# Estimation of Free Water Evaporation from Hamun Wetlands Using Satellite Imagery

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**Abstract:** To study the application of satellite remote sensing to estimate free water surface evaporation a research was carried out in southeast of Iran, Sistan area and Hamun wetlands. An energy balance algorithm called HRSE (Hamun Remotely Sensed Evaporation) was used to estimate the evaporation rate using NOAA-AVHRR images. Energy balance components including net radiation and heat storage in water body were determined using satellite remote sensing. The main variable within these components is surface temperature which was calculated by a calibrated split window equation for the study area. Thermal channels of AVHRR images were used to determine surface temperature. Using estimated sensible heat with other components, the energy balance equation led to estimate latent heat flux density. Comparison of energy balance latent heat of HRSE with Penman-Monteith model latent heat for free water showed a linear relation which used to separate advection from total sensible heat flux density.

**Key Words:** advection, energy balance, evaporation, Hamun Wetlands, latent heat, remote sensing, satellite imagery, sensible heat, Sistan, split window, surface temperature

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## 1 INTRODUCTION

Management of wetlands and other freshwater ecosystems needs estimates of open water evaporation. Also, understanding open water evaporation is necessary in planning economic uses of these water resources. Open water evaporation serves as a convenient index of the evaporation demand of a particular climate (Linacre, 2004) and, plays an important role not only in the water budget of a wetland, but also in the energy budget. Evaporation and evapotranspiration are major components of the hydrologic cycle, where approximately more than 60 percent of precipitation over land is lost through these phenomena globally (Dingman, 2002; Rivas and Caselles, 2004).

Several difficulties arise when modeling evaporation of arid region wetlands. In these open water bodies, evaporation is the major component of water balance, which generally has rarely been measured directly, especially in developing countries (Vallet-Coulomb et al., 2001). Huge sensible heat flows from adjacent warm-hot dry lands (large amount of advective energy flux density) increasing the evaporation rate of free surface water bodies, drastically. Therefore, it is very difficult to estimate evaporation of open water using ordinary methods. Spatial variability of wetland surface must be added to these cases. Evaporation pattern at a regional scale integrate factors such as change in land cover, rainfall distribution and deforestation (Chen et al., 2002).

For a vast geographical area, satellite remote sensing has enormous possibilities for regular monitoring and management of wetlands (Ozesmi and Bauer, 2002). Ever since the advent of earth-observing satellites, remotely sensed images have provided a promising source of data for examining the characteristics of land surfaces. Remote sensing techniques offer rapid acquisition of data with a generally short turn-around time, at a cost lower than that of ground surveys (Castaneda and Herrero, 2005). There are two major methods to estimate wetland evapotranspiration using remotely sensed data. A water budget approach that uses remotely sensed water surface and vegetation covered areas with vegetation indices and ground data for wetland hydrology. The other being an energy balanced method which is very common in modelling evaporation using satellite imagery (Xin, 2004). The most popular energy balance method is SEBAL (Bastiaanssen et al., 1998). SEBAL was used to model regional evapotranspiration in several researches such as Ayenew (2003) and Mohamed et al. (2004). Evaporation from arid region wetlands is the most important component of water budget. The Hamun Wetlands in southeast of Iran include three national and international wetlands which were registered in Ramsar Convention in 1975 and are located in the north, northeast and west of Sistan Plain. They are not only wildlife protected areas, but also the major fresh water ecosystem of the central plateau of Iran. Hamun Wetlands are characterized by huge evaporation. Hamuns were fully dried during the recent drought from May to November 1999 during less than 6 months. Hamuns have become the subject of many researches by planners and engineers to estimate wetlands evaporation and save water for the expanding population as well as the whole ecosystem. Numerous studies and projects were proposed to estimate evaporation from Hamun Wetlands Surface. The Environment and Water Research Center (EWRC) collected and criticized most of the past studies (EWRC, 2002). Most of these studies relied on the computation of evaporation using meteorological ground station data.

Due to extremely scarce ground hydrometeorological data in the vast study area of Hamun Wetlands, using a remotely sensed approach is the only alternative to study evaporation and evapotranspiration in this part of Iran. In this paper, application of a SEBAL based method to estimate evaporation from Hamun Wetlands surface is introduced.

