Ecological Informatics 72 (2022) 101830

Contents lists available at ScienceDirect

Ecological Informatics

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

Assessing the role of internal phosphorus recycling on eutrophication in four lakes in China and Malaysia

Chai Jian Tay [a,b,*], Hock Lye Koh [c], Mohd Hafiz Mohd [d], Su Yean Teh [d]

[a] Department of Physical and Mathematical Science, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia
[b] Centre for Mathematical Sciences, College of Computing and Applied Sciences, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[c] Jeffrey Sachs Center on Sustainable Development, Sunway University, Bandar Sunway, 47500, Selangor, Malaysia
[d] School of Mathematical Sciences, Universiti Sains Malaysia, 11800 USM, Pulau Pinang, Malaysia

A R T I C L E I N F O

Keywords:
Water
Lake modelling
Sustainable lake management
Bifurcation
Paradox of enrichment

A B S T R A C T

Internal phosphorus recycling (IPR) is an important nutrient source driving algal growth and eutrophication in lakes. The complexity of eutrophication behaviours caused by high IPR complicates lake management and undermines restoration efforts. Hence, knowledge about the possible types of bifurcation behaviours caused by high IPR is essential for effective and sustainable lake eutrophication management. For this purpose, numerical bifurcation analysis is performed on an algae-phosphorus model to investigate how IPR drives complex and rich eutrophication behaviours in two tropical and two subtropical lakes. The two tropical lakes are Tasik Harapan and Sunway Lagoon in Malaysia, while the two subtropical lakes are Lake Fuxian and Lake Taihu in China. For each specified level of IPR, co-dimension one bifurcation analysis is performed by means of XPPAUT. Co-dimension two bifurcation analysis is then carried out by means of MatCont. At low IPR, Lake Fuxian exhibits reversible behaviour, accompanied by higher external phosphorus loading (EPL) thresholds. Lake Fuxian is also more conducive to stable equilibrium and its lake dynamics are easily predictable. At moderate IPR, Sunway Lagoon is likely to exhibit stable equilibrium, accompanied by possible shifting between two stable steady states (hysteresis behaviour) and oscillations. With higher IPR, Lake Taihu and Tasik Harapan are prone to irreversibility, accompanied by lower EPL thresholds. Because of increased complexity in lake dynamics in Lake Taihu and Tasik Harapan, small changes in EPL or in algal mortality rates could trigger various transitions in lake dynamics. Overall, high IPR can trigger unexpected sharp increases in algal concentration and can reduce the resilience of an oligotrophic lake. For shallow lakes, high IPR would cause unexpected sharp increases in algal concentrations, undermine resilience of lakes, complicate lake management, and delay lake recovery process.

1. Introduction

Lake eutrophication is characterized by a proliferation of algae growth driven by excessive nutrients particularly phosphorus, which is essential for algal growth (Carpenter, 2008). Algal concentration, A (μg/L, chlorophyll a) is a common indicator used for lake eutrophication. The phosphorus sources driving algal growth originate from both external phosphorus loading (EPL) and internal phosphorus recycling (IPR) (Tong et al., 2021a). EPL consists mainly of industrial effluent, agricultural runoff, and urban sewage. IPR involves the release of phosphorus from the bottom sediment into the water column. A lake can abruptly shift from a clear water (oligotrophic) state to a turbid water (eutrophic) state after crossing a critical threshold. This abrupt shift is known as regime shift (Scheffer et al., 2001).

1.1. *Regime shift*

Regime shift can be driven by extrinsic disturbances (for example EPL and climatic changes) or intrinsic mechanism (for example IPR) (Vermaire et al., 2017). Published studies on regime shift in lake generally focused on the effects of extrinsic disturbances such as EPL (Gebremariam et al., 2021; Xu et al., 2020; Zhang et al., 2021). The impacts of intrinsic mechanism such as IPR on regime shift in lake have received far less attention, despite the recognition that strong IPR alone

* Corresponding author at: Department of Physical and Mathematical Science, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia.
E-mail address: taycj@utar.edu.my (C.J. Tay).

https://doi.org/10.1016/j.ecoinf.2022.101830
Received 18 May 2022; Received in revised form 19 September 2022; Accepted 20 September 2022
Available online 29 September 2022