International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

GP Model for Predicting Evaporation and Seepage Losses from Reservoir

C. Sivapragasam[1], J.J. Maran, T. Chandrabose, K.S.M. Samsutheen and N. Ganesan
Department of Civil Engineering, Kalasalingam University
Anand Nagar, Krishnankoil, Virudhunagar (District), Tamilnadu - 626 190, INDIA
E-mail: [1]sivapragasam@yahoo.com

ABSTRACT: Evaporation is one of the least satisfactorily explained components of the hydrologic cycle because, unlike say stream flow, it cannot be directly measured but must be estimated based on mass transfer, or energy or water budget methods. As a consequence, a variety of techniques have been derived for determining or estimating vapour transport from water surfaces. Numerous researchers have attempted to estimate the evaporation values from climatic variables, and most of these methods require data that are not easily available. Simple methods that are reported try to fit a linear relationship between the variables. However, the process of evaporation is highly non-linear in nature, as is evidenced by many of the estimation procedures. Many researchers have emphasized the need for accurate estimates of evaporation in hydrologic modeling studies. These requirements could be addressed through better models that will address the inherent non-linearities in the process. Further, there is a requirement for methods that consider only a few variables, since estimates are often needed where limited meteorological data only are available. In this study, a Genetic Programming based mathematical model is developed for Pilavakkal reservoir system in Tamilnadu where both evaporation loss and seepage losses are reported, which further complicates the whole modeling process. The proposed model gave very high Correlation coefficient of 0.94 and 0.85 for the two reservoirs under Pilavakkal scheme, namely Kovilar and Periyar reservoirs respectively. Genetic Programming is found to be a potential technique for modeling inherent non-linearities in the model.

INTRODUCTION

In the water balance of reservoir system, evaporation plays a crucial role particularly so for the reservoir systems of smaller size located in the semi-arid or arid regions. Due to differences in the heating and cooling of water bodies, evaporation from small shallow reservoirs is usually considered to be quite different from that of large reservoirs. This is further enhanced in case of smaller reservoir located in a semi arid region due to hot dry air moving from land surface. Besides, in many cases, seepage losses from reservoirs also contribute significantly. Thus, any attempt towards optimal design of reservoir capacity or release from reservoirs should account for these losses appropriately. Lack of proper consideration may lead to err on the side of greater risk, as reported by Hugo (2002).

Many methods are reported in the estimation of evaporation losses from free water surfaces, which can be grouped into several categories, including: empirical methods (e.g. Kohler *et al.*, 1955), water budget methods (e.g. Guitjens, 1982), energy budget methods (e.g. Fritschen, 1966), mass transfer methods (e.g. Harbeck, 1962); and combination methods (e.g. Penman, 1948). Evaporation pans provide one of the easiest, cheapest and most widely used methods of evaporation estimation. However, there is no single model or method put forth for the estimation of evaporation and seepage losses together which are highly non-linear. Further, even for estimating evaporation losses, there are no definite guidelines for selecting the most appropriate model to be used for a given situation.

Recently, there has been a growing interest in the modeling of non-linear relationships, and a variety of test procedures for detecting the non-linearities have been developed. Towards this end, Darwinian based evolutionary algorithm, Genetic Programming (GP), seems to be a very potential technique. In this study, the same has been adopted for estimating/predicting evaporation and seepage losses from reservoirs. The advantage of this algorithm lies in the fact that from a given set of climatological and/or other parameters believed to affect the process of evaporation and seepage, GP selects the most suitable parameters, and thus by suitable intuitive analysis and necessary data,

[1]Conference speaker

empirical mathematical models most suited to the system under consideration can be easily evolved.

The proposed method is applied to develop mathematical models for evaporation and seepage losses from two small reservoirs (Periyar and Kovilar) located in the semi-arid Vaipar sub basin of south Tamilnadu (India).

