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Performances Evaluation of Surface Water Areas Extraction Techniques Using Landsat ETM+ Data: Case Study Aswan High Dam Lake (AHDL)

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Abstract

Aswan High Dam Lake (AHDL) is the major freshwater body supplying Egypt with water used for various purposes. This paper aims to detect the better technique for extraction of the water surface of AHDL. Eight techniques are tested using Landsat ETM+ image and their performances in extracting the surface water area are evaluated. The eight techniques include Supervised and Unsupervised image classification techniques, Water Ratio Index [WRI], Normalized Difference Vegetation Index [NDVI], Normalized Difference Water Index [NDWI], Modified Normalized Difference Water Index [MNDWI], Automated Water Extraction Index [AWEI], and Normalized Difference Moisture Index [NDMI]. The results illustrate the effectiveness of the unsupervised technique, as it gave an overall accuracy about 99.91%. It is recommended to apply this technique in areas with similar conditions to efficiently extract the surface water areas from Landsat ETM+ data.

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Keywords: Aswan High Dam Lake; Landsat; Image classification; Surface water extraction; Performance evaluation, RS/GIS.

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1. Introduction

Surface water component is an essential part of the water cycle, particularly, fresh water of lakes. It is also critical significant in various scientific disciplines, such as the assessment of present and future water resources, river dynamics, agriculture suitability, climate models, flood mapping, etc. It is also, vital for humans, food crops, and ecosystems. Consequently, accurate extraction of surface water areas of water body of lakes is very crucial. Aswan High Dam Lake (AHDL) has a length of about 500 km, 325 km in Egypt and 175 km in Sudan. This lake is vital to Egypt, as it stores and regulates Nile water, being the main source of fresh water, for about 85% of its population. Also, it is considered a big source of fish production in Egypt. Water surface extraction of AHDL is critical to monitor changes of the lake surface area, as regular monitoring can provide the basis for understanding the human influence on the lake so as to manage it more effectively [1]. There are several methods and techniques of Remote Sensing and GIS to identify land and water areas considering band variations of different multi-spectral images. Many researches were done related to the field of water features extraction. The most important ones can be presented as follows: Ebaid [2] mentioned that classification of Landsat images is considered the best techniques for water texture recognition. Muala [3] concluded that the NDWI gave accurate results than the MNDWI for delineating the Roseires reservoir area that is located on the Blue Nile. Rokni [1] illustrated that NDWI indicated higher performance as compared with other indexes for the extraction of surface water area from Landsat data. Xu [4] concluded that the MNDWI is more suitable than the NDWI for enhancing and extracting water information for a water region with a background dominated by built-up land areas. Li [5] studied eleven NDWI models based on EO-1 Advanced Land Imager (ALI), Landsat Thematic Mapper (TM), and Landsat Enhanced Thematic Mapper Plus (ETM+) data to assess their performances in land surface water mapping.

The main objective of this study is to evaluate the performances of different surface water areas extraction techniques. The extraction techniques include Supervised and Unsupervised image classification techniques [2, 6], Water Ratio Index [WRI] [1], Normalized Difference Vegetation Index [NDVI] [1], Normalized Difference Water Index [NDWI] [3], Modified Normalized Difference Water Index [MNDWI] [3], Automated Water Extraction Index [AWEI] [7], and Normalized Difference Moisture Index [NDMI] [8]. They are used for the extraction of the water surface of AHDL from Landsat data. After that, the accuracy assessment of these performances is performed and evaluated.

2. Study Area and Data Collection

The portion of AHDL that extend inside Egyptian part of the lake (Lake Nasser) was selected as the study area as shown in Fig. 1.

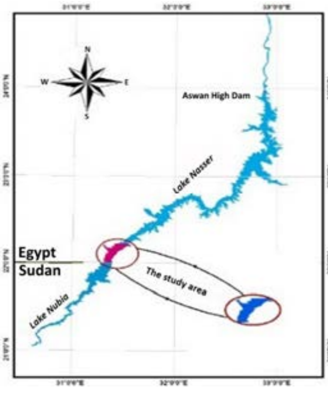

Fig. 1. Location of the study area in AHDL.

