academicJournals

Vol. 5(6), pp. 351-359, June 2013
DOI 10.5897/IJWREE2012.0402
ISSN 2141-6613 © 2013 Academic Journals
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Satellite remote sensing and geographic information systems (GIS) to assess changes in the water level in the Duhok dam

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Accepted 26 April, 2013

The use of satellite remote sensing (RS) has salient progress in water budget calculation and it performs in watershed management. An RS technique can properly enhance hydrogeologic surveys. Moreover, to have an intimate understanding of the changes in water level fluctuations, it is also important to relate them to the surrounding eomorphic, structural, climatic and geologic factors. This research serves twofold. The first one is to operationalize the use of RS and Geographic Information Systems (GIS) techniques to assess the change of water surface area in Duhok dam located in Duhok city, Kurdistan region-Iraq. The second is to present and interpret the available statistical data on water level fluctuations in Duhok dam. The change of water surface in the Duhok dam is examined over a 11 year period using satellite images taken between 2001 and 2012. Three Landsat Enhanced Thematic Mapper Plus (Landsat 7 ETM+) images acquired on 13 June, 2001, 11 June, 2006 and on 11 June, 2012, respectively, were used. The change is tracked from the images using Band 7 with the help of Normalized Difference Water Index (NDWI). The accuracy assessed by using the Normalized Difference Area index (NDAI), and the change in water surface area analysed by comparing it with the related meteorological data of the dam. Results show that the estimated water surface area by RS matches the one on the ground with small relative error (less than 2.15%). A decrease of slightly more than 23% was observed in the water surface area this 11 year period. In addition, over this time period, climate conditions (rainfall, temperature and evaporation) in the study area have been changed significantly. These changes could have affected the reservoir surface area, but so also could external human interference around the dam.

Key words: Geographic information systems (GIS), normalized difference water index (NDWI), normalized difference area index (NDAI), remote sensing (RS), water resource management.

INTRODUCTION

Droughts and other type of disasters put pressure in the resources that, many countries build up dams and reservoirs, and to meet the demands of human needs. Therefore, storage water, (for example in the dam) considers a source of water for many sectors of the economy such as agriculture, domestic and industrial water supply, hydropower, water transport and others. Dams are structures built to create a water reservoir, a hydraulic head and a water surface. Monitoring the status of the water reservoir in the dam is critical because it is an important life support, recreational, commercial and aesthetic resource to humans. Such process requires several equipments to record the status of the dam and continuous observation. However, field measurements of the dam level are still costly and require a lot of effort and time (Yunus and Fidelia, 2012).

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RS is a major source of data and information and widely used to detect changes and update existing maps. It provides a meaningful method for detecting land/water changes, for example measuring chlorophyll, water colour and suspended sediments over large areas (Chen et al., 2012; Duan et al., 2012). Almost, all of the researchers believe that land use change is one of the most important factors in some of the hazards such as flood, soil erosion and sediment yield, ecological and environment dynamics and soil property changes (Hauser et al., 2012; Wijesekara et al., 2012). Also change detection with RS data provides cheap and quick information about the status of the water reservoir in dams and the land use/land cover (Mustafa et al., 2012; Verma A et al., 2013). Moreover, GIS techniques are also used in processing multiple data that are of concern to a dam water storage assessment project. The combined use of RS with GIS has proven useful for the timely assessment of land use dynamics (Mustafa et al., 2012; Wang et al., 2010). Many studies have investigated land use dynamics associated with dam construction and reservoir impoundment using RS and GIS techniques (Ouyang et al., 2010; Zhao et al., 2010).

The purpose of this work is to determine whether the water surface area of the Duhok dam has noticeably decreased during the last eleven years (2001 to 2012). To do this, the change of water level in the Duhok dam over time was investigated using an RS and GIS technique. Temporal changes in the dam were determined by evaluation of Landsat satellite images. Meteorological data for this area was examined and its relationship with water level changes was determined.

MATERIALS AND DATA

Physical characteristics of the study area

Location and environs

Duhok dam is a high earth fill dam with central clay core and gravel shell located on Rubar Duhok 2 km to the north of the Duhok city, between latitudes 36°52′35″and 36°54′21″N, and longitudes 42°59′51″ and 43°00′40″E (Figure 1). It is established in 1988 and the main aim of the dam was irrigation of the agricultural areas inside Duhok city and areas around it till Summel city through a tunnel, now the reservoir area of the dam is used for supplying Duhok city with water beside became as a touristic area. During the last 11 years (2001 to 2012), the maximum and the minimum reservoir surface area were around 2492603.2 and 1014851.12 m^2, respectively. In these conditions, the maximum and the minimum depth of the reservoir was 614.6 and 593.26 m. Moreover, the maximum and the minimum of the inflow water were 2365947 and 0.0 m^3, respectively, whereas the maximum and the minimum outflow were 108000 and 500 m^3, respectively.

