Taikichiro Mori Memorial Research Grants Graduate Student Researcher Development Grant Report

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Research Project: Performance Evaluation of water extraction indices using Satellite images in mountain area

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Abstract— Water is one of the most important earth resources which is essential to human health, society and environment. Studies on water extraction and changes have been subjects of academic studies for many years. Remote sensing as an efficient and reliable tool has been used in recent years and Landsat satellite imagery were one of the most common data due to their advantages in spatial resolution and cost. Improvement of new Landsat 8, the Operational Land Imager (OLI) data attracted more attentions recently. This study uses the Landsat 8 OLI imagery data source for water information extraction based on the Normalized Difference Water Index (NDWI), Modified Normalized Water Index (MNDWI) and Automated Water Extraction Index (AWEI) to compare the effect of using The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) in mountainous area. The study area is Kermanshah, in west of Iran, a mountainous area which has difficulties for water extraction due to shadows and dark objects. Due to small area of water bodies in study area user's accuracy were used for evaluation of results. User accuracy for water class gives results of 23.68%, 24.34% and 22.57% for NDWI, MNDWI and AWEI, respectively. In other words, around 77% of pixels which classified as water are not water and are misclassified pixels. Applying DEM data improves results to 27.44%, 29.1% and 27.22% for NDWI, MNDWI and AWEI, respectively which shows slight increase of 3.76%, 4.88% and 4.65%.

Keywords—water extraction; Landsat 8 OLI; index; DEM; mountainous area

I. INTRODUCTION

Water is one of the most important earth resources which is essential to human health, society and environment. Studies on water extraction and changes have been interest of academic studies for many years. Water bodies like man-made reservoirs, lakes, ponds, etc. are key tools for the management of water resources. Even though these water bodies constitute a relatively small portion of the total available water on the Earth surface, they are important freshwater features because they are main resources for drinking water. Remote sensing as an efficient and reliable tool has been used in recent years. Remote sensing techniques plays a key role in many areas of water issues such as; wetland monitoring, flood monitoring, flood disaster assessment, surface water area estimation, and water resources management [1]. It provides advanced technical means for detecting the spatial distribution of water bodies, monitoring them and extracting other information. It overcomes many shortcomings of traditional ground based surveys, such as high cost, time-consuming and influence of many other unknown factors in the field [2].

One of the widely used imagery data for water extraction and monitoring area is Landsat imageries because of their advantages in spatial resolution and cost [3][4]. Different methods used to extract surface water features using remote sensing data that [3] classified them as four different categories; thematic classification, linear immixing, single band threshold, and two-band spectral indices. Indices are one of the common ways of water extraction in optical imageries and many indices have been proposed. One of the well-known indices is the Normalized Difference Water Index (NDWI) proposed by [5] that uses green and NIR bands to extract water. The index uses 0 threshold to discriminate water from its background, but [6]'s study found it inappropriate threshold and to improve the index they introduced a new index as Modified Normalized Difference Water Index (MNDWI) where substituted a middle infrared band for the near infrared band. Results showed that enhancement in detection of surface water from non-water background and its improvement in build-up areas and shadow were considerable. For improving classification accuracy in dark surfaces and shadow areas, an Automated Water Extraction Index (AWEI)proposed by [7], where their results prove a remarkable enhancement in classification accuracy respect to MNDWI and Maximum Likelihood (ML) classifiers. They used 4 different bands of blue, green, NIR and SWIR to increase contrast between water and noon-water surfaces.

Different satellite sensors with varying spatial, temporal and spectral resolution have been used for surface water extraction [8]. Compared to other remote sensing data, Landsat satellite series have been most frequently used for water information extraction and land cover thanks to its advantages regard to free of cost data availability, global coverage, continuity over 40 years and spatial resolution [9]. New Operational Land Imager (OLI) aboard Landsat-8 was launched in February 2013; its multispectral imagery offers significant improvements in both data quality and spectral coverage, also promises enhanced environmental monitoring respect to signal-to- noise ratio and radiometric resolution [10]. This study uses Landsat 8 OLI imagery to investigate how different indices of NDWI, MNDWI and AWEI perform for surface water extraction in mountainous areas and applies ASTER GDEM data to exclude shadow areas in order to examine in what extent results will improve.

Many studies mention that extraction of water bodies in mountainous areas is affected highly by shadow and dark surfaces, using GDEM data helps to eliminate high elevation shadow areas. This study tries to investigate using DEM data how can improve classification results by considering normal distribution of elevation in the study area. In this research normal distribution of elevation for the study area is considered to find the most proper use of GDEM data.

