Discussion of "Generalized regression neural networks for evapotranspiration modelling"*

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There is no doubt that so-called "artificial neural networks" (ANN) are powerful computational tools to model complex nonlinear systems. In my view, an ANN establishes a data-driven nonlinear relationship between inputs and outputs of a system. The fact that such a nonlinear model is generally very complicated (usually one does not even write down the equations) renders it a black-box model. The fact that the model contains numerous parameters makes imperative the use of an advanced optimization method to calibrate its parameters. Once an ANN is fitted, it can be used to predict outputs from known inputs. Thus, there have been numerous successful applications of ANN in forecasting the future evolution of complex systems (e.g. Casdagli & Eubank, 1992; Weigend & Gershenfeld, 1994). However, I am afraid that there has also been an abuse in other cases, indirectly assisted by the numerous technical details, inapproachable for the majority of scientists (in our case hydrologists), and even by the exotic ANN vocabulary. The paper by Kişi (2006) stimulated my "reflex" questions about "neural networks", their use and abuse, and helped me to organize them so that they can be addressed to the "central nervous system".

I start with the vocabulary itself. How "neural" are ANN? This question may be philosophical and related to the nature of the so called "artificial intelligence". I am not prepared to discuss in depth this type of question, for which profound analyses can be found in Dreyfus & Dreyfus (1986), Penrose (1989, 1994, 1996) and Hodges (2000–2002). However, I thought of a simplified version of this question: Is it necessary to call these mathematical models "neural" networks? Structures such as graphs and networks are very common in science (including hydrology, hydraulics and water resources), and consist of nodes (or vertices) and arcs (edges, or arrows in directed graphs and networks). Why in this case should we speak of "neurons" instead of nodes or arcs? After all, while in other cases (e.g. a river network, a water distribution network) the network has a physical hypostasis, in ANN the network is just a convenient pictorial representation of a complicated mathematical nonlinear relationship, which could be handled even without the notion of a network. A lot of similar questions can arise: Why use such terms as "one-pass learning algorithm with a highly parallel structure" or "training vector"? Isn't it more understandable to speak about "model calibration", "model fitting" and "parameter optimization" instead of "learning" or "training"? If yes, why have these anthropomorphized terms been so prevalent?

Furthermore, is an ANN approach appropriate for any type of problem? Kişi (2006) seems to reply positively to this question. His motivation for the paper is simply this: "However, the application of ANN to evapotranspiration modelling is limited in the literature. ... To the knowledge of the author, no work has been reported

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in the literature that addresses the application of generalized regression neural networks (GRNN) to [reference evapotranspiration] ET_0 estimation. This provided an impetus to investigate the potential of the GRNN for better mapping of the process." So, the motivation seems to be a matter of whether others have or have not published research on this issue. Shouldn't one have some thoughts on the utility of the approach in principle for the specific problem, before proceeding to its adoption?

To make these questions clearer, let us see what the author proposed in his paper: "The ET_0 obtained by the FAO-56 [Penman-Monteith] PM was standardized … Finally, these normalized data were used for the calibration of GRNN models. A program code, including ANN toolboxes, was written in MATLAB language for the GRNN simulations." This can be outlined as follows: Take the FAO Penman-Monteith equation. Take the required meteorological inputs (historical time series) and apply the equation to estimate the Penman-Monteith evapotranspiration as output. Then disregard the equation, take only the input and output data and "train" an ANN to produce the output from the input data. On this point, I wonder: If I have the data and the equation (which is simple, explicit, and clear), why do I need to use an ANN (a black-box complicated model whose detailed mathematical behaviour I do not know) to reproduce (approximately) the outputs that the simple equation yields precisely? Certainly, it is justifiable to apply an ANN approach if the relationship of output to inputs is complex and not known. But in this very case isn't it both simple and completely known? I characterize the Penman-Monteith model as simple, because mathematically it is an algebraic equation (as contrasted, for instance, to differential equations without closed solutions that describe most hydrometeorological processes). And I maintain that, in this paper, the relationship of inputs to outputs is completely known because the author has assumed that it is fully described by the Penman-Monteith model, which he applied to estimate the output. That is, in this paper the output is not known from measurements, but from application of the Penman-Monteith equation, which subsequently the author proposes to replace with the ANN built upon the equation. Does the replacement of an explicit equation with a MATLAB code of a black box serve any purpose?

