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Investigating the impact of anthropogenic activities on Lake Abha through remote sensing

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Abstract
In Saudi Arabia the government's land grants policy and liberal interest free loans to its public have triggered tremendous urban growth all over the country. The urbanization progress has made the available limited surface fresh water resources of the country in deep stress in terms of water quality. Countries such as Saudi Arabia, with enormous human resources cannot afford to lose the scarcely available surface fresh water resources. The current study makes an attempt to analyze the anthropogenic activities in the watershed surrounding Lake Abha through remote sensing techniques and assess its implications on water quality as found in the scientific research for lakes, streams and marine ecosystems. In this paper, a high resolution multispectral Worldview-2 (WV-2) and Landsat imageries (Landsat 1, Landsat 2, and Landsat 8) are utilized to assess the past and present land use and land cover (LULC) practices in the watershed. The image analysis revealed agricultural practices and construction activities as the two major sources of nonpoint pollution in the watershed that is directly impacting the quality of water in Lake Abha. If the local stakeholders are not mobilized to prevent the deterioration of Lake water quality, it would require huge human resources to restore the pristine condition of this lake and other water bodies in the kingdom.

1. Introduction

The recent trend of urbanization in Saudi Arabia is one of the fastest in the world. Government's land grants policy and liberal interest free loans have resulted in massive expansion of cities and towns all over the country (Al-Hathloul and Mughal 2004; Mandeli 2008). Further, the Kingdom of Saudi Arabia has always attached great importance to the agricultural sector and has given it priority in its various development plans[1]. The total potential agriculture land of the country is 52.7 million hectares out of which agriculture is practiced only on 1.2 million hectares (Multsch et al. 2013). The agricultural sector consumes around 90% of the water budget ((ElNesr et al. 2010). To boost the sectors for water, agriculture and other economic resources, the Kingdom of Saudi Arabia in its current fiscal year (2014) allocated SR 61 billion (16. 3 billion USD) which is an increase of 5.7 percent to the previous budget[2] (KSA 2014b).

Saudi Arabia's climate is very dry with extreme temperatures and generally is not very suitable for farming and faces an acute water shortage due to absence of permanent lakes and rivers (Alzahrani et al. 2012; Ouda 2013; Ouda et al. 2013; Zaharani et al. 2011).

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[1] www.foa.org/nr/water/aquastat/countries_regions/Saudi_arabia/index.stm
[2] http://www.saudiembassy.net/latest_news/news12231301.aspx

However, the government has always supported and encouraged the private sector to invest in the agricultural sector and has provided various incentives such as subsidies, interest-free loans, free distribution of uncultivated land, free seeds and fertilizers, low-cost water, fuel and electricity, and duty-free imports of raw materials and machinery[3] (KSA 2014a) in addition to the development of infrastructure (roads, dams, irrigation and drainage canals). The private sector has responded positively to such incentives and has played a major role in the Kingdom's agricultural development.

The major impacts on lakes are diversions, eutrophication, invasive species, land-use change, overexploitation of resources, and pollution (Beeton 2002). Many researchers have observed that with rise in population, excessive agricultural practices and construction activities with no mitigation measures in place the quality of water in lakes, rivers and marsh lands have deteriorated (see table 1) and have also caused at many places the water bodies to shrink in size (Gurlin et al. 2011; Khan and Ansari 2005; Luan and Zhou 2013; Necsoiu et al. 2013; Waltham and Sholji 2001; Zorrilla-Miras et al. 2014).

Table 1. *Effects of eutrophication on lakes and reservoirs (taken from Smith et al 1999)*

Increased biomass of freshwater phytoplankton and periphyton
Shifts in phytoplankton species composition to taxa that may be toxic or inedible (e.g. bloom forming cyanobacteria)
Changes in vascular plant production, biomass, and species composition
Reduced water clarity
Decreases in the perceived aesthetic value of the water body
Taste, odor, and water supply filtration problems
Possible health risks in water supplies
Elevated pH and dissolved oxygen depletion in the water column
Increased fish production and harvest
Shifts in fish species composition towards less desirable species
Increased probability of fish kills

Land use changes in the watershed can result in significant changes in the soil erosion and nutrient runoff. Agriculture and urban activities are major sources of phosphorus and nitrogen to aquatic ecosystems (Carpenter et al. 1998). Studies in New Hampshire have shown that phosphorous export from agricultural lands is 5 times greater than forested lands, and urban areas may be more than 10 times greater (EFS 2010). The detrimental impact of sediment and associated pollutants on water quality is widely acknowledged (Rickson 2014). Soil erosion is a source of non-point pollution resulting from land-use and agricultural practices (see Fig.3 and Fig.4) and has tremendous impact on receiving water bodies leading to an increase in the risk of flooding, filling of reservoirs, and eutrophication (Pricope 2009).

