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Analysis of distributions and dynamics for water side inflows in the Drin River basin, Albania

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***Abstract*—The analysis of q-distributions, multi-fractal power spectrum and discrete scale of the invariance are combined in the study of the side inflows in artificial lakes of the Drin River,Albania. Here, for the daily averaged inflows we obtain that q-Gaussians fitted to the empiric distribution offer more information than any other probability density functions and parts of this system exhibit specific dynamics. Under q-statistics consideration, we find that the distribution based on daily records for a period of 25 years is practically unstable, with variance and mean indefinite. In other side, the series of averaged inflow over few successive days, or series belonging to the same months seems to be driven from a stable distribution with variance and mean definite. The multi fractal power spectrum analysis is found useful in the identification of a stable process of measurements, as it represent a smooth curve in the case of stable distribution according to Tsallis statistics, and a not continuous curve otherwise. Next, considering the dynamics of the inflows during intensive rain period as in 2011, we identify traces of log periodicity, indicating possible self-organization behavior, and hence a discrete scale of invariance behaviour. Nevertheless, clear regimes of this type were not found and again the log periodic pattern is more highlighted if data were averaged over few successive points. We conclude in this case that the daily inflows are highly perturbed and therefore the references will be done in few days averaged instead, or even better with series of the same month. As there is nothing special in our system studied, we hope those finding to be true for other system of such type and therefore specific methods of complex systems analysis could be very helpful for better understanding such behavior, and to improve the methodology of measurement therein.**

***Index Terms*—Hydrologic system, q-Gaussians, multi fractals, log periodic**

I. INTRODUCTION

The study of hydrological phenomena and processes governing their dynamics has attracted the attention of researchers in scientific and engineering aspects. There is a common agreement that distributions of the values of observables in such systems are typically lognormal or sometimes weibull [1]. Manny studies argue that hydrologic data behave as complex systems [2], and therefore more information could be read under such consideration. Consequently, the distributions on such systems were considered under Tsallis statistics [3] like many other similar systems. We provided recently such a view for some similar cases in Albanian environment [16-18]. Really, complexity consideration for hydrological systems dates long ago before this name became popular, starting the pioneering works on self-similar and fractal structures by British hydrologist Hurst. Accordingly and extending similar consideration, we will consider here elements of complex system methods on the study of the water side inflows in lakes of Drin River and its floods flows. If it is considered just as a particular hydrologic system, it seems to be nothing special, but as we will brief here, it consist to an important economic area and hence, dealing improvements of the analysis matters. There are three hydropower plants (HPP) constructed on this river, and the lowlands surrounding the ending stage of the river immediately next to the last dam(Vau i Dejes), suffer time to time from flooding, mainly caused by forced discharge of waters . In another view it will be a case study for typically similar such systems around the world, where complex system methods will help to better understand and analyze historic data gathered on a limited period, or based on standard paradigms. Let introduce very briefly our system under investigation. Drin river is 285 km long and has the full average flow of 320m^3/s. Its branches seize 5.187 km^2 of area and the ratio max/min of water flow is around 5.2. It provides the third greatest water discharge in the European Mediterranean [4]. Three artificial lakes were constructed on the river: Fierza dam is the entry gate, next is the lake of Koman and the last one (and the oldest one) is on Vau i Dejes, near to the city of Shkodra.