Geological structures

Figure 2a is a simplified geological map of Duhok dam and its surrounding area. The figure resulted from a combination of three bands Landsat 7 ETM+ (Bands: 7, 5, and 3) adapted from (Mohamad et al., 2012). An examination of the geology of the area shows that the dam is situated within Bekhair anticline extends from the tri-junction of Syria-Iraqi-Turkish borders in the Northwest to the vicinity of Shaikhan area in the Southeast trending NW-SE. The area of Duhok dam is represented by a hilly plain of an altitude of 550 to 600 m surrounded to the South and North by mountain chains. The prevailing part of the area consists of steep bare mountain slopes, cut by numerous vallies and gorges with steep slopes which direct the water to the tributaries of Rubar Duhok. The most frequently exposed rock units around the reservoir belong to the Gercus and Kolosh Formations consist of mudstone with siltstone, sandstone and shale. The lithostratigraphic units that have been recognized within the study area are formations that belong to the Cretaceous-Holocene age. The Duhok dam body is founded on Gercus formation (Middle Eocene) consist of red mudstone with siltstone and sandstone, and some gypsum which are an impermeable layers, and in order to be sure that water cannot penetrate through the layers, some wells were drugged in it and were grouted by cement, while tunnels alignment pass through Gercus and Pilaspi formations. A new generalized physiographic map (Figure 2b), showing morpho-structural units and streams in the area that was prepared using Mapinfo program in order to show where the water level fluctuates in the reservoir. The main river in the area is Rubar Duhok which is formed by two main tributaries (streams) from the north and northeast and getting out of the Bekhair anticline through Besere gorge, then connected with Sendur stream to form Rubar Duhok. After construction of Duhok dam, Sendur stream is completely used to fill the reservoir. Stream patterns may develop randomly on uniform soil, or in response to the weakness in the underlying geology. There are two types of drainage patterns that are recognized in the area. The first type dendrite and reflecting homogeneous soil and rocks, and relatively uniform geological structure. The second is parallel and exists in the northern part reflecting areas of pronounced localized slope. Number of thermal springs is found in the valley of the two main branches of the rubar Duhok river.

The abbreviated name used stand for Marly limestone (Figure 2) and red mudstone (Pilaspi), Red Mudstone with siltstone and sandstone, and some gypsum (Gercus), Dolomite and Limestone (Khurmala), Shale, siltstone and sandstone with chert (Kolosh), Marl and marly limestone (Shiranish), Crystaline Limestone containing chert with Marl and Marly Limestone (Bekhme).

Climate

The climate of the studied area is similar to the Mediterranean climate conditions, with an influence of the relatively high altitude of the surrounding mountains. According to (Koeppe and De Long, 1959) the chief characteristics of the Mediterranean climate are dry summer and a modest amount of precipitation through winter. The summer season is hot with bright sunshine and low relative humidity. Higher relative humidity and correspondingly lower amount of sunshine mark the winter season as compared with summer (Aqrawi, 2003). The climate of the studied area is characterized by cold weather with snowfalls on the high mountains during the winter season. There are periodic drought periods that return themselves through specific periods and theses drought lead to groundwater recharge shortage. During winter season, the temperature and potential evapotranspiration are at minimum (1.56°C and 1.20 mm, respectively) and the rainfall are at maximum (358.41 mm). Summer starts by June and ends by the end of August; the temperature and potential evapotranspiration are maximum (43.30°C and 13.70 mm, respectively), while the rainfall is minimum (0.00 mm). Spring is cold to temperate with considerable amount of rainfall. The mean annual rainfall was about

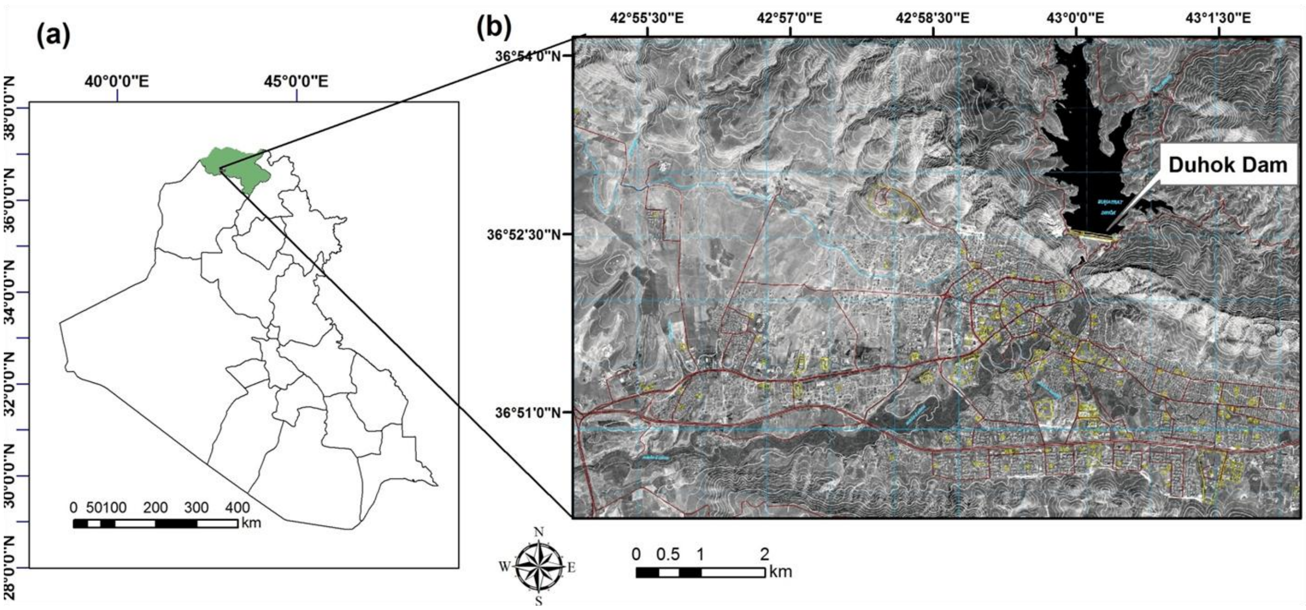

Figure 1. (a) Map region of Iraq. (b) Location of Duhok dam.

