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Optimal strategies for water management and self-restoration of the ecosystems: nonlinear dynamics, stability and controllability

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Abstract: Water management strategies for water quality and availability at different population/weather/economic scenarios are considered. Different compartmental model of the water transfer between the atmosphere, surface waters, soils, groundwater to the consumer have been studied on the data available for several regions of the Ukraine. It is shown; different models predict similar non-linear dynamics with possible bifurcations between the probable trajectories depending on the population growth/death/migration rates, meteorological conditions at the global climate changes, and economic development of the region. Stability and controllability of the systems on a set of the control functions is studied. The multiscale sample entropy (MSE) approach has been used for estimation of the irregularity and stochasticity of different scenario curves. It is shown, the MSE value measured on the available experimental data can be a good predictor of the best control strategy for water management when the behaviour of the dynamical system correspond to the self-restoration processes proper to a closed ecosystem.

Keywords: ecosystems, data analyses, nonlinear dynamics, mathematical modelling, stability and controllability

1. Introduction

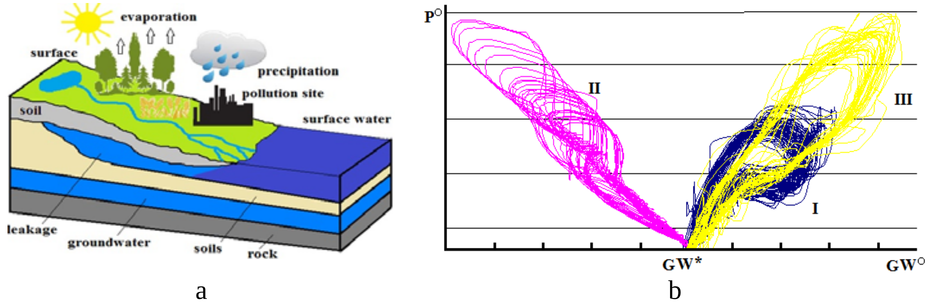
Drinking water quality of and availability, as well as the self-restoration abilities of ecosystems especially at the urban areas are important and difficult problems especially at the conditions of global climate change [1]. Recently the system dynamics approaches have become the most promising for quantitative estimations of possible future scenarios at given sets of model parameters proper to different ecosystems [2, 3]. The water dynamics in such systems can demonstrate chaotic dynamics [4]. In this study the scenarios with deterministic/chaotic dynamics, bifurcations, stability and controllability of the ecosystem dynamics are considered for the water management on urban territories with given distribution of the pollution sites, soils, ground and surface waters, etc.

2. Results and Discussion

An ecological system can be studied on the compartmental models with different contents of water, mineral/organic components and pollutions (Fig.1a). Such models are based on the equations of balance between the water sources and its use in manufacture, agriculture, domestic area of given relatively closed areas. The domestic water sector, as the main consumer of water, is expanding due to population growth, which in turn is a function of several variables, including birth rate (b), death rate (d), and migration rate (m) that could also be functions of time. The balance equation is [1-4]

$$N'(t) = (\text{b+m-d})N(t)\,, \tag{1}$$

where N(t) is the population; time t is determined in months or years; $(\cdot)'$ is the time derivative; b,m and d are birth, migration and death rate coefficients for the region studied.



a b

Fig. 1. Compartments of the ecological system (a) and dynamical curves GW(P) (b)

The water available W(t) is determined by the balance between water sources and sinks

$$W'(t) = k_1 SW(t) + k_2 GW(t) + k_3 CW(t) - k_4 U(t) - k_5 LW(t), \quad (2)$$

where SW and GW(t) are the surface and ground water, CW is controlled water saved due water economy, UW is the general used water (in industry, agriculture, domestic, etc.), LW is the lost water. The coefficients $k_{1-5}(t)$ are known from statistical reports

Other equations are hydrologic water balance in the region, efficient changes in the groundwater potential and precipitation dynamics [1-4]

$$\Sigma Q_{in}(t) - \Sigma Q_{out}(t) = -Q_{pw}(t) + Q_{uw}(t) + Q_{sw}(t) + Q_r(t) - Q_{vp}(t) - Q_{pl}(t), \quad (3)$$

where Q_{pw}, Q_{uw}, Q_{sw}, Q_r, Q_{vp}, Q_{pl} are percolated water, ground, surface, returned, evaporated and absorbed waters that calculated on table data with specific coefficients.

A set of trajectories of the dynamical system (1)-(3) with additional equations computed on data for Kharkov region with different future scenarios is presented in Fig.1b. It is shown, different levels of non-dimensional precipitation (P°) could result in the same level of the groundwater (GW°) and, thus, in the amount of drinking water available. Non-linear dynamics, bifurcations and control have been studied based on the multiscale sample entropy (MSE) approach.

3. Concluding Remarks

Based on the systems dynamics approach modeling the nonlinear dynamics with possible chaotic behaviour in water management and drinking water availability at different scenarios in the population, climate and economic development of a region is shown. The multiscale sample entropy value is proven to be a good predictor of the optimal strategy for water management when the behaviour of the dynamical system correspond to the self-restoration processes proper to a closed ecosystem.

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