1.1. The Problem of Eutrophication

About 50 years ago, eutrophication has been understood to have serious environmental impacts on fresh water environments as well as estuarine and coastal systems (Ferreira et al. 2011). Eutrophication phenomenon has been widely studied and recognized as a global problem (Henry and Heinke 1996; Liu et al. 2009; Qin et al. 2013; Sharpley 2003; van Beusekom 2005). Ecosystems (Table 2) were described based on their supplies of growth-limiting nutrients (Smith et al. 1999). Waters having relatively large supplies of nutrients are termed eutrophic (well nourished), and those having poor nutrient supplies are termed oligotrophic (poorly nourished) and the one with intermediate nutrient supplies are termed mesotrophic. According to Sharpley (2003)and Smith et al. (1999) eutrophication can be explained as the natural aging of lakes or streams brought on by nutrient enrichment. Qin et al. (2013) pointed out that shallow lakes are more prone to eutrophication. Among the driving factors are an increasing human population, domestic sewage, the use of artificial fertilizers, animal production, deforestation and atmospheric input from combustion of fossil fuels. According to Henry and Heinke (1996) eutrophication can be compared with the unsteady state system in which the rate of accumulation is changing with time. The filling of lakes with sediments from the surrounding watershed including discharge of untreated sewage and agriculture or industrial wastes hastening the filling process is an example of eutrophication. According to Jensen (2009) the sediments are flushed into receiving water bodies from a variety of sources including upland agricultural cropland erosion, weathering of mountainous terrain, shoreline erosion caused by natural waves or boat traffic, and volcanic eruption (El Atta et al. 2013). Soil erosion in a watershed contributes to sediment loads to surface waters, which results in faster filling of major rivers, reservoirs, farm ponds, flood-control impoundments, and estuaries. This can shorten the useful life of reservoirs, ponds and flood-control devices and require dredging of rivers and estuaries. Sediments also affect water quality and its suitability for drinking, recreation and industrial purposes. It serves as a carrier and storage agent of pesticides, absorbed phosphorous, nitrogen and organic compounds and can be an indicator of pollution. Liebig's law of the minimum states that growth will be limited by the nutrient that is least available relative to the organisms need. Excess phosphate levels in water can lead to increased algal growth, eutrophication and reduced water quality (Warwick et al. 2013). Phosphorous is usually limiting in fresh waters whereas, nitrogen is limiting in estuaries and coastal waters. In water bodies where eutrophication is a problem, the nutrient load must be controlled (Peter 2006). Nitrogen loads are likely to increase through population growth, expanded land development and increased agriculture (Khan and Ansari 2005; Scavia and Bricker 2006). As pointed out in Table 2, the relative contributions of external supplies of nutrients from point sources and nonpoint sources to a water body can differ from watershed to watershed depending upon local population densities and land-use (Smith et al. 1999).

3 http://www.saudiembassy.net/about/country-information/agriculture_water/

Table 2. *Sources of point and nonpoint chemical inputs recognized by US statutes (from Carpenter et al. 1998 cited in Smith et al. 1999)*

Point Sources
Wastewater effluent (municipal and industrial)
Runoff and Leachate from waste disposal sites
Runoff and infiltration from animal feedlots
Runoff from mines, oil fields, and unsewered industrial sites
Storm sewer outfalls from cities with populations > 100,000
Overflow of combined storm and sanitary sewers
Runoff from construction sites with area > 2 ha
Nonpoint sources
Runoff from agriculture (including return flows from irrigated agriculture)
Runoff from pastures and rangelands
Urban runoff from unsewered areas and sewered areas with population < 100,000
Septic tank leakage and runoff from failed septic systems
Runoff from construction sites with an area < 2 ha.
Runoff from abandoned mines
Atmospheric deposition over a water surface
Activities on land that generate contaminants, such as logging, wetland conversion, construction and development of land or waterways

Nutrients discharge from point sources are easier to control because of their known location whereas, non point sources of nutrients release are more common and difficult to detect and control. Nutrients are carried from NPS in the form of urban runoff, construction, mining, agriculture, solid waste disposal, stream bank erosion, and sewage disposal (Jensen 2009). Eutrophication restricts water use for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition. Associated periodic surface blooms of cyanobacteria (blue-green algae) occur in drinking water supplies and may pose a serious health hazard to animals and humans (Sharpley 2003).

Many lakes of the Kingdom of Saudi Arabia are rarely monitored or assessed. Rapid change in land use and land cover over the last 40 years has seriously impacted the quality of water in Lake Abha. Since long agriculture and construction activities are the most important human pursuits in the watershed, resulting in soil erosion that is ending up in Lake Abha. Extensive use of fertilizers and pesticides during the growing season has seriously deteriorated water quality in Lake Abha. Absence of storm water sewers in the study area has further aggravated the situation.

1.2. Remote Sensing Technique

Remote sensing techniques have been widely applied to monitor water quality in fresh water and marine systems (Batista et al. 2003; Giardino et al. 2010; Gurlin et al. 2011; Hadjimitsis et al. 2010; Jensen 2009; McCullough et al. 2012; Rundquist et al. 1995; Yang and Everitt 2010; Sheela et al. 2012). Water quality monitoring provides an integrated evaluation of physical, chemical, and biological characteristics of aquatic systems (Hadjimitsis et al. 2010). The conventional (*in situ*) way to monitor water quality involves costly and time consuming surveys in which water samples are taken and then laboratory testing is required so as to retrieve water quality physical indicators. The *in situ* method allows accurate measurement within a water body but only at discrete points without synoptic coverage of the whole water body. Conversely, satellite remote sensing has been found in the literature to be a valuable tool for providing complete and synoptic geographical coverage of water quality in fresh and marine sources of water (Giardino et al. 2010; Hadjimitsis et al. 2010; Jensen 2009). Remote sensing also allows monitoring the landscape effectively and efficiently, identifying water bodies with significant water quality problems, so that it can help support developing lake management strategies (Giardino et al. 2010).