STUDY AREA DESCRIPTION

Pilavakkal reservoir system consisting of Periyar and Kovilar reservoirs in Virudhunagar District of Tamilnadu State, India is considered in this study. These two reservoirs lie in the upper part of the Vaippar basin, separated 5 km apart and located at (9°41′ N, 77°23′ E) and (9°38′ N, 77°32′ E) respectively. Periyar and Kovilar dams are earthen dams and are provided with river sluices and canal sluices to feed the downstream command area. These reservoirs are constructed across the two non-perennial Periyar and Kovilar rivers, which carry only intermittent flash flows depending on the seasonal rainfall. Kovilar reservoir has a larger surface area with relatively shallow water depth when compared to Periyar reservoir. There are no meteorological stations available within the command area of reservoir system. But there is one station maintained by the ground water wing of the state public works department located approximately at a distance of 20 kms from the Pilavakkal system command at Kavalur. This meteorological station represents the whole of Vaippar basin. Historical fortnightly records of several hydro meteorological variables, including temperature, wind speed and relative humidity are obtained for a period of 1992 to 2000 from this meteorological station.

GENETIC PROGRAMMING

Genetic Programming (GP) is an evolutionary algorithm to approximate the equation, in symbolic form, that best describes how the output relates to the input variables. GP works by imitating aspects of natural evolution to generate a solution that maximizes (or minimizes) some fitness function (Koza, 1992). The algorithm considers an initial population of randomly generated programs (equations), derived from the random combination of input variables, random numbers and functions which include arithmetic operators (+, –, ×, ÷), mathematical functions (sin, cos, exp, log), logican/comparison functions etc, which has to be appropriately chosen based on some understanding of the process. Typically the population of a Genetic Programming process contains a few hundred individuals and evolves through the action of evolutionary operators known as crossover, mutation and selection. The programs that best fit are selected to exchange part of the information between them to produce better programs through evolutionary operators which mimic the natural world reproduction process. Exchanging the parts of best programs with each other is called crossover and randomly changing programs to create new programs is called mutation. A population of solution candidates evolves through many generations towards a solution using certain evolutionary operators and a 'survival-of-the fittest' selection scheme. Selection involves evaluating the fitness of each population member and choosing the fittest to continue to the next generation; there are various selection strategies which can be used to determine which of the population members will survive to the next generation (Koza, 1992). The programs which less fitted the data are discarded. This evolution process is repeated over successive generations and is driven towards finding symbolic expressions describing the data, which can be scientifically interpreted to derive knowledge about the process. Details on GP can be obtained from (Koza, 1992; Babovic and Keijzer, 2000; Khu *et al.*, 2001; Sivapragasam *et al.*, 2006). In this study, the Discipulus (1998) software used for implementing GP.

MODEL DEVELOPMENT

The evaporation-seepage estimation models for Periyar and Kovilar reservoirs are constructed based on the historically available meteorological data as well as the real time changes in the reservoir water level. The analysis is carried out for a fortnightly time period of operation. Meteorological parameters will primarily address the evaporation process. In addition, surface area of the reservoir at a given depth of reservoir storage (a derived parameter) is also considered for evaporation modeling. This surface area is a representative surface area obtained by dividing storage volume of the reservoir by the depth of reservoir storage. For seepage, due to lack of information on parameters such as the soil moisture (saturation) condition, permeability, any geological formations such as cracks etc which affects seepage directly, the only parameter which is considered in model development is the depth of reservoir storage.

Since the evaporation and seepage losses for future time periods have to be estimated and because no separate model is constructed to estimate the meteorological information for these future periods, it is assumed that the average climatic condition during a particular time period in the current year may not be very different from the preceding year's climatic conditions, unless the basin undergoes some drastic natural or man made changes (which is found to be absent in this basin). Thus, the average climatic condition during the first fortnight of November 2005 (say) may not very much differ from that of November 2004. As such, the meteorological parameters observed during November 2004 can be taken as representative parameters for November 2005. With this assumption, the parameters considered for model development can be expressed in the functional form as below,

$$E_t = f\left(h_{t-1}, SA_{t-1}, T_{t-24}, RH_{t-24}, N_{h_{t-24}}, V_{t-24}\right) \quad \ldots (1)$$

where E_t = Evaporation losses at time t (Mm^3)