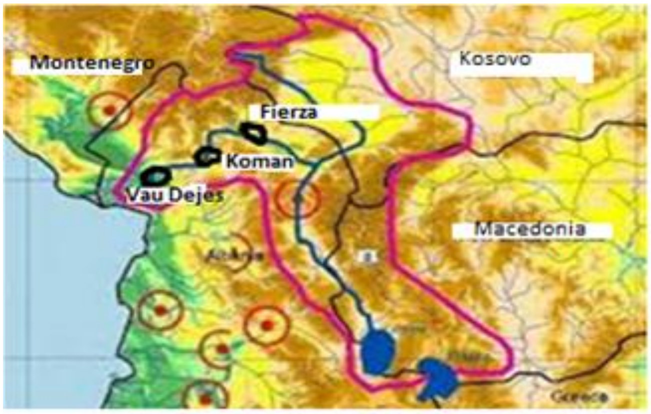

Fig1. Basin of Drin River and three dams

The Lake of Fierza is the regulator of the cascade and it gathers waters from a large area belonging to Kosovo, Macedonia and Albania. A part of its water inflow is conditioned from the management of the input doors from Ohrid Lake which is under Macedonian authority. The lake of Koman is the middle point and has the complementary role of the regulatory switch. The waters reaching this lake flow from Albanian Alps. The next dam is in the Vau Dejes and is the door of flood to the lowland of Shkodra. Electricity production is strongly conditioned to the water discharge limit to the lowland and water inflows in the basins so the

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management and operational regimes are strictly regulated. The inflows from rainfall and snowfall on the area are coupled with terrain specifics, imposing unpredictable modification on side and natural water inflow. Therefore a dynamic view of the system is plausible and the possible improvement on descriptive statistics should be considered. Next, the multi fractal analysis is largely included in the study of hydrological studies [11],[12] whereas for similar systems is reported the presence discrete scale of invariance behavior [9]. Partially this basin has been considered recently [17,18], and we will reconsider it in an integral view, including the management aspect during extreme behavior on the system. Here we analyze each lake separately so we will consider the side water inflows. We use the data gathered form routine measurement in the period of 25 year for Koman and Vau i Dejes lake, and 10 years for Fierza. They consist on daily average inflows (in m3/s), another data series analyzed herein belong to hourly inflows during an intensive flood period at 2011.