2. Materials and Methods

2.1. Study Area

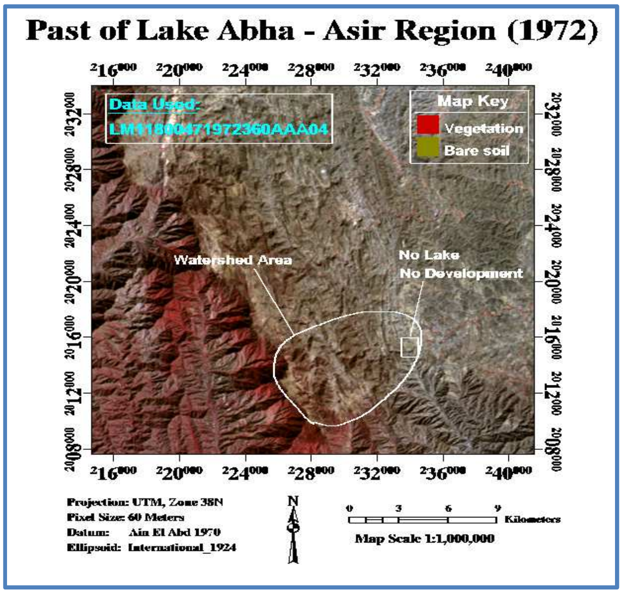

Fig. 1. *The watershed area of Abha Lake in Landsat-1 image (1972) before the Lake was built.*

Figure 1 is a Landsat 1 image of Abha acquired in 1972 showing the watershed area with no sign of lake in the scene. Abha is located in Asir region in the middle of the south western part of the Kingdom of Saudi Arabia. It lies between latitude 17°25′ and 19°50′ to the North and longitude 50.00° to 41°50′ to the East. It has an area of 81,000 km^2 and an estimated population of 1,913,392 (Khan and Ansari 2005; SCDSI 2010). The average annual precipitation in the Asir region is estimated up to 500 mm per year (Al-Turki 1995; Multsch et al. 2013). According to (Şen and Al-Suba'i 2002) the amount of precipitation is more during summer season (usually starting from the second half of July until end of August) due to local convection. The down pouring is in the form of torrential storms, causing floods to unprotected downstream areas on the coastal plains of the Red Sea (Al-Ahmadi and Al-Ahmadi 2013; Şen and Al-Suba'i 2002; Shehata and Amin 1997).

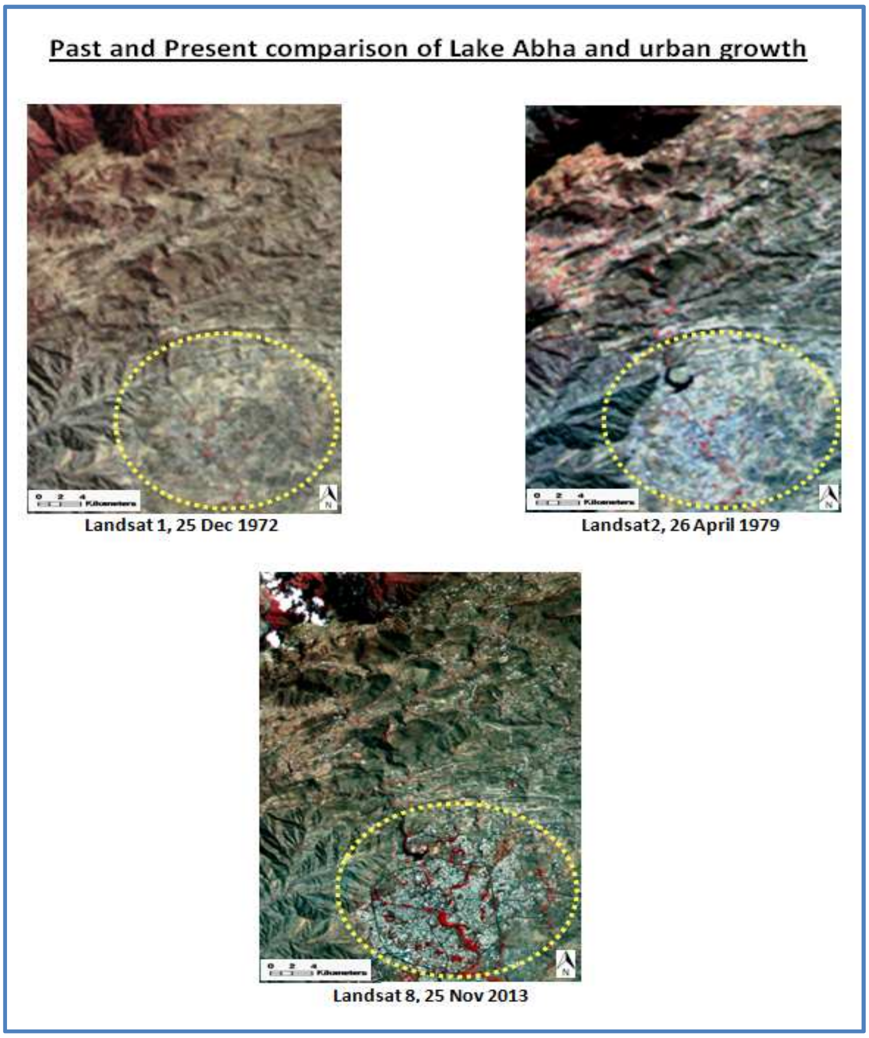

Fig. 2. *Lake Abha can be seen in the Landsat 2 image (dated 26 April, 1979). The trend of urban growth during the last 40 years can also be witnessed in the various Landsat images.*