II. STUDY AREA AND DATA SOURCES

A. *study area*

Kermanshah Province is located in west of Iran, between 33 04’ to 35 17’ N and 45 25’ to 46 06’ E. The study area is located in north of the state. Geologically, Kermanshah is part of Zagros Mountains and due to lack of precipitation during dry season, specifically summer time, local need of water is provided by different size of reservoirs. They are the main source of fresh water for the study area. Moreover, selected study area is a mountain area, where there are lands between hills or mountains, full of dark and shadow surfaces, a good example to test applicability of classifiers and indices to distinguish water surfaces. Four different sizes of reservoirs are considered in selected area to examine classification accuracy of small size water surfaces as well as big size ones (*Figure 1*).

B. *Image data*

Landsat 8 Operational Land Imager (OLI) imageries were used in this research. New Landsat imageries includes three new bands respect to Landsat TM data; a deep blue band for coastal or aerosol studies, a shortwave infrared band for cirrus detection, and a Quality Assessment band [11]. Moreover, a refined range for spectral resolution is defined, specifically for NIR band. This research obtained data from the United States Geological Survey (USGS) Earth Resources Observation and Science Center (EROS). Date of image data were selected in July 2014 due to cloud free time of study area and availability of reference data at the same time. Landsat imageries of this research are L1T product type with resolution of 30 meters.

C. *DEM*

Data used as Digital Elevation Model (DEM) is product of The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM). ASTER GDEM is distributed as Georeferenced Tagged Image File Format (GeoTIFF) files, and in geographic coordinates (latitude, longitude). The data are posted on a 1 arc-second (approximately 30 m at the equator) grid and referenced to the 1984 World Geodetic System (WGS84)/1996 Earth Gravitational Model (EGM96) geoid [12].

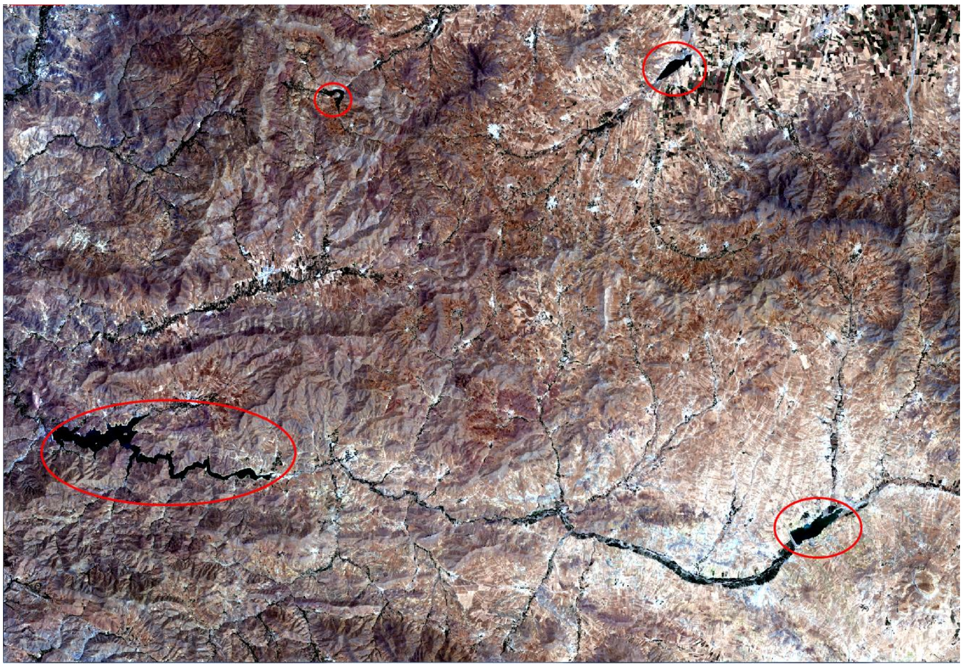


Figure 1: location of reservoirs in the study area

III. METHOD

A. *Water extraction indices*

This study applied ENVI 4.7 software for imagery analysis and visualization of indices. First, atmospheric correction was done and then subset of study area was extracted. Indices relay on different reflectance of each band, based on this fact many indices has been introduced. NDWI uses the difference reflectance value of NIR and Green bands to extract water bodies, its equation is as follow:

$$NDWI = \frac{b_{green} - b_{NIR}}{b_{green} + b_{NIR}} \quad (1)$$

For modified NDWI or MNDWI [6] introduced an index considering mid-infrared band which corresponds to SWIR1 in Landsat 8 OLI that equation is:

$$MNDWI = \frac{b_{green} - b_{SWIR1}}{b_{green} + b_{SWIR1}} \quad (2)$$

Considering more number of bands based on idea of improving results, AWEI uses green, blue, NIR, SWIR1 and SWIR2 bands. Two equation were proposed for extracting water from non-water which is as follow:

