A CASE STUDY OF HYDROMETRIC VARIABLES IN THE LAKES OF DRIN CASCADE, ALBANIA

SAFET SULA, DODË PRENGA

Faculty of Natural Sciences, University of Tirana, Tirana, Albania

e-mail: safetsula@yahoo.com

Abstract

In this work we analyzed some properties of the hydrometric quantities in the Drin HPP system, Albania. Firstly we examined the presence of the critical events and complex behavior by checking the log-periodic signature and fractal structure in the time data series of some key variable of the system. Their presence has been associated with the complex interaction between a number of hydrologic and operational or management factors. We indentified the presence of local trends or the persistence of the changes of the values, and the time for regime change including high magnitude of the move. We used neural network techniques to predict smoother behavior of some response variables e.g., the level of the water, by simulation scenarios of the predictors as discharges from the feeding lake. This procedure was conclusive to predict plausible scenarios in the sense of smoothening of the awkward self-organization regimes. Following this procedure, by using a 20 year daily side inflows series, we realized acceptable few month-periods forecasting for the inflows averaged in 5 days. This analysis can be helpful for the improvement of the water and processes management on the cascade.

Key words: Hydrometric, neural network, complexity, multifractal.

Abstrakt

Në këtë punim kemi konsideruar disa veti të madhësive karakteristike hidrometrike në sistemin e kaskadës së hidrocentraleve të lumit Drin. Fillimisht këtu analizohet prezenca e ngjarjeve kritike dhe sjelljeve komplekse duke shqyrtuar praninë e trendit log-periodik dhe strukturën multifraktele të serive kohore, të vlerave për disa madhësi kryesore të sistemit. Kështu kemi identifikuar praninë karakterizuese të shtesave njëkahëshe që dëshmojne trende lokale pasuar me kërcime te forta, si dhe çastet kohore të ndryshimeve për regjimet lokale të trendeve. Prania e këtyre dinamikave është lidhur me natyrën komplekse të bashkëveprimit të faktorëve hidrologikë dhe atyre të shfrytëzimit operacional. Më tej kemi përdorur teknikën e rrjeteve neurale për të realizuar simulimin e ecurive më të buta të disa madhësive që rezultojnë përgjigje si psh: niveli i ujit në digë, nëpërmjet simulimit të skenarëve oportunë të shkarkimeve nga liqeni paraardhës. Ky modelim është gjetur i përshtatshëm në evidentimin e sjelljeve të papëlqyera sikurse janë oshilimet e forta log-periodike. Me të njejtën metodë, duke shfrytëzuar të dhënat 20 vjeçare të prurjeve ditore ujore në kaskade, është realizuar një parashkimi i pranueshëm i prurjeve mesatare 5-ditore për një periudhë mbi një mujore.

Fjalëkyçe: Hidrometrik, rrjete neural, sisteme kompleks, multi-fraktal.

Introduction

The hydrological system of the artificial lakes in the cascade of the Drin River (Albania) is specific regarding its hydrometric profiles and operational management particularities. Note that its three HPP's provide about 93% of the electricity produced in the country according to the official reports see (www.akbn.gov.al or www.kesh.al). Precaution on the management of the waters on those plants has been substantially and constantly important for the management bodies. Three of the plants respectively Vau I Dejes HPP (with an installed capacity of 250 MW), Fierza HPP Plant (with an installed capacity of 500 MW) and Koman HPP (with an installed capacity of 600 MW) have been constructed to operate as single system. Their working regimes have been strictly stipulated by the rigid norms fixed in the Regulations adopted at 1982 by an official authority involving scientists and engineers. However, the management the system of the HPP remains a complicated problem bringing time to time unknowns to be challenged. In (Meon, 2013) it has been underlined that the rapid hydrodynamics of the specific watershed area impose special attention in terms of each HPP's monitoring and operation. In normal conditions, the operational regime is regulated by the balances of the production needs and strategic energy reserve requirements, whereas in extraordinary hydrological conditions, the constraints previewed in system Regulation are obligatory to be followed. So, if extraordinary floods would occur, the discharge system would be inevitably activated despite the costs of considerable flooding in the lowlands of Shkodra and Lezha. Another problem related to this system is the management of the balance between the power production and water reserve. Clearly that prediction and forecasting is very important management activities and a standard starting point in this case is the descriptive analysis based on the distributions for the hydrometric data. In practice, the mostly used pdf functions are Gumbel, Weibull, lognormal as in the case water flows in rivers, Gumbel for rainfall in some zones (Bowers et al, 2012) etc. Therefore, the analysis should reconsider the distribution (pdf) of real hydrometric data. In (Sula, 2016) we have obtained that the distribution describing the side inflows has mostly a q-Gaussian form which has been proposed in (Tsallis, 2009) for various real systems. Next, the anxious dynamics of a specific quantities could be analyzed using the methodology proposed in (Sornette, 2001) for other stochastic systems, whereas the interior dynamics of the system could be analyzed using complexity approaches and fractal structure as detailed in (Pavlos, 2019) or in (Umarov, 2010) etc.