Lake Abha is a manmade lake situated at Abha, the capital of Asir region. The highest point in the watershed of Lake Abha is at an elevation of 2815 meters, whereas, the lowest point where the lake is situated is at an elevation of 1715 meters above sea level. The length and width of the watershed is roughly 8 by 6 kilometers. The total Catchment area of the lake is roughly 5000 hectares (Fig. 2). It was built in 1974 during the reign of King Faisal bin Abdul Aziz. The lake was built to control water stream and rain harvesting. The Lat/Lon of lake Abha is 18° 09′ 37.56″ N and 42° 26′ 17.10″ E (UTM; Zone 38 North). The height of the dam is 33 m and it has an estimated capacity of about 2.13 million cubic meters[4]. The area of the lake as estimated from the Worldview-2 (WV-2) imagery was 1250 m^2.

2.2. Satellite Imagery

A high resolution multispectral Worldview-2 (a bundle of panchromatic and multispectral bands) cloud free data dated 12-10-2012 is used in this research. This data is well suited for assessment of small lakes and reservoirs. In addition to worldview-2 data, Landsat data (Landsat 1; Landsat 2;

[4] www.moi.gov.sa

Landsat TM5 and Landsat 8) is also used for the years 1972; 1979 and 2013.

2.3. Worldview-2 Data

The WorldView-2 a high-resolution multispectral imaging satellite was launched on October 8, 2009, from Vandenberg Air force base. WorldView-2 instrument is a pushbroom imager with nominal swath width of 16.4 km. The instrument acquires 11-bit data in nine spectral bands covering panchromatic, coastal, blue, green, yellow, red, red edge, NIR1, and NIR2 (Updike and Comp 2010). At nadir, the collected nominal ground sample distance is 0.46 m (panchromatic) and 1.84 m (multispectral). Commercially available products are resampled to 0.5 m (panchromatic) and 2.0 m (multispectral).

The Worldview-2 image (see table 3) used in this research was procured from Space Imaging Middle East/DigitalGlobe – Dubai office.

2.4. Landsat Data

Landsat satellite (Williams et al. 2006) was first placed in orbit in 1972 and established the U.S. as the world leader in land remote sensing. The Landsat series of Earth observation satellites were successfully used for systematic collection of land images. The Landsat system has contributed significantly to the understanding of the Earth's environment. The Landsat data used in this research (see table 4) was downloaded with permission from United States Geological Survey (USGS).

Table. 3. *Characteristics of World-view-2 data used in the research.*

Satellite data/Dated	Resolution	Resampling kernel	Product Level	Output Format	Available Bands Spectral resolutions (nm)
Worldview-2 (10-09-2012)	16 bit	Nearest Neighbor	LV2A	Geotiff	Panchromatic (625.0) Coastal Blue (427.3) Blue (477.9) Green (546.2) Yellow (607.8) Red (658.8) Red Edge (723.7) NIR1 (831.3) NIR2 (908.0)

Table 4. *Characteristics of Landsat data used in the research*

Landsat data used/Dated	Sensor	Characteristics	Available Bands
Landsat 1 (Dec 25, 1972) Landsat 2 (April 26, 1979)	Multispectral Scanner (MSS)	• Four spectral bands (green, red, two near-IR) • 80 m resolution • Multispectral scanner versus camera • Quantization (6 bit)	• Band 4 Visible green (0.5 to 0.6 µm) • Band 5 Visible red (0.6 to 0.7 µm) • Band 6 Near-Infrared (0.7 to 0.8 µm) • Band 7 Near-Infrared (0.8 to 1.1 µm)
Landsat 8 (Nov 08, 2013)		• Nine spectral bands, including a pan band • PAN (15 m) • VNIR – SWIR (30 m) • Cirrus (30 m) • Two Thermal Infrared Sensor • TIRS (100 m)	• Band 1 Visible (0.43 - 0.45 µm) • Band 2 Visible (0.450 - 0.51 µm) • Band 3 Visible (0.53 - 0.59 µm) • Band 4 Red (0.64 - 0.67 µm) • Band 5 NIR (0.85 - 0.88 µm) • Band 6 SWIR 1(1.57 - 1.65 µm) • Band 7 SWIR 2 (2.11 - 2.29 µm) • Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) • Band 9 Cirrus (1.36 - 1.38 µm) 30 m • Band 10 TIRS 1 (10.6 - 11.19 µm) • Band 11 TIRS 2 (11.5 - 12.51 µm)

2.5. Preprocessing of Satellite Data

Satellite imageries were processed by using Environment for visualizing images (ENVI™ 5.1) software on a DELL™ OPTIPLEX 790 core i5 platform. All the visible-near-infrared (VNIR) and shortwave-infrared (SWIR) bands of Worldview-2 and Landsat images were radiometrically calibrated and then converted to apparent reflectance using QUick Atmospheric Correction Method. The images were reprojected to Transverse Mercator projection (Ain ElAbd 1970). We preferred nearest neighbor sampling for extraction of biophysical information from remote sensor data because it does not alter the pixel brightness values during resampling. It is often the subtle changes in brightness values that make all the difference when distinguishing one type of vegetation from another, an edge associated with a geologic lineament, or different levels of turbidity, chlorophyll, or temperature in a lake (Jensen 2009). The Worldview-2 multispectral (VNIR) bands (in apparent reflectance) were then pan-sharpened with the panchromatic band by the application of Graham-Schmidt technique to obtain the resolution of calibrated panchromatic band (0.5 m).