II. Q-DISTRIBUTIONS, MULTIFRACTAL POWER SPECTRUM AND LOGPERIODICITY IN COMPLEX SYSTEMS.

Considering the complexity of hydrological system, the problem of identification of the probability distribution is more than a routine calculation. Under statistical view, different probability density functions were studied and reported in such cases [9], but usually lognormal shape has been largely accepted. We emphasize that in physical point of view the distribution is identified with the macrostate of the system under study, which result from the entropy optimization under specified constraints. We remark that in practical measurement for real systems, there is no big effort paid to the elaboration of data to find the distribution they belong to. Physically speaking the effect of fluctuation or even not appropriate timing selection during the process of the data recording, could affect remarkably the overall measurement. Hence different processes could interfere in distribution estimate, and therefore complexity methods are expected to help in that. Under a pure mathematical view according to the limit theorems as Central Limit Theorem, the distribution behaves as attractor of the dynamics. For example in chaotic systems this attractor should be a Gaussian if the mean and the variance of random variable are known [8] and if the assumption of no correlation between variables is fixed. To describe systems with correlation present, C.Tsallis proposed the q-independence concept which leads to the Tsallis entropy. For the union $A \cup B$ two particular q-independent events one states $S^T_{A\cup B} = S^T_A + S^T_B + (1-q)^T_A * S^T_B$ wherefrom the entropy of the system $S^T_q = \frac{1}{q-1}\left[1-\sum_{i=1}^{w} p_i^q\right]$ [19]. By optimization of such entropy, if the system under consideration has the mean of a observable x finite, the distribution will result in a q-Gibs function namely $p(x) = \alpha\{1-\beta(1-q)(x-\mu)\}^{\frac{1}{1-q}}$ and if variance is finite, the distribution is a q-Gaussian in the form $p(x) = \alpha\{1-\beta(1-q)(x-\mu)^2\}^{\frac{1}{1-q}}$ [8]. The q-exponential functions were introduced in the general forms $e_q(x) = [1+(1-q)x]_+^{\frac{1}{1-q}}$ where subscript (+) means $[x]_+ = 0, x \geq 0$ and zero otherwise. Q-exponentials behave typically as power law in the large limit, that make them interesting in characterizing complex system where power law distributions are so common. There are plenty of literature reviews on q-functions and q-algebras [8] whereof many other specifics of complex systems are analyzed. Specifically, in the case of correlated variables, a q-homologue of the Central Limit Theorem is acknowledged [8] and proofed. Thereof, under q-statistics assumptions, the attractor of the dynamics should be a q-function, which solidifies the Tsallis renormalizing theory. Again from the statistical mechanics one can speak for q-properties of the processes decorating or governing systems in a specific state. Accordingly q-additive and q-multiplicative processes were considered as generator of q-Gaussian and q-lognormal distributions [20]. In the concrete analysis we will use Tsallis arguments because of their powerful ability to describe dynamics and statistics specifics as we recently used [18]. In this case we will focus ourselves in a comparative view of each system and some statistical aspects related to them. Remember that Tsallis analysis includes many q-parameters, but generally a triplet is significantly more important [7]. This triplet consists in the sensitivity (q_{sens}), relaxation (q_{relax}) and the stationary q_{stac} parameter. The sensitivity parameter is found using relationship $\frac{1}{1-q_{sensitive}} = \frac{1}{\alpha_{\min}} - \frac{1}{\alpha_{\max}}$ where $\alpha_{\min,\max}$ are the singularity point of the fractal power spectrum function of the structure [7]. The relaxation q-parameter estimates the relaxation rate of the observables and generally is calculated from the q-exponential fitted to the time autocorrelation function of the series. Adding to this, the fractal behavior is important information in our study too because it measure a very important characteristics of complex behavior, scaling property. Multi-fractal property consists in the local power law behavior say $X(n+a) - X(n) \sim a^{h(n)}$ where h(x) is called the singularity exponent. The ensembles of points having the same h exponent produce the fractal dimension D(h), that identify the (logarithmic) ratio of the change in the detail to the change in the scale, related to the hierarchy relationship. Another characteristic parameter of scaling is the multi fractal spectrum $f(\alpha)$ that measures the density of the local similarity in scaling $\rho_\alpha(\varepsilon) = a^{-f(\varepsilon)}$ where ε is a local size [12], [13]. Another important property in complex systems is the discrete scaling say $F(\lambda x) = \lambda^\alpha F(x)$ for some discrete value of λ. The time behavior in this case is theoretically predicated a log periodic function $I = I_0 + a * x^m + bx^m \cos[o\log(x)+\varphi] + cx^m \cos[2o\log(x)+\varphi]$ [9]. Interesting relationships between those parameters are predicted theoretically and tested in real systems. In the spirit of Sornnete idea [9] and based on our recent findings in [16] and [18] we consider the management of the water level during a heavy raining period to check possible presence of the discrete scale invariance that will be considered as result of the resultant anxious activity to keep dams safe under forced huge discharges.

III. USING Q-DISTRIBUTIONS AND MULTIFRACTAL POWER SPECTRUM IN THE STUDY OF SIDE INFLOWS ON THE LAKES OF DRIN RIVER.

Recently we've considered the distributions of the water inflows of Fierza [17] and Koman [18] lakes in the framework of Tsallis analysis. Here we reconsider such systems analyzing the concrete relationship of the multi-fractal structure and characteristic distributions. All those two elements will be affected form the preliminary step of pdf identification, the grouping procedure into bins. Sometimes this step might have been passed silently, but we stop in it first, trying an appropriate histogram optimization.

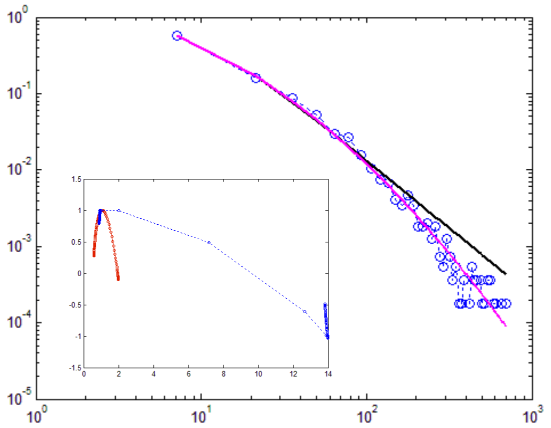

Fig1. Lognormal (magenta) and q-Gaussian (black) distribution, Inflows in Vau Dejes Lake (logarithmic axis). Small picture, the multi fractal power spectrum for original data (blue) and 3 day averaged (red)