1. Signatures of critical events and multifractal properties in some hydrometric data of Lakes of Drin River

In this paragraph we considered some basic elements of the nonlinear dynamics to acknowledge the nature of dominant processes that characterize the evolution of variables. In this framework we analyzed the multifractal spectrum, the self-organization properties and the evidence of extreme behavior tendency for the water level of the water and side inflows. From an informal communication with specialists of the HPP we have learned that the discharges and inflows data series have not been taken from hydrometric measurement but they were calculated using an empirical formula employing the level of the water. Therefore the study of this variable is estimated as unnecessary in principle. However, in the case of Koman Lake, the side inflows include discharges from the Fierza Lake, and therefore they contain valuable information for the interaction between parts of the whole hydrological system of the cascade.

The water supply for Koman Lake consists in the side inflows and Fierza discharges. Next, it feed waters at the end-HPP chain of Vau i Dejes Lake. Therefore, this part of the hydrological system of Drin cascade is very important and plays an additional regulatory role of the water fluxes. During normal operational activities of the HPP units, the system is projected to balance all the fluxes and the end point of the chain does not suffer excess of the water flows, nor abnormal events in the production process occurs. From the other side, if hydrological extreme effects are present, the Regulation has stipulated various scenarios including huge discharges to prevent the collapse of the HPP-system. In this case, the follow-up of the rigid procedures of the Regulation may fail in some moments, premature or delayed discharges might be operated during the management process, and therefore the time series of the height of the water, inflows and discharges become typical nonlinear dynamical system. Now, the study of the properties and features of such systems has a particular importance.

1. 1. Multifractal structure of the side inflows in Koman during the intensive rainfall period at 2011

Herein we considered the measured side inflows in the lake of Koman recorded each hour in the period January-June 2011 which includes an intensive rainfall period at January - February. Firstly we performed a descriptive check of the fractal structure of the sub-series based on 1 hour, 3 hour and 6 hour averaged side inflows. In the mono-fractal we obtained that the Hurst exponent for those series fall in the range [0.6-0.8]. For the original series of the hourly inflows we observed a remarkable smoothness shatter in the multifractal spectrum at the minimal value of the zeros of singularity dimension. Therefore they are not suitable for multi-fractal analysis study. The two other series exhibit a clear multifractal behavior, as seen in the monotonic shape of the function of the q-order Hurst versus auxiliary q parameter in the MDFDA procedure provided by the algorithm in (Ihlen, 2012). As a result, the self-affinity and other resemblance and trending aspect can be analyzed for those secondary series. It says that the hourly timing is thinnest than natural behavior of the processes which contribute to the side inflows, whereas the timing measurement procedure based on averaging inflows in 3-hour is more natural. From the analytic perspective we concluded that the hourly records are too noisy and the next step analysis is effectuated for the 3 hour or more averaged data.