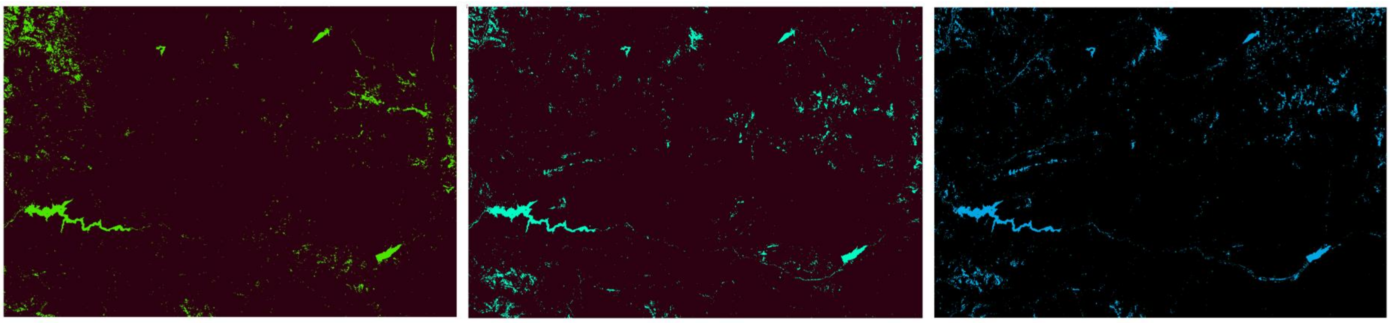
$$AWEI_{nsh} = b_{green} + b_{blue} \times 0.25 - 1.5 \times (b_{nir} + b_{swir1}) - 0.25 \times b_{swir2} \quad (3)$$

$$AWEI_{sh} = 4 \times (b_{green} - b_{swir1}) - (0.25 \times b_{nir} + 2.75 \times b_{swir2}) \quad (4)$$

This study only uses $AWEI_{nsh}$ where $AWEI_{sh}$ gives very poor and inaccurate results for this case study.

B. *Accuracy assessment*

For validation and evaluation of the implemented approaches, the most common way to express classification results is a confusion matrix. For this study, overall accuracy and user's accuracy is considered for evaluation of results.



(a) (b) (c)

Figure 2: The optical result maps of each index on OLI imagery: (a) NDWI, (b) MNDWI and (c) AWEI

To compute a confusion matrix, the results were assessed through check the labeled data by classifier and the reference data. Reference data of this study were digitalized using high resolution images of Google Earth at close time of acquired satellite images.

IV. RESULT AND DISCUSSION

A. Indices

Results of applying three indices are shown in Figure 2. All of these indices could properly extract water reservoirs but their main weakness is misclassified pixels; non-water pixels which classified as water are mainly occurred in shadow areas. Overall accuracy for NDWI, MNDWI and AWEI indices are respectively 98.08%, 98.15% and 97.98%, even though overall accuracy for all of indices is considered reasonable and high, the key accuracy numbers to notice are the producer's and user's accuracy. User accuracy for water gives results of 23.68%, 24.34% and 22.57% for NDWI, MNDWI and AWEI, respectively. It means for example NDWI classifies around 23% of pixels as water where they are water in our reference data, which is a poor result. In other words, around 77% of pixels which classified as water are not water and are misclassified pixels. These results show around 75% commission error for three indices in general.