It is located between latitudes 21° 59' 30'' and 22° 12' 36'' N (upstream the Aswan High Dam). The study area includes a surface of the water that characterized by its large number of meandering, and also include some lake's secondary channels

(Khors). This study area considered one of the most difficult portions of AHDL for extracting efficiently of its water surface. Therefore, it is important to find the best method for extracting the water surface of this area for applying it to the entire lake in the future studies. To achieve the purpose of the paper, satellite data are used particularly, Landsat ETM+ image (Path/Row=175/045) was adopted in this research. The image data from 18 March 2009 was acquired from the internet in GeoTIFF (systematic correction) product [9]. For thus, it is free of geometric, radiometric and noise errors. Furthermore, it is no need to the pre-processing step in the different applications of this image. This data was georeferenced by the Global Land Cover Facility (GLCF) to the WGS84 ellipsoid with Universal Transverse Mercator (UTM) projection, zone 36 north. The characteristics of the Landsat ETM+ bands were summarized in Table 1 [10]. Fig. 2 represents the original acquired satellite image and the location of the study area in this image.

Table 1. Landsat Enhanced Thematic Mapper plus (ETM+) Bands.

Bands	Name	Band Width (λ, μm)	Spatial Resolution
1	Blue	0.45-0.515	30 m
2	Green	0.525-0.605	30 m
3	Red	0.63-0.69	30 m
4	Near Infrared (NIR)	0.76-0.90	30 m
5	Middle-infrared(MIR)	1.55-1.75	30 m
6	Thermal IR	10.4-12.5	60 m
7	Shortwave IR(SWIR)	2.08-2.35	30 m
8	Panchromatic	0.52-0.92	15 m

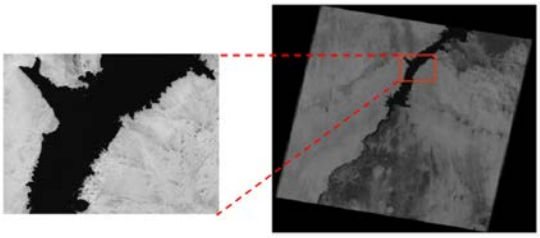

Fig. 2. Location of the study area in the original Landsat ETM+ image (band 4).

3. Methodology

To achieve the aim of the present paper, the following tasks were performed: image classification process (supervised and unsupervised classification methods), computation of the spectral water indices, generation of the reference map, extraction of surface water areas and accuracy assessment of the extracted water areas. Figure 3 shows a flowchart of the procedures adopted in this study to extract the water surface area.

3.1. Image classification process using 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 (land-water) map.

3.2. Image classification process using 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 [11]. This classification technique is performed to obtain the classified image (land- water) map.

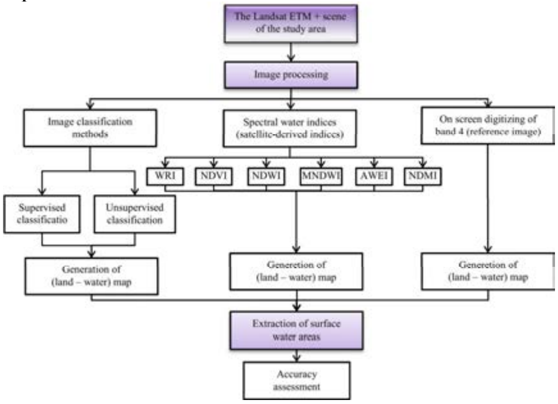

Fig. 3. Flowchart of the procedures adopted in this study to extract the water surface area.

3.3. Computation of satellite-derived indices (spectral water indices)

The spectral water indices that are computed in this study for water features extraction process, their equations and ranges for water bodies were summarized as below:

- Water Ratio Index (*WRI*) [1]

$$WRI = \frac{(Green+Red)}{(NIR+MIR)} \quad (1)$$

where the water body value is greater than 1;

- Normalized Difference Vegetation Index (*NDVI*) [1]

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (2)$$

where water bodies have negative values;

- Normalized Difference Water Index (*NDWI*) [3]

$$NDWI = \frac{(Green-NIR)}{(Green+NIR)} \quad (3)$$

where water bodies have positive values;

- Modified Normalized Difference Water Index (*MNDWI*) [3]

$$MNDWI = \frac{(Green-MIR)}{(Green+MIR)} \quad (4)$$

where water bodies have positive values;

- Automated Water Extraction Index (*AWEI*)[7]

$$AWEI = 4 \times (Green - MIR) - (0.25 \times NIR + 2.75 \times SWIR) \quad (5)$$

where Water bodies have positive values;

- Normalized Difference Moisture Index (*NDMI*) [8]

$$NDMI = \frac{(NIR-MIR)}{(NIR+MIR)} \tag{6}$$

where water bodies have positive values.

The above mentioned spectral water indices are computed to generate (land-water) map for each index.