To better estimate the specifics of the distributions we use the ability of q-Gaussians to report the level of the instability of the overall state of the system; hence the bin width in histogram optimization could be improved. Remember that the optimization histogram is a necessary step to avoid fake distributions, and is based on the request of the moment invariance's, that is the moments could not be affected form this step. But if the variance is not definite (as in unstable distributions), the bins size could not be calculated using standard rules. This is just our (and perhaps most occurring)

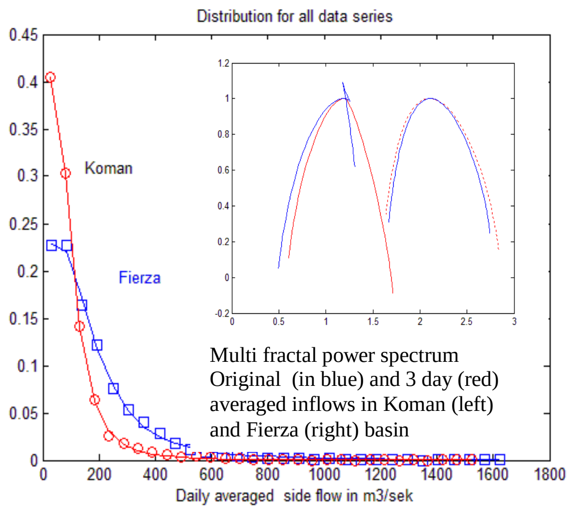

Fig2. Q-distributions : inflows of Fierza (red) and Koman (blue). Small panel the multiracial spectrum for 1 day (blue) and 3 day (red) averaged

case. We observe that different distribution fits better in different binning, so the multi-fractal power spectrum is considered to help in the analysis. In general, lognormal shapes are good distribution candidates, as expected, but q-Gaussians are less sensitive to the bin size. Elsewhere, the verification of chaotic multi-scale and multi-fractal dynamics underlying the time series observations is found of the high theoretical interest because the coupling of q-statistics with fractal dynamics [21]. We use those findings to discriminate between distributions in the sense of our analysis. In a very simplified figure, if the multi fractal spectrum shows a complicated curve, q-analysis will miss at least $q_{sensitive}$ and therefore will be incomplete. If the multi-fractal power spectrum looks smooth and is continuous, this scaling signifies a regular behavior and hence q-statistics is considered and elaborated. We obtain that the inflows to each basin seems to be drawn from different distribution, and

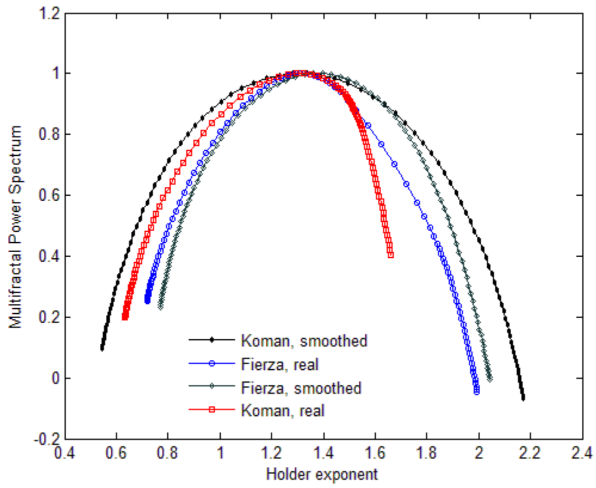

Fig3. Multi-fractal power spectrum correlated with "stability" of distributions.