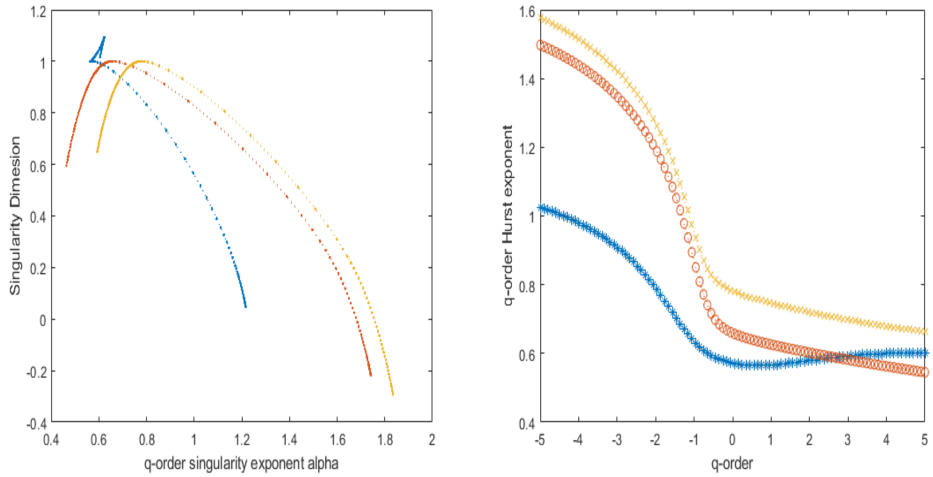

Figure 1. Q-order Hurst exponent in the multifractal analysis. Monotonicity in the curves (q-H,q) testify the multifractality in the structure

In this case we obtained that the Hurst exponent is about 0.8 which indicates the persistence behavior and hence, the presence of the trend on the time data series, fallowing the ideas elaborated in (Pavlos, 2019). The origin of this trend could be related to the purposed activities by the engineering of the operational processes, but inadequacy on employing management procedures could be considered as well. The observed trend is not stationary and it seems that the system exhibited self-organization behaviors which are surely not preferred ones. By interpreting the observed persistence and Hurst–exponent value, we expect that an instantly increase on the inflow is likely to be followed by another increase and a decrease would probably be succeeded by another decrease. This behavior might indicate the presence of local extreme events and anxious regime in an adapted econometric parlance. Its presence indicates an abnormal regime and therefore a disputable efficiency of operational activities. This last might have the origin in the shortcoming of the employing the rigid rules provided in the Regulation, or this last should be amended.

1. 2. Anxious signature of the water level in the Koman dam during intensive rainfall at 2011

Within our best knowledge, the water level is the most scrutinized variable in the HPP management. Following the above mentioned indications we explored the log-periodic signature (LPP) in this variable to analyze the presence of the discrete scale of invariance (DSI) property, which consists in a particular case of multifractal structure, see (Sornette, 2001). The DSI property leads to the self-organization dynamics that characterizes the extreme events and phase (regime) change phenomena similarly to the phase transitions in magnetic according to (Sornete, 2009). In this reference, the log-periodic function has been proposed in the form

$$y = y_0 + (x - x_c)^m (A + B cos\omega \log(x - x_c) + \varphi) \quad (1)$$

where x_c represents the critical (singularity) point, ω is cyclic frequency in logarithmic time domain, φ is the initial phase and y_0, A, B are constants of the model. In our case the variable (x) signifies the time (t) whereas $x_c \equiv t_c$ represents the critical time which is the time instant when the regime change is most likely to occur. Considering the case where DSI structure is not dominant, in (Prenga & Ifti, 2016) has been proposed an approximate form for (1) by applying q- logarithm $\log_q x = \frac{x^{1-q}-1}{1-q}$ and hence the weak DSI properties or near to self-organization behavior could be expressed by the following form

$$y = y_0 + (t - t_c)^m (A + B cos\left(\omega \left(\frac{(t-t_c)^{1-q}-1}{1-q}\right) + \varphi\right)) \quad (2)$$

So, by using (1) and (2) , we observed that the height of the water level or the maximal water load in the lake, seems to has have followed an near to anxious dynamics in the period studied, Figure 2. The fitting procedure has been performed by using an ad-hoc genetic algorithm we made purposely. For the sake of clearness to the readers, we noticed that standard regressions techniques don't work in the fitting of functions of the type (1) or (2) due to their highly nonlinear form. The ad hoc genetic algorithm and evaluation procedures for some practical systems have been described in (Prenga, 2013) and references therein, so we are not going in details here.

