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Estimating evaporation in semi-arid areas facing data scarcity: Example of the El Haouareb dam (Merguellil catchment, Central Tunisia)

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ABSTRACT

Study region: The El Haouareb dam (Merguellil catchment) in central Tunisia, which is typical of semi-arid environments.
Study focus: Most estimates of evaporation from water bodies located in semi-arid environments suffer from the lack of data, or biased field measurements. It is thus important for hydrologists to assess the relative performance of the various available methods used to estimate this water loss, as well as their uncertainties. We confronted physical approaches based on contrasted theoretical formulae (Dalton, simplified BREB, Penman) and geochemical approaches based on mass conservation (stable isotopes and chloride). We compared the results with Colorado pan measurements, and tested the methods' sensitivity to various physical parameters and data gaps.
New hydrological insights for the region: In this region, where mean annual rainfall is 300 mm, estimates of evaporation of the El Haouareb Dam lake ranged from 1400 to 1900 mm a^{-1}, depending on the method and the year. The Penman approach was found to be the most robust and gave an annual mean of 1600 mm a^{-1}. Evaporation values were refined by combining results from the different methods. Mean interannual evaporation was estimated to be 1700 mm a^{-1}, with an uncertainty of 15%. From this work, we propose an annual Colorado pan conversion coefficient of 0.8 which can be adjusted, 1.0 for spring and 0.76 for the rest of the year.

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1. Introduction

Semi-arid environments are well known for the strong spatial and temporal variability of climatic conditions and hydrological processes, as well as for rapid changes caused by human activities (e.g. Cudennec et al., 2007; Leduc et al., 2007). This particular sensitivity and the increased environmental fragility are of global concern because semi-arid and arid areas cover one third of the continents and are home to more than 20% of the world population. In these regions, evaporation implies a complete loss of water resources at the basin scale. For both scientific and social reasons, a reliable estimate of loss due to evaporation is thus needed for improved management of water resources (e.g. Martínez-Granados et al., 2011; Massuel et al., 2014).

Direct measurements of lake evaporation are very rare and mostly limited to very short periods. The Eddy CoVariance (ECV) method allows to measure the vertical turbulent fluxes within the surface atmospheric boundary layer and in turn the latent heat flux. It has been led, for example 51 days in Japan in a study by Ikebuchi et al. (1988), 42 days in Indonesia by Sene et al. (1991), 20 and 44 days in Israel by Assouline and Mahrer (1993) and also in Israel, 21 days then 104 days by Tanny et al. (2008, 2011). More recently, scintillometers have been used to help measure the latent heat flux above the entire open water surface and not only a small area as for the ECV method, thus taking into account potential edge or advection effects in the measurements. McJannet et al. (2013a) used the scintillometry method and obtained reliable estimates of evaporation for a period of 18 months over Logan's dam in Australia. They compared evaporation derived from scintillometer data over a transect covering the whole dam to ECV data obtained on a floating platform at the centre of the dam, with a very good consistency between both measurements. However, this work focused on a lake with a homogeneous surface. Computation of available energy for a heterogenous surface (open water and vegetated or bare soils) is more complicated. Latent heat is indeed retrieved as the residual term of the energy balance from sensible heat measured by the scintillometer. Some authors have also shown the importance of edge effects (Webster and Sherman, 1995; Condie and Webster, 1997) which affect the equilibrium layer over the lake surface over relatively short distances only. For lakes with large surface changes over relatively short time periods, one can apply similar methods as those derived for vegetated surfaces (Chehbouni et al., 2000) but this is clearly beyond the scope of this study.

In the absence of a major experiment involving direct measurements such as ECV or scintillometry methods, indirect estimations based on theoretical formulae or geochemical tracers influenced by the evaporation process have been exploited for decades. Often derived from temperature data like Dalton, Penman and Bowen Ratio Energy Balance (BREB), they have been used in different environmental conditions and varying data availability. Chemical approaches have been less widely used but generally give good results. At the annual time scale, Vallet-Coulomb et al. (2001), and using 50-day intervals, Gibson et al. (1996), found less than 10% difference from the results of physics-based approaches.

In a thorough review, McMahon et al. (2013) discussed the theoretical background of many indirect approaches in detail. But generally speaking, authors do not agree which indirect method is the most reliable, and estimated evaporation rates can vary as much as 30%, as shown by Tanny et al. (2008) who compared five combined methods (Penman, Penman–Monteith–Unsworth, Penman–Brutsaert, Priestley–Taylor and Penman–Doorenbos–Pruitt) with direct measurements. Daily evaporation estimated with the BREB method can differ by a factor of 4 from daily evaporation measured with eddy correlation (Ikebuchi et al., 1988). McJannet et al. (2013b) obtained quite different results with combined models, for example, a difference of 15% between modelled and measured evaporation using the De Bruin–Keijman and Priestley–Taylor methods but of only 5% with the Penman–Monteith approach. Kashyap and Panda (2001) found discrepancies from −1.36 to +22.32% between the estimation of evapotranspiration with ten different methods (combinated, radiation and temperature based) and direct measurement by lysimeter in India.

Comparisons between several indirect methods also showed significant discrepancies. McMahon et al. (2013) pointed to differences of 20% between evaporation estimated using the Penman equation with two different wind functions for 68 sites in Australia. Elsawwaf et al. (2010a) showed a very bad linear correlation ($R^2 < 0.3$) between monthly evaporation rates estimated with BREB and five other traditional methods (Priestley–Taylor, De Bruin-Keijman, Dalton derived mass transfer method, Papadakis, and Penman).