3. Results and Discussion

Natural soil erosion occurs when soil is blown by the wind or washed away by rain water. Anthropogenic activities causing soil erosion are deforestation, land development for construction and agricultural practices in the watershed area. Population growth, expanded land development, and intensified agriculture are likely to increase nutrients loads substantially. It has been stated in the literature that the rate of soil erosion and nutrient release depends on various factors such as speed and volume of rain water; amount of vegetation; slope of land; dryness and size of soil particles (Ekwue et al. 2009; Heshmati et al. 2012; Ng Kee Kwong et al. 2002; Sharpley 2003). Figure 3 shows the excessive soil erosion mostly due to agricultural activities and to some extent through land sliding in the watershed above Lake Abha. As stated in the introduction, Abha receives torrential rains during summer’s season thus resulting in enormous quantity of soil erosion and nutrient (Nitrogen and phosphorous) release from the cultivated lands located at the steep slopes in the watershed and ending up into Lake Abha. Figure 3 clearly shows that more than half of soil in the watershed is disturbed due to agricultural practices. The discharge of untreated sewage, agricultural wastes and surface runoff hastens the eutrophication process (Jensen 2009).

Accurate long-term water quality monitoring programs are essential for effective lake management (McCullough et al. 2012). In many countries, state and county agencies are required to reduce point source discharges to surface waters (Jensen 2009). Nitrate concentrations of rivers and lakes are correlated with human population densities in the watershed (Glavan et al. 2012; Peierls et al. 1991; Rogora et al. 2012; Zan et al. 2012). The main contributor in loss of soil nutrients to the lake and its drainage basin is the runoff from the surrounding agricultural landscape (Kleinman et al. 2006; Philipson née Ammenberg 2003). Nonpoint sources of phosphorous in receiving water bodies are mainly agriculture and urban land-use (Carpenter et al. 1998; Mbonimpa et al. 2014).

Excessive Agricultural/Construction Activities above Lake Abha

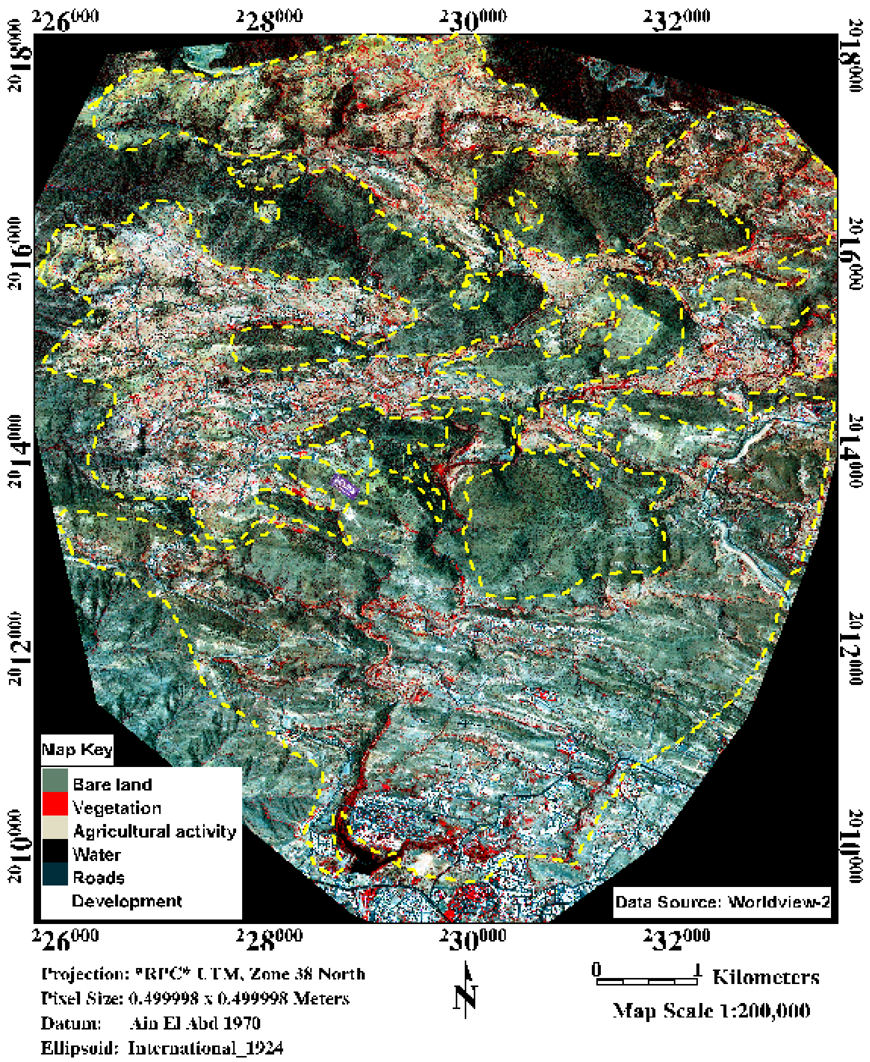

Fig. 3. *Excessive construction and agricultural activities in the watershed (WV-2 image) surrounding Lake Abha is seriously impacting the Lake water quality.*