We identified a good fit of water level data series to the (q) log-periodic form (2) with the q values estimated at q~1.01 which signifies the weak LPP presence on the data series. The complex nature of the interaction between all the factors is expected to avoid a proper LPP behavior and the extreme events were avoided as result of the regulated control of the water level, but the LPP presence suggest that the system itself engages continuously in the dangerous self-organization behavior. It is the result of the stochastic resonances between side inflows, discharge from Fierza Lake and outflows during the operational processes of the Koman HPP itself. In the best scenarios we can say that the management of the water masses has departed from the optimal performance. We remarked that the critical time has been estimated around 1320 hours after the starting time, which fall outside the analyzed intervals and practically has resulted in a regime change, so the all interval is assumed to have suffered highly nonlinear dynamics with DSI presence.

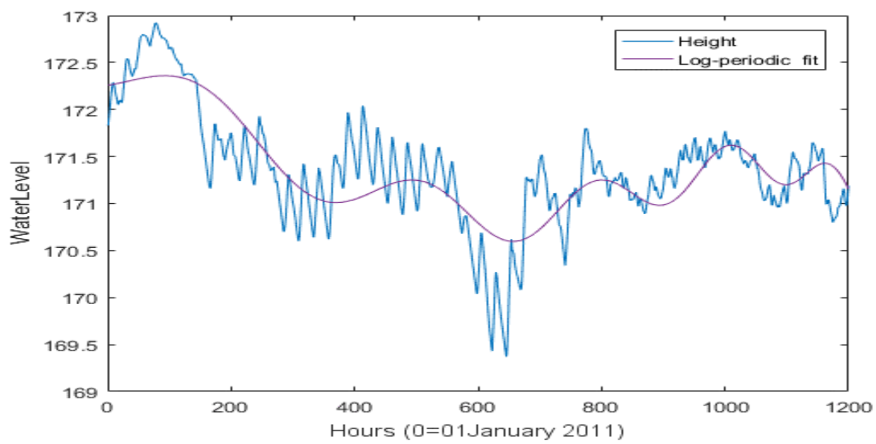

Figure 2. Time graph of water level in Koman, 01.01.2011-09.02.2011

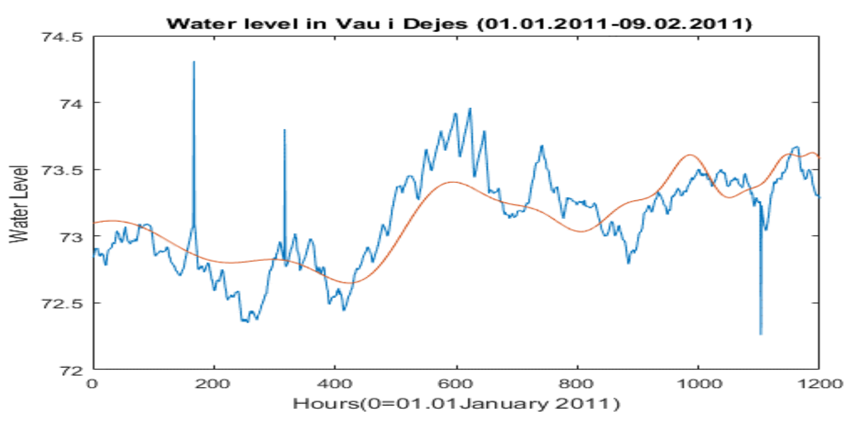

Figure 3. Anxious regime in the trend of the water quotes, Lake of Vau I Dejes

Similarly, we observed that the water level in the Lake of Vau i Dejes has fitted well with a log-periodic shape. Again an anxious management could be responsible for such behavior and the efficiency of this procedure was not optimized. Note that the term 'management' herein includes all operations that produce a given output. In this case, the level of the water has a strong component related to the total waters discharges. As result, the subsequent part of the Drin River has been feed with waters with highly nonlinear behavior including self-organization dynamics. Simply said, the flooding were characterized by dangerous water waving that affected the lowlands directly and indirectly.

