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IMPACT OF THE KARKHEH RIVER DAM ON THE SURFACE TEMPERATURE OF THE HAWIZEH MARSH

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ABSTRACT

In 2003, Iran began construction of a dam along the shared border of the Hawizeh Marsh -a transboundary wetland between Iran-Iraq. The project was completed in late 2007. After damage already done to the marsh in the 1980s under previous leadership, Iraq had in 2003 begun efforts to restore the marsh ecosystem. The objective of this study is to determine if this dam has affected the Hawizeh ecosystem. Because of political instability and for security reasons, physical measurement of marsh characteristics has not been possible, so remotely measured data was needed to assess the impact. This study used nine years of Landsat 7 satellite images of thermal bands to determine the impact of the dam on land surface temperature, LST. LSTs were compared for both the areas above and below the dam before and after dam construction and filling. Results showed that LST increased by an average of 2.8°C below the dam, where water flow decreased, and decreased by the same amount above the dam, where a reservoir was formed. Given the temperature sensitivity of many living organisms, one can conclude that the dam impacted the marsh ecosystem.

KEY WORDS: satellite remote sensing, Hawizeh marsh, dam impacts.

1. INTRODUCTION

Water quality represents the physical, chemical, and biological properties of water. Human interventions, including dams, on natural water systems have caused many environmental problems, such as demersal fish death, nuisance and sometimes toxic algal blooms, and the disappearance of seagrass and other aquatic organisms (Liu et al., 2003). Water quality monitoring allows for an integrated evaluation of aquatic system characteristics in relation to human impacts, health concerns, and ecological conditions (Hadjimitsis et al., 2010). Conventional methods of water quality monitoring, however, involve costly and time-consuming field measurements over temporal and spatial distributions that are often not possible.

Water temperature plays a leading role in determining the physical, chemical, and biological processes occurring within the water. Specifically, temperature affects dissolved oxygen concentrations, which impact the numbers and types of organisms that a water body can support. It is important to analyze the temporal variations in water temperature from seasonal changes and human impacts. Furthermore, the distribution, transportation, and interaction of nutrients are also affected by water column temperature and nutrient quantities may significantly impact a water body's health. Because of the relationship between temperature and both dissolved oxygen and nutrient loads, water temperature is a good indicator of the vertical mixing condition and can be used to estimate primary production and phytoplankton growth rates. In addition, a water body's temperature is important, especially when dealing with endangered fish populations that are sensitive to even small water temperature changes (Gholizadeh et al., 2016).

Satellite remote sensing

Recent advances in computer science and engineering have had a profound influence on environmental and water quality monitoring, resulting in a broader development of remote sensing technology. Computers can store and analyze large sets of data generated by remote sensing devices. Also, the use of Geographical Information Systems (GIS) provides efficient tools for storing, manipulating, and analyzing remote sensing data. GIS can enhance the contributions of water quality modeling for practical water quality forecasting, which is essential for sustainable water resources management and development. Therefore, the practicality and interoperability of remote sensing and GIS techniques have increased the use of these technologies in assessment of water resources (Gholizadeh et al., 2016).

Remote sensing techniques that can measure energy reflected and emitted by a water body's surface, can be used to measure water surface temperature when physical measurements are not possible. Satellite remote sensing and GIS are the most effective, low cost, and reliable tools for monitoring water quality as they can provide a spatial and temporal view of surface water quality parameters. In the terrestrial environment, thermal infrared (TIR) remote sensing of surface water temperature has been widely used (Gholizadeh et al., 2016). Specifically, TIR bands can measure the amount of infrared radiant heat emitted from land surfaces and the radiant temperature of water bodies (Hadjimitsis et al., 2010).

