Journal of Environmental Management 223 (2018) 676–684

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Holistic water quality dynamics in rural artificial shallow water bodies

Abul Hasan Md Badiul Alam*, Koichi Unami, Masayuki Fujihara

Graduate School of Agriculture, Kyoto University, Kitashirakawa-Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan

ARTICLE INFO

Keywords:
Water quality dynamics
Stochastic differential equation
Diurnal variation
Water quality parameter
Shallow water body
Water environment vulnerability

ABSTRACT

The water environment in diversely used rural artificial water bodies is generally varied with seasonal and diurnal changes, stability of which is significant in water resources management. Understanding of interaction among different water quality parameters that depend on their diurnal variations is the concern of this study. A rural homestead pond used for aquaculture in Bangladesh and a micro-dam used as an irrigation tank for paddy farming in Japan are chosen for contrasting the analysis of data. The observed data series of four typical water quality parameters exhibits the diurnal variations, which are primarily inferred to be driven by solar radiation and complex bio-chemical interactions. The study proposes a stochastic differential equation model to represent holistic water quality dynamics based on continuous measurements. The water quality parameters are considered as temporally continuous Markov process, where their individual effects on each parameter are evaluated in a specific time step and immediately reflected to the next observation. The model parameters are calibrated and the stability is discussed based on the eigenvalues of model parameters. The result mostly shows the mean reverting properties for dissolved oxygen and water temperature, while pH and oxidation reduction potential are rather depend on other parameters or external disturbance.

1. Introduction

Due to the exponential population growth as well as their increased food demand, the rural water resources in different countries of tropical to temperate regions are diversely used for agricultural and economic purposes such as paddy farming, irrigation, aquaculture, landscape, conservation of aquatic species, etc. These uses are depended on the variations of physical characteristics of water bodies, their source of water and water availability. Even the same water body is served for multiple purposes. Most of these water bodies are artificially created and characterized with well-mixed water, small in size and shallow in depth. In addition, a wide-range of them is gradually tended to eutrophic due to the increased human activities and external disturbance in recent years. In a study of Rixen et al. (2010), eutrophication is stated as the main reason for spreading of dead zones, which are not dead exactly but reveal oxygen level too low and other nutrients at high toxic level to sustain plant and animal life. The water environment in the rural water bodies is generally fluctuated both seasonally and diurnally. When the fluctuation is over the threshold level of a water quality parameter, it may influence the eutrophication process. However, water quality management as well as the optimum quantitative distribution of water and sustainability in the systems are complex issues involving hydrology, hydraulics, economics and ecology. In this context, the diurnal variation of different water quality parameters, a key element of these issues, is the major concern to be explained from a mathematical viewpoint. Hence, Alam et al. (2016) proposes scientific methodologies to study the water quality dynamics in shallow ponded water bodies at rural community levels. The study can also explain the diurnal variation of water quality parameters. The developed methodologies are applied and considered in this paper with continuously measured data of typical water quality parameters to capture their diurnal changes. Contrasting field studies are conducted in two study sites of tropical and temperate climate zones to formulate abstract mathematical approach of water quality dynamics.

Tropical Monsoon weather in South Asia usually shows the characters of a unimodal rainfall intensity curve and a specific long dry spell. Due to this variation of Monsoon weather, numerous shallow water ponds are found in the rural villages of a tropical country like, Bangladesh. These are artificially developed in the rural homestead area to support the domestic activities. Although their worth in the rural economy is already proved as small-scale aquaculture, the stability of water environment can provide a solid foundation for this practice. Similarly, there are about 200,000 existing irrigation tanks in Japan, a country of temperate zone. The individual capacity of these tanks is mostly less than 5000 m^3. In general, the upstream irrigation tanks are mainly used as reservoir for rice cultivation, though some downstream tanks are served as trap of siltation and water purifier. To make efficient use of those small water resources and lands in farming

* Corresponding author.
E-mail addresses: alam@kais.kyoto-u.ac.jp, alam.ahmb@gmail.com (A.H.M.B. Alam), unami@adm.kais.kyoto-u.ac.jp (K. Unami), fujihara@kais.kyoto-u.ac.jp (M. Fujihara).

https://doi.org/10.1016/j.jenvman.2018.06.076
Received 31 December 2017; Received in revised form 30 May 2018; Accepted 25 June 2018

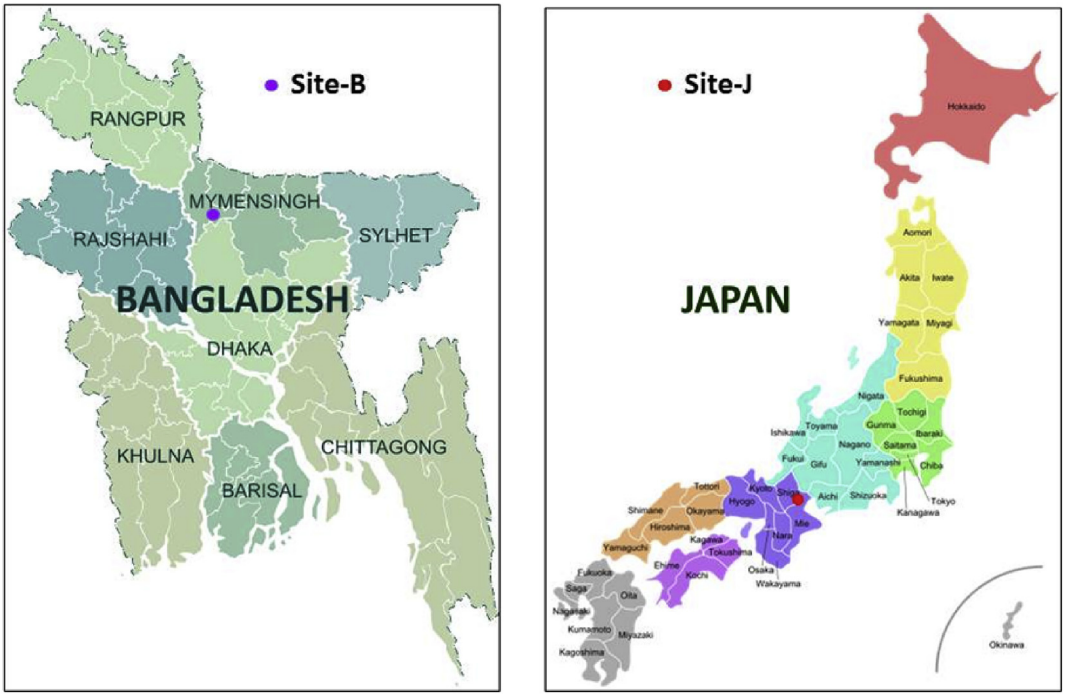

Fig. 1. Location of the study sites in Bangladesh (Site-B) and Japan (Site-J).

systems, integrated irrigation-aquaculture (IIA) offers an excellent opportunity (Phong et al., 2010). This technique is not new in farming systems, but fish farming within IIA has not expanded equally to the increased irrigation facilities due to lack of a complete scientific framework. The study on water quality dynamics can play a vital role for the development of that scientific background.

Many previous studies are carried out for describing the temporal variations of water quality on the basis of seasonal or monthly or daily based data of different water quality parameters. The typical water quality parameters in small and shallow water bodies include dissolved oxygen (DO), water temperature, pH and oxidation reduction potential (ORP). Ansa-Asare et al. (2000) stated that the presence of algae and other aquatic species in eutrophic shallow ponded water bodies significantly influenced the diurnal variations of typical water quality parameters, as a result of complex chemical and biological interactions. Similar findings of CO_2, DO and pH in ponded paddy field were also reported by Usui and Kasubuchi (2013). Zang et al. (2011) assessed the relationships between pH, DO and chlorophyll based on aquaculture practice, and indicated the significant positive correlations among them in eutrophic non-aquaculture waters. They also identified diurnal variations for both pH and DO, and found corresponding positive correlations between these water quality parameters. Korkanç et al. (2017) evaluated the spatial and temporal water quality in a dam watershed using the monthly monitoring data of different physical and chemical parameters, and identified the positive/negative correlations within the parameters. Zeinalzadeh and Rezaei (2017) assessed the ability of the principal component analysis technique in determining spatial and temporal changes of surface water quality based on monthly data, and reported the effects of different landscape and agricultural drainage water on changes of water quality in the downstream water. Taylor et al. (2016) quantified the impact of agricultural mitigation options on water quality at a daily resolution and suggested for calibration of water quality model with high-frequency water quality datasets. Cui and Chui (2017) examined the temporal variations in water quality parameters using 15 min time-scale data in a brackish tidal pond to understand the governing processes and management strategies. They identified the strong correlations and diurnal variations in water temperature, DO and pH in response to the changes of solar radiation.

Although described interactions of water quality factors in above studies are significant for future water resources management, any clear conception cannot be extracted about the dynamics of water quality parameters during the diurnal variations of water environment, and none of these studies can evaluate the interaction of a wide number of water quality parameters. In this context, it is interesting to research the holistic dynamics of typical water quality parameters in shallow ponded water bodies based on short time-scale continuous measurements. Here, the word 'holistic' means all intra- and interactions of any real number water quality parameters which are involved with the shallow water environment. This study firstly describes the investigated problems of two contrasting study sites. Then, a stochastic differential equation (SDE) model is proposed to represent water quality dynamics in artificial shallow water bodies at the study sites, and finally the stability of water environment is discussed for different cases of ecosystems. This is the first attempt to represent the water quality dynamics in a SDE model. The model can also consider any number of water quality parameters in a single mathematical framework. Therefore, the study has the potentiality to open a new paradigm of water resources research.

2. Methods

2.1. Selection of study sites

Two intensive study sites are chosen in Bangladesh and Japan to contrast the study and analyse the investigated results; these sites are referred to as Site-B and Site-J, respectively, in the following part of this paper. The names of the study sites are taken according to the initial letter of the names of the countries where the study sites are located. The locations of the study sites are shown in Fig. 1 (source of original maps are open access internet). For the measurement of short unit time-scale continuous data of typical water quality parameters, a shallow water body is chosen from each of the study sites. The reasons behind this selection are described in details within this section.

The first study site 'Site-B' is a Bangladeshi small watershed with double-cropping paddy rice system and located in the rural area of Godashimla, Jamalpur District, Bangladesh. According to the FAO