2. Prediction and forecasting by usingneural network models

The forecasting for the behavior of stochastic process is highly plausible, but at the same time it is difficult even in the sense of the predations of the probabilities for given occurrence. In such cases, a very intriguing computation method named Neural Network Model (NN) gives very good results. There is a large literature, schoolbooks and case study or application of NN see (Bose N.K, 1996) or (Adeli, 1999), (Khashei, 2010) etc. Briefly speaking, in the neural network algorithm, the system of quantities $\{x_i\}$ is supposed to affect the responses {y} by the intermediacy of a transfer function that mimic the activation of the reaction in vivid organisms. The formal equation is

$$y = f(wx + b) \tag{3}$$

where y is the outcome or response quantity, {x} are the cause variables , w represents the weight for each one, b is the bias and f is the transfer function. The form (3) can be considered as a step and therefore the algorithms employs them as layers and more complicated but more effective forms are proposed for NN applications. For some cases, in the role of x would be use the shortened series of recent {y} values and the model can be used in predicating future values. Very fruitful information about NN can be found in the tutorials of Python Lisrel, Matlab etc which include dedicated tools for such techniques. Now, going back to the remarks of above analysis, we pinpointed that shortcoming on the efficiency of the water management might have been mostly as result of low forecasting capability conditioned from the methodic used, rigidity of the regulations and other additional or unknown factors. In the following we explore the capacities of NN method in improving such an important process.

2.2. Exploring the predictor-response relationship and regime improvement

Supposing that a smother dynamics would be plausible scenarios in the sense of the improvement of the multidimensional and all purpose system management, we employed those findings to empower the prediction capacity. So, for a better scenario in the water level realization, we proposed to model and search for appropriate hypothesized set of predictor parameters by using neural network modeling. Firstly, we used NN in the forecasting of the behavior of the key variable analyzed above, the water level in the lake of Koman HPP. In the model (3) we have considered $x = \{Side\, Inflows,\ inFlows\, , outflows\}$.

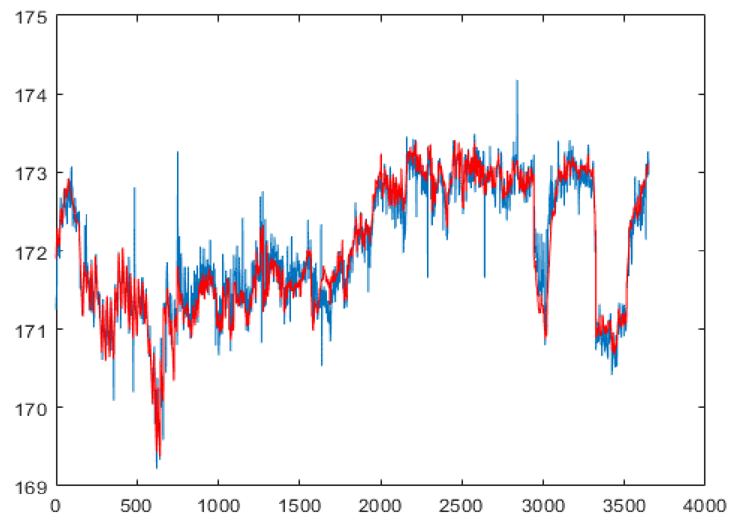

Figure 1. Reproduction of the maximal quotes as function of some input variables)

In the first step we searched for the best NN, say the one that reproduce the data within an admissible small error. Searching for improved reproduction we have checked different time window (intervals) series, too. Afterwards, we simulate a hypothesized response by the modifying the discharges from the Lake (Fierza) aiming in obtaining an output (h_{new}) which does not suffer the anxious behavior. Note that the Lake of Fierza plays a regulator role for all the HPP-chain of the cascade. In general, we obtained a good reproduction of the data for the series of the time intervals not including very large changes in the successive values e.g., not in vicinity of the local extreme events, Figure 3. We observed that small modification of the input parameters resulted in considerable deviances in the response.

A possible reason for this outcome is supposed to the non-stationary of the states for the variables used in NN simulation as factors. A better realization may need more independent data and additional technique in appointing the input data values for the variables considered. However, we managed to produce a better realization of the water level than the one meet in the real series. It exhibits lower amplitudes and do have a weaker LPP property, Figure 4. The series used hereto as hypothesized discharges from the Fierza Lake have been chosen without considering the constraints of the Regulation, nor based on operational requirements, and therefore they are typically nonrealistic, but in principle the idea worked and can be worked out for potential application