so, from the statistical physics point of view they belongs to "different state" of system. The distribution for the inflows to the lake of Vau i Dejes for example is found to be mostly lognormal and the multi-fractal spectrum of daily inflows is the found a broken curves. Moreover this distribution is fitted better than q-Gaussian in a large bin size interval (Fig1). Averaging in 3 day interval, the multi-fractal structure is recovered and q-Gaussian fits as good as the lognormal. In the case of side inflows in Koman or Fierza, q-Gaussians shows the same goodness of fit with lognormal but they offer much more information as recently we've noticed [16], [18]. In the case of Vau i Dejes inflows, q_{stat} obtained from the q-Gaussian fitted to the empiric distribution is ~2.3 that correspond to a very instable state, with variance and mean indefinite. We relate this finding with stochastic accumulation of fluctuation in such way that the multiplicative nature is dominant, and therefore lognormal shape could be considered. It is worth to add here that the surroundings of this lake where the water came from belong to naked terrain and not large area. But if we consider the average inflows for more than 2 days, the fitting of the q-Gaussian became very good. For the two other lakes of the cascade the daily side inflows belong to the population that exhibit q-Gaussian distribution (fig2). In the case of Fierza, the distribution of the daily averaged side inflows from 1991 to 2014 is fitted very well with a q-Gaussian function The Tsallis triplet herein is obtained at [0.1483 1.9639 3.0476]. As the value of the $q_{stat}$is found higher than 5/3 we can say that the state of the system is far from the stationary one and the mean variance of inflows are indefinite according to the Tsallis theory [6],[7]. Here, the multi fractal spectrum $f(\alpha)$ curve is concave and continuous (fig3) so the $q_{sensitive}$ parameter is evaluated with good accuracy using the formula invoking the singularities of $\alpha_{\min,\max} = \arg(f(\alpha) = 0)$. Last element of the triplet Tsallis, the q-relaxation parameter $q_{relaxion} = \arg(ACF = \exp_q(t)$ is evaluated with good accuracy because the autocorrelation function fits well to a q-exponential shape. Furthermore the triplet Tsallis obtained fulfills the theoretically expected interrelationship $q_{sensitive} < q_{stationary} < q_{relaxation}$. For the Lake of Koman we administered a similar but shorter data series of daily average inflow from 1998 to 201. Again we obtain a very good fit of a q-Gaussian shape to the empiric distribution. The triplet is obtained [0.1827 1.6385 2.7141], so the upper value again exceeds the limit of 5/3, but with a small quantity. We refer this state again as variance-indefinite, but being on the limit we hope that we can find appropriate measurement of the inflows that could belong to the mean and variance definite states. We admit that local fluctuation (temporal in the real series) impede the data series to fit on a stable distribution, hence we diminish this effect by grouping few successive data in the original series. Remember that inflows are reported in m3/s, so the averaging process is a routine, but silently neglected in data recording reports. So, for the averaged values over 3 successive days the triplet is found [0.3842 1.5947 2.2413] and the upper limit of boundary within 95% confidence do not exceeds the limit value of 1.667. In this case we classify those data as variance defined. The relationship between q-parameters $q_{sensitive} < q_{stationary} < q_{relaxation}$ is fulfilled. Therefore each of triplets will be interpreted as physical parameter according to Tsallis theory. So we see that the rate of the entropy production is moderate-high (0.38 in the case of the Koman inflows, whereas for Fierza it is moderate-low, 0.18). We identify them as indicator rate of change of the state in dynamical aspect. For 5 days averaging interval we observe that the relaxation function is not fitted well with a q-exponential so the corresponding q-parameter is not evaluated. The two others element of the triplet are found [0.1056 1.8907] in the case of Fierza and [0.5125 1.5786]