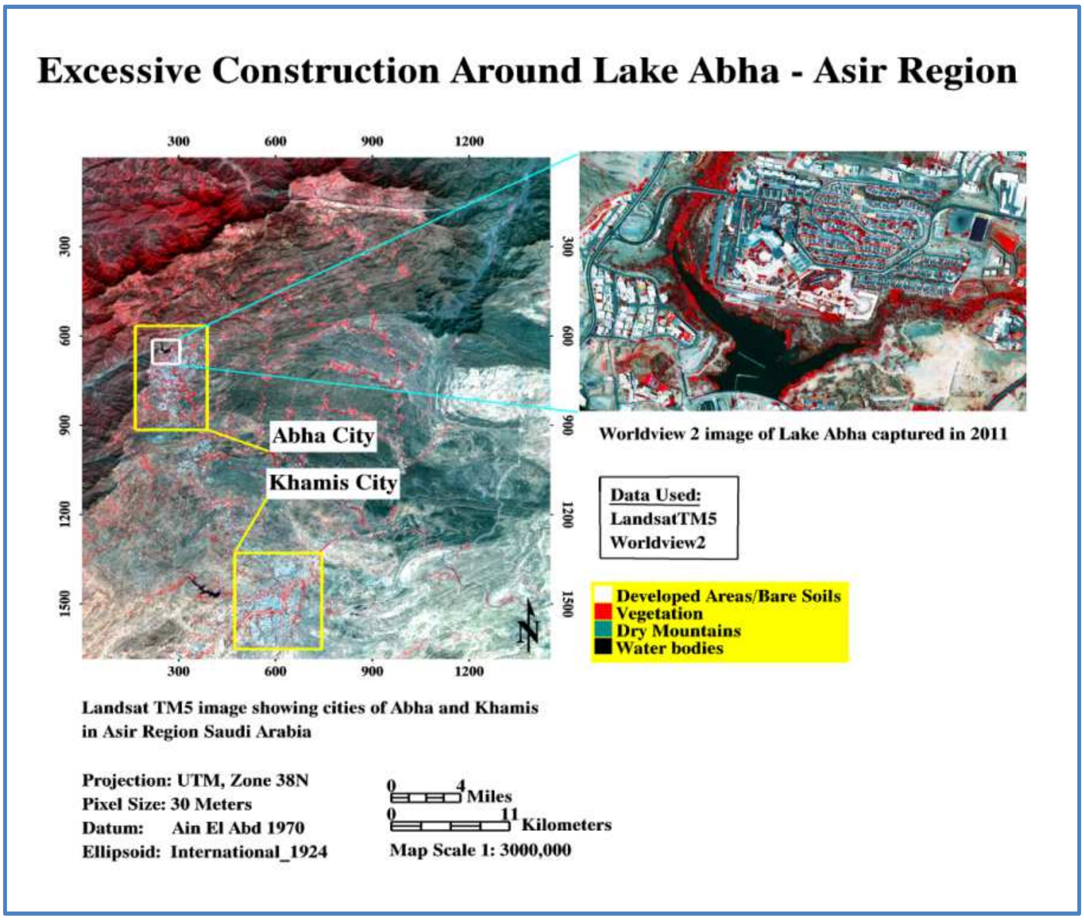

Fig. 4. *Excessive construction around Lake Abha can be seen in the WV-2 image (R) (Dated 12-10-2012).*

4. Summary and Conclusions

From the research carried out in this paper, it has been demonstrated that the use of remote sensing technique can be very effectively utilized in identifying and quantifying the anthropogenic activities in the watershed of Lake Abha that is directly endangering the water quality of the lake. In this research the nonpoint source of water pollution were clearly highlighted (see Figures 3 and 4). In Figure 3 the nonpoint source of pollution is excessive agricultural practices in the upland above Lake Abha, whereas, in Figure 4 the nonpoint source is residential areas surrounding Lake Abha. The thematic maps derived from Worldview-2 image reveals large-scale patterns of spatial variability (see Fig.3) that could not be feasibly obtained through traditional field sampling methods. The processing and analysis of satellite imageries (high resolution multispectral) of the target area will reveal and help provide the authorities of the Kingdom's ministry of water and electricity with alternate method for water quality monitoring. The remote sensing technique can also be extended for monitoring the quality of coastal waters of Red Sea and Arabian Gulf. It is also recommended that the authorities of the ministry of water and electricity should augment their conventional *in situ* methods of monitoring water analysis by integrating the remote sensing analysis of fresh water bodies.

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References

[1] Al-Ahmadi K, Al-Ahmadi S (2013) Spatiotemporal variations in rainfall–topographic relationships in southwestern Saudi Arabia. Arabian Journal of Geosciences:1-16

[2] Al-Hathloul S, Mughal MA (2004) Urban growth management-the Saudi experience. Habitat International 28 (4):609-623

[3] Al-Turki S (1995) Water resources in Saudi Arabia with particular reference to Tihama Asir province. Durham University,

[4] Alzahrani KH, Muneer SE, Taha AS, Baig MB (2012) Appropriate cropping pattern as an approach to enhancing irrigation water efficiency in the Kingdom of Saudi Arabia. JAPS, Journal of Animal and Plant Sciences 22 (1):224-232

[5] Batista MTFA, Colaeo AC, Capelo SG, de Mascarenhas JMB Landsat/Ikonos applied to water quality monitoring in south of Portugal. In: International Symposium on Remote Sensing, 2003. International Society for Optics and Photonics, pp 373-378