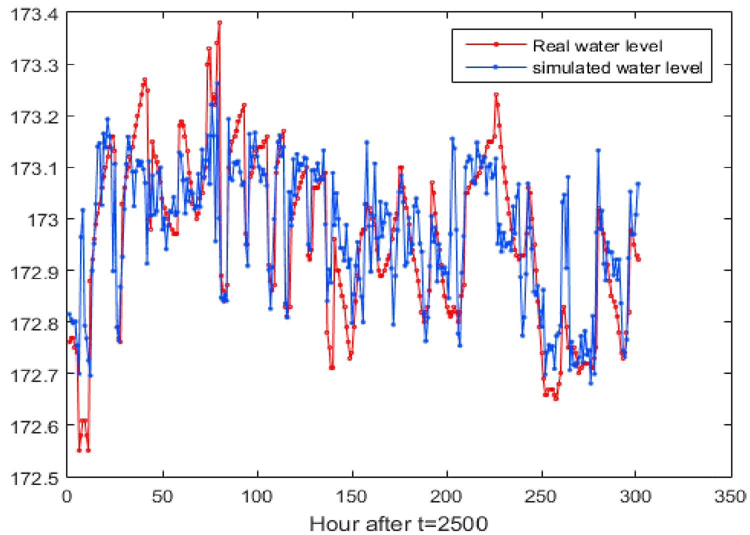

Figure 2. Prediction of the water level by changing the discharges from Fierza

2.3. Time data series prediction and forecasting

In this paragraph we considered the problem of forecasting and prediction for some quantities of high relevance. In this case we considered the daily side inflows in the Koman Lake for a 20-year period and proposed to use NN models to forecast it. Following the remarks addressed in (Prenga, 2013), we hunted for the stationary states to ascertain a meaningful measurement of the quantity and thereafter to try for prediction about its future values. We expect that highly non-stationary state would are more difficult to be explored by the learning process on the neural network procedure, and therefore output data from the model would are likely to be non reliable.

In this step, we assumed that the stationary of the state would be reflected in the stationary of the distribution of the quantity under examination. Therefore we investigated this property subseries produced by averaging the inflows of original sere in various time intervals. To realize the analysis of the stationary for the pdf obtained so far, we employed the q-Gaussians properties according to the theoretical analysis given in (Tsallis, 1999), Umarov (2010) etc. Note that q-Gaussian distribution is a t-localized and scaled distribution, and is stationary for q <5/3. So far, we obtained that the histogram of the original series (daily side inflows) has fitted to a q-Gaussian with q>2. According (Umarov, 2010), the mean and the variance are not defined in those distributions and so the series itself is not appropriate to be used for the next step.

