The Egyptian International Journal of Engineering Sciences and Technology

Vol. 19 No. 2 (2016-Special Issue) 275–281

http://www.eijest.zu.edu.eg

ISSN:1687-1006

Performances Evaluation of Water Body Extraction Techniques Using Landsat ETM+ Data: Case- Study of Lake Nubia, Sudan

Mohamed A. Elsahabi[a], Abdelazim M. Negm[b]*, Kamal A. Ali[a]

[a]*Civil Engineering Dept., Aswan University, Aswan 81542, Egypt*

[b]*Head of Natural Resources Lab., Dept. of Environmental Engineering, Egypt-Japan University of Science and Technology E-JUST,New Borg EL-Arab,Alexandria,Egypt (seconded from Faculty of Engineering, Zagazig University, Zagazig, Egypt*

ARTICLE INFO

Article history:
Received 26 May 2016
Accepted 20 June 2016
Available online 1 July 2016

Keywords:
Lake Nubia;
Performance evaluation;
Surface water areas extraction;
Landsat ETM;
Image classification.

ABSTRACT

Lake Nubia (LN) is the Sudanese portion of Aswan High Dam Lake (AHDL). This paper aims to detect the better technique for extraction of the water surface of LN. Eight techniques are tested using Landsat ETM+ image and their performances in extracting the surface water area are evaluated. The eight techniques include Automated Water Extraction Index [AWEI], Normalized Difference Moisture Index [NDMI], Normalized Difference Water Index [NDWI], Modified Normalized Difference Water Index [MNDWI], Normalized Difference Vegetation Index [NDVI], Water Ratio Index [WRI], Supervised and Unsupervised image classification techniques. The results indicate the effectiveness and superiority of the unsupervised technique, as it gave the highest overall accuracy (about 97.23%) and the lowest absolute error. It is recommended to apply this technique to efficiently monitor changes in the surface water areas of the lakes using Landsat ETM+ data.

1. Introduction

Water surface extraction of any lake is critical to monitor changes of its surface areas, as regular monitoring can provide the basis for understanding the human influence on the lake so as to manage it more effectively. Consequently, accurate extraction of surface water areas of water body of lakes is very crucial. The Aswan High Dam Lake (AHDL) is considered one of the largest man-made lakes in Africa, which extends for 500 km south of the dam to the cataract at Dal in Sudan. The major portion of this lake lies in Egypt and is known as Lake Nasser. On the Sudanese side, it is referred as Lake Nubia (LN) [1]. Although many water surface extraction studies have been carried out on Lake Nasser (e.g. Muala [2], El-Sammany [3], and Ebaid [4]), the literature contains very few floristic records for Lake Nubia (El-Sammany [3]). Furthermore, many investigations of water areas estimation were carried out in other parts of the world (e.g. Ling [5], Xu [6], Du [7], Rokni [8] and Ma [9]).

Remotely sensed imagery has many applications in water resources assessment and management. These applications have involved the extraction of water information by various techniques [6]. So, the present study aims to evaluate the performances of different techniques for extraction of LN surface water area from Landsat data. These techniques

* Corresponding author. Tel.: +2-010-573-5345; fax: +203-459-9520.
E-mail address: negm@ejust.edu.eg, amnegm@zu.edu.eg.

include spectral water indices and image classification methods [3]. After that, the accuracy assessment of these techniques is performed and evaluated.