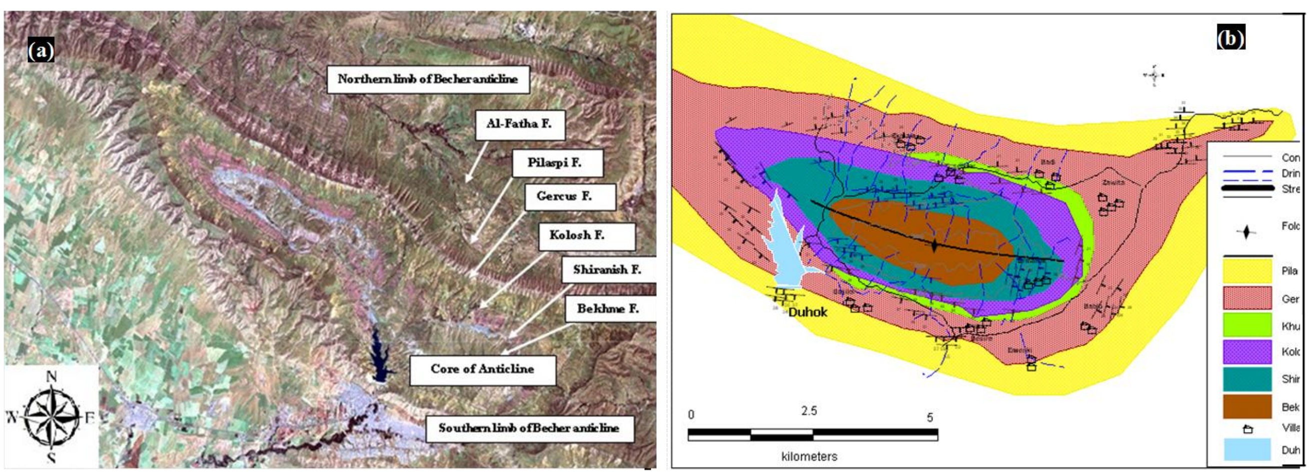

Figure 2. (a) Geological map of the studied area, prepared by using an ETM+ Landsat image, (b) Generalized physiographic map of the study area.

514.00 mm for the period (2001 to 2012), while the average annual temperature for the same period was about 20.44°C.

Data

The study is primarily based on the ground data and Landsat 7 ETM+ data from June 13, 2001 to June 11, 2012. The ground data was used to calibrate the RS results and to assess differences.

Ground data

They were collected from the Duhok dam station. The data comprised daily water stages, relation water area and water stage area of the dam. This data was used graphs that can be used to assess the water surface area using information from RS.

RS data

To determine the temporal changes in the water surface area of Duhok dam, three Landsat 7 ETM+ images acquired on 13 June, 2001, 11 June, 2006 and on 11, June 2012, respectively, were used. Landsat satellites are the most common satellites used for the examination of natural phenomena. Although this satellite has a low spatial resolution, it has a higher spectral resolution than is obtained by other satellites. Data from the three images cover a time period of