$T_{(t-24)}$ = Temperature at the same fortnight one year before (in °C)

$V_{(t-24)}$ = Wind velocity at the same fortnight one year before (in Kmph)

$N_{h(t-24)}$ = Sunshine hour at the same fortnight one year before (in Hours/day)

$RH_{(t-24)}$ = Relative humidity at the same fortnight one year before t (in %)

$SA_{(t-1)}$ = Surface area of reservoir one fortnight before (in m^2)

$h_{(t-1)}$ = Reservoir storage depth one fortnight before (in m)

Selection of GP mathematical functions needs the knowledge about the process. Generally seepage loss variations are expected to be exponential in nature, whereas evaporation losses are some non-linear combinations of input parameters. Since, evaporation and seepage losses are simultaneously present, it can be expected that the combined effect may appear in the form of functions that are not necessarily strictly exponential. One way to model this dual effect is to introduce sine and cosine functions as alternate functions for modeling with GP, besides the usual arithmetic functions. Accordingly, the final set of GP functions are considered in the model development are Addition, Multiplication, Subtraction, Exponential and Trigonometric.

GP is run with the above mentioned variables after normalizing them together with the chosen mathematical functions. The following models are obtained for Periyar and Kovilar reservoirs.

Evaporation-Seepage Model for Periyar Reservoir

For Periyar reservoir, the GP obtained evaporation-seepage loss model is given by Eqn. (2),

$$E_t = \frac{0.081.h_{t-1}{}^3 T_{t-24}^4 V_{t-24}}{(RH_{t-24})^4 (N_{ht-24})^2} \quad \ldots (2)$$

As observed from Eqn. (2), it is clear that the process of evaporation is mainly affected by wind velocity (as the normalized velocity term is of degree one). This is evident as Periyar reservoir is found to be not surrounded by forests and thus permitting free circulation of winds over the water surface. Further, the surface area is not found to affect the process. Figure 1 shows the comparison of actual evaporation-seepage losses and that obtained by Eqn. (2). The correlation coefficient is found to be 0.85. As seen Figure, the prediction during the peak summer months (April–May) is very poor when compared to other months. This may be due to the possibility of higher seepage losses due to formation of cracks etc about which quantifiable information is not available.

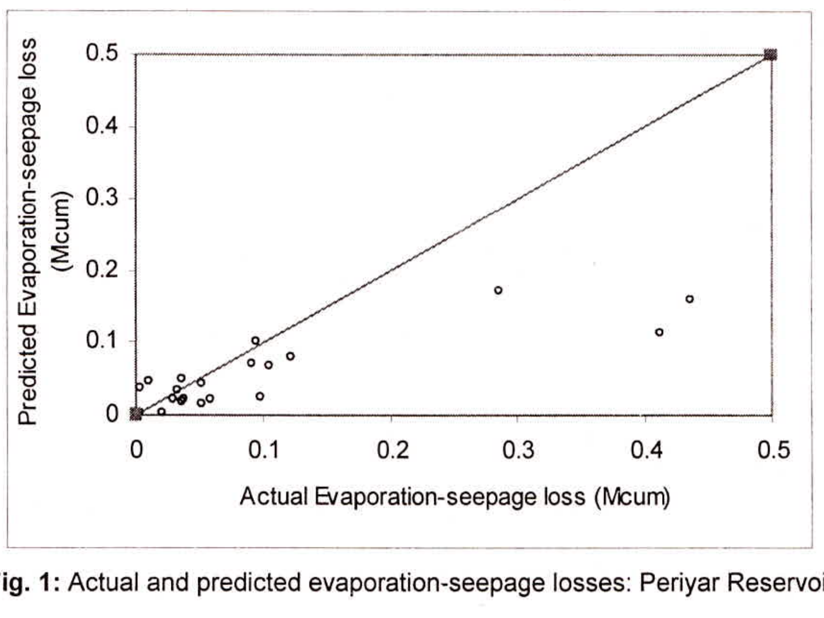

Fig. 1: Actual and predicted evaporation-seepage losses: Periyar Reservoir

Evaporation-Seepage Model for Kovilar Reservoir

For Kovilar reservoir, the GP obtained evaporation-seepage loss model is given by Eqn. (3),