2. Study Area and Data Collection

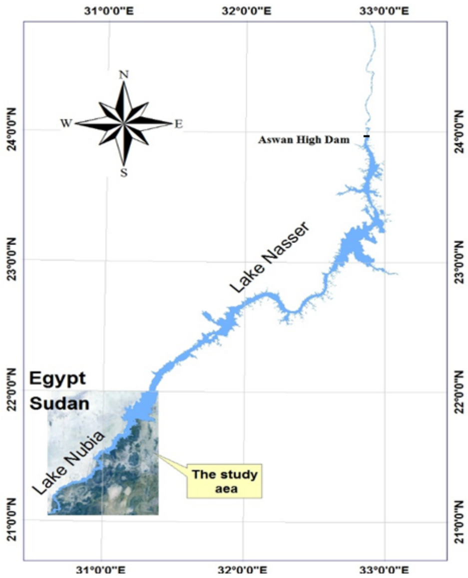


Fig. 1. Map of AHDL including the Landsat ETM+ scene of the study area

The portion of AHDL that extend inside Sudanese part of the lake (Lake Nubia) was selected as the study area. It is located between latitudes 21° 02\ 00\\ and 22° 00\ 00\\ N (upstream the Aswan High Dam). The southern two thirds of study area (Lake Nubia) are narrow. The remaining northern part is much wider as shown in Fig. 1.

To achieve the aim of this paper Landsat ETM+ image (Path/Row=175/045) was adopted in this research. This image was acquired in 1 September 2000 from the internet in GeoTIFF (systematic correction) product [10]. This image was georeferenced by the Global Land Cover Facility (GLCF) to the WGS84 ellipsoid with Universal Transverse Mercator (UTM) projection, zone 36 north. Fig. 1 represents the Landsat scene of the study area and its location on AHDL map.

3. Methodology

To achieve the objectives of the present paper, the following tasks which involved in the flowchart shown in Fig. 2 were performed using ArcGIS software:

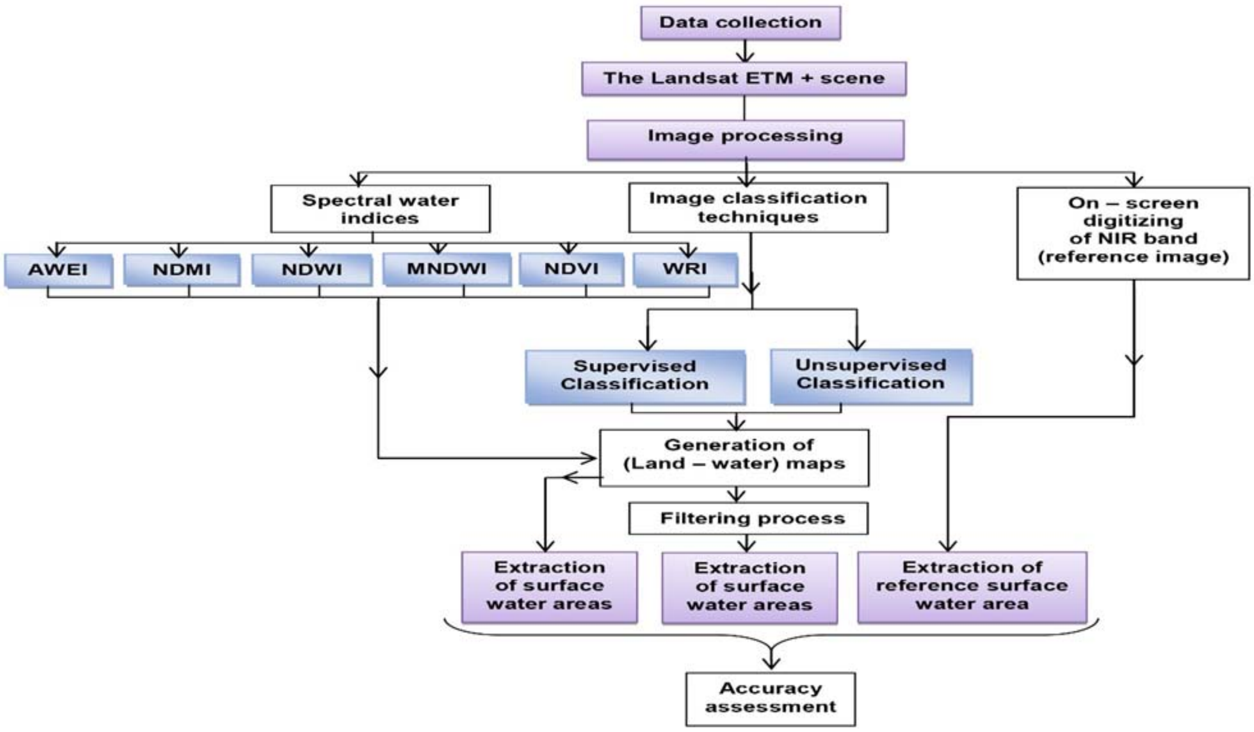


Fig. 2. Flowchart of the overall steps adopted in this study to extract the water surface area.