Land surface temperature (LST) is a fundamental variable in Earth's energy balance, and it impacts the physical, chemical, and biological processes of Earth's surface (Bonafoni et el., 2016). During the last four decades, satellite-derived surface temperature data have been utilized to monitor and analyses water bodies. The Landsat series of satellites have been used to retrieve land surface temperature (Orhan et al., 2014). Land surface temperature is one of the most important parameters that can be measured by satellite remote sensing, as its variations in space and time are used to estimate evapotranspiration, vegetation water stress, and soil moisture (Madinian et al., 2018). In addition to Landsat, different space-borne platforms, such as ASTER, AVHRR, and MODIS, have also been used to retrieve the land surface temperatures (Bonafoni et el., 2016).

Hawizeh Marsh

Iraq's Mesopotamian marshes - known as the Garden of Eden- have been historically considered the cradle of Western civilization. Mesopotamia refers to the land located between the Tigris and the Euphrates rivers and is the largest wetlands area in southwest Asia, covering more than 15,000 square kilometers. During the Iraq–Iran war of the 1980s, the marsh ecosystem and its inhabitants experienced large-scale destruction. This destruction continued during the 1990s, when the former regime systematically desiccated over 90% of the marsh (Fawzi et al. 2016). Over 35% of the Hawizeh marsh, was drained, while the other two marshes, the Central - also known as the Qurna marsh- and Al-Hammar were virtually destroyed (Richardson et al., 2006). More recently, in 2003, the marsh was reflooded and some dikes and dams were removed, and after three years improvement in restoring fish and plant species was measured (Mohamed et al., 2008).

The Hawizeh and Central marshes were once famous for their biodiversity and cultural richness. They were the permanent habitat for millions of birds and a flyway for millions more migrating between Siberia and Africa. More than 80 bird species were found in the marshes in the last complete census in the 1970s. Populations of rare species such as the Marbled Teal (40% to 60% of the world population) and the Basrah reed warbler (90% of the world population), which had been thought close to extinction, were recently observed in a winter bird survey of the marshes. Coastal fish populations in the Persian Gulf used the marshlands for spawning migrations, and the marshes also served as nursery grounds for penaeid shrimp and numerous marine fish species. The marshlands have served as a natural filter for waste and other pollutants from the Tigris and Euphrates rivers, thus protecting the Persian Gulf (Richardson et al., 2006). Before the marsh was damaged, Marsh Arab women generated income via applying their traditional ecological knowledge and skills to use marsh resources, but now their roles have been limited to domestic activities. Furthermore, these women can no longer teach their marsh-specific knowledge and skills to the next generation, and these valuable and ancient cultural memories are being lost (Fawzi et al., 2016).

The Hawizeh marsh, while a unique part of the Mesopotamian marshes, is also considered a wetland of international importance and, with an area of 48131 hectares, forms a large part of the marshlands of southern Iraq, located east of the Tigris River on the Iraqi-Iranian border as shown in Figure 1 (Ramsar, 2012). In July 2016, the Hawizeh Marsh became a UNESCO World Heritage Site. Prior to that, since 2007, it was considered the first Iraqi Ramsar Site, where 'Ramsar site is a wetland of international importance' under the Ramsar Convention (NI, 2018). The Al-Hawizeh Marsh is considered to be a most sensitive environment, such that any change in its fragile ecosystem due to anthropogenic activities can endanger the habitats of birds, fish, and other aquatic organisms (Gholizadeh et al., 2016 and MoE, 2014).

In Iraq, the main contributors to the Al-Hawizeh marsh are the rivers of Al-Kahla, Al-Mesharah, and sometimes the Crown-of-Battles Canal. The Al-Hawizeh marsh is highly affected by the quantity and quality of water coming from its tributaries in Iran. Three rivers that contribute to the marsh, Teeb, Dewaireg, and Karkha, all originate in Iran (Muhsin, 2011). The first two rivers are seasonal, while the Karkha is perennial. In recent years, water flows into the Mesopotamian Marshes have been sharply reduced by a series of transboundary dam construction projects. In 2003, Iran started construction on the Karkheh River Dam, a transboundary dam close to the border with Iraq, as shown in Figure 1. The dam project was completed in 2007 and during construction, estimated water reduction in Iraq destroyed approximately 80% of the marsh area, which desiccated the Al-Hawizeh wetlands on the Iran–Iraq border (Fawzi et al., 2016). Prior to this new dam construction, in 2003 Iraq had begun initial efforts to restore the marsh.