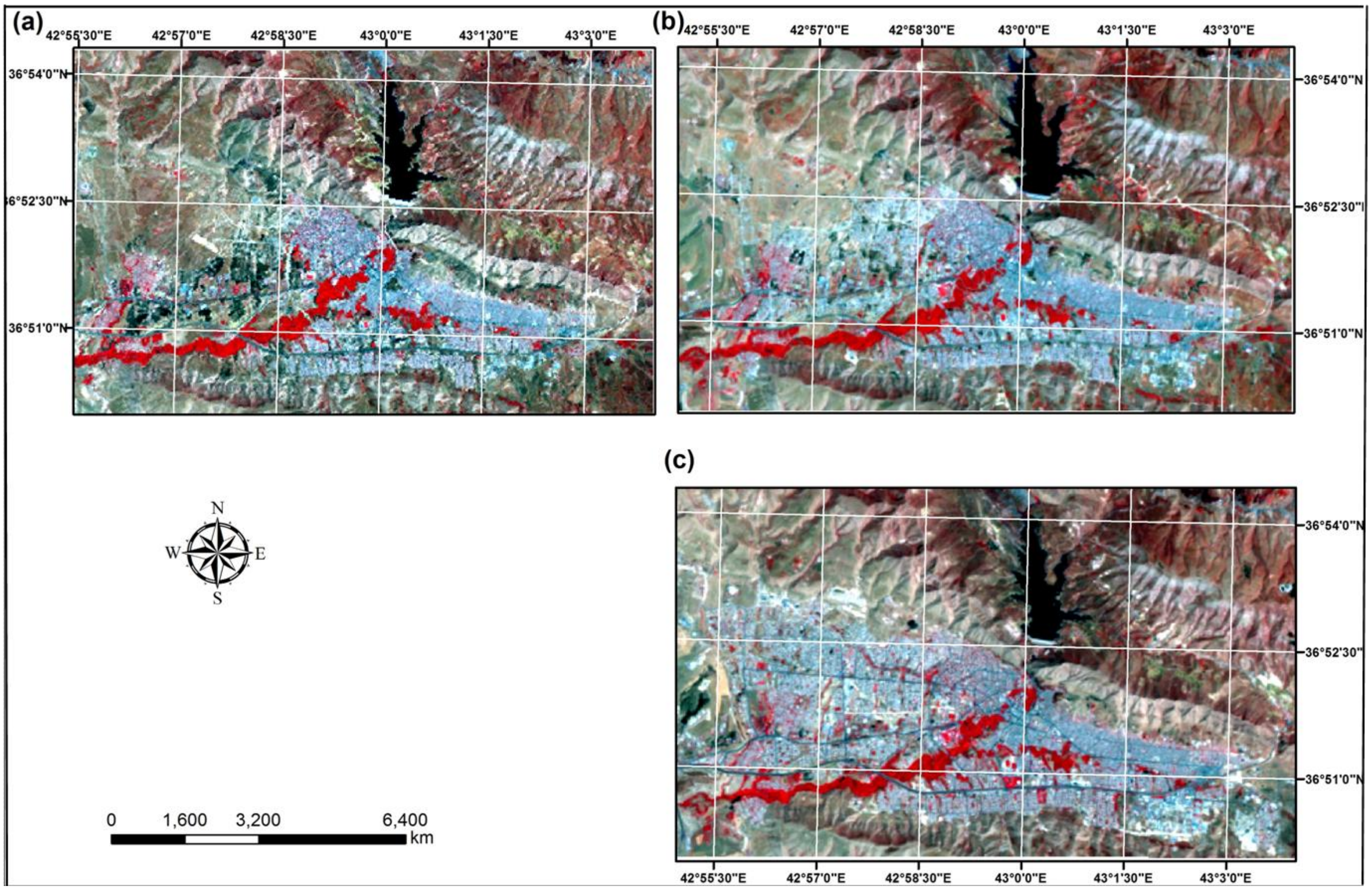

Figure 3. Colour composite Landsat ETM+ images of the study area. (a) June 13, 2001. (b) June 11, 2006. (c) June 11, 2012.

11 years. The Landsat ETM+ images of the study area are shown in Figure 3, resulting from a combination of three bands 4, 3, and 2 by using ENVI software. The datasets are cloud-free scenes acquired, relatively, during the summer of the year. Reference data for ground control points (GCPs) and accuracy assessment, including topographic maps (scale 1:12 500), and a land use map (scale 1:12 500) were used in this work.

METHODS

The data processing and manipulation were conducted using ENVI (V. 4.7, ITT Visual Information Solutions Group (ITT VIS), formerly known as Research Systems Inc. (RSI), Boulder, CO, USA) and ArcGIS (V. 10.0, Environmental Systems Research Institute (ESRI), Redlands, CA, USA) softwares. In addition, a field survey was carried out in June 2012 to collect ground control, and ground truth points by using Garmin eTrex GPS. The GPS device had an accuracy within a range of ±3 m for 95% of time as a confidence interval. The processing procedures which are adopted in this work are summarized in Figure 4 and will be discussed in the following part of this work.

Satellite images processing

Geometric correction

The major task of the image preprocessing is the geometric registration (Moufaddal, 2005). In this work, Landsat data were co-registered to the topographic base maps at a scale of 1:12 500 (that is, image-to-map registration) using the Universal Transverse Mercator (UTM) Projection Zone 38 North with a World Geodetic System (WGS) 84 datum. Image-to-map registration was done using 22 GCPs at a root mean square error (RMSE) of less than 0.61 pixels. The first-order polynomial transformation and the nearest neighbour method of sampling were used to maintain the original pixel brightness values and to resample the pixels at a spacing of 30 m in both directions.

Atmospheric correction

Many atmospheric correction methods have been proposed for use with multi-spectral satellite imagery (Hadjimitsis et al., 2004). The Darkest Pixel (DP) atmospheric correction method was applied to the current work. The simplest DP correction method provided a reasonable correction, at least for cloud-free skies (Hadjimitsis et al., 2004). To assure that the three images used in this work appear as if they were acquired under the very same conditions, a relative radiometric normalization technique was performed.

Water surface area delineation

There are different techniques to detect water in the RS image. In this work the grey scale view was used for better detection of water in the Landsat image through the use of single band (Band 7). The