$$E_t = 0.03[SA_{t-1}(SA_{t-1} - 2h_{t-1}) + RH_{t-24}(RH_{t-24} - 2h_{t-1})] + h_{t-1}.N_{ht-24} [0.2(h_{t-1}^2 + SA_{t-1}^2 + 0.5.RH_{t-24}^2) + 0.1h_{t-1}.RH_{t-24} - 0.51h_{t-1} + 0.18SA_{t-1} + 0.07]V_{t-24} \quad \dots (3)$$

Neglecting the fifth order terms, the equation can be simplified to,

$$E_t = 0.03h_{t-1}.V_{t-24}[SA_{t-1}(SA_{t-1} - 2h_{t-1}) + RH_{t-24}(RH_{t-24} - 2h_{t-1}) - 17] + V_{t-24}(0.18SA_{t-1} + 0.07) \quad \dots (4)$$

In this case, the correlation coefficient is found to be 0.95. Here, the temperature and sunshine hours are found to be comparatively less effective in determining the evaporation-seepage losses as this reservoir is covered with relatively dense forest area making the sunlight difficult to reach effectively. The predominant factor is again the velocity of wind. Figure 2 shows the comparison of actual and predicted evaporation-seepage losses. It can be observed that, as expected, the prediction in summer season is found to be poor due to the similar reason as explained already for Periyar reservoir.

SENSITIVITY ANALYSIS

In order to identify the most important factor(s) that affect the evaporation and seepage process, a sensitivity analysis was carried out. Here a particular parameter is removed from inputs to model generation and models are reconstructed. To understand the effect of wind better, the wind velocity is underestimated and overestimated by 5% and the evaporation-seepage losses estimated from Eqns. (2) and (3) above for Periyar and Kovilar reservoirs respectively. The correlation-coefficient is tabulated in Table 1.

From the sensitivity analysis, it is noted that removal of other parameters (except Wind velocity) did not introduce significant error in the evaporation and seepage loss estimation. However, even a minute error in the wind velocity value is found to affect the modeling process drastically. For example, for Kovilar reservoir, the correlation coefficient drops to 0.43 when the wind velocity is underestimated by 5%, and removal of wind velocity component results in a negative correlation.

Table 1: Sensitivity Analysis for Periyar and Kovilar Reservoirs

Model	*Correlation Coefficient*	
	Periyar	*Kovilar*
Full model	0.86	0.95
Excl. T	0.74	0.67
Excl. RH	0.70	0.34
Excl. T and RH	0.54	–
Excl. wind velocity	0.66	–0.41
Increasing by 5%	0.71	0.78
Decreasing by 5%	0.83	0.43

