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Spatially distributed potential evapotranspiration modeling and climate projections

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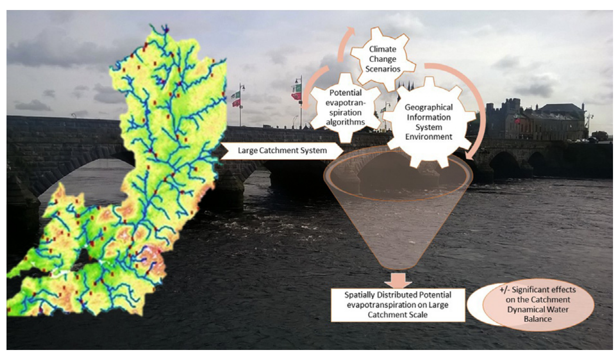
HIGHLIGHTS

- Empirical models well simulate spatially distributed potential evapotranspiration.
- All the simulated scenarios predicted an increase in potential evapotranspiration.
- A clear variation in potential evapotranspiration is visible in the coastal areas.
- Climate change has significant impacts on the future potential evapotranspiration.

GRAPHICAL ABSTRACT



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ABSTRACT

Evapotranspiration integrates energy and mass transfer between the Earth's surface and atmosphere and is the most active mechanism linking the atmosphere, hydrosphsophere, lithosphere and biosphere. This study focuses on the fine resolution modeling and projection of spatially distributed potential evapotranspiration on the large catchment scale as response to climate change. Six potential evapotranspiration designed algorithms, systematically selected based on a structured criteria and data availability, have been applied and then validated to long-term mean monthly data for the Shannon River catchment with a 50 m^2 cell size. The best validated algorithm was therefore applied to evaluate the possible effect of future climate change on potential evapotranspiration rates. Spatially distributed potential evapotranspiration projections have been modeled based on climate change projections from multi-GCM ensembles for three future time intervals (2020, 2050 and 2080) using a range of different Representative Concentration Pathways producing four scenarios for each time interval. Finally, seasonal results have been compared to baseline results to evaluate the impact of climate change on the potential evapotranspiration and therefor on the catchment dynamical water balance. The results present evidence that the modeled climate change scenarios would have a significant impact on the future potential evapotranspiration rates. All the simulated scenarios predicted an increase in potential evapotranspiration for each modeled future time interval, which would significantly affect the dynamical catchment water balance. This study addresses the gap in the literature of using GIS-based algorithms to model fine-scale spatially distributed potential evapotranspiration on the large catchment systems based on climatological observations and simulations in different climatological zones. Providing fine-scale potential evapotranspiration data is very crucial to assess the dynamical catchment water balance to setup management scenarios for the water abstractions. This study illustrates a transferable systematic method to design GIS-based algorithms to simulate spatially distributed potential evapotranspiration on the large catchment systems.

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1. Introduction

After precipitation, evapotranspiration is the largest component of the terrestrial hydrological budget and thus critical for water resources evaluation and sustainable water management policies (Liu and Phinn, 2003; Portugali et al., 1994; Wu, 2002). Evapotranspiration is responsible for transferring moisture from the earth's surface to the atmosphere in vapor form. Due to complex interactions between meteorological and site-specific factors, evapotranspiration is extremely difficult to quantify. Water balance modeling requires the spatial estimation of potential evapotranspiration (PETS) throughout the catchment; that is the evapotranspiration, which would occur under optimal conditions. Evapotranspiration includes two processes that occur simultaneously in the soil-plant-atmosphere system, direct evaporation of moisture from the Earth's surface, and the exchange of water vapor, which occurs within the leaves of plants (transpiration) (Swenson and Wahr, 2006; Wilson et al., 2001). Evapotranspiration has long been recognized as a central process in the hydrological cycle (Penman, 1948; Rosenzweig, 1968; Holdridge, 1959; Gordon, 1998). The term potential evapotranspiration represents the ET, which would occur under optimal conditions where evapotranspiration is not limited by factors such as soil moisture. Evapotranspiration represents the most active of land-based hydrological processes, with approximately 65% of precipitation being evaporated and transpired (Kite and Droogers, 2000; Shukla and Mintz, 1982). Evapotranspiration fulfills numerous roles throughout its cycle. It accomplishes energy (heat) and mass (water vapor) transfer between the Earth's surface and atmosphere, and is the most active mechanism connecting the atmosphere, hydrosphsophere, lithosphere and biosphere (Zhao et al., 2004; Kite and Droogers, 2000; Zhang et al., 2001). Evapotranspiration is not only responsible for modulating atmospheric moisture but also temperature. Therefore, it can be seen that this process provides a vital link between the climatic, hydrological and ecological systems. Potential evapotranspiration remains one of the least satisfactorily explained processes in the hydrological cycle, principally because of its spatial variability (Andréassian, 2004; Andréassian et al., 2004; Oudin et al., 2005).

Due to the complexity and difficulties faced in the measurement of PETS, it is predominately estimated using formulae and observed meteorological data. There exists a vast number of models for estimating PETS, which may be grouped into several categories such as radiation, water budget, mass transfer, temperature, and combination methods. These methods vary greatly in terms of complexity, data requirements, and reliability.