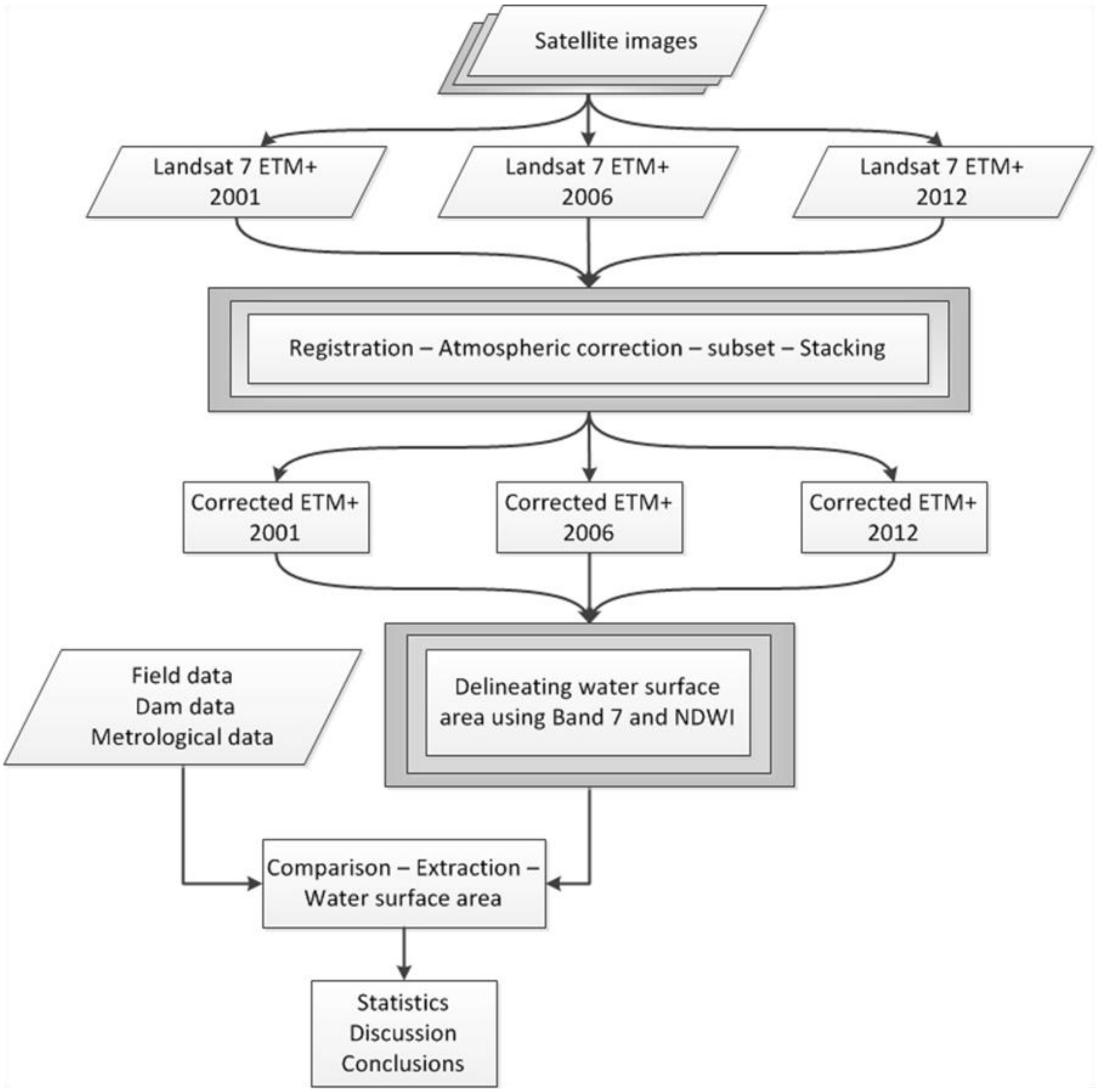

Figure 4. Flow diagram showing the methodology steps.

enhanced RS image was a black and white image where water bodies are represented in black. Moreover, the *Normalized Difference Water Index* (NDWI) was also used as an assistance index in determining the water surface area. However, NDWI normally uses to estimate vegetation water content. The NDWI were computed for each pixel using the following equation (Gao, 1996):

$$\mathrm{NDWI} = \frac{Band_4 - Band_5}{Band_4 + Band_5} \quad (1)$$

The values of NDWI are in the range between –1 and +1. Since we are only interested about the water content in the pixel, we introduced a threshold by selecting NDWI pixel values which are greater than 0.20 to determine the boundary of the dam.

RESULTS AND DISCUSSION

Difference in area estimation

The area determination is one of the methods to assess the goodness of the classification. Hence the deviation from Area satellite ($Area_{SAT}$) to Area field ($Area_{FD}$) should be seen in relation to their size so that the deviation becomes comparable. For such a purpose, the *Normalized Difference Area Index* (NDAI) is used to see