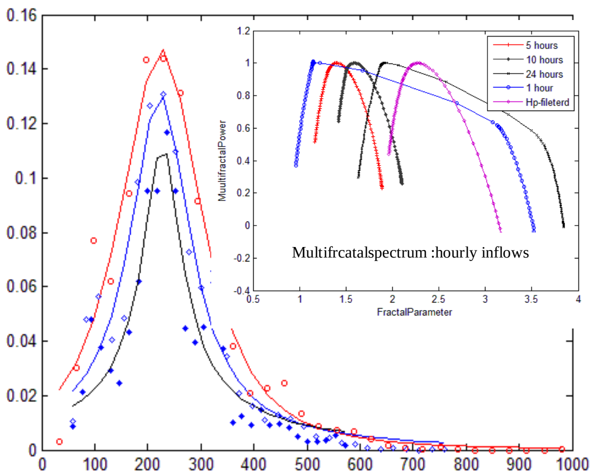

Fig4.Q-gaussians for hourly averaged inflows: in red, 1hour; in blue, 5 hours; in black, HP-filtered. For the intervals of averaging more than 5 hours and up to 10 hours, q-statistics is adequate

for Koman. We see that when the multifractal power spectrum is concave, hence under our assumption a q-statistical analysis is fruitful. Next we study the series of hourly averages of total inflows of Drin for the period January-July 2011. The triplet now is [0.2419 1.6944 8.9263] but the multifractal spectrum is not smoothly concave implying the $q_{sensitive}$ value to be evaluated to a distinguishable inaccuracy (fig4). We consider it again as indicator of remarkable effect of fluctuation that could be avoided if the averaging would be realized over some hours. Hence for five hour averaging interval the triplet is obtained at [-1.0395 2.0805 8.0930]. For the 10 hours interval the triplet is [-1.4902 2.1874 5.7096] and generally, smoothing data for 3 hours or more, gave similar results. We observe that the q-relaxation parameter diminishes as the average interval increases, but become less accurate, and when the averaging interval is more than 24 hours, the picture become noisy in the sense of multi-fractal spectrum. But this limit is unpractical in our series due to the small number of data points. Q-Gaussians are regularly well fitted with the distributions and the stationary indicator $q_{stationary}$ shows that the state of the system is far from stationary state. Therefore, to a better understanding of the behavior on those systems, a careful regrouping of the successive data has to be realized. It seems that the records based on empiric intervals interval may leads to an important loose of the information. Very short interval of averaging records for inflows, can cause the over partition of the series, and large intervals will result in cancelation of important information. Therefore, a more physical averaging time should be considered. It corresponds to the most stable distribution according to the q-statistics analysis. In other words, the measurement of the inflows for intervals less than a limit seems to be meaningless in this sense. In our case, a better choice corresponds to the averaging interval of few hours. It is clear that this finding is true only for the system under consideration, others requiring different averaging time interval, as we've reported recently [10]. Such conclusions are impossible to be deduced from other statistical consideration and hence the Tsallis statistics consist in a fruitful tool for those studies. Generally speaking, this methodology will help researchers and even engineers or other technicians to better describe and manage such systems. Another direct consequence is that the system must be considered in its dynamic aspect, because the stationary state where observables are well definite is not found in common. Particularly this will help for the management of the effects of the extreme events or periodic behavior, in the sense of preventing over simplifying such systems behaviour.

IV. ESTIMATION OF THE POSSIBLE DISCRETE SCALE OF THE INVARIANCE BY THE ANALYSIS OF THE LOG PERIODICITY PRESENCE IN THE TREND.

An intriguing aspect of complex system approaches consist in the effort to push the analyses in the quantitative domain for systems that are far from equilibrium and therefore, the observables could not be known with good accuracy. It is a routine therefore to combine different techniques, and we will elaborate somewhat in the following some application for our system in consideration. The estimation of the probability for extreme values can be improved using q-distributions, the problem of estimation of when this probability is maximal, requires a DSI analysis, according to the idea of Sornette et al [9]. Log periodic behavior is considered as an indicator of specific self-organization behavior. Hereby the possible extreme events occurrence on the near future or the probabilities of a regime change [10] can be estimated. It will be result of coupled mechanisms that cause a temporal entering to a self-origination regime, even not characteristic in long range term but locally it is possible to be true. We are not focusing our work on theoretical arguments rather direct an concrete finding, so the time evolution of the inflows are considered under an empiric DSI analysis. So far, we follow a standard calculation of those items that began with a careful examination of the series, identification of possible time interval of log