## 2 STUDY AREA

The geographical boundary of the region is from 30$^o$ to 32$^o$ northern latitude and 60$^o$ to 62$^o$ eastern longitude. In this flat area, the average altitude is about 500 meters above sea level. The Sistan Plain in the southeast of Iran is one of those regions that experiences high amount of advection fluxes annually especially during summer time (May to October). The monthly average of maximum wind speed at 10 m height during this period is about 8 m/s. Sistan is an area subject to hydro-meteorological extremes, such as large floods and severe persistence droughts. There are not any considerable groundwater resources in this part of Iran and the annual precipitation is less than 60 mm whereas records of class A pan evaporation shows annual evaporation of more than 4500 mm (Daneshkar Arasteh et al., 2004). The only water resource in this region is the Hirmand River, a trans-boundary river between Iran and Afghanistan (Fig. 1). The Hirmand is the tenth-largest river in Asia and drains much of Afghanistan. The main branch of the Hirmand forms the international boundary between Iran and Afghanistan. And, the Hirmand water right is the major geopolitical crises between the two countries. Hirmand River flows to the interconnected wetland system of Hamuns with a total area of 4000 km2 for full condition.

**Fig. 1:** Study area of Hamun Wetlands in southeast of Iran

## 3 Methology

The theoretical and computational approaches of SEBAL are described in Bastiaanssen et al., (1998). Using an energy balance at the surface, energy consumed by the evaporation process is calculated as a residual of the surface energy equation:

$$\lambda E = R_n - G - H \tag{1}$$

where, $\lambda E$, is the latent energy consumed by evaporation; $R_n$, is net radiation (sum of all incoming and outgoing shortwave and longwave radiations at the surface); G, is sensible heat flux conducted into the ground or stored in water bodies; and H, is sensible heat flux convected into the air including both convected and advected energy.

The utility of using energy balance is that actual evaporation rather than potential evaporation is computed. Nevertheless, the computation of $\lambda E$ is only as accurate as are the values for $R_n$, G, and H.

Daneshkar Arasteh (2004) developed a remotely sensed model to estimate Hamun Wetlands surface evaporation named HRSE (Hamun Remotely Sensed Evaporation model) on the base of energy balance approach of SEBAL.

The algorithm used in HRSE for $R_n$ is similar to that described for SEBAL by Bastiaanssen et al. (1998). Basically, $R_n$ is computed from satellite-measured broad-band reflectances and surface temperature. But, G is estimated from $R_n$, surface temperature, and vegetation indices for covered area of wetlands by vegetation as well as SEBAL and for free water, G is estimated using the gradient between surface temperature and deep water temperature; and H is estimated from surface temperature ranges, air humidity, and wind speed using an empirical equation. Therefore, HRSE is a variant of SEBAL and has been extended to provide tighter integration with ground-based data.

Another difference between HRSE and SEBAL is hidden in the evaporation fraction, the ratio of instantaneous latent heat flux ($\lambda E$) and Rn-G. The main assumption to obtain daily evaporation from instantaneous SEBAL evaporation is that both instantaneous and daily evaporation fraction are similar i.e. there is a linear relation between daily and instantaneous evaporation. Daneshkar Arasteh (2004) claimed that evaporation is a nonlinear procedure and changing an instantaneous magnitude to a daily one with a linear transformation varies seriously with the daily independent variables exerted to the nonlinear procedure of evaporation. He suggested transforming the instantaneous remotely sensed initial data to a daily parameter using such a linear relationship, then substituting daily variables in energy balance and computing the daily evaporation, directly. Daneshkar Arasteh (2005) used HRSE to partition energy balance components in Hamun Wetlands area. He showed advection has a value of about 30 percent of net radiation in this part of the world. An amount that has almost been never seen anywhere. It seems that the Sistan area and Hamun Wetlands are very unique with many catastrophes.

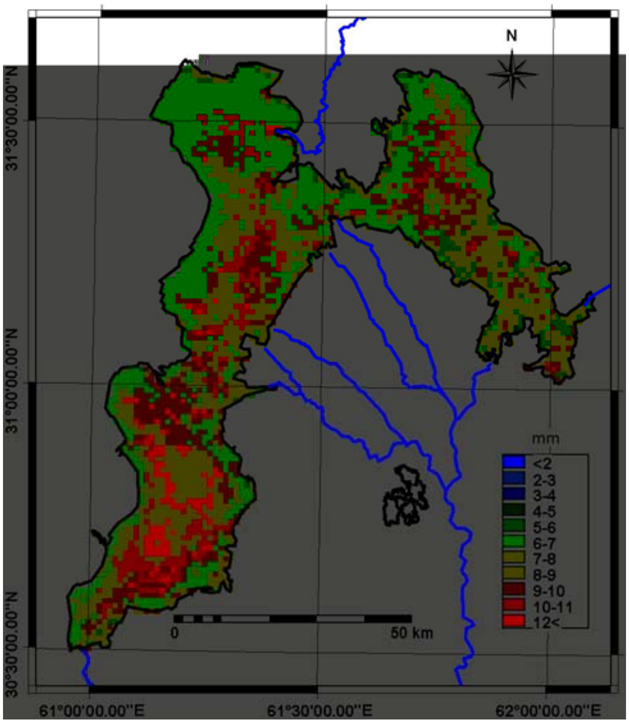
Surface temperature is the most used parameter in HRSE which is modeled by the split window method calibrated for the study area by Daneshkar Arasteh et al. (2005). They used NOAA-AVHRR channel 4 and 5 brightness temperatures and ground data in their calibration. In this paper, HRSE results in Hamun Wetlands will be compared with ground based energy balance evaporation by the most popular method of Penman-Monteith.