3.1. Computation of spectral water indices

The computed spectral water indices in this study for water features extraction process are depending on the Landsat ETM+ bands (Green = Band 2, Red = Band 3, NIR (near-infrared) = Band 4, MIR (middle-infrared) = Band 5, SWIR (shortwave-infrared) = Band 7). These indices are computed to generate (land-water) map for each index.

The equations of the spectral water indices and their ranges for water bodies are indicated as below:

- Automated Water Extraction Index (AWEI) [11]

$$AWEI = 4 \times (Green - MIR) - (0.25 \times NIR + 2.75 \times SWIR) \quad (1)$$

where water bodies have positive values.

- Normalized Difference Moisture Index (NDMI) [8]

$$NDMI = (NIR - MIR)/(NIR + MIR) \quad (2)$$

where water bodies have positive values.

- Normalized Difference Water Index (NDWI) [12]

$$NDWI = (Green - NIR)/(Green + NIR) \quad (3)$$

where water bodies have positive values.

- Modified Normalized Difference Water Index (MNDWI) [12]

$$MNDWI = (Green - MIR)/(Green + MIR) \quad (4)$$

where water bodies have positive values.

- Normalized Difference Vegetation Index (NDVI) [13]

$$NDVI = (NIR - Red)/(NIR + Red) \quad (5)$$

where water bodies have negative values.

- Water Ratio Index (WRI) [8]

$$WRI = (Green + Red)/(NIR + MIR) \quad (6)$$

where the water body value is greater than 1.

3.2. Image classification techniques

Classification of land cover features from remotely sensed image data is considered one of the main applications in the remote sensing field.

- *Supervised classification technique*

Supervised classification methods are more widely used. It is the process of using samples of known identity to classify pixels of unknown identity. This classification technique is performed to get the classified image which represent (land- water) map.

- *Unsupervised classification technique*

In this process, there is no knowledge about land cover class names. The user must specify some parameters such as the approximate number of needed clusters to obtain, the maximum cluster size, the minimum distance, that is allowed between different clusters, etc. Thus, in the unsupervised approach we determine spectrally separable classes and then define their informational utility [14]. This classification technique is performed to obtain the classified image that represent (land- water) map.

3.3. Filtering process

The filtering process is applied to the generated (land-water) maps in order to reduce the effect of misclassification between land and water areas. This process based on automatic delineation and omission of the small areas in the land which are misclassified as water areas.

3.4. Extraction of surface water areas

The surface water areas are extracted from both the reference image and the generated (land-water) maps.

- *Extraction of the reference surface water area.*

The reference surface water area is extracted utilizing careful on-screen digitizing of lake surface boundaries by visual interpretation of water bodies in Landsat ETM+ image (NIR band). The NIR band is selected in this study due to its higher ability to discriminate water from land areas [8]. AS NIR is strongly absorbed by water and is strongly reflected by the terrestrial vegetation and dry soil.

- *Extraction of the surface water areas from the generated (land-water) maps.*

The extraction of surface water areas from all filtered and non-filtered (land- water) maps are carried out by discriminating the water from land using ArcGIS software.

3.5. Accuracy assessment

The extracted surface water areas were overlaid with the reference surface water area to display the degree of misclassification error in water surfaces extraction. Finally, the overall accuracy [15], and the absolute errors in the extracted water areas are computed to evaluate and analyse the accuracy and validation of the tested techniques before and after applying the filter process in this study for surface water areas extraction.