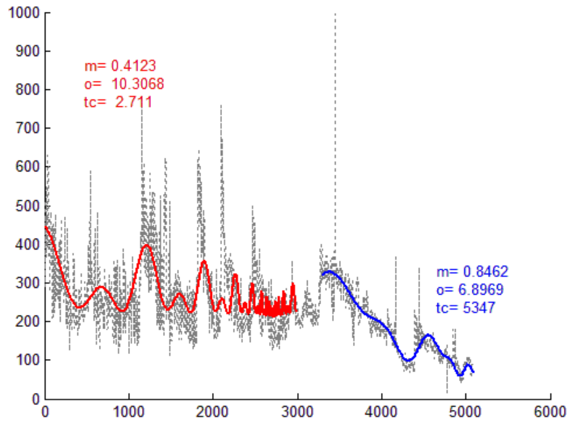

Fig5. Possible log-periodic trend on the hourly averaged inflows. In gray, real point, by hard lines, fitted curves

periodicity regime, and evaluation of a log periodic fit to the real time data evolution, that is the identification of solution vector [m o t_c f] in the equation presented in the introduction above. The algorithmic procedure of log-periodic fits is similar as described on reference [8] and is described in details our previews works for other systems. For the log periodic fitted shape the power exponent (m), angular frequency (o) and critical time (t_c) are considered and are displayed on the graph. Hence we limit the space of solution for exponent (m) in [0,1] making use of the arguments of Johansen-Ledoitte-Sornette (JLS) [10]. In the case of the angular frequency (o) we set empirically the search-domain

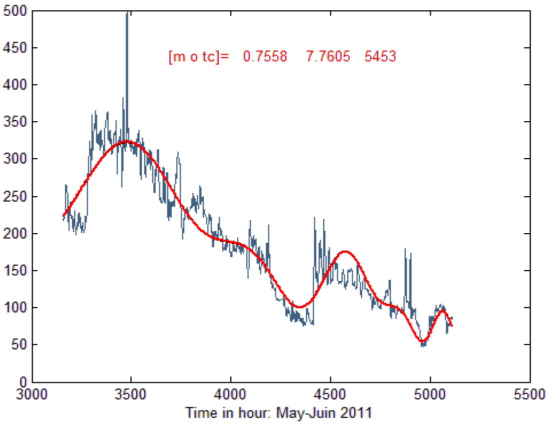

Fig6. Possible log -periodic trend of smoothed data. Hourly averaged Drin inflows, 2011

of solution in the interval [0,500] intending to capture long term oscillation. Therefore, we tactically neglect the findings of similar studies that high angular frequencies are related to the stochastic resonance or to the effect of multiple noises, because we hope that they are just the mechanism that cause DSI appearance which we commented here above. For critical time we appoint the interval from middle point of the windows considered to the half more, but only values that do not exceed some ten percent of the longitude of time interval

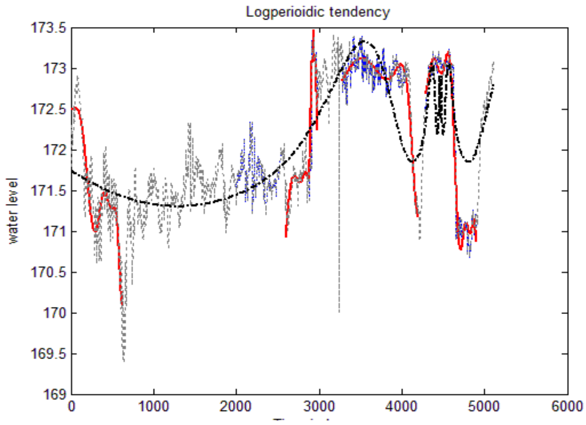

Fig7. Log periodic behavior of water level (Koman), January-June 2011: Short term regime by red line, black line, full time regime. Grey line, real data

are considered. To account for the spurious data effect we considered smoothed series as above prescribed by averaging over successive time points but we see that this operation didn't affect the solution, just makes the picture appear clearer. We obtained that the hourly-averaged inflows for Drin River at the period January-June 2011 can be approached to a log periodic shape and the solution is found