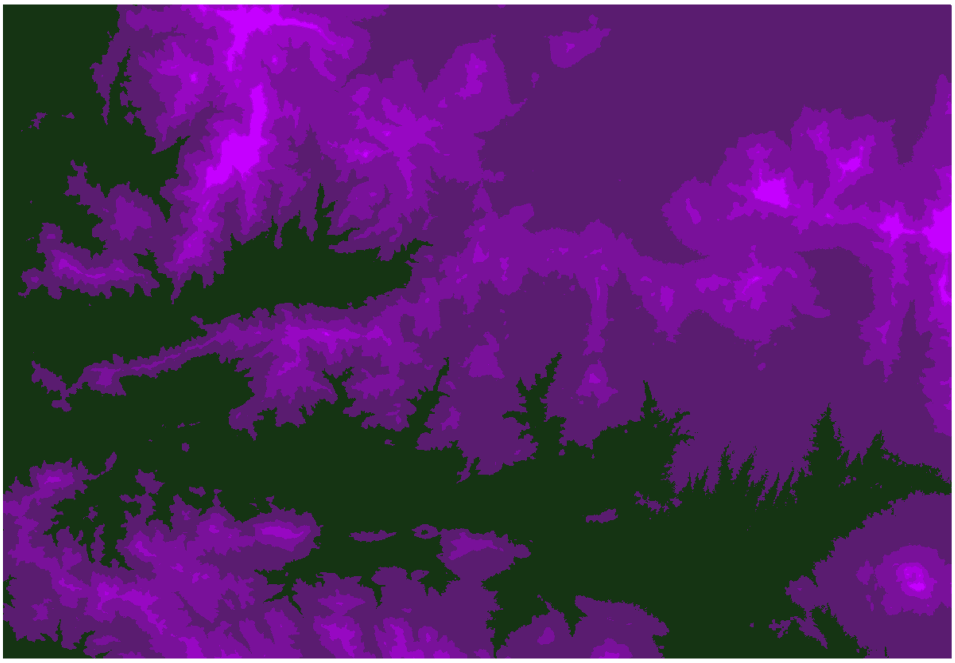


Figure 3: Overlay map of 5 different elevation classes based on DEM data

High overall accuracy and low user accuracy for water class is due to large number of non-water class, around 99% of study area is non-water class, so correct classification of non-water class highly effects on overall accuracy and final results. This is the main reason should be taken in account to do not relay on overall accuracy.

B. DEM

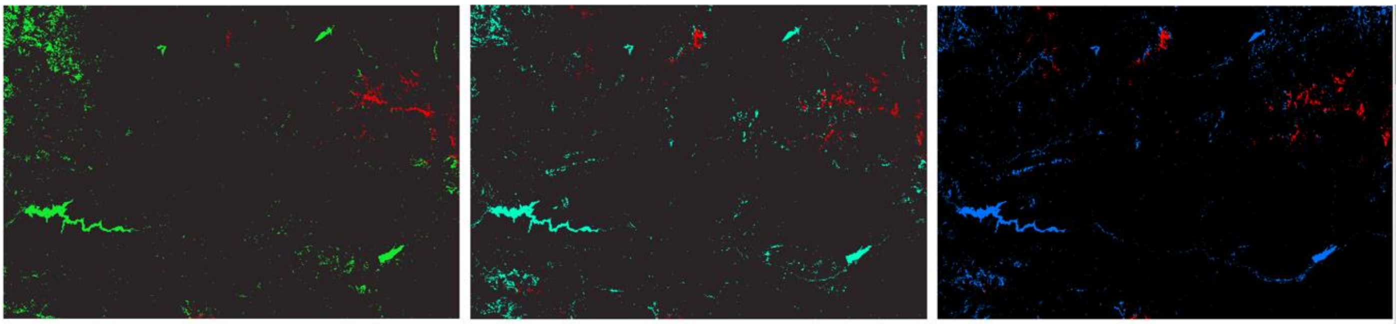
Using advantages of DEM data for this study helped to improve user's accuracy. 5 classes were defined based on standard deviation of elevation distribution in the study area (Figure 3). Three classes were applied to remove misclassified pixels where they defined as highest elevation class, second elevation class and third elevation class with 1%, 2.1% and 13.6% of standard deviation, respectively. Results show that by increases contribution of elevation, the number of misclassified pixels as water decrease. User's accuracy after applying highest elevation class improves to 24.5%, 25% and 23.6% for NDWI, MNDWI and AWEI where it was 23.68%, 24.34% and 22.57%. This improvement is even more for third

elevation class that increases to 27.44%, 29.1% and 27.22% for NDWI, MNDWI and AWEI, respectively (Table 1).

The highest improvement is for MNDWI with 4.88% increase of user's accuracy where it has the highest user's accuracy before and after applying DEM data. Results of other two indices, NDWI and AWEI, also increase 3.76% and 4.65%. Distribution of misclassified pixels extracted by third elevation class is presented in Figure 4.

Table 1: User's accuracy of each index before and after applying DEM data

	NDWI	MNDWI	AWEI
without DEM	23.68%	24.34%	22.57%
DEM1	24.48%	25.03%	23.25%
DEM2	24.82%	25.36%	23.63%
DEM3	27.44%	29.16%	27.22%



(a) (b) (c)

Figure 4: Map of excluded misclassified pixels extracted by third level of elevation data: (a) NDWI, (b) MNDWI and (c) AWEI

V. CONCLUSION

This study investigated application of DEM data for improving results of three different indices of NDWI, MNDWI and AWEI for Landsat 8 OLI images. As the focus of this research was on mountainous area, the idea of using DEM data was considered to reduce the effect of shadow areas that is usually happen in mountainous area and is one of the main problem of indices based on several studies. Because the main area of selected the study area is non-water area, for accuracy assessment this study focused on user's accuracy. User's accuracy of NDWI, MNDWI and AWEI were calculated as 23.68%, 24.34% and 22.57% respectively, where this results slightly improves by applying DEM data to maximum of 27.44%, 29.1% and 27.22%. The highest improvement is for MNDWI with 4.88% increase of user's accuracy where it has the highest user's accuracy before and after applying DEM data.

Future work to improve the results can focus on using slope and aspect data to investigate if it can be applicable for mountainous area. The results of this study can be considered to be combine with new study to develop an approach for extracting water bodies more accurately.

VI. REFERENCES

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