[6] Beeton AM (2002) Large freshwater lakes: present state, trends, and future. Environmental Conservation 29 (01):21-38

[7] Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological applications 8 (3):559-568

[8] EFS (2010) Environmental fact sheet. Department of environmental services. http://des.nh.gov/organization/commissioner/pip/factsheets/bb/documents/bb-3.pdf. Accessed February 14th 2014

[9] Ekwue EI, Bharat C, Samaroo K (2009) Effect of soil type, peat and farmyard manure addition, slope and their interactions on wash erosion by overland flow of some Trinidadian soils. Biosystems Engineering 102 (2):236-243. doi:http://dx.doi.org/10.1016/j.biosystemseng.2008.11.012

[10] El Atta H, Aref I, Ahmed A (2013) Effect of Acacia spp. on soil properties in the highlands of Saudi Arabia. Life Science Journal 10 (4)

[11] ElNesr M, Alazba A, Abu-Zreig M (2010) Spatio-temporal variability of evapotranspiration over the Kingdom of Saudi Arabia. Applied engineering in agriculture 26 (5):833

[12] Ferreira JG, Andersen JH, Borja A, Bricker SB, Camp J, Cardoso da Silva M, Garcés E, Heiskanen AS, Humborg C, Ignatiades L, Lancelot C, Menesguen A, Tett P, Hoepffner N, Claussen U (2011) Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93 (2):117-131

[13] Giardino C, Bresciani M, Villa P, Martinelli A (2010) Application of remote sensing in water resource management: the case study of Lake Trasimeno, Italy. Water resources management 24 (14):3885-3899

[14] Glavan M, White SM, Holman IP (2012) Water quality targets and maintenance of valued landscape character – Experience in the Axe catchment, UK. Journal of Environmental Management 103 (0):142-153. doi:http://dx.doi.org/10.1016/j.jenvman.2012.03.009

[15] Gurlin D, Gitelson AA, Moses WJ (2011) Remote estimation of chla concentration in turbid productive waters—Return to a simple two-band NIR-red model? Remote Sensing of Environment 115 (12):3479-3490

[16] Hadjimitsis DG, Hadjimitsis MG, Toulios L, Clayton C (2010) Use of space technology for assisting water quality assessment and monitoring of inland water bodies. Physics and Chemistry of the Earth, Parts A/B/C 35 (1):115-120

[17] Henry JG, Heinke GW (1996) Environmental science and engineering, vol 1. Prentice Hall Englewood Cliffs (NJ),

[18] Heshmati M, Arifin A, Shamshuddin J, Majid NM (2012) Predicting N, P, K and organic carbon depletion in soils using MPSIAC model at the Merek catchment, Iran. Geoderma 175–176 (0):64-77. doi:http://dx.doi.org/10.1016/j.geoderma.2011.12.028

[19] Jensen JR (2009) Remote Sensing of the Environment: An Earth Resource Perspective 2/e. Pearson Education India,

[20] Karaska MA, Huguenin RL, Beacham JL, Wang M-H, Jensen JR, Kaufmann RS (2004) AVIRIS measurements of chlorophyll, suspended minerals, dissolved organic carbon, and turbidity in the Neuse River, North Carolina. Photogrammetric engineering and remote sensing 70 (1):125-134

[21] Khan FA, Ansari AA (2005) Eutrophication: an ecological vision. The Botanical Review 71 (4):449-482

[22] Kleinman PJ, Srinivasan M, Dell CJ, Schmidt JP, Sharpley AN, Bryant RB (2006) Role of rainfall intensity and hydrology in nutrient transport via surface runoff. Journal of environmental quality 35 (4):1248-1259

[23] KSA (2014a) About Saudi Arabia. Agriculture and Water. Royal Embassy of Saudi Arabia. http://www.saudiembassy.net/country-information/agriculture_water/default.aspx. Accessed February 17 2014

[24] KSA (2014b) Saudi Arabia announces record budget for 2014. Royal Embassy of Saudi Arabia http://www.saudiembassy.net/latest_news/news12231301.aspx. Accessed February 17 2014

[25] Liu WC, Chen WB, Kimura N (2009) Impact of phosphorus load reduction on water quality in a stratified reservoir-eutrophication modeling study. Environmental Monitoring and Assessment 159 (1-4):393-406

[26] Luan Z, Zhou D (2013) Impacts of Intensified Agriculture Developments on Marsh Wetlands. The Scientific World Journal 2013

[27] Mandeli KN (2008) The realities of integrating physical planning and local management into urban development: A case study of Jeddah, Saudi Arabia. Habitat International 32 (4):512-533

[28] Mbonimpa EG, Yuan Y, Nash MS, Mehaffey MH (2014) Sediment and total phosphorous contributors in Rock River watershed. Journal of Environmental Management 133 (0):214-221. doi:http://dx.doi.org/10.1016/j.jenvman.2013.11.030

[29] McCullough IM, Loftin CS, Sader SA (2012) Combining lake and watershed characteristics with Landsat TM data for remote estimation of regional lake clarity. Remote Sensing of Environment 123:109-115

[30] Multsch S, Al-Rumaikhani Y, Frede H-G, Breuer L (2013) A Site-sPecific Agricultural water Requirement and footprint Estimator (SPARE: WATER 1.0). Geoscientific Model Development 6 (4):1043-1059