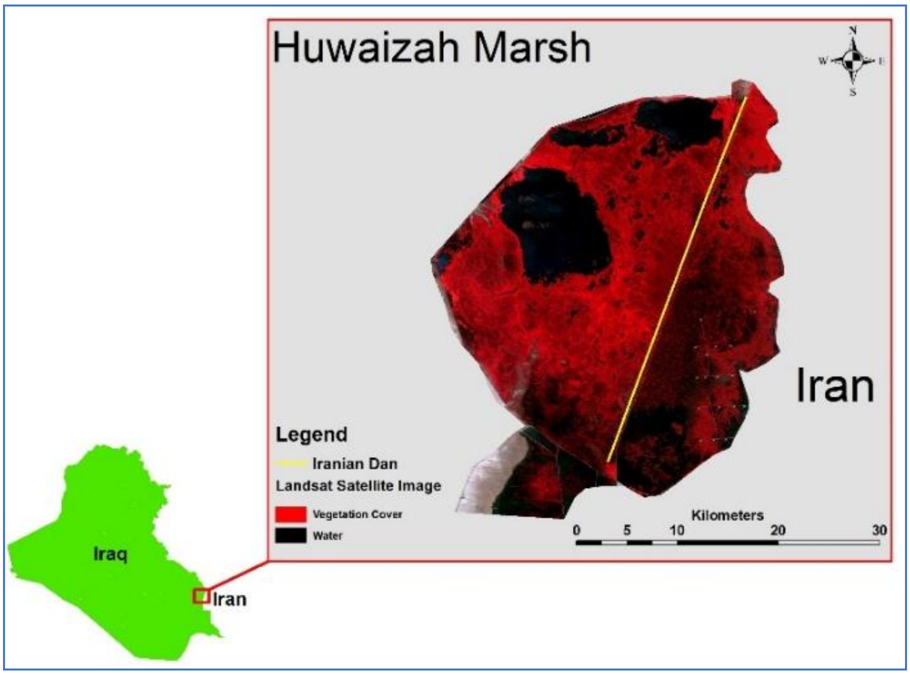

Figure1: Landsat image 2018 of the study area that shows Iranian dam (source: Oday Jeewan 2018).

Research Objectives

The objective of this study was to clarify whether the existence of the Karkheh River Dam has affected the sustainability of the Hawizeh Marshes ecosystem. For security reasons, physical measurements have not been possible, so Landsat 7 satellite images with previously developed calibration models were used to determine the land surface temperature, which is used as a measure of ecosystem change due to the temperature sensitivity of many fish and aquatic plant species. Specifically, the thermal band with spectral range (10.40 - 12.50 µm) and resolution 120 m (USGS, 2020) of the Landsat 7 satellite was collected to create a temperature profile from 1998 to 2002, and 2004 to 2007. Geographic Information System, Environment for Visualizing Images (ENVI), and programming language (R) were also used to create time-series maps of land surface temperature (LST) (esa, 2020).

Land surface temperature is a measure of surface energy and water balances, with principal significance for several applications, such as climate change, urban climate, the hydrologic cycle, and vegetation monitoring (Rozenstein et al., 2014). Landsat 6 - also known as Enhanced Thematic Mapper (ETM)- was launched on October 5, 1993, as an enhancement version of the instruments on Landsat 4 and Landsat 5, and it includes 7 bands in addition to a panchromatic band.

2. MATERIALS AND METHODS

The thermal band of the Landsat 7 Satellite was used to enable the atmospheric correction of thermal data with a spatial resolution of 60 m and a revisit time of 16 days (Rozenstein et al., 2014). Time-series thermal satellite images for the last 9 years (1998 -2007) were used to calculate and compare land surface temperature. Specifically, satellite data for the month of September was used for each year because it is a month with little cloud cover to impede measurements. To avoid diurnal temperature variation, thermal measurements from the same time of day and averaged over the month were used. Figure 2 shows the steps in converting thermal band measurements to land surface temperatures of the marsh study areas. Both ENVI & GIS programs were used for this purpose and to show spatial and temporal temperature variations.

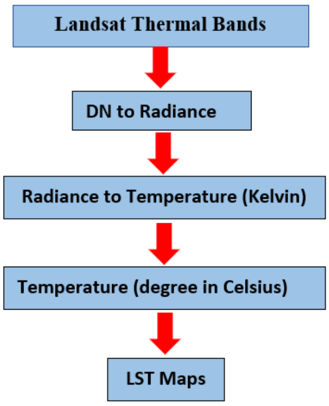

Figure 2 – Steps of Land Surface Temperature calculation from Landsat7.

Calculating LST

To calculate land surface temperature, first Landsat Thermal bands, collected as digital numbers, DN, were converted to spectral radiance via an equation developed by Chander and Markham (2003) and USGS (2013). Spectral radiance, sr, and quantized calibrated values in digital numbers were obtained to calculate radiance.

$$L_{\gamma} = \frac{LMax_{\lambda} - LMin_{\lambda}}{QCalMax - QCalMin} \times (DN - QCalMin) + LMin_{\lambda}$$

where;L_{λ} is the spectral radiance at the sensor's aperture in W/(m^2*sr*µm); DN is the quantized calibrated pixel value, $L_{max\lambda}$ *and* $L_{min\lambda}$ are maximum and minimum spectral radiance of thermal band respectively, QCalMin and QCalMax are the minimum and maximum quantized calibrated pixel value in DNs, respectively. The spectral radiance and quantized calibrated values in DNs from the relevant header file was obtained before calculating the radiance (Arzu Erener et al., 2018).

The spectral radiance obtained by the above equation, was then converted to satellite brightness temperature with the conversion equation:

$$T(k) = k2/(\ln(k1/L\lambda) + 1)$$

Where T(k) is the effective at satellite temperature in Kelvin (K), L**λ** is the spectral radiance; k2 and k1 are the thermal band pre-launch calibration constants. For Landsat7 ETM+, k2= 1282.71, and k1=666.09 (Arzu Erener, 2018). Temperature in Kelvin was then converted to temperature in Celsius.

ENVI software was used to open Landsat7 thermal bands and extract the reflectance values from selected images at the desired locations. Image processing of ENVI along with the above steps was used to create LST layers for the nine years of the time-series observation. Throughout, GIS was used to create a point shapefile layer of thirty-six data points distributed geographically equally, 1 km apart, on both sides of the dam, as shown in Figure 3, so that temperatures 0.5 km from the dam on both sides was measured. Because of the location of the dam on the Iraq-Iran border, eighteen points on the Iraq side represent the area downstream of the dam and eighteen points on the Iran side represent the area upstream of the dam. These points represent the average values - 4 years before and 4 years after after building the dam - of LST. ArcGIS tools were used to create maps that show the land surface temperature distribution of the Al-Huwizah marshes between 1998 and 2007. These are presented in Figure 4.

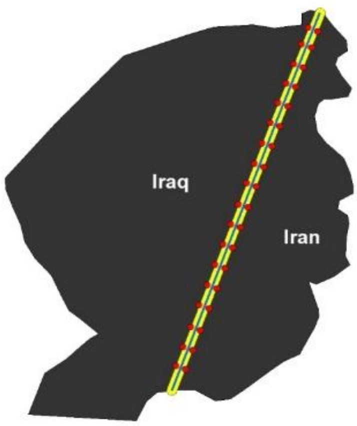

Figure 3- Distribution points of average values of the land surface temperature of Hawizeh Marshes.

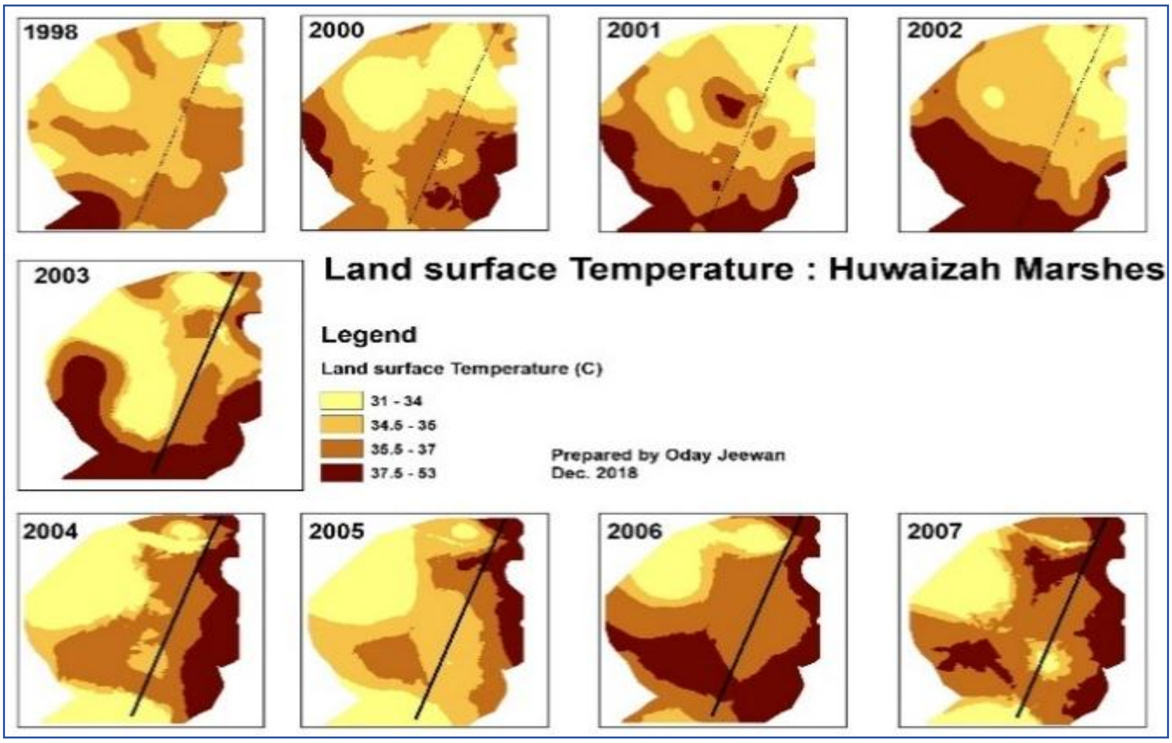

Figure 4: Land surface temperature of Hawizeh Marshes 1998-2007.

Statistical Comparison

R, a programming language and tool commonly used in statistical computing, data analytics, and scientific research was used to compare and analyze temperature data. Specifically, a ***paired t-test*** was used to illustrate if there are significant differences in the mean average of LST before dam construction (1998-2002), during construction and filling in mid to end of 2003, and after construction (2004-2007). Temperature data is given in Table 1. Prior to statistical analysis, Shapiro test normality assumptions were determined to be met.

3. RESULTS AND DISCUSSION

For the thirty-six locations at which thermal data was collected, average measured temperatures both before (years 1998 and 2000-2002) and after dam construction and filling (2004-2007) are given in Table 1. Data from 1999 was not available. Again, all data were collected in September of the respective year at the same time of day to eliminate diurnal temperature differences. During each September, multiple satellite flyovers, and hence measurements, occurred, with the average of these over four years of data collection given in Table 1. Two significant trends emerged from the data. First, the average temperature over all eighteen measured points on the Iraq side of the border in the years prior to any dam construction was 37.7 ^{o}C and after construction and filling, it was 40.5^{o}C, an increase in average temperature of 2.8^{o}C. For the eighteen measured points on the Iran side of the border average temperature in the years prior to construction was 37.5°C, approximately the same as the Iraq side pre-construction. But after dam completion and filling, it fell to 34.7°C, a decrease in temperature of 2.8°C. This is consistent with what one would expect for shallower water and reduced flow downstream of a dam and creation of a deeper reservoir upstream, where cooler waters at the reservoir bottom keep surface water temperature lower. So, after dam construction an average temperature difference of 5.6°C existed upstream and downstream of the dam.

Statistical analysis of land surface temperature of the Hawizeh Marshes between 1998-2002 and 2004-2007 showed a significant increase in water surface temperature of the marshes near the Iraqi side. The average value of LST increased 2.8°C on the Iraqi side, below the dam, ($p< 0.01$, $\alpha= 0.05$). Statistical analysis of the measured increase on the upstream side of the dam was also significant at 2.8°C ($p<0.01$, $\alpha= 0.05$).

Table 1: Average LST of Al Hawizeh Marsh before and after dam construction.

Landsat measurement point	Country	LST Average before dam (1998-2002) °C	LST Average after dam (2004-2007) °C
1	Iraq	34.6	35.9
2	Iraq	34.5	37.7
3	Iraq	34.8	38.1
4	Iraq	38.2	42.8
5	Iraq	37.5	41.1
6	Iraq	35.1	38.6
7	Iran	34.8	33.1
8	Iran	39.5	33.1
9	Iran	33.7	32.8
10	Iran	32.7	32.3
11	Iran	34.6	32.9
12	Iran	34.1	33.5
13	Iran	44.3	37.6
14	Iraq	41.3	43.7
15	Iran	35.7	33.5
16	Iraq	36.2	39.8
17	Iran	35.1	32.8
18	Iraq	34.1	36.9
19	Iran	34.8	33.7
20	Iraq	33.5	34.6
21	Iran	35.5	34.5
22	Iraq	37.5	39.1
23	Iran	38.8	35.3
24	Iraq	41.4	44.5
25	Iran	39.7	35.3

26	Iraq	39.8	41.9
27	Iran	41.6	36.2
28	Iraq	41.1	43.8
29	Iran	39.1	35.9
30	Iraq	39.2	41.3
31	Iran	38.2	35.9
32	Iraq	39.5	41.8
33	Iraq	40.1	42.4
34	Iran	41.2	37.4
35	Iran	40.9	38.1
36	Iraq	40.9	44.5

4. CONCLUSION

Satellite remote sensing can be used to assess the quality of inland waters when physical measurements are not possible. In the Al Hawizeh marsh of southern Iraq, surface temperature increased by almost 5^{o}C once the dam project was complete. Since increased temperature reduces the quantity of dissolved oxygen in water and because many fish and aquatic organisms are highly sensitive to water temperature changes, it can be concluded that the dam negatively impacted the marsh ecosystem, especially on the Iraqi side downstream of the dam. With a reduction in water flow downstream of the dam and the significantly increased temperature, biodiversity in the ecosystem would be affected. This rising land surface temperature can lead to huge effects on physical, chemical, and biological water quality characteristics. Moreover, it affects the food chain of aquatic life.

To help remedy this potential ecological disaster, it is recommended that serious negotiations between Iraq and Iran take place to solve the transboundary water issues. Adequate water must flow downstream of the dam to restore the land and water temperature to support natural ecosystems and restoration efforts should ensure the sustainable biodiversity of the marshes.

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