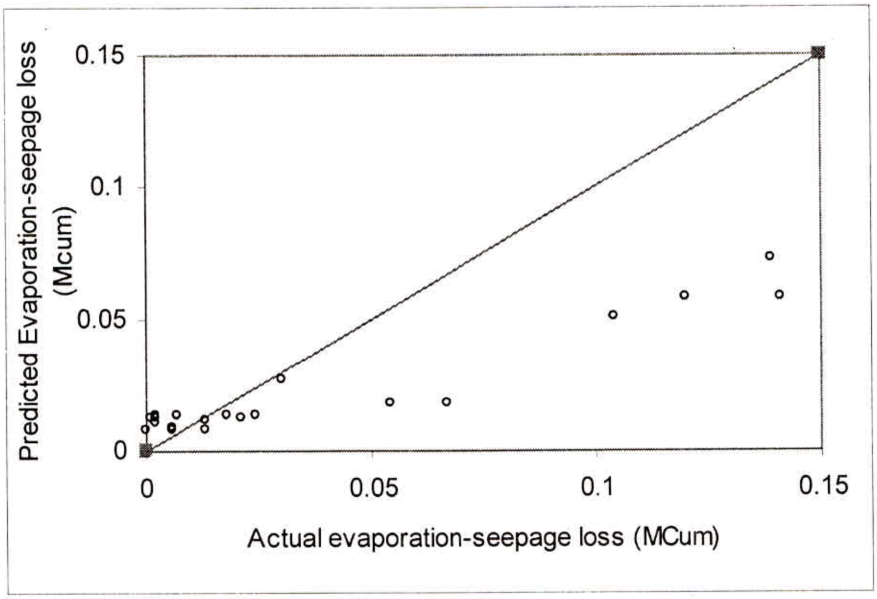

Fig. 2: Actual and predicted evaporation-seepage losses: Kovilar Reservoir

CONCLUSIONS

The following conclusions can be arrived at based on this study:

(a) Though the two reservoirs (Periyar and Kovilar) are physically located merely at a distance of 5 km, the evaporation-seepage models developed for them are entirely different from each other. The extents to which different parameters affect the process also vary considerably. This substantiates the need for developing local/regional models. The calibration of conventional models to find appropriate values of the coefficients is highly unlikely to suitably model the difference in evaporation-seepage processes in the two reservoirs.

(b) The sensitivity analysis done in both reservoirs indicates that wind velocity is the most important factor which affects the processes more drastically when compared to other parameters. Hence this emphasizes the need for accurate measurement of wind velocity in order to forecast the evaporation & seepage losses correctly.

(c) In the present study, though the meteorological parameters are obtained from a far away meteorological centre and are therefore not fully representative of the reservoir site, yet the model gives reasonably accurate forecasts. However, this fact cannot be generalized before carrying out similar studies on other sites.

ACKNOWLEDGEMENTS

This paper is a part of the research work funded by the Department of Science and Technology (DST), Government of India. The authors wish to acknowledge the financial support rendered by the DST.

REFERENCES

Babovic, V. and Keijzer, M. (2000). "Rainfall runoff modeling based on genetic programming". *Nord Hydr* 33: 331–346.

Discipulus owner's manual. (1998). RML Technologies: Littleton, CO. (www.aimlearning.com)

Fritschen, L.J. (1966). "Energy balance method". *Proc. of American Society of Agricultural Engineers Conference on Evapo-transpiration and its role in Water Resources Management*, Chicago, IL. St. Joseph, MI.: 34–37.

Guitjens, J.C. (1982). "Models of alfalfa yield and evapotranspiration". *J of Irri and Drain Div*, 108(3): 212–222.

Harbeck, G.E. (1962). "A Practical Field Technique for Measuring Reservoir Evaporation Utilizing Mass-transfer Theory", *U.S. Geological Survey*, Paper 272-E: 101–105.

Hugo, A.L. 2002. "Reservoir Design and Operation with Variable Lake Hydrology". *J. Water Res Plng and Mgt*, 128(6): 399–405.

Khu, S.T., Liong, S.-Y., Babovic, V., Madsen, H. and Muttil, N. (2001). "Genetic programming and its application in real-time runoff forecasting". *J Am War Res Asso* 37:439–451.

Kohler, M.A., Nordenson, T.J. and Fox, W.E. (1955). "Evaporation from pans and lakes". *Weather Bureau Research Paper 38*. US Department of Commerce, Washington, D.C.

Koza, J.R. (1992). *Genetic Programming: On the Programming of Computers by Natural Selection*, Cambridge, MA.

Penman, H.L. (1948). "Natural evaporation from open water, bare soil and grass". *Proc. of the Royal Society of London. Series A*, Mathematical and Physical Sciences, 193(1032):120–145.

Sivapragasam, C. Vincent and Vasudevan, G. (2007). "GP Model for Forecast of Short and Noisy Data," *Hydrol. Proc. J.* 21(2): 266–272.

Sudheer, K.P., Gosain, A.K., MohanaRangan, D., Saheb, S.M. (2002). "Modeling evaporation using an artificial neural network algorithm". *J of Hydro Proc.*16:3189–3202.