[31] Necsoiu M, Dinwiddie CL, Walter GR, Larsen A, Stothoff SA (2013) Multi-temporal image analysis of historical aerial photographs and recent satellite imagery reveals evolution of water body surface area and polygonal terrain morphology in Kobuk Valley National Park, Alaska. Environmental Research Letters 8 (2):025007

[32] Ng Kee Kwong KF, Bholah A, Volcy L, Pynee K (2002) Nitrogen and phosphorus transport by surface runoff from a silty clay loam soil under sugarcane in the humid tropical environment of Mauritius. Agriculture, Ecosystems & Environment 91 (1–3):147-157. doi:http://dx.doi.org/10.1016/S0167-8809(01)00237-7

[33] Ouda OK (2013) Review of Saudi Arabia municipal water tariff. World Environment 3 (2):66-70

[34] Ouda OK, Shawesh A, Al-Olabi T, Younes F, Al-Waked R (2013) Review of domestic water conservation practices in Saudi Arabia. Applied Water Science 3 (4):689-699

[35] Peierls BL, Caraco NF, Pace ML, Cole JJ (1991) Human influence on river nitrogen. Nature 350:386-387

[36] Peter S (2006) Water and Wastewater Treatment Engineering. Creative Commons BY-NC-SA, Massachusetts Institute of Technology

[37] Philipson née Ammenberg P (2003) Environmental Applications of Aquatic Remote Sensing. Uppsala University, Uppsala

[38] Pricope NG (2009) Assessment of Spatial Patterns of Sediment Transport and Delivery for Soil and Water Conservation Programs. Journal of Spatial Hydrology 9 (1)

[39] Qin B, Gao G, Zhu G, Zhang Y, Song Y, Tang X, Xu H, Deng J (2013) Lake eutrophication and its ecosystem response. Chinese Science Bulletin 58 (9):961-970

[40] Rickson R (2014) Can control of soil erosion mitigate water pollution by sediments? Science of The Total Environment 468:1187-1197

[41] Rogora M, Arisci S, Marchetto A (2012) The role of nitrogen deposition in the recent nitrate decline in lakes and rivers in Northern Italy. Science of The Total Environment 417–418 (0):214-223. doi:http://dx.doi.org/10.1016/j.scitotenv.2011.12.067

[42] Rundquist DC, Schalles JF, Peake JS (1995) The response of volume reflectance to manipulated algal concentrations above bright and dark bottoms at various depths in an experimental pool. Geocarto international 10 (4):5-14

[43] Scavia D, Bricker SB (2006) Coastal eutrophication assessment in the United States. In: Nitrogen Cycling in the Americas: Natural and Anthropogenic Influences and Controls. Springer, pp 187-208

[44] SCDSI (2010) Population Distribution by Gender and (Saudis and Non Saudis) by Areas. Saudi Central Department of Statistics & Information. http://www.cdsi.gov.sa/. Accessed February 03 2014

[45] Şen Z, Al-Suba'i K (2002) Hydrological considerations for dam siting in arid regions: a Saudi Arabian study. Hydrological sciences journal 47 (2):173-186

[46] Sharpley A, Foy B, Withers P (2000) Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview. Journal of Environmental Quality 29 (1):1-9

[47] Sharpley AN (2003) Agricultural phosphorus and eutrophication. US Department of Agriculture, Agricultural Research Service,

[48] Sheela A, Letha J, Joseph S, Ramachandran K, Chacko M (2012) Computation of physical characteristics of a lake system using IRS P6 (LISS-III) imagery. International Journal of Applied Earth Observation and Geoinformation 14 (1):221-232

[49] Shehata W, Amin A (1997) Geotechnical hazards associated with desert environment. Natural hazards 16 (1):81-95

[50] Smith VH, Tilman GD, Nekola JC (1999) Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental pollution 100 (1):179-196

[51] Updike T, Comp C (2010) Radiometric use of WorldView-2 imagery. Technical Note Digital Globe

[52] van Beusekom JE (2005) A historic perspective on Wadden Sea eutrophication. Helgoland Marine Research 59 (1):45-54

[53] Waltham T, Sholji I (2001) The demise of the Aral Sea–an environmental disaster. Geology Today 17 (6):218-228

[54] Warwick C, Guerreiro A, Soares A (2013) Sensing and analysis of soluble phosphates in environmental samples: A review. Biosensors and Bioelectronics 41:1-11

[55] Williams DL, Goward S, Arvidson T (2006) Landsat: Yesterday, today, and tomorrow. Photogrammetric Engineering and Remote Sensing 72 (10):1171

[56] Yang C, Everitt JH (2010) Mapping three invasive weeds using airborne hyperspectral imagery. Ecological informatics 5 (5):429-439

[57] Zaharani K, Al-Shayaa M, Baig M (2011) Water Conservation in the Kingdom of Saudi Arabia for Better Environment: Implications for Extension and Education. Bulgarian Journal of Agricultural Science 17 (3):389-395

[58] Zan F, Huo S, Xi B, Zhang J, Liao H, Wang Y, Yeager KM (2012) A 60-year sedimentary record of natural and anthropogenic impacts on Lake Chenghai, China. Journal of Environmental Sciences 24 (4):602-609. doi:http://dx.doi.org/10.1016/S1001-0742(11)60784-5

[59] Zorrilla-Miras P, Palomo I, Gómez-Baggethun E, Martín-López B, Lomas P, Montes C (2014) Effects of land-use change on wetland ecosystem services: A case study in the Doñana marshes (SW Spain). Landscape and Urban Planning 122:160-174.