4. Results and discussion

Different methods including image classification techniques and spectral water indices are used to extract the surface water from the Landsat ETM+ image. The absolute error and the overall accuracy for all tested methods are computed to assess the accuracy of the results. Fig. 3 shows the derived (land-water) maps from these methods. The extracted water surfaces from (land-water) maps and from the reference band of Landsat image were illustrated in Fig. 4.

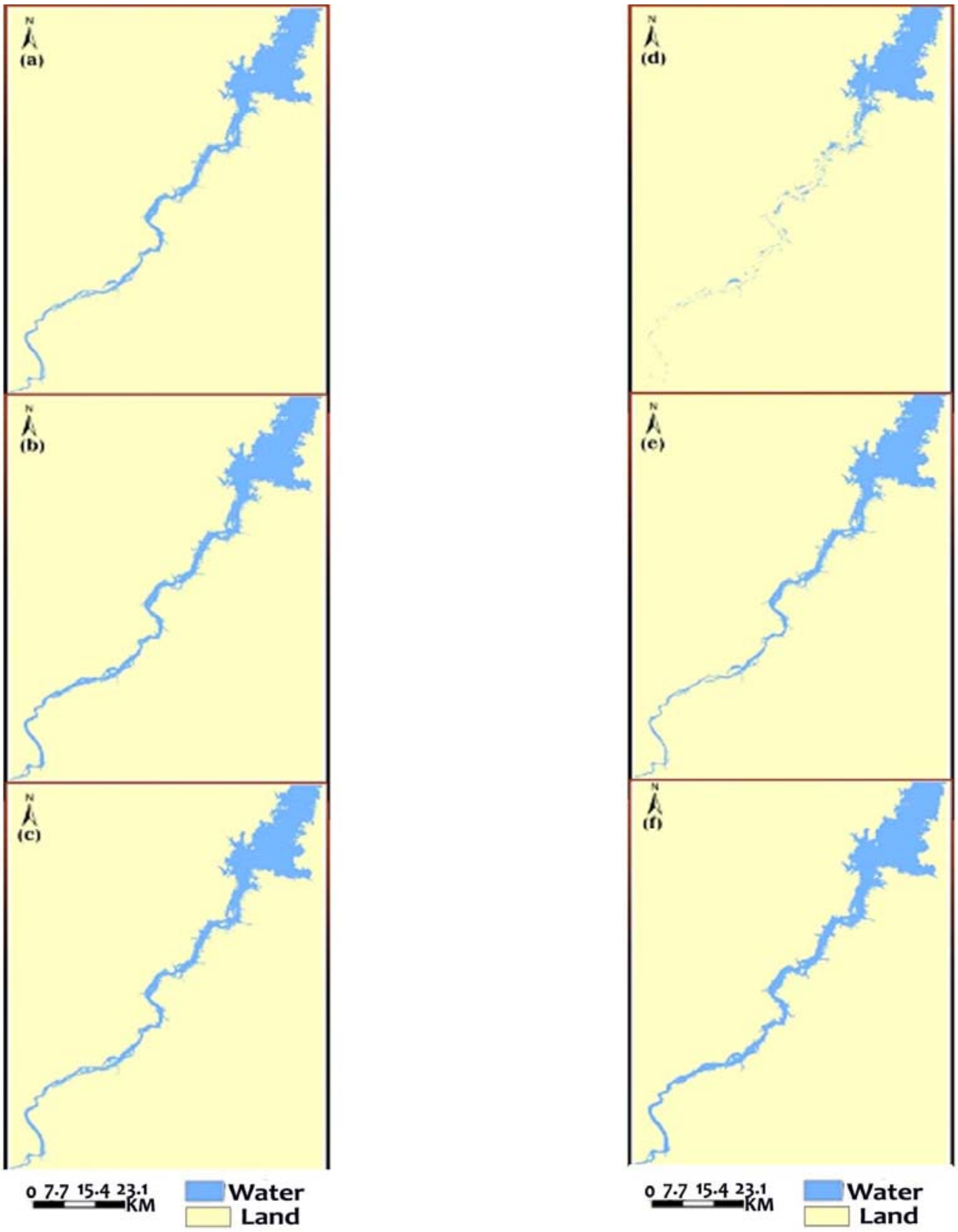
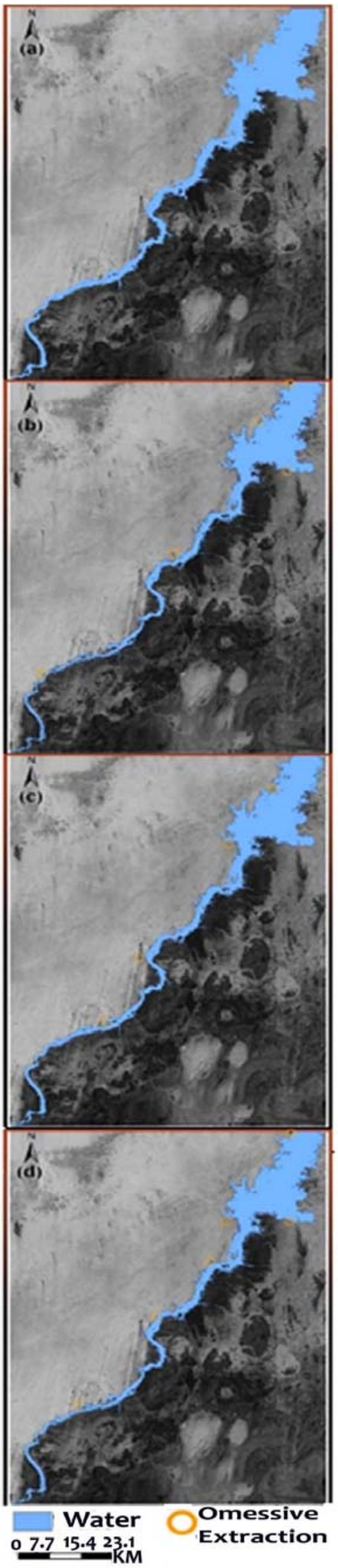