3.4. Generation of the reference map

The reference map is generated utilizing careful on-screen digitizing of lake surface boundaries in Landsat ETM+ image (band 4) using visual interpretation. Band4, which represents (NIR) band of Landsat data, is usually preferred for visual interpretation of water bodies; because NIR is strongly absorbed by water and is strongly reflected by the terrestrial vegetation and dry soil. Therefore, band4 is selected in this study due to its higher ability to discriminate water and land areas [1].

3.5. Extraction of surface water areas

The extraction of surface water areas from all (land- water) maps are achieved by discriminating the water from land using ArcGIS software.

3.6. Accuracy assessment of the extracted water areas

The derived water layers were overlaid with the reference water layer to display the degree of misclassification error in water surfaces extraction. Finally, the overall accuracy [12], and the absolute error are computed to support the accuracy assessment analysis.

4. Results and discussion

Different techniques including supervised classification (SCL), unsupervised classification(USCL), WRI, NDVI, NDWI, MNDWI, AWEI, and NDMI are used to extract the surface water from the Landsat ETM+ data. The absolute error and the overall accuracy are computed to assess the accuracy of the results. Fig. 4 shows the derived (land-water) maps from the above mentioned techniques and the reference image. The extracted water surfaces from (land-water) maps were illustrated in Fig. 5. The areas of the extracted water surfaces of the study area are presented in Table 2. The analysis of the accuracy assessment is shown in Table 3. Moreover, the overall accuracy of each studied technique was indicated in Fig. 6. 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, the derived (land- water) map from NDVI was considered unacceptable and unreliable map which contain an unrealistic distribution of water surface through the study area. Therefore, the NDVI technique is not evaluated and is considered a disqualified method for extracting the water surface of the study area.

In this study, the unsupervised classification technique performed significantly better compared with other techniques for surface water extraction. The overall accuracy of the unsupervised technique is about 99.91%. 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 inaccuracies and omissions occurred, as shown in Fig. 4 and Fig. 5 respectively, 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. In addition, the unsupervised classification allows unique classes to be recognized as distinct –units. On the other hand, the supervised classification may allow these unique classes to go unrecognized and could inadvertently be incorporated into other classes creating error throughout the entire classification.

Table 2. Areas of reference and extracted water surfaces.

Map	Reference	SCL	USCL	WRI	NDVI	NDVI	MNDWI	AWEI	NDMI
Water Surface area (km^2)	286.471	279.979	286.724	280.466	-	286.124	286.542	283.350	287.642

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 98.37%. The AWEI is formulated to eliminate effectively dark built surfaces in areas with an urban background. In the study area, where there are no urban areas, the NDWI, and the MNDWI performed better compared with the AWEI for surface water extraction process.

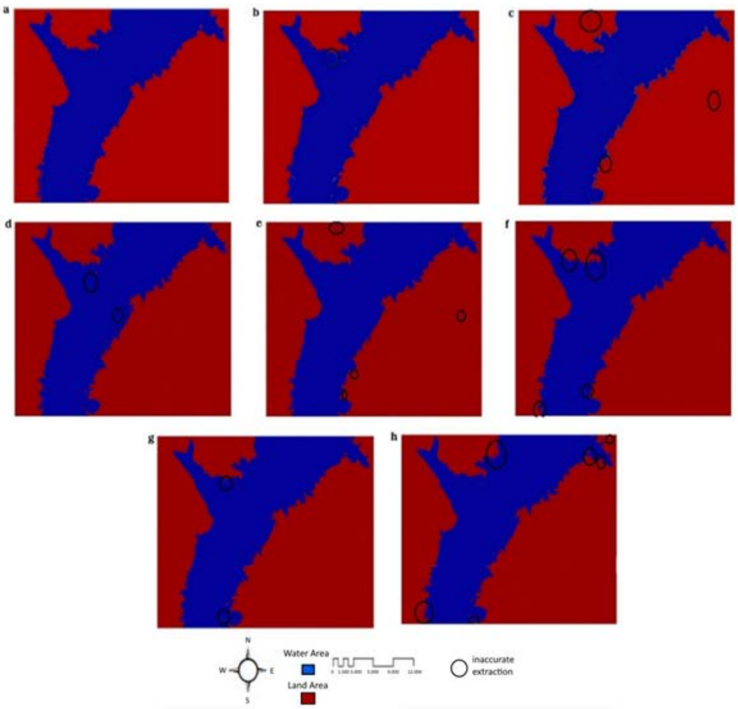

Fig. 4. The reference and the resulting (land-water) maps from Landsat EEM+ image (2009): (a) Reference map; (b) Supervised classification map; (c) Unsupervised classification map; (d) WRI map; (e) NDWI map; (f) MNDWI map; (g) AWEI map; (h) NDMI map.