Developing a GIS tool for modeling spatially distributed PETS from an undefined number of meteorological stations from monthly data of precipitation and temperature is the main objective of this paper. This tool provides the user with the PETS results on a seasonal and annual basis as well as an option to calculate values on a monthly frequency. The PETS GIS tool is presented using many methods with the ability to calibrate and validate the results. This study presents the primary results of the calculated PETS for both the baseline period and the future periods, based on climate change projections, for the Shannon River catchment in Ireland (Gharbia et al., 2016d; Gharbia et al., 2016b; Gharbia et al., 2015b; Gharbia et al., 2016a; Gharbia et al., 2015a). The River Shannon catchment, the focus of this study, is the largest transboundary river system and catchment in the island of Ireland and one of the most important water and power resources in the Republic of Ireland, see Fig. 1. Met Éireann, the Irish National Meteorological Service, calculates daily estimates of PETS at 25 synoptic weather stations throughout Ireland using the FAO Penman-Monteith method, 4 of which are located within the Shannon River catchment. As the catchment covers in excess of 18,000 km^2, it is evident that 4-point estimates are not sufficient to estimate spatially distributed PETS. The Penman-Monteith method is widely considered as a standard method for the calculation of PETS. However, its application, particularly for this large catchment, is questionable due to the need for specific data for a variety of

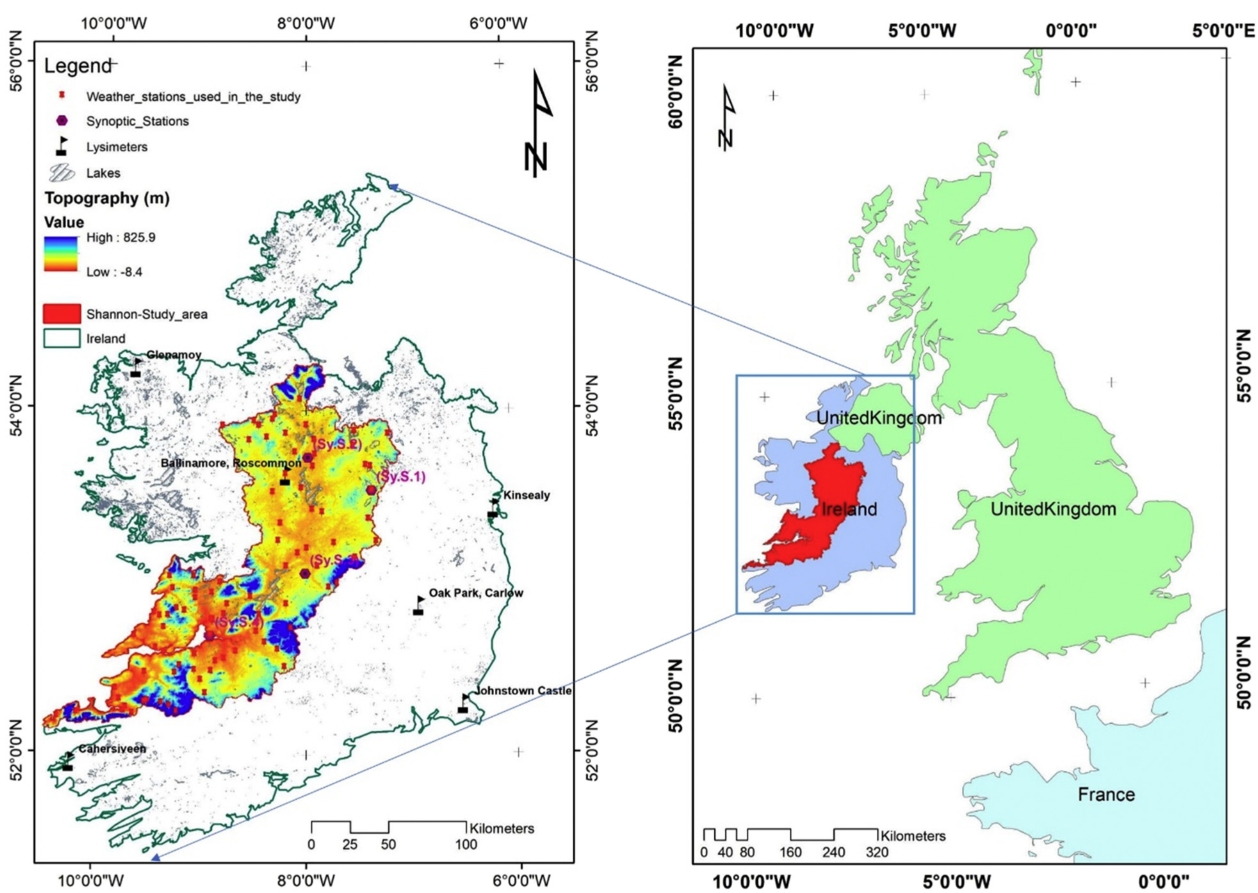

Fig. 1. Location map for the Shannon River catchment.