Water Qual Expo Health (2014) 6:1–5
DOI 10.1007/s12403-014-0125-7

EDITORIAL

Perspectives and Challenges on Climate Change and its Effects on Water Quality and Health

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Received: 25 March 2014 / Accepted: 12 April 2014 / Published online: 29 April 2014

Abstract Climate change and its effects on water quality and health are an important problem which is challenging different aspects of our present day society. In this special issue, we have approached this problem area by gathering the perspectives of the leading scientists in this field of research. In this editorial, this subject is introduced from a dynamic system analysis perspective as a unifying point of view which is expanded on in several papers that are included in the special issue.

Keywords Complex systems · Resilience · Dynamic systems · Climate change · Environment

Dynamic Systems and Climate Change

As scientists specializing in the environmental health field, we are well aware of the fact that the components of the environmental systems we are working with are constantly changing and these changes produce significant impacts on the behavior of the overall system over the short and also the long term. Given the complexity this introduces, sometimes there is a tendency to treat environmental health systems as systems which are relatively simple as we consider only parts of the system and avoid looking at the broader picture. This approach limits the analysis of the overall system which is constantly responding to change (Friedman 2013). What is the cause of this complacency and what are the consequences especially in view of the more recent and critical topic of climate change and its effects on populations which is the topic of this special issue? Probably the tendency to ignore complexity is originating from the overwhelming uncertainty associated with the broad description of the problem and the characterization of the interlaced linkages within the components of the system. The consequence is failure to analyze the overall system behavior satisfactorily.

As engineers and scientists working in environmental health and climate change fields, we are trained and probably are very good at understanding and solving complicated problems within our specialization areas. This of course requires specialization in narrow fields of research and isolated analysis of specific applications. We are also well aware of the fact that the systems we have to work with cannot be characterized as "complicated systems," but they need to be characterized as "complex systems." Complex systems cannot be studied in isolation and will require the involvement of a team of specialists from numerous fields and also the generalists to show us the links between the components that are involved.

A complex system is comprised many components with many interlaced relations among its components. In these systems, the behavior of each component depends on the behavior of the other components, which influences the response of the overall system. That is the observed change in system behavior is due to the cumulative impact of the change within the individual components of the system and vice versa. In climate change studies, the complex systems analysis approach has been advocated in the literature but not yet fully implemented. The approach to analyze the issues in the combined field of climate change and health effects needs to be based on the premise that the combined field is more complex than the complexity of its components. The analysis strategies used for this system need to include the understanding that the effects of the change that is imposed on the system behavior by its components are not in stable

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or in steady state condition. The premise we have in traditional analysis, which is "the change is possible to control" is not going to be successful in this case as well, as it was not successful in other component-by-component analysis approach. That approach will not be a good strategy to analyze complex human-climate-environment (HCE) systems as well.

Climate Change and its Effects on Water Quality and Health

For the purposes of this Editorial which will introduce the special issue on "Climate change and its effects on water quality and health," we may start with the review of the components of HCE systems where a summary is provided in Khedun and Singh (2014). Traditionally, the methodology used in the analysis of simplified systems focuses on the evaluation of the effect of one stressor on one component via a single or multiple environmental pathways and this approach does not consider the role of the combination of several environmental and more importantly non-environmental stressors on the overall system. In Khedun and Singh (2014), the necessity of deviation from this approach is outlined. Here the term "stressor" is used to identify a process that may cause an adverse effect on human well-being; and the community refers to a group of people that share a common characteristic. Overall, some of these stressors may contribute to adverse effects on humans and community, and others might increase resiliency of the system which is a function of the social support dynamics. How these factors interact with each other and influence the behavior of the components and the overall system behavior has significant human health implications as discussed in Hoque et al. (2014). In order to protect populations from adverse effects, an understanding of the complex interactions between various stressors among various segments of HCE system is critical and this analysis needs to also include the appropriate treatment of the uncertainty associated with the data whether it is of stochastic, deterministic, or heuristic origin.

In traditional HCE analysis, after partial success or even maybe complete success of the narrow goals of a study is achieved, we always find ourselves in justifying the study outcome when we try to articulate the end story and extrapolate its implementation within the broader framework of the complex system. That is when we fail to be convincing and that is when mistakes are made in the HCE analysis. The main reason of this failure is that the original study was narrow to start with and has ignored the inherent complexity and the effect of the changes the system is experiencing when decisions are made in the long term. In that interpretation, the projection simply becomes a speculative extrapolation of the narrow knowledge gained in the narrow field of the application. The reason behind this deficiency is because the integrated analysis of complex systems has not been the focus of the HCE assessment.

There are examples of complex HCE systems that are currently on the agenda of researchers and research organizations. For example, there are various problems that are associated with climate change and its effect on human-environmental systems (Barringer 2014; Biao et al. 2014; Alfredini et al. 2014; Karamouz et al. 2014; Niazi et al. 2014; NSF 2009; USEPA 2014) as they are reported in this special issue and elsewhere. The premise in most of the climate studies is that the warmer temperatures may increase air and water pollution or increase sea levels or create other hydrologic and catastrophic events and this in turn will have adverse effects on humans (Hansen et al. 2006; Solomon et al. 2007; Meehl et al. 2007; Solomon et al. 2009). In these studies, we are well aware of the fact that the complex HCE system will not respond to "change" in a smooth and predictable manner. Based on the predictions made and the management decisions selected, a stressed or perturbed complex HCE system can suddenly shift from a seemingly stable steady state behavior to a state that would be difficult to return to its original state after the change takes its toll on the system (Aral 2014). Further, not only these complex systems we work with in nature and also society change, but also over the long term they also change how they change. This is a very important characteristic of complex system behavior. Thus, "it is possible to control change" premise of our traditional analysis becomes immediately unachievable for the analysis of complex systems. In complex systems, the individual components of the system and the interactions between them may lead to large-scale changes and behaviors which are not easily predicted from the knowledge and the analysis of the behavior of the individual components. This concept is in contrast to the perspective of a world that is in near equilibrium and/or is in steady state as they are defined in most of the current HCE applications. The broader problem of climate change and its human health implications requires thinking out of the mainstream line of thought for the analysis to be meaningful and the outcome to be useful.

Unfortunately, for cases where humans are involved, the outcome of an irrecoverable change is either the loss of life or the loss of the social fabric of our societies which cannot be easily associated with cost. That is a tipping point we would like to avoid as much as possible at all times in contrast to other fields where some failures may be tolerated and cost can be recuperated. Thus, in the HCE systems, we find ourselves in a more precarious position. These problems cannot be solved through the traditional perspectives of the analysis of complicated problems but maybe addressed adequately by attempting to adopt to change as we treat the system under study as a complex system.

Resilience Approach

In analyzing complex systems, in addition to understanding how dynamic systems behave, it is also important to understand the return to equilibrium (stability) concept. For that analysis, the concepts originally developed for ecological system analysis that embraces the concept of resilience and its components; latitude, resistance, precariousness, and panarchy are very important (Gunderson and Pritchard 2002; Holland 1995; Kauffman 1993; Neubert and Caswell 1997). Resilience of a complex system is defined as the capacity of the system to absorb disturbances while undergoing change as it retains essentially its function, structure and identity, and response state. In essence, in the context of the HCE, a resilient risk behavior would be the one that would have the capacity to respond to the stresses introduced on the state of the system such as high temperatures, high sea levels, melting of ice caps, frequent catastrophic hydrologic events, population dynamics, and other social stressors without exhibiting failure modes such as deterioration of the social fabric of our society or loss of life. Within the perspective of the HCE, the loss of resilience leads to more vulnerable states in which even minor disturbances can cause a significant shift to other states that is difficult or even impossible to recover from. Thus, vulnerability is the flip side of resilience concept and occurs when a system loses its resilience and becomes vulnerable to change that previously could have been absorbed. The resilience concept has four components which are quantifiable using basic engineering- and science-based tools—**Latitude (L), Resistance (R), Precariousness (Pr), and Panarchy (Pa)**. Latitude is defined as the maximum amount the system can be changed before it loses its ability to recover; Resistance is the ease or difficulty of enacting a change on the system; Precariousness is the current trajectory of the complex system, and how close it currently is to a threshold which, if breached, makes recovery difficult or impossible or moves the system to another state; Panarchy is an indicator to measure how the above three attributes are influenced by the states and dynamics of the other systems that comprise the overall complex system at scales above and below the scale of interest. In this manner, when all stressors are included in the resilience landscape, Fig. 1, the overall system analyzed will be an integrated complex system.

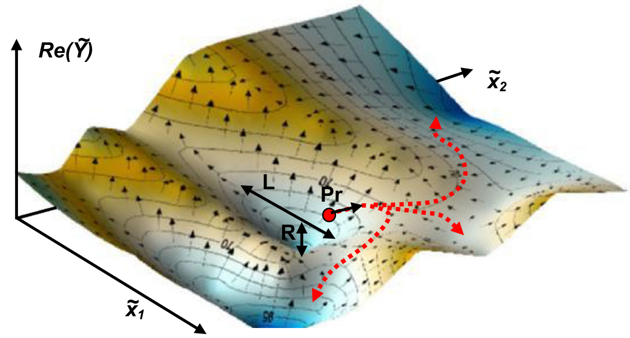

Fig. 1 Resilience landscape of a complex system Re $(\widetilde{Y})$ and potential stressed system trajectories for a system of two state variables, $\widetilde{Y} = F(\widetilde{X_1}, \widetilde{X_2})$

Since human perception or response is an important component in the concept of resilience-based HCE systems, we should also include the quantifiable concept of adaptability and transformability to our tools of optimal analysis in a heuristic sense. These measures are related to the capacity of making desirable system basins of attraction in the resilience landscape wider and/or deeper, while shrinking undesirable states to produce a harmonious behavior. The introduction of new stability landscapes by the introduction of new components and ways of making the overall system work harmoniously is also a part of the overall approach. In essence, in this line of thinking, the stability dynamics of the linked systems of HCE merge from the three complementary attributes of resilience, adaptability, and transformability. As much as the resilience to HCE system dynamics can be defined using basic engineering and scientific principles, we also acknowledge the fact that resilience-based HCE systems should be also linked to social resilience concept. Here the definition of Social-HCE system (SHCE) should be introduced, which is an integrated system of HCE and human society with reciprocal feedback and interdependence. This concept emphasizes the humans-in-society perspective. The concept associated with social resilience is the measure of the ability of a community to cope with the stress imposed on the community. Notably, social resilience differs fundamentally from natural or engineered systems resilience since it exhibits the capacity of humans to anticipate, learn, and plan for the future and this plays an important role in SHCE studies. Unfortunately, although these concepts are used in the literature in various applications, their computational counterparts in the resilience landscape and the return to equilibrium analysis are at their infancy as we would like to see defined and used in our computational models and engineering applications. The mathematical techniques which will provide this information already exist in the stability analysis of complex dynamic systems, however, this approach has not yet found its place in the computational resilience analysis literature except a few ecological studies (Guan et al. 2013) in which sustainability and resilience concepts are treated from a computational perspective. Thus, there is a lot of work to be done in quantitative resilience analysis of SHCE systems. Some of the studies included in this special issue on "Climate change and its effects on water quality and health" may provide a perspective on these approaches (Aral 2014). Other studies reported in this issue reveal the interlinking nature of the components of the system that is under study in this complex field.

Direction of Complex Systems Research

The US National Science foundation (NSF) Advisory Committee for Environmental Research and Education released a report that advocates a significant change in direction in the way environmental system research and education will be perceived by this agency in the future (NSF 2009). In this report, the NSF committee is advocating that physical and life scientists, engineers, educators, and social scientists must work collaboratively to understand and evaluate the behavior of complex systems under the changes imposed on the system. An important theme of this report is that scientists need to consider that the environmental health systems that involve human component may be approaching thresholds of irreversible change given the nature of the complexity of the stressors. This is also due to the unpredictable nature of human transformability and adaptability characteristic which also renders the analysis to be rather complex. Unfortunately, a similar scientific view and a strategy of analysis have yet to be considered by the leading international organizations for the SHEC systems. The concepts embedded in the computational resilience analysis may shed some light to the problems we face in the SHCE systems. This line of research needs to be pursued by the scientific community although the computational aspects are overwhelming and the current qualitative analysis that appears in the literature is not satisfactory.

We do not Need to Resist Change; We Need to Embrace it

The quantitative resilience thinking may yield an actionable set of observations and practices that is based on the broad understanding of complex SHCE systems. This approach does not assume or require that the system studied is near equilibrium or in equilibrium state, or it is controllable. For the previous paradigms of environmental health management, precise understanding of the system was needed and the policy decisions made relied on the accuracy of this understanding. Currently, the mathematics of resilience thinking is at its infancy and needs a refocus. Also the deterministic analysis mode that is currently used in few of the resilience analysis studies reported in the literature is not sufficient to analyze the resilience of complex SHCE systems. However, the idea is promising and many applications in complex systems analysis that involve humans and policy making are shifting to models that include the resilience concepts (Guan et al. 2013). This approach may offer a broader understanding of possible system behavior and the effects of stochastic and heuristic human intervention on this behavior. It seems that not resisting change, but instead embracing it by changing our analysis from the study of complicated problems to the computational study of complex problems following the line of thinking introduced in computational and optimal resilience analysis would be a more proactive approach. In this special issue on "Climate change and its effects on water quality and health," the purpose was to identify the components of this complex system and introduce some of the computational aspects of this analysis.

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