Fig. 3. The resulting (land-water) maps from Landsat ETM+ image (2000). (a) AWEI map; (b) NDMI map; (c) MNDWI map; (d) WRI map; (e) Supervised classification map; (f) Unsupervised classification map.



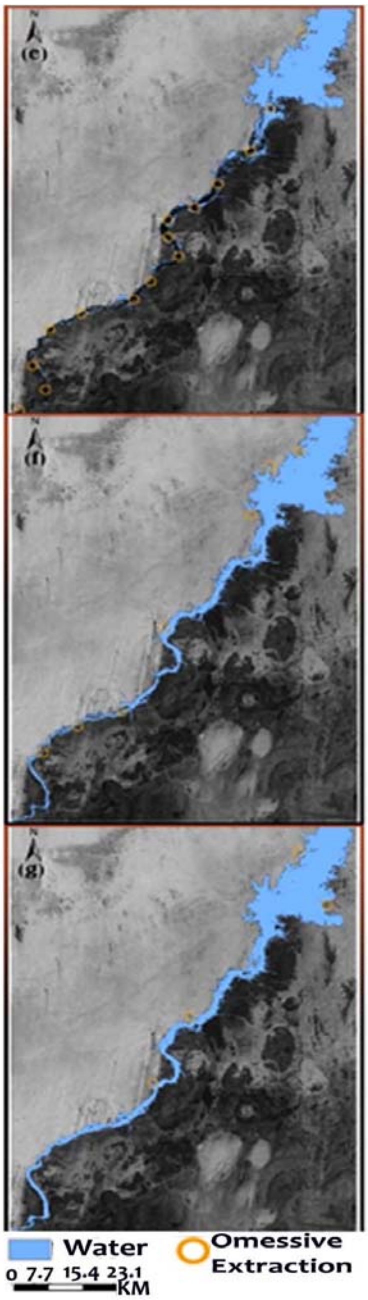


Fig. 4. The extracted water surface (WS) which overlaid on the reference image. (a) Reference WS; (b) Extracted WS by AWEI; (c) Extracted WS by NDMI; (d) Extracted WS by MNDWI; (e) Extracted WS by WRI; (f) Extracted WS by supervised classification technique; (g) Extracted WS by unsupervised classification technique.