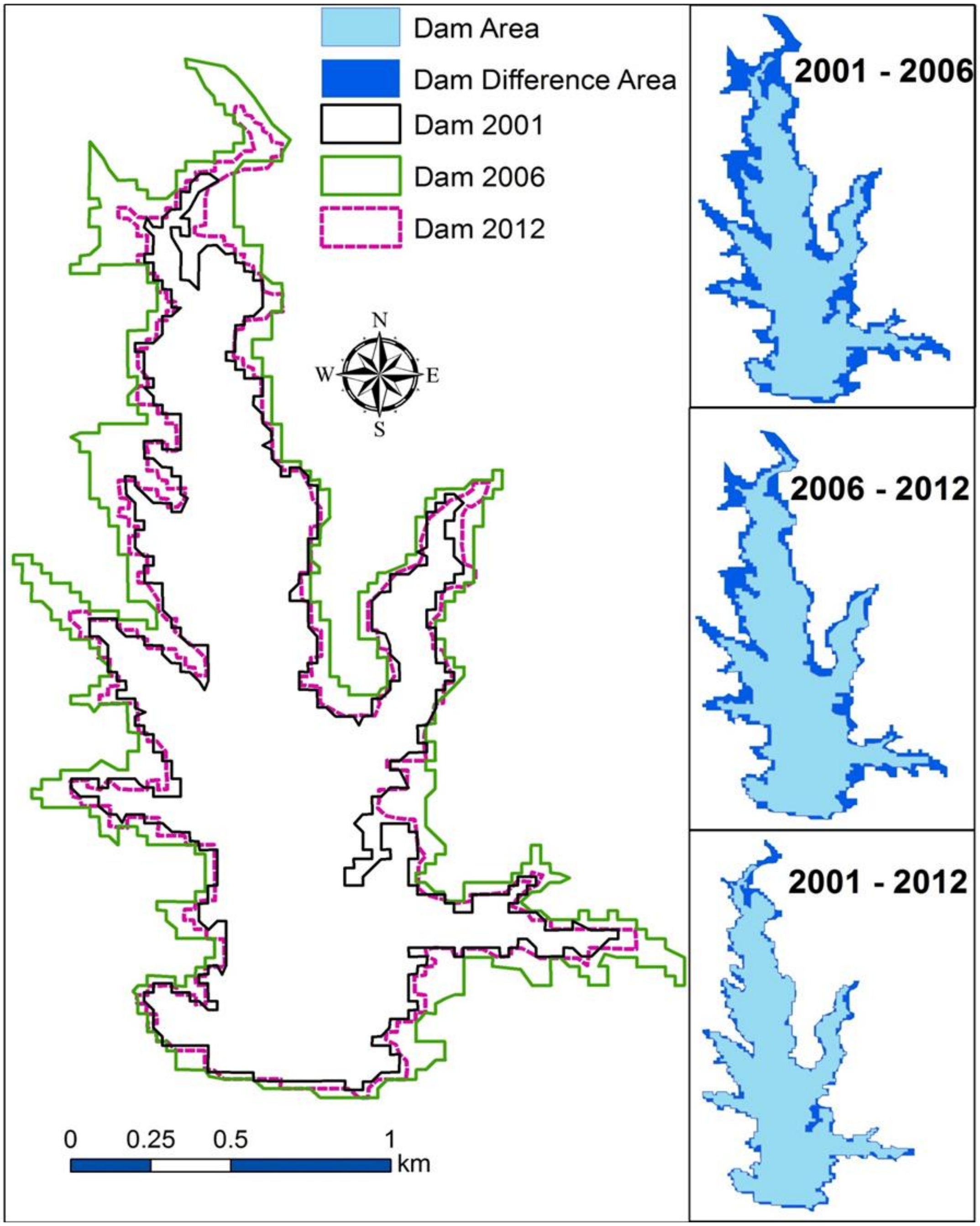

Figure 5. Water surface area of the Duhok dam versus year, estimated by RS images.

how the area from RS matches with the area of the dam in the ground. NDAI can be calculated using the following formula:

$$\mathrm{NDAI} = \frac{\mathrm{Area_{FD}} - \mathrm{Area_{SAT}}}{\mathrm{Area_{FD}} + \mathrm{Area_{SAT}}} \quad (2)$$

NDAI values have a potential range from -1 to 1. Dam NDAI with values close to 0 have the best match between $\mathrm{Area_{FD}}$ and $\mathrm{Area_{SAT}}$, while values increasing to extreme stand for the increasing deviation between surface areas. Negative values resemble dam where $\mathrm{Area_{SAT}} > \mathrm{Area_{FD}}$ and positive values represent $\mathrm{Area_{SAT}} < \mathrm{Area_{FD}}$. The NDAI in 2001, 2006, and 2012 are -0.0042, -0.010 and -0.0050, respectively. The determined water surface area is shown in Figure 5. These values are spite small differences in the water surface area estimation and the $\mathrm{Area_{SAT}}$ overestimated $\mathrm{Area_{FD}}$ (Table 1). The small difference, however, considered as errors. The reason for this level in accuracy can be related to the spatial resolution of the image. Another reason can be that the ground data may have some mistakes on the water stage daily readings that affected the estimated area. Overall, for this work, the differences between the $Area_{SAT}$ and $Area_{FD}$ are small and close to zero which indicates that our method is reasonable and acceptable relative to the spatial resolution of the satellite images.

Using RS imagery to determine the water surface area in dams has some advantages. First, RS imagery assisted in the easy recognition of dam reservoirs since the spatial and spectral resolution of the images enables the mapping of water, wetland and soil in the dam and the surrounding area. Also, regions that are difficult to access to field work can be easily observed by RS equipment. Second, RS imagery is very important when there is no previously dated ground truth data. In the protection of water source areas, archive images can play an important role in facilitating the monitoring of temporal changes.