Ground data are collected from two first order meteorological stations which were located in the study area. Their data were used to estimate evaporation with the method of Penman-Monteith as mention before.

## 4 Results and Discussion

To investigate the evaporative characteristics of Hamun Wetlands, 50 NOAA-14 AVHRR images from May 1994 to May 2000 were processed using the HRSE method. Fig. 2 shows one of the processed images. As it is shown in Fig. 2, the evaporation rate varies between 5 to 12 mm/day for May 24, 1996 and the deeper parts of wetlands evaporate more than the marginal parts. Comparison of ground-based energy balance and HRSE latent heat flux densities showed relatively good agreement between the two methods (Fig. 3).

**Fig. 2:** Free water evaporation and vegetation cover evapotranspiration of Hamun Wetlands using HRSE model for NOAA-AVHRR image May 24, 1996




Since, Penman-Monteith model is the most common and popular method of estimation of evaporation and evapotranspiration, comparison of HRSE results with this method was studied. Fig. 4 shows the evaporation rate from Hamun Wetlands on the base of Penman-Monteith method.

As Fig. 4 shows, evaporation rate from wetlands varies between 3 to 9 mm/day for May 24, 1996. Comparison of Figs. 3 and 4 shows that the Penman-Monteith method estimates evaporation rate from Hamun Wetlands surface about 30 percent less than HRSE and Fig. 5 confirms it. This under-estimation relates to energy transport from adjacent deserts by advection. To obtain an estimation of the excess energy transferred from upwind direction, the difference of latent heat estimated with the two methods was considered. Since, regional advection means flow of energy in the direction of the thermal gradient, the relation between excess latent heat and remotely sensed surface temperature was considered too (Fig. 6).

**Fig. 3:** Comparison of evaporation rate estimated by HRSE and ground-based energy balance methods

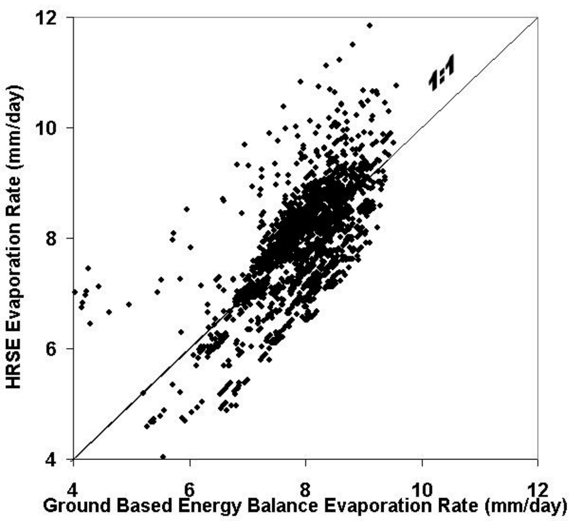



**Fig. 4:** Free water evaporation and vegetation cover evapotranspiration of Hamun Wetlands using Penman-Monteith model for NOAA-AVHRR image May 24, 1996

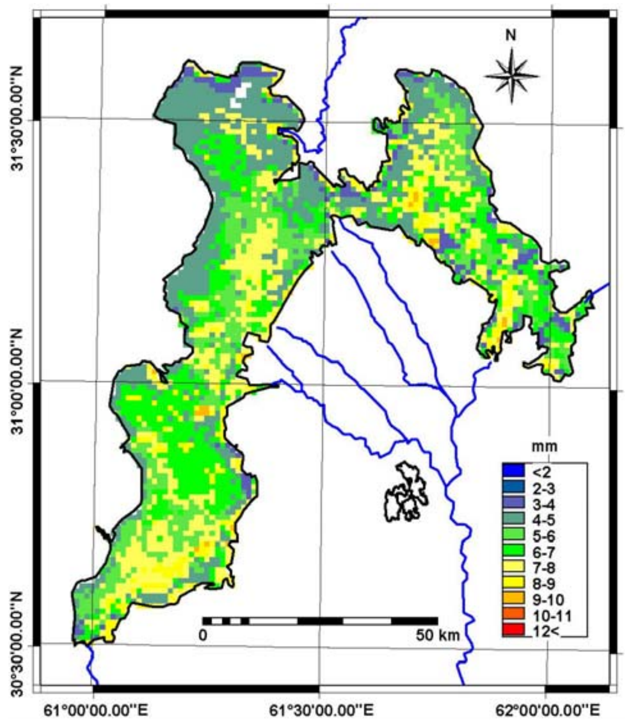



**Fig. 5:** Comparison of latent heat flux density modeled by HRSE and Penman-Monteith methods

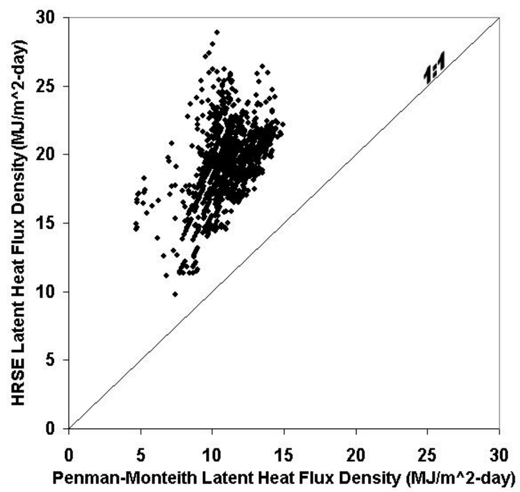
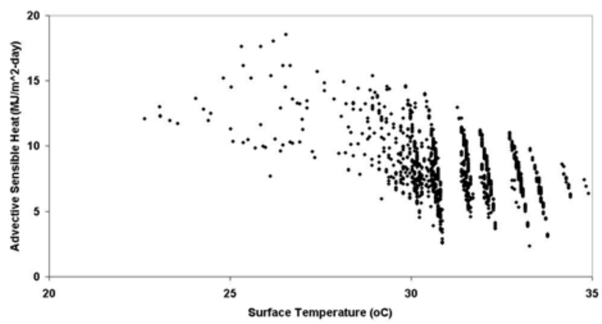


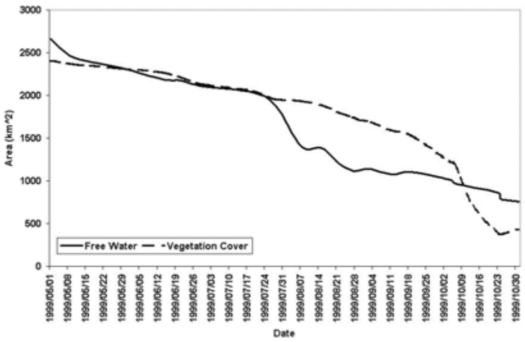

**Fig. 6:** Estimated advective heat flux density in relation to remotely sensed surface temperature




As it is seen in Fig. 6, excess energy is related to surface temperature, inversely. As expected from the direction of the thermal gradient, energy flows downward from northwest to southeast of the study area.

Considering the processed images showed that Hamun Wetlands have been fully dried from the beginning of May to late October 1999. Fig. 7 shows how wetlands with more than 2500 $km^2$ area have been dried within a period of less than 6 months that inflow to wetlands had been cut off. Therefore, Hamun wetlands are very sensitive to inflow because of large amount of annual evaporation especially from May to October.

**Fig. 7:** Drying manner of Hamun Wetlands during drought of 1999-2002




## 5 SUMMARY AND CONCLUSIONS

Evaporation is the most important unknown factor in the water budget of the Hamun Wetlands, Iran. Due to scarce ground hydrometeorological data in the Hamun Wetlands area, using a remotely sensed approach is the only alternative to study evaporation.

Remote sensing techniques compute evaporation directly from energy balance without the need to consider other complex hydrological processes. Application of energy balance leads to an estimation of the actual evaporation and dispenses the estimation of potential evaporation which needs more information about moisture condition and other hydrological properties of wetlands.

It was shown that common well known models such as the Penman-Monteith require calibration in the area, because of the regional advection occurring annually from May to October. For this, further study of the other methods such as mass transfer and energy budget are highly recommended. And also, it is recommended to carry an investigation on advective energy distribution in the Sistan area and its influence on water surface evaporation. But, first of all, it is needed to equip the hydrometric stations with required measuring devices as well as a floating energy balance station on the Hamun area.

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