Still, one may argue that, once an ANN model has been fitted, it can serve other purposes, such as approximation of the original equation and sensitivity analysis including the sensitivity to missing data or missing variables. Indeed, such issues are all discussed in Kişi (2006). Again, several questions arise. If our aim is approximation, what is the real value of an ANN? Isn't it more insightful to make an approximation using classical analytical and numerical tools (given that in this case we know the equation describing the system)? Doesn't an explicit equation deserve an explicit approximation? Isn't it more practical to adopt one of the existing empirical approximate equations of evapotranspiration? If our aim is sensitivity analysis, does an ANN approach have any advantage over classical methods? Isn't it more insightful to use, for instance, partial derivatives to assess the influence of a specific input? Isn't it more informative to use a probabilistic description of the inputs and a Monte Carlo simulation to obtain some insight on the degree that the different inputs affect evapotranspiration? Is it really possible for an ANN to provide an insightful sensitivity analysis of the problem at hand?

To shed light on the last question, I will use the results of the sensitivity analysis of Kişi (2006), according to which "[The temperature] *T* seems to be more effective than [the relative humidity] RH and [the wind speed] U_2 in estimation of ET_0 because of the fact that adding T into the input combination … significantly increases the model performance", but later "In contrast to the Pomona Station, RH seems to be more effective than T in estimation of ET_0". We can discuss these results from a theoretical and a practical viewpoint. From a theoretical viewpoint, simple inspection of the Penman-Monteith equation reveals that RH does not appear in it. It is only used to estimate the vapour pressure and finally the vapour pressure deficit, the difference from saturation vapour pressure. All these variables presuppose that the temperature is known, otherwise how can one estimate them? So, what is the meaning of preferring to know RH over T? The same value of RH results in very different vapour pressure deficits in summer and in winter. From a practical viewpoint, it is well understood that any meteorological station includes at least a thermometer, the simplest meteorological instrument. Besides, in conventional meteorological stations, RH is obtained from two temperature readings, dry bulb and wet bulb, and this simple technique is also used even in modern non-conventional stations for testing the sensors consistency and accuracy. It is then difficult to imagine that we may know RH and not T. What is then the meaning of comparing which of T and RH is most effective in estimation of ET_0? Furthermore, in a sensitivity analysis framework, one must have in mind that the measurement of T is much more accurate than that of RH and that the (temporal and spatial) variability of RH exhibits a more random pattern in comparison to T; these are quantifiable by classical methods but seem to be ignored in an ANN approach. This example may indicate that sensitivity analyses performed by ANN can be as black-box, sightless, and inconsistent with physical realism and practical needs, as the ANN itself.

One of the most interesting points of the paper by Kişi (2006) is the comparison of the ANN results with other existing approximations, i.e. simplified empirical methods, such as the Hargreaves and Ritchie equations. Here the natural question is, how fair is it to compare an ANN fitted on a specific site with a general equation applied on this site? One is reminded that the ANN contains numerous adjustable parameters optimized for the site-specific data, whereas Hargreaves and Ritchie equations do not contain any adjustable parameters at all. It is not, then, a surprise to conclude that "the GRNN1 model outperforms all other models in terms of various performance criteria." It is amazing, however, that a simple linear modification of the results of Hargreaves and Ritchie equations (the author calls them calibrated versions of the equations) suffices to make their performance as good as that of the ANN. And the same methods outperform the ANN if some data are missing, filled in from neighbouring stations. Thus, the author correctly suggests that "the results imply that the C_Hargreaves and Ritchie empirical methods may be used instead of GRNN models in cross-station applications."

After all these analyses, I wonder how justified the conclusion is that "The study demonstrated that modelling of daily reference evapotranspiration is possible through the use of the GRNN technique." Wouldn't a negative conclusion, that an ANN approach does not offer too much in evapotranspiration estimation, be more useful? Having said that, I think that the practice of emphasizing negative results in research publications has been regarded as negative itself, while, in my opinion, it is very positive and useful. In this respect, I look forward to reading such assessments of ANNs, in which their usefulness is discussed along with their limitations.

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