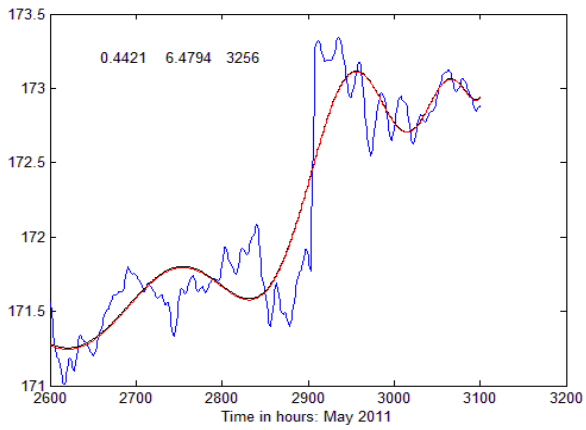

Fig.8. Short term regime, water level during intensive rain and perhaps under anxious management of the water level. Koman

at [m o t_c]=[0.4562 6.3568 6371]. Time origin is set t=1 at hour 01 of 1 January 2011 and the critical time corresponds at 53 days after the end of the series (end of the august). The lack of records out of the interval [January-June] do not permit us to perform the moving windows analyses in this case; hence, we limit our self on the search for possible DSI regime inside this interval where we've identified two distinguished log periodic behavior (fig5). Smoothing the data from high fluctuation value, we observe that the log periodic shape fits better, keeping the parameters nearly the same, which indicate possible true presence of DSI . For the second regime (covering May-June) hourly inflows the solution vector is found [0.756 7.76 5453] whereof the critical time correspond with real change of the regime at the end of June (fig6).

Log periodic shape is observed and examined for the water level of the Koman Lake (fig7-8). Those last are supposed to have the origin on dynamics of activities to keep the dam safe under intensive rainfall. From the outside view they report a

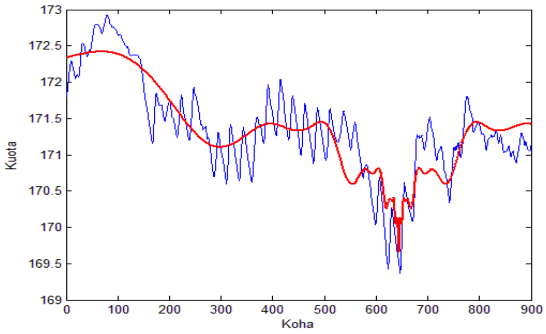

Fig9. Switching regime of log-periodicity.

non- balanced behavior on water management. As mentioned above the many day averaged inflows on Lake of Fierza for 25 years period do exhibit log periodic behaviour. The number of points produced so far is very small for quantitative analysis, but it makes more sense for our purpose. For a large shrink as of 60 days, the log periodic approach has shown 4 regimesthat match with each other. We observe that for high value of the boundary of angular frequency the fit will be better in the reproduction of cyclic behaviour but worse in amplitude fit. Therefore we limit our self in a reasonable limit at o_{limit}=20, now in the spirit of the discussion of reference [10]. As conclusion we can report a presence of log periodic behavior, self-organization in discrete scale invariances regime for the naked data series.

V. CONCLUSIONS

The dynamics of the 25 year of daily inflows on lakes of Drin River-Albania, considered under q-statistics shows an interesting findings. The stationary parameter q_{stat} was generally obtained higher than 5/3 indicating that the system is found usually in variance-indefinite states. This could be from insufficient data records for this specific case or even not appropriate time averaging. By selecting an appropriate interval of averaging data, the variance–definite state could be reached. Moreover, we see that the trend of monthly or largely averaged inflows is fitted well with log periodic functions. This approach will be useful to deal with extreme events as could be the prolonged very high or very low side inflows. Another interesting finding herein is the presence of log-periodic behavior in the water level on the intermediate lake (Koman) during heavy rainfall times. We propose therefore the applying of two approaches, the Tsallis statistics and JLS models, to improve the management of such systems.

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