The areas of the extracted water surfaces of the study area and the analysis of the accuracy assessment before applying the filtering process are shown in Table 1. Applying the filtering process to the derived the (land-water) maps improved the overall accuracy by about 1% for all techniques.

The derived (land- water) maps from NDWI and NDVI were considered unacceptable and unreliable maps which contain an unrealistic distribution of water surface through the study area for the following reasons:

- The enhanced water features using the NDWI are mixed with the surrounding land, particularly the eastern part of the study area, as the land nature is similar to the built - up areas in this part.
- The NDVI was developed mainly for separating green vegetation from other surfaces. Because of the lack of green vegetation surrounding the water surface in the study area.

Therefore, the NDWI and NDVI techniques are not evaluated and are considered disqualified methods for extracting the water surface of the study area.

The MNDWI was developed to modify the NDWI in detecting water features for water regions with backgrounds dominated by built- up areas.

The AWEI is formulated to eliminate effectively dark built surfaces in areas with an urban background.

In this study area, where there are no urban areas, the MNDWI performed better compared with the AWEI for surface water extraction process.

Table 1. The computed water areas and the accuracy assessment analysis before applying the filter process.

Technique	Water surface area(km^2)	Absolut error (km2)	Overall accuracy (%)
Reference	549.313	—	—
AWEI	523.591	25.722	92.82
NDMI	551.133	1.820	95.36
NDWI	—	—	—
MNDWI	551.859	2.546	94.65
NDVI	—	—	—
WRI	410.494	138.819	72.11
Supervised classification	516.052	33.261	90.71
Unsupervised classification	549.923	0.610	96.34

In this study, the unsupervised classification technique performed significantly better compared with other techniques for surface water extraction of LN. The obtained results agree well with a previous study for Nasser Lake [16]. The overall accuracy of the unsupervised technique is about 96.34%. The visual comparison shows that the boundaries of the mapped water surfaces match the actual boundaries of the water in the reference image very closely. However, some omissions occurred, as shown in Fig. 4, which considered the primary cause of errors in the results. These omissions affect the values of the accuracy of all techniques.

It is observed that the unsupervised classification technique produces a better performance than the supervised classification technique; because the opportunity for human error is minimized with the unsupervised classification.

The NDMI was developed for detection of vegetation water liquid, and thus would not be efficient for extraction of water features. However, it performs well for surface water extraction; it gave an overall accuracy about 95.36%.

It is obvious from Table 1 that WRI technique could not effectively achieve accuracy results in comparison with the other techniques in extracting the water surface of the study area.

Based on the surface water areas that computed in Table 1, the unsupervised classification, NDMI and MNDWI techniques overestimated the change in the area between the extracted surface water areas and the reference area. On contrast, the other techniques highly underestimated the change in the area between the extracted surface water areas and the reference area.

The accuracy assessment analysis using the absolute error shows the superiority of the unsupervised classification, MNDWI and NDMI techniques for surface water areas extraction compared with other techniques.

On the other hand, the application of the filter improves the results within 1% where the overall accuracy indicated by Table 1 are improved slightly to 93.93%, 96.27%, 95.63%, 73.4%, 91.94% and 97.23% for AWEI, NDMI, MNDWI, WRI, supervised and unsupervised classification method respectively

5. Conclusions

The results indicated that the unsupervised classification technique provided the highest performance (overall accuracy equal 96.34% without filtering and 97.23% with filter process) as compared with other techniques for the extraction of surface water from Landsat data. On contrast WRI gave the lowest performance with an overall accuracy equal

72.11 without filter and 73.40% with filter. The accuracy of the other methods is in the range of 91.94% to 96.27% with filter process. The results also, indicated that the accuracy of the surface water areas extraction techniques were improved by applying the filtering process to the derived (land-water) maps by about 1%. It should be mentioned that the resulting errors in the water surface extraction process are mainly due to the omission of water pixels around the edges of the lake. Moreover, the NDVI and the NDWI were incapable of extracting the water surface of Lake Nubia study area. The authors recommend to apply the unsupervised technique for lakes having similar conditions to extract the surface water areas from Landsat ETM+ data.