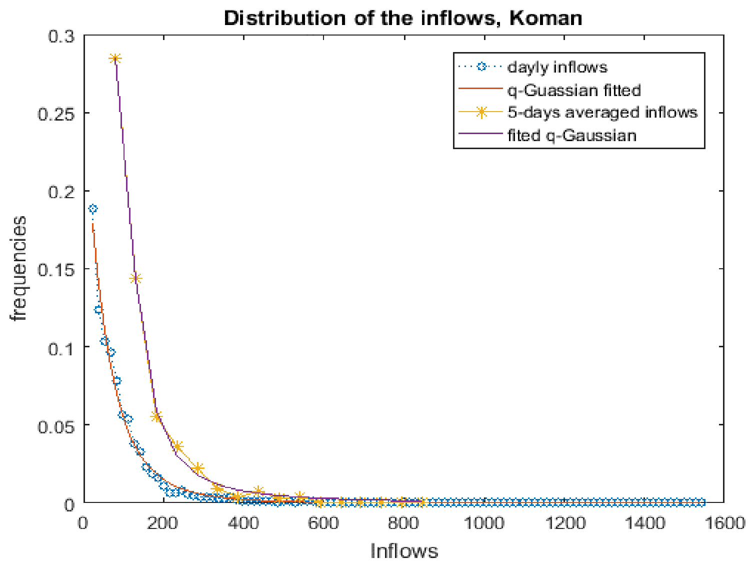

Figure 4. Distribution of the inflows in feeding the lake of Koman

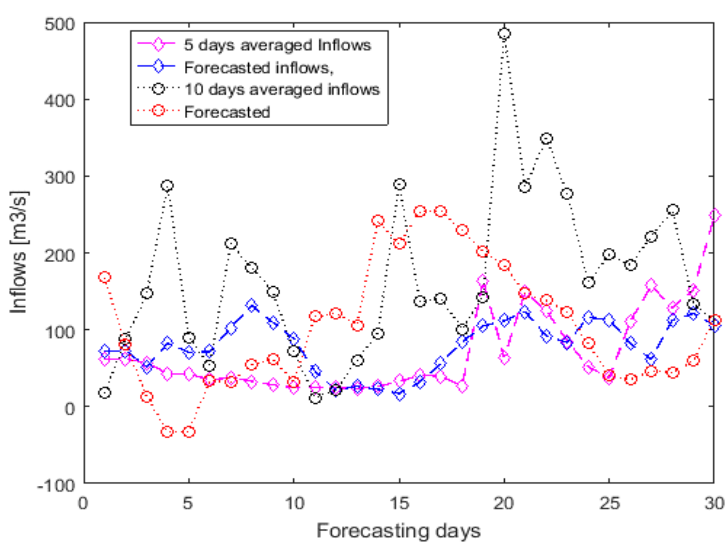

Figure 5. Forecasting scenarios

Next, by employing the series of more than 3 days averages of the inflows, the distribution becomes more stable and we used next the averaging interval for 5 and 10 days. Once the stationary series has been identified, see Figure 3, we followed the forecasting step by employing NN time series forecast. So, we constructed variables {X} by successively displacing the starting and ending time by one unit using Lag=120 and then we run the neural network to produce the responses. Next, by using this trained network we forecasted the values for 30-incoming periods. To compare the results, we have cut our series by this quantity so $h \rightarrow h(1, t-30)$ and the series to be checked here are $h_{real}(end-30: end)$; $h_{claculated}(end-30: end)$.

The optimization of the histogram was realized by Fredman-Djaconic optimal bin size technique. Finally we have proceeded by the NN time series forecasting. The prediction for 5 days averaged inflows has been found at sufficiently good level of accuracy, and therefore the method can be used successfully to manage the water in the lake and to improve operational regimes as well, Figure 4. We observed empirically that in the forecasting reliability and quality can be improved by using larger data set and by avoiding calculation for the time intervals hosting extreme events and intensive dynamics.

Conclusions

In this work we have analyzed some aspects of the dynamics for the side inflows and the level of the water in two HPP of the Drin hydro-system. We considered three foremost dynamical properties: the extreme events presence by checking log-periodic precursor signature (LPP), the overall trend and persistence by analyzing multi-fractal structure of the data series, and the forecasting ability by using neural network techniques. All checked series were found nonlinear in their time behavior, and apparently difficult to be used in deterministic modeling. In particular, the distributions of the frequencies of hourly and daily side inflows values were found usually no stationary, so their means and deviances could not be assessed in statistical sense. In those conditions, there is little chance of realization of reliable forecasting for those quantities or performing qualitative assessment using empirical modeling. Complexity features should be employed in modeling and forecasting.

Next, by analyzing the multi-fractal structure we obtained that the series are usually persistent which indicates the presence of the local trend succeeded by strong changes. This behavior signifies the departure of the system from the smooth dynamics and therefore the management for those variables has not been effortless form the efficiency of water use, the production and the security point of views. Specifically we obtained that the quotes of the water level in Koman and Vau i Dejes lakes during heavy rainfall period have suffered complex behavior quite similar with the anxious dynamics. We observed that this self-organization trend- nearly log-periodic but missing the critical final stage- has been destroyed periodically, supposedly from the controlled activities based on the Normative Regulation rules. Searching for a smother dynamics in water level, we observed that the modifying of the discharges from the feeding lake (Fierza) was productive. In this case, good results were obtained when using the cut series far from the anxious regimes. For practical achievement and possible Regulation amendment in those terms, more data are needed and the model itself should be improved.

Finally we considered a desired effort in all stochastic events, forecasting of the hydrometric quantities. So far, we obtained good results in the forecasting of the inflows by using averaged in five days inflows and considering the 20 year long daily inflows data. The range of acceptable prediction is obtained for more than one month period, which can be set longer if more data are in disposal for elaboration. Those findings can be recommended in methodical aspect to be considered in the framework of the overall management of the operations for the system of the HPP in the Drin Cascade. Aiming in developing strategies to improve water management, we suggested thereby a deep analytical reading of the hydrometric data based on the straightforward statistical methodology.

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