Meteorological data and water surface area

The rainfall and evaporation graphs, for the region in which Duhok dam is situated, are given in Figure 6, temperature graphs in Figure 7 and monthly rainfall in Figure 8. The average rainfall for the 11 year period was 514.00 mm in Duhok dam and its environs. According to the date of the satellite images used in this work, the total rainfall was 410.6 mm in 2001, 795.3 mm in 2006 and 533.2 mm in 2012 (Table 1). The total rainfall in 2006 is higher than the average rainfall, resulting in an increase in the water surface area of the Duhok dam. Moreover, based on the provided data by dam station, the minimum and the maximum inflow were 0.0 and 2365947.0 m^3 respectively, while the outflow from the dam most of the time was approximately fixed with 50000.0 m^3. According to the date of the satellite images used in this work, the total inflow and outflow were 21526792.0 and 18250000.0 m^3, respectively in 2001, 23978484.0 and 18250000.0 m^3, respectively in 2006, and 3156590.0 and 1553150.0 m^3, respectively in 2012 (Table 1). It is clear that the total inflow is always higher than the total outflow; however the inflow in 2012 is lower than the one in 2006 and 2001. In addition, the inflow in 2006 is higher than the average inflow. Thus, the water surface area increase can be considered a result of the high rainfall and the high inflow.

When the meteorological data is examined it can be seen that the average temperature over the 11 years is 20.44°C. The average temperature was 20.40°C in 2001, 20.25°C in 2006 and 20.36°C in 2012 (Table 1).

In addition, the maximum and minimum temperature for the period first 5 years from 2001 till 2006 were 26.16, and 14.52, respectively, and were 25.71, and 15.49 respectively, for the period 2006 to 2012 (Table 2). The total evaporation was 72.30 mm in 2001, 73.50 mm in 2006 and 77.11 mm in 2012 (Table 1), which was higher than that in 2001 and 2006. Moreover, the maximum and minimum evaporation for the period 2001 to 2006 were 62.2, and 82.1, respectively, and were 58.8, and 76.2 respectively, for the period 2006 to 2012 (Table 2). Thus, it can be stated that the water surface area of the Duhok dam has increased during the period of 2001 to 2006 and has decreased during the period of 2006 to 2012; however, this result cannot be solely related to the meteorological data, in particular the rainfall. There are also some other factors including a drainage channel built in the region, embankments constructed across the flowing water for irrigation and for drinking water supply, and wells were built.

There are two important factors which could cause this change: climate conditions (only climate conditions were investigated) and exterior interventions made to the dam. Comparing the climate changes over the period from 2001 to 2012, the average temperature increased by 0.494%, total rainfall decreased by 32.956% and evaporation increased by 4.912%, as seen in Table 1. Therefore, it is likely that climate conditions affected the surface area of the dam. However, climate conditions are not the only reason why the dam surface area decreased by more than 23.00%. A further factor is the use of dam water for irrigation and drinking which also need to be examined.

The temporal change in water surface area of Duhok dam examined in this work shows that the water surface area was nearly the same in the of 2001 and the 2012. By comparison, the water surface areas in 2006 and 2012, it can see that in 2012 the water surface area had decreased by 23.00%. Between 2006 and 2012 rainfall in the region decreased but evaporation and temperature increased (Figures 6 and 7). All these analyses indicate the decrease in water reserves in the dam.

Conclusions

In this work, the changes in the water reserves in Duhok dam, which is important for ecology, tourism and historically, over a 11 year period was investigated using RS and GIS techniques. Landsat images from 2001, 2006 and 2012 were assessed and the results were interpreted together with related meteorological data. Over the 11 year period an increase in water surface area has detected in 2006, while a decrease in water surface area and thus, in water reserves was detected in 2012. Among the reasons for the decrease/increased are climate changes and human external interference around the dam (wells, drainage channels, irrigation, domestic consumption). The current situation of Duhok dam threatens the hydrological and the ecological balance of the region. Continuous monitoring of such environmental