Acknowledgements

Aswan University and Egypt-Japan University of Science and Technology (E-JUST are hereby acknowledged for providing the facilities utilized during this research work.

References

[1] M. M. Ali, "Shoreline vegetation of Lake Nubia, Sudan", Hydrobiologia 570, pp.101–105, Springer 2006.

[2] E. Muala, Y.A. Mohamed, Z. Duan and P. Zaag, "Estimation of reservoir discharges fre Nasser and Roseires Reservoir in the Nile Basin using satellite altimetry and imagery data", Remote Sens. 6, pp. 7522–7545, 2014.

[3] M. S. El-Sammany and A. M. El-Moustafa, "Adaptation of Surface Water Modeling System for Sediment Transport Investigations in Lake Nasser", Journal of Nile Basin Water Science and Engineering Vol. 4, Issue 1, pp. 71–85, 2011.

[4] H.M.I. Ebaid and S. S. Ismail, "Lake Nasser evaporation Reduction Study", Journal of advanced research, Vol.1, pp. 315-322, October 2010.

[5] F. Ling, X. Cai, W. Li, F. Xiao, X. Li and Y. Du, "Monitoring river discharge with remotely sensed imagery using river island area as an indicator", Journal of Applied Remote Sensing, Vol.6, pp. 063564 (1-14), 2012.

[6] H. Xu, "Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery", International Journal of Remote Sensing Vol. 27, No. 14, pp. 3025-3033, July 2006.

[7] Z. Du, B. Linghu, F. Ling, W. Li, W. Tian, H. Wang, Y. Gui, B. Sun and X. Zhang, "Estimating surface water area changes using time-series Landsat data in the Qingjiang River Basin, China", Journal of Applied Remote Sensing, Vol.6, pp. 063609 (1-16), 2012.

[8] K. Rokni, A. Ahmad, A. Selamat and S. Hazini, "Water feature extraction and change detection using multitemporal Landsat imagery", Journal of Remote Sensing 6, pp. 4173-4189, 2014

[9] M. Ma, X. Wang, F. Veroustraete and L. Dong, "Change in area of Ebinur Lake during the 1998–2005 period", International Journal of Remote Sensing, vol. 28, pp. 5523–5533, 2007.

[10] The Global Land Cover Facility (GLCF) provides earth science data and products, 2014. Available from: http://glcfapp.glcf.umd.edu/data/landsat/, last accessed: May 09, 2014.

[11] G.L. Feyisa, H. Meilby, R. Fensholt and S.R. Proud, "Automated water extraction index: A new technique for surface water mapping using Landsat imagery", Remote Sensing of Environment 140, pp. 23–35, 2014.

[12] H. M. El-Asmar, M. E. Hereher and S. B. El Kafrawy, " Surface area change detection of the Burullus Lagoon, North of the Nile Delta, Egypt, using water indices: A remote sensing approach", The Egyptian Journal of Remote Sensing and Space Sciences 16, pp.119–123, 2013.

[13] E.H. Wilson and S.A. Sader, "Detection of forest harvest type using multiple dates of Landsat TM imagery", Remote Sensing of Environment 80, pp. 385–396, 2002.

[14] T.M. Lillesand, R.W. Kiefer and J.W. Chipman. “Remote sensing and image interpretation (fifth edition)”, John wiley and Sons, Inc. 2004.

[15] J.R. Jensen, "Introductory digital image processing: A remote sensing perspective (second edition)", New Jersey, USA.

[16] M. A. Elsahabi, A. A. Negm and A-H. M.A. El-Tahan, " Performances Evaluation of Surface Water Areas Extraction Techniques Using Landsat ETM+ Data: Case Study Aswan High Dam Lake (AHDL)", 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania