) 1998, (b) 2007 and (c) 2016.

Table 3. Areal extent of the surface water bodies for pre-monsoon years (in km<sup>2</sup>)

SURFACE WATER DETECTION ALGORITHM	YEAR 1977	YEAR 1988	YEAR 1997	YEAR 2006	YEAR 2015
WRI	-	56.68	35.84	59.83	58.79
NDWI	42.11	59.55	40.06	61.64	41.20
MNDWI	-	94.24	40.74	65.29	40.16

Table 4. Areal extent of the surface water bodies for post-monsoon years (in km<sup>2</sup>)

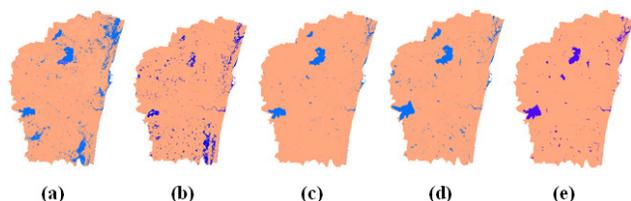
SURFACE WATER DETECTION ALGORITHM	YEAR 1978	YEAR 1989	YEAR 1998	YEAR 2007	YEAR 2016
WRI	-	-	55.55	49.13	177.94
NDWI	68.59	8.35	92.87	83.23	91.62
MNDWI	-	-	121.09	96.09	686.02

### 3.1.2 Normalised Difference Water Index (NDWI)

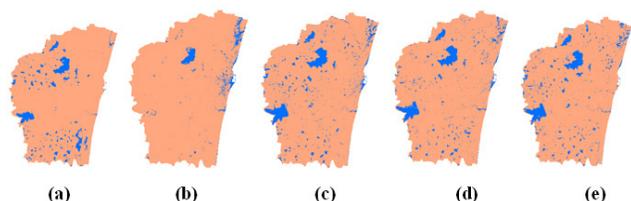
The NDWI takes advantage of the fact that water has a high reflectance in the green band while it has strong absorptions in the Near Infra-Red bands. Therefore, it is based on the ratio as highlighted by McFeeters<sup>8</sup>:

$$NDWI = (GREEN - NIR) / (GREEN + NIR)$$

The NDWI algorithm was applied on all the five sets of images, that is, 1977–78, 1988–89, 1997–98, 2006–2007 and 2015–16. The resultant water bodies mapped by this technique are shown in Figures 4 and 5. The computed NDWI values for the entire CMA region using all the imageries are provided in Tables 3 and 4.



**Figure 4.** NDWI images showing extracted surface water bodies for the pre-monsoon years (a) 1977, (b) 1988, (c) 1997, (d) 2006 and (e) 2015.



**Figure 5.** NDWI images showing extracted surface water bodies for the post-monsoon years (a) 1978, (b) 1989, (c) 1998, (d) 2007 and (e) 2016.

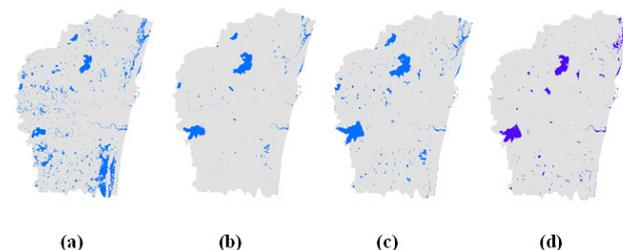
### 3.1.3 Modified Normalized Difference Water Index (MNDWI)

The MNDWI as highlighted by Xu<sup>9</sup> replaces the Near Infra-Red band with the Middle Infra-Red band and thus, it eliminates the noises caused by the built-up area and vegetation. The noises result in negative values and hence, they are easily eliminated by the use of the algorithm. The positive values reflect the extracted water bodies. Therefore, similar to the WRI technique, the use of MNDWI is restricted to only those imageries that have the Middle Infra-Red band. Hence, MNDWI is applicable only for those images pertaining to the years 1977, 1987 and 1989.

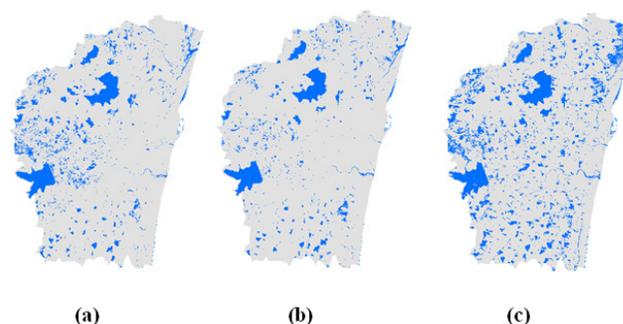
The MNDWI indexes that were computed for the pre-

monsoon seasons of the years 1988, 1997, 2006 and 2015 and the identified water bodies are shown in Figure 6. The computed corresponding MNDWI values for these years are presented in Table 3. The MNDWI indexes that were computed for the post-monsoon seasons of the years 1998, 2007 and 2016 and the identified water bodies are shown in Figure 7. The computed MNDWI values for these years are presented in Table 4.

$$MNDWI = (GREEN - MIR) / (GREEN + MIR)$$



**Figure 6.** MNDWI images showing extracted surface water bodies for the pre-monsoon years (a) 1988, (b) 1997, (c) 2006 and (d) 2015.



**Figure 7.** MNDWI images showing extracted surface water bodies for the post-monsoon years (a) 1998, (b) 2007 and (c) 2016.

### 3.1.4 Rainfall

The manifestation of water bodies through the extraction techniques as described in the previous sections are directly related to the rainfall that occurs over the CMA area during the specific years of study. Table 5 provides data on the rainfall that occurred in the three districts of Chennai, Kanchipuram and Tiruvallur districts that constitute the CMA<sup>10,11</sup>. Based on the ratio of the areal extents of each of these districts within the CMA, the total rainfall for the specific years of the entire CMA area was computed and this is provided in the last column of Table 5. The rainfall data for the year 2005 is included as the precipitation was high that year and this fact can

influence the real areal extents of the water bodies that were studied for the year 2006 and 2007.

**Table 5.** Rainfall data for the study area<sup>10,11</sup>

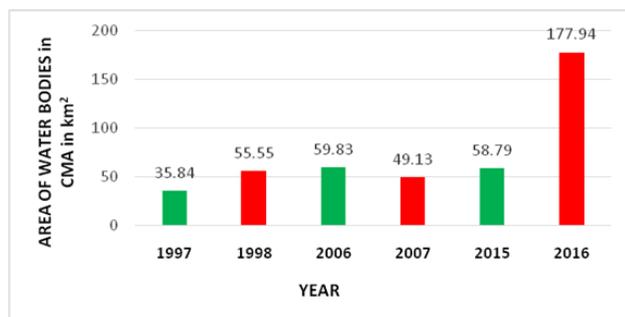
YEAR	Chennai mm	Kanchipuram mm	Tiruvallur mm	CMA mm
1977	215	511	712	1438
1988	205	453	674	1333
1997	222	474	717	1412
2005	367	785	1074	2226
2006	208	444	623	1275
2015	4382	5740	7822	17944

## 4. Discussion

### 4.1 Water Ratio Index (WRI)

The WRI for the pairs of years 1997–1998, 2006–2007 and 2015–2016 indicate the following (Figure 8):

- There is a 55% increase in the area of the surface water bodies in the post-monsoon season of 1998 when compared to the pre-monsoon season of 1997. This corresponds to a rainfall of 1412 mm.
- There is a decrease of 17.9% in the area of water bodies in the post-monsoon season of 2007 as compared to the pre-monsoon season of 2006. This corresponds to a rainfall of 1275 mm. However, there was an unusual increase in the area of the water bodies in the CMA in the 2006 pre-monsoon period owing to an excess of rainfall in the 2005 monsoon season when the precipitation was 2226 mm.
- There is an increase of 202.7% in the total areal extent of all surface water bodies situated within the CMA during 2016 owing to the unprecedented rainfall of 17944 mm in the monsoon season of 2015.
- However, the WRI values could not be calculated for the years 1977, 1978 and 1989 as these images did not have the required MIR band.

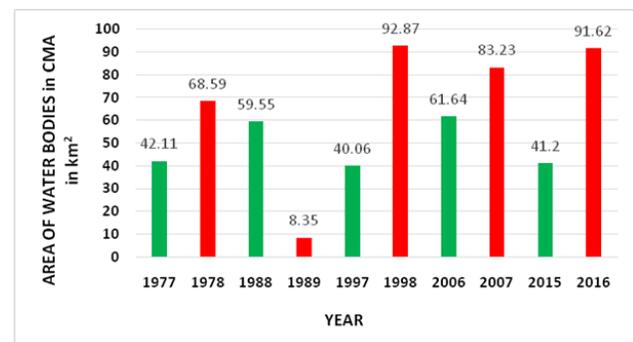


**Figure 8.** WRI indexes for pre- (in green) and post-monsoon (in red) seasons.

### 4.2 Normalized Difference Water Index (NDWI)

The NDWI for the entire study years of 1977–1978, 1988–1989, 1997–1998, 2006–2007 and 2015–2016 indicate the following (Figure 9):

- There is a 56.47% increase in the area of the surface water bodies in the post-monsoon season of 1978 when compared to the pre-monsoon season of 1977. This corresponds to a rainfall of 1438 mm.
- There is a decrease of 85.64% in the areal extent of the surface water bodies in CMA in the post-monsoon season of 1989. This corresponds to a rainfall of 1333 mm in the pre-monsoon season of 1988.
- There is an unusual increase of 52.81% in the surface water bodies of the post-monsoon season of 1998 owing to the occurrence of a high amount of rainfall in the pre-monsoon season of 1997. This corresponds to a rainfall of 1412 mm.
- There is a 21.59% increase in the areal extent of the surface water bodies in the post-monsoon season of the year 2007 when compared to the pre-monsoon season of 2006, which corresponds to a rainfall of 1275 mm and the previous year monsoon season of 2005, when the precipitation was 2226 mm.
- There is an unusual increase of 122.37% in the total areal extent of the surface water bodies of the post-monsoon season of 2016 owing to the unprecedented rainfall of 17944 mm in the monsoon season of 2015.



**Figure 9.** NDWI indexes for pre- (in green) and post-monsoon (in red) seasons.

### 4.3 Modified Normalized Difference Water Index (MNDWI)

The MNDWI for the pairs of years 1997–1998, 2006–2007 and 2015–2016 indicate the following (Figure 10):

- There is an increase of 197.22% in the areal extent of the surface water bodies in the post-monsoon season

of 1998 when compared to the pre-monsoon season of 1997. This corresponds to a rainfall of 1412 mm.

- There is an increase of 30.8% in the total area of the surface water bodies situated in CMA in the post-monsoon season of 2007 when compared to the pre-monsoon season of 2006. This corresponds to a rainfall of 1275 mm. However, there was an unusual increase in the area of the water bodies in the CMA in the 2006 pre-monsoon period owing to an excess of rainfall in the 2005 monsoon season when the precipitation was 2226 mm.
- There is an unusual increase of 1608.21% in the areal extent of the surface water bodies situated in the CMA in the post-monsoon season of 2016 owing to the unprecedented rainfall of 17944 mm in the monsoon season of the year 2015.
- However, the MNDWI values could not be calculated for the years 1977, 1978 and 1989 as these images did not have the required MIR band.

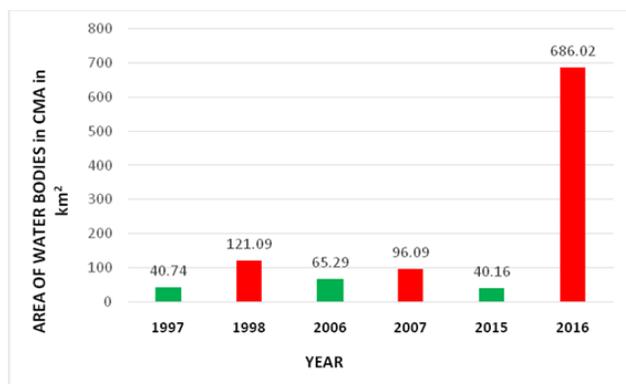


Figure 10. MNDWI for pre- (in green) and post-monsoon (in red) seasons.

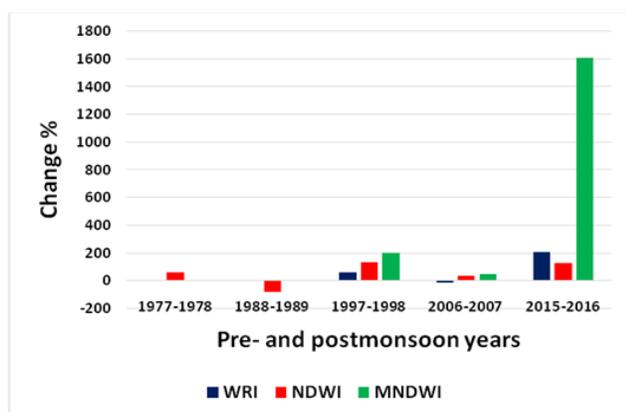


Figure 11. Pre- and post-monsoon changes in areal extent of water bodies within CMA.

## 5. Conclusions

Based on the results and discussions provided in Sections 3 and 4, the following conclusions can be arrived at:

- The indices for the delineation of the areal extent of water bodies such as, WRI, NDWI and MNDWI when applied on Landsat images through ArcGIS and ERDAS Imagine software provide reliable spatiotemporal information.
- The NDWI can be utilized for interpretation of the areal extent of water bodies in a wide variety of imageries.
- WRI and MNDWI are restricted for use only in images that have the MIR band.
- The CMA shows good correlation of the areal extent of surface water bodies with that of the rainfall data.
- MNDWI provides for a sophisticated and refined estimation of the extent of surface water bodies within the CMA when compared to WRI and NDWI (Figures 6, 7, and 11). This is particularly evident for the flood affected years 2015–2016. The extracted images can be utilized by planning authorities in order to understand the inundated areas within the CMA, analyse the causes for the same, and take suitable decisions for the prevention of such occurrences in the future.

## 6. Acknowledgement

The authors are grateful for the imageries provided by the USGS Earth Explorer. We would also like to thank the Department of Civil Engineering, SRM University for all the help extended.

## 7. References

1. Sudha MC, Ravichandran S, Sakthivadivel R. Water bodies protection index for assessing the sustainability status of lakes under the influence of urbanization: A case study of south Chennai, India. *Environment, Development and Sustainability*. 2013 Oct; 15(5):1157–71.
2. Chennai Metropolitan Development Authority (CMDA). Available from: <http://www.cmdachennai.gov.in/>
3. A. Anbarasan. Development of operational guidelines for equitable distribution of surface water to Chennai city [PhD Thesis]. Chennai: Faculty of Civil Engineering, Anna University; 2010. Available from: [http://shodhganga.inflibnet.ac.in:8080/jspui/bitstream/10603/27024/8/08\\_chapter%203.pdf](http://shodhganga.inflibnet.ac.in:8080/jspui/bitstream/10603/27024/8/08_chapter%203.pdf)

4. USGS [Internet]. Available from: <http://earthexplorer.usgs.gov/>
5. Landsat 7 Science Data Users Handbook [Internet]. 2012. Available from: <https://pubs.er.usgs.gov/publication/7000070>
6. Zanter K. Landsat 8 (L8) data users handbook. LSDS-1574 Version 1.0 [Internet], 2005. Available from: [landsat.usgs.gov/l8handbook.php](http://landsat.usgs.gov/l8handbook.php)
7. Shen L, Li C. Water body extraction from Landsat ETM+ imagery using adaboost algorithm. IEEE. 2010 18th International Conference on Geoinformatics; Beijing. 2010. Jun 18-20. p. 1–4.
8. McFeeters SK. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*. 1996 May; 17(7):1425–32.
9. Xu H. Modification of Normalised Difference Water Index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*. 2006 Jul; 27(14):3025–33.
10. Climate Madras/Minambakkam. Climate data: 1957-2016. [Internet]. Reported date by Weather Station: 432790 (VOMM). 2016. Available from: <http://en.tutiempo.net/climate/ws-432790.html>
11. Indian Metrological Department. Posted by: Nisreen Ahmed, posted on: 1st September, 2012. 2016. Available from: <http://www.indiawaterportal.org/articles/district-wise-monthly-rainfall-data-list-raingaugestations-india-meteorological-department>