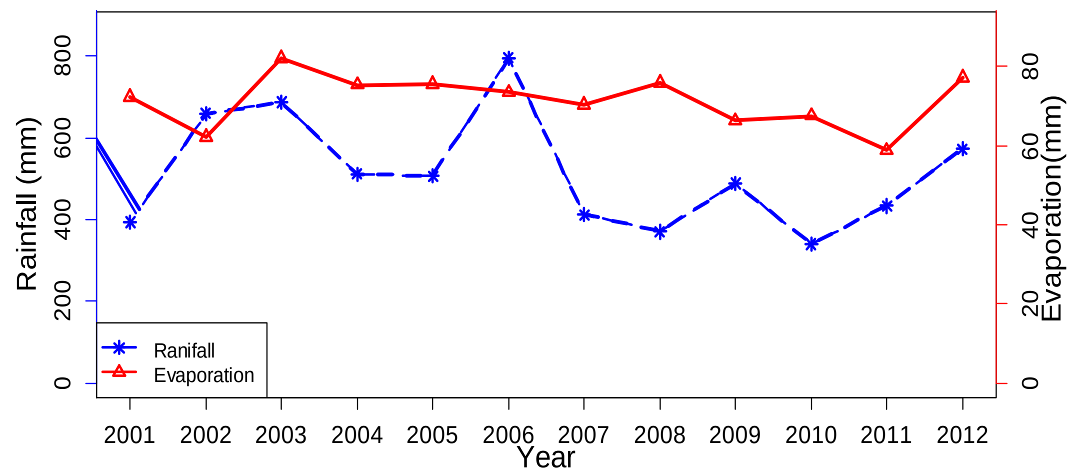

Figure 6. Average rainfall and evaporation between 2001 and 2012

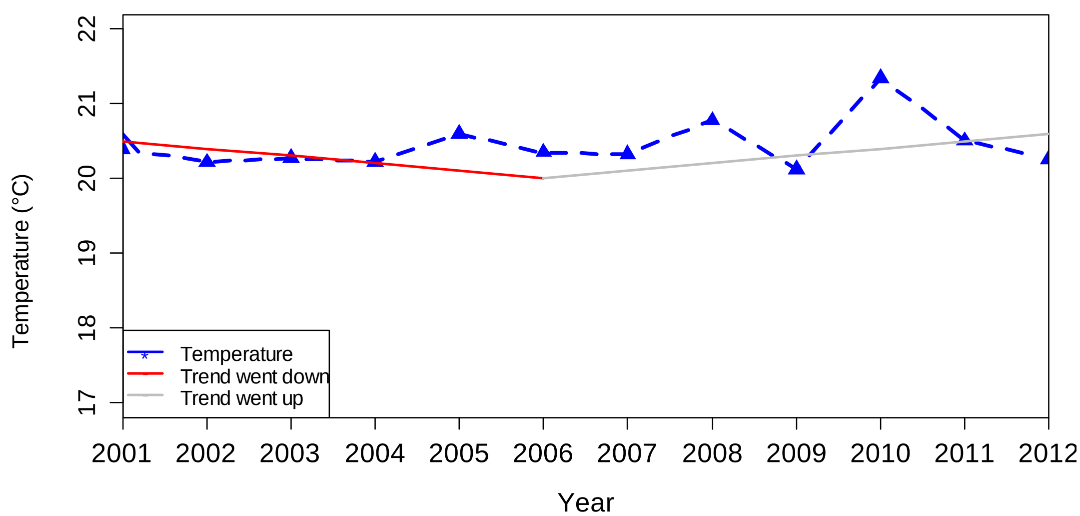

Figure 7. Average temperature between 2001 and 2012.

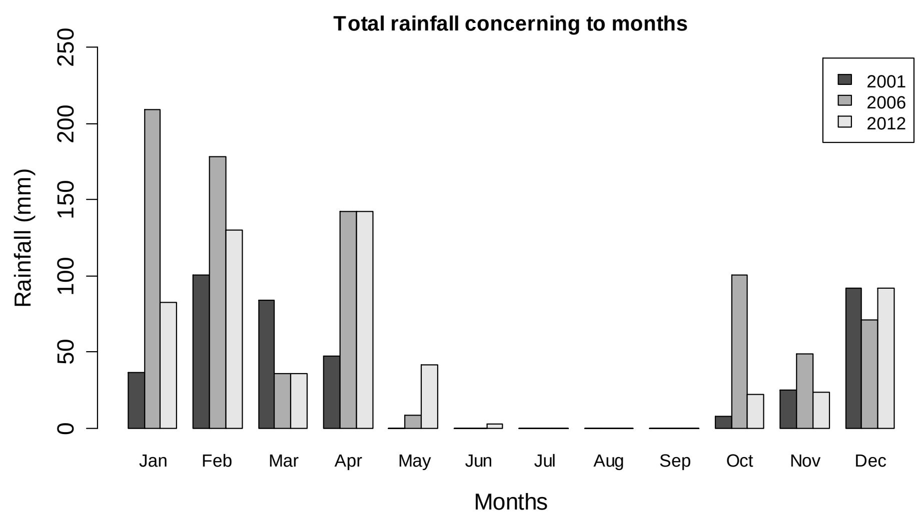

Figure 8. Rainfall graphics for years 2001, 2006 and 2012.

Table 1. Filed water surface area ($Area_{FD}$), estimated water surface area ($Area_{SAT}$), and Normalized difference Area index (NDAI) of the Duhok dam between 2001 and 2012.

Criteria		2001	2006	2012
Surface area (m^2)	$Area_{FD}$	1,580,793.64	2,325,645.52	1,790,742.08
	$Area_{SAT}$	1,594,317.54	2,375,811.31	1,808,889.99
	NDAI	-0.0042	-0.0106	-0.0050
Average temperature (°C)		20.40	20.25	20.36
Total evaporation (mm)		72.30	73.50	77.11
Total rainfall (mm)		410.6	795.3	533.2
Total inflow (m^3)		21526792	23978484	3156590
Total outflow (m^3)		18250000	18250000	1553150

Table 2. Significance statistical of rainfall, temperature, and evaporation within two periods (2001-2006 and 2006-2012).

	Period	Max	Min	Average
Rainfall (mm)	2001-2006	393.6	795.3	592.1
	2006-2012	339.9	573.2	435.916
Temprature (°C)	2001-2006	26.16	14.52	20.34
	2006-2012	25.71	15.49	20.60
Evaporation (mm)	2001-2006	62.2	82.1	73.5
	2006-2012	58.8	76.2	69.2

regions is essential in order to take the necessary measures to protect water resource areas. In addition, this work showed that satellite data is useful for monitoring and estimating changes in the environment.

ACKNOWLEDGEMENTS

The authors would like to thank the director of the Duhok dam (Mr Faisal Noori) for providing field data of the Duhok dam. We also thank NASA for the production and distribution of the Landsat images. Funding for this work was provided by The University of Zakho (UOZ), and it is very appreciated by the authors.

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