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Lake and Watershed Management: Issues and Challenges in Managing Lake Water Quality

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Abstract – High-intensity land-use activities occur near lakes including in their watershed and increase of population density in areas neighbouring the lakes have caused overexploitation of lake water resources and discharge of large volumes of pollutants into lakes water. As a consequence led to escalating deterioration of lake water quality. Water quality conditions of lakes are significantly influence by their watershed behaviours. The lentic nature of lakes allows problems to build up and symptoms to go unnoticed for a lengthy period and commonly only appearing at a delayed and dangerous stage given that similarly a slow and often equally long period is needed to treat before positive results begin to show again. Hence, it is quite complex to comprehend types and strengths of pressures that impact water quality status, when do the changes will occur and what the status of water quality would be, not only on the presence situation but over the long term. Lake water quality and catchment relationship is an intricate issue and required the lake managers and planners to be attentive and prepared to engage in sustained actions over a long-term time frame relating to the development of lakes because progression of degradation inside a lake mostly takes place on a wider and deeper scale than is readily apparent. The comprehensive understanding on anthropogenic upheaval and hydrological linkages within lake watershed influences the dynamics of the lake water quality and is vital to the resulting livelihood including the cultural, biodiversity, and economic activities that are supported by lakes. This paper highlights the issues and challenges in managing lake water quality, variables that significantly influence lake catchment-water quality relationship, discussing the water quality parameters that must be regularly monitored, and proposing a management support tool as the expected research output to ensure lake water quality is not compromise while meeting the country's socio-economic demand.

***Keywords*:** water quality, integrated watershed management, lake environment, sustainable development

1. Introduction

Lake water quality is progressively deteriorating because of pollutants from its catchment activities [15][16][17]. Even with specific jurisdiction, it is difficult to contain pollution coming from the upstream, due to rapid population growth, massive urbanization, and intensified landuse alteration, especially the non-point source types [15][16][17].

The priority of water resource management research is to achieve a balance between environment, economy and social needs. In order to achieve a sustainable management, the drivers that contribute to the impairment must be clearly understood and identified. Furthermore the limitations and problems faced by lake managers, authorities, stakeholders and policy makers with regards of sustainable water quality management must be explored, acknowledged, determined, and thoroughly discussed. Without a full comprehension and imperative measures taken, improving the current situation to a better level is never be attained.

The lentic nature of lakes has caused it to act like a sink or sponge absorbing all the pollutants which accumulate without any symptom being noticed at early stage and escalating over period of time causing symptoms only appear at later stage[8][23]. In addition, lake ecosystem is also unable to operate in self sustaining ways because of interferences or damage over a period of time exceeds their capacity for self repair [8][23].

Hence, the rule of thumb in good management practice of lake water quality management is to have a complete understanding of morphology of the lake being managed. The shape and size of a lake basin affects nearly all physical, chemical and biological parameters of the lake. Lake area, lake volume, maximum and average depth are parameters that are related with nutrient cycling [7][8]. A Deeper lakes are characterised by thicker surface layer which determines the photosynthetically available irradiance, the efficiency of nutrient cycling and the vertical distribution of organisms[18]. On the other hand smaller and shallow lakes are strongly affected by wind-induced sediment re-suspension which results to significant changes on their water chemistry and geochemical cycles[18]. Mean depth is also an important factor for controlling productivity while the size of lake is related to the depth of thermocline[8][18]. Moreover, the shape of the lake can be associated with bottom dynamic conditions[8]. The slope of littoral zone has a great influence on the biomass and the distribution of submerged macrophytes communities[8]. A gently sloped littoral allows the deposition of fine materials and can modulate the wave action in favour of establishment of aquatic macrophytes[4][7].

What is lacking in the current situation is the ability of the lake managers to understand he morphology of their own lake. It is important to have a deep understanding of lake morphology because it is one of the leading factor influencing the lake trophic status including water quality health status. The knowledge is relatively minimal among not only lake managers, but the policy makers, decision makers, and key stakeholders on the significant correlation of watershed and water quality relationship and the intensity of watershed activities impacting lake water quality status because of the complex response dynamics of lake ecosystem, which is the accumulated negatives effects of land use dynamics may not be immediately visible and problems will surface at a later stage with condition has turned beyond bad[1][8].

Thus, this is a major reason of why there is no intensive monitoring regime and assessment systems that link between lake water quality and catchment activities, although there are numerous studies showing how significant activities within lake watershed or lake basin influence the lake water quality status. At the moment, current lake management practice in Malaysia is lack of active coordination between lake watershed and water quality in implementing sustainable lake water quality management [1][19]. The watershed planning and development is not included in environmental management target, and assessment of what would be the impact on lake water quality. Hence the reason results of the 2005 desktop study indicated 62% of the ninety (90) lakes studied in Malaysia were facing eutrophication issues [19]. There is no further studies based on this alarming findings and is believed the situation is progressively escalating.

The concern of how lake water quality being managed is due to the fact health status of lake water quality especially urban recreational lakes has significant impact on the public well-being, property values and the number of tourist visits [13][22]. A clean and pristine lake is one of the key indicator on measuring the sