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Evaporation estimation for Lake Nasser based on remote sensing technology

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Abstract Lake Nasser in Upper Egypt is of a great importance for Egypt as it represents a large reservoir for the country's freshwater resources. Precise studying of all elements contributing to the water balance of Lake Nasser is very crucial for better management of Egypt's water resources. Evaporation is considered an important factor of the water balance system that causes a huge loss of the lake's waters. In this study, evaporation rate for Lake Nasser is estimated using the surface energy balance approach based on remote sensing technology.

Evaporation rate obtained from this method is instantaneous since it is estimated during the satellite overpass over the lake. However, evaporative fraction method is used to estimate the daily rate from the instantaneous one. The surface energy balance combined with remote sensing data proves promising to estimate evaporation rates for large water bodies. These could lead to more accurate monitoring of evaporation rates in the lake area without being dependent on field observations, which are sometimes unavailable or uncertain for these types of studies.

1. Introduction

Lake Nasser is one of the largest artificial water reservoirs worldwide. The lake was created with the construction of Aswan High Dam 5 km upstream of Aswan city in Upper Egypt in 1964. Lake Nasser is located in an arid region in the south of Egypt. Evaporation is considered to be the most effective factor in understanding the water losses from the lake. Evaporation in Lake Nasser is of quite interest to many researchers and institutions in Egypt. For many years, the Egyptian Ministry of Water Resources and Irrigation adopted the figure of 7.54 mm/day as an annual mean evaporation rate with a maximum rate in June 10.8 mm/day, and a minimum in December 3.95 mm/day [1].

Understanding the physics of evaporation started early in the last century when Bowen [2] showed how available energy partitioning between latent heat flux and sensible heat flux could be determined using temperature gradients and humidity. Penman [3,4] mixed the energy balance concept with aerodynamic aspects of evaporation to develop an equation for estimating evaporation in 1948 that is widely adopted by water experts. In the next decades that follow, several theoretical and experimental models for evaluating evaporation techniques

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had been expanded. These included the Bowen Ratio Energy Budget (BREB) method and eddy-correlations techniques. These techniques are dependent on experimental data for verifications and the measurement of evaporation with equipment that evaluates the Bowen's ratio. A limitation of these techniques is that they yield essentially point values of evaporation, and therefore, are applicable only to a homogeneous area surrounding the equipment that is exposed to the same environmental factors [5]. Other methods to estimate evaporation rates include the water-budget method, methods of the so-called Dalton group such as the bulk aerodynamic or mass transfer method, methods in the so-called combination group such as Penman, Priestley–Taylor, and deBruin–Keijman methods, and methods in the temperature group such as the Papadakis method among others [6–8].

Most of the previous evaporation studies for Lake Nasser applied conventional methods, except Omar and El-Bakry [9] and Sadek et al. [10], who applied the BREB method, but with very limited data [11]. Elsawwaf et al. [11] compared results from six conventional methods for evaporation quantification with the values obtained by the BREB method based on calculations at the daily time scale covering a 10-year period (1995–2004). Evaporation rates of these conventional methods and the BREB method were estimated at the location of three meteorological floating stations data. Several of the six conventional methods showed substantial bias when compared with the BREB method. The conventional evaporation methods were adjusted to include the net energy advected term following the same procedure of Rosenberry et al. [12] to obtain close relation with the BREB values [11].

By the end of the last century, the Surface Energy Balance Algorithm for Land (SEBAL) was developed by Bastiaanssen et al. [13]. The model uses complex radiation and energy balance algorithms to estimate evapotranspiration from plants and soil. Ashfaque and Bastiaanssen [14] adopted the SEBAL technology in combination with remote sensing data to estimate evaporation for Lake Naivasha, Kenya. In this study, they compared daily evaporation rate based on evaporative fraction method and the surface energy balance approach with pan data based average evaporation estimation. In this study, daily estimation of evaporation was estimated using Landsat Thematic Mapper (TM) spectral data. The Landsat TM based estimation was compared with the pan data estimated average evaporation on the same date for the period of 1957–1990. Comparison between the two approaches to estimate evaporation showed reasonable results.

The application of the Simple Method [15] and surface energy balance approach using remotely-sensed data were applied to Rift Valley Lakes of Ethiopia. The Simple Method and a remote sensing-based lake evaporation estimates were compared to the Penman, Energy Balance, Pan, Radiation, and Complementary Relationship Lake Evaporation (CRLE) methods applied in the region [15]. Comparison of monthly Lake ET from the Landsat images to the Simple and Penman Methods showed that the remote sensing surface energy balance approach is promising for large scale applications to understand the spatial variation of the latent heat flux. Comparison of the lake evaporation estimates among lakes showed that Lake Langano, the mercky lake with high sediment loads, had lower average monthly evaporation than the other three lakes, which had less sediment loads, deeper and clearer than Lake Langano [15]. The presence of suspended sediment in lakes could lead to a higher surface temperature, and the higher near surface temperature can be related to a lower ET. This can be one of the weaknesses of the surface energy balance approach using thermal data from remote sensing [15].

The aim of this research is to evaluate evaporation rate estimates in Lake Nasser using the surface energy balance approach by adopting the SEBAL technology with Landsat TM spectral data of the lake. Evaporation estimates on several dates using the SEBAL technology and Landsat TM data were compared, and correlated with evaporation rates from six conventional methods. Monthly average evaporation estimates for the lake using the combination group methods such as the Penman, Priestley–Taylor, and deBruin–Keijman methods, the Mass Transfer method, the Papadakis method, and BREB method were obtained for the study dates from the research conducted by Elsawwaf et al. [11].

2. Study area and data

Lake Nasser was created after the construction of Aswan High Dam in 1964 south of Aswan city passing through the Egyptian Sudanese borders. The lake has a surface area of about 6500 km^2 and a length of about 500 km. The lake is formally divided into two lakes, one of length 350 km in Egypt, which is called Lake Nasser and the other of length 150 km located in Sudan, and is called Lake Nubia. The Egyptian part of the Lake lies between latitudes 22°00′N and 23°58′N, and longitudes 31°07′E and 33°15′E. The main source of water supply to the lake comes from the watersheds at the equatorial lakes and the Ethiopian plateau. This study is focusing on the Egyptian part of the lake. The surface area of the lake is changing according to the water discharges in the lake and the annual amount of flood. The lake has an average width of 10 km and a maximum width of 60 km and an average depth of 25 m and a maximum depth of 90 m. Field trip missions used to be organized by Nile Research Institute (NRI) to take samples and to observe several parameters of the lake related to sedimentation, water quality, etc. These observations are usually made at some specific cross sections across the Lake.

Three automatic floating stations belong to the High Aswan Dam Authority were installed in 1995. The three stations are located upstream of the Aswan High Dam (AHD), at Raft 2 km, Allaqi 75 km, and Abu-Simble 280 km (Fig. 1). Each floating system is recording hourly data of maximum, minimum and mean air temperature, relative humidity, surface water temperature, 2 m depth water temperature, wind speed, and wind direction. The three stations are working with full capacity since 1995 for the stations at Raft and Allaqi, and from 2000 for the station at Abusembel.

In this study, seven Landsat images in the period from October 1998 to October 2000 (Table 1) were used for the estimation of latent heat flux and lake evaporation. For the study dates, only meteorological data of the Raft station were available.

3. SEBAL methodology

3.1. Instantaneous estimation

In the surface energy budget approach (Fig. 2) for a deep lake or reservoir, latent heat flux, LE, sensible heat flux, H, change