The enhanced water features using the NDWI are often mixed with built-up land and the area of extracted water can be overestimated. The MNDWI was developed to modify the NDWI in detecting water features for water regions with backgrounds dominated by built- up areas.

In this study, NDWI produced approximately an overall accuracy very close to the accuracy of MNDWI; as almost there aren't any built up areas surrounding the water boundaries in the study area.

It is obvious from Table 3 that the unsupervised classification and the WRI techniques could not effectively achieve accuracy results in comparison with the other techniques in extracting the water surface of the study area.

Based on the reference water surface area that computed in Table 2, the NDWI technique underestimated the change between the extracted water surface areas and the reference water area about 0.347 Km^2, while the change was overestimated about 0.253 Km^2, 0.071 Km^2 and 1.171 Km^2 using unsupervised classification, MNDWI and NDMI techniques, respectively.

The supervised classification, WRI and AWEI techniques highly underestimated the change in the area between the extracted water surface areas and the reference area.

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

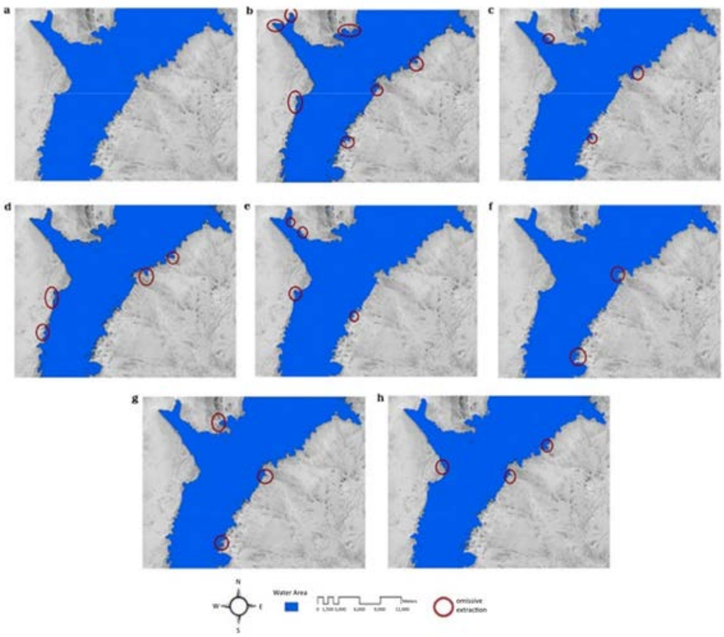

Fig. 5. The extracted water surface (WS) which overlaid on the reference image: (a) Reference WS; (b) Extracted WS by supervised classification technique; (c) Extracted WS by unsupervised classification technique; (d) Extracted WS by WRI; (e) Extracted WS by NDWI; (f) Extracted WS by MNDWI; (g) Extracted WS by AWEI; (h) Extracted WS by NDMI.

Table 3. The accuracy assessment analysis

Technique	Sup. Cl.	Unsup. Cl	WRI	NDWI	MNDWI	AWEI	NDMI
Abs. Error Km^2	6.492	0.253	6.005	0.347	0.071	3.121	1.171
Overall accuracy %	97.72	99.91	97.90	99.32	99.39	98.91	98.37

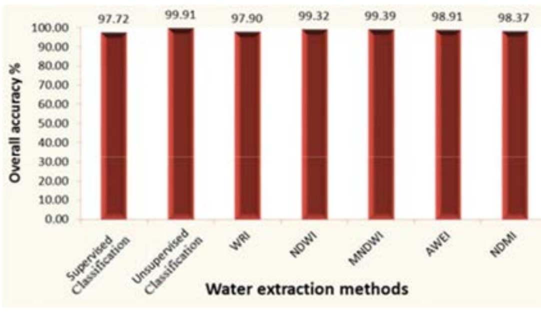

Fig. 6. The overall accuracy of water surface extraction techniques.

5. Conclusions

This paper presents and discusses the results of the performance evaluation for the extraction of surface water process based on using Landsat ETM+ image. The results indicate that the superiority and higher performance of the unsupervised classification technique (overall accuracy equal 99.91%) as compared with other techniques for the extraction of surface water from Landsat data. The accuracy of the other methods is in the range of 97.72% to 99.91%. 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 was incapable of extracting the water surface of the Aswan High Dam Lake study area. The authors recommended that the same study should be repeated on other lakes to confirm the performance of the tested methods on lakes in general. Also, it is highly recommended to use the same tested methods in this paper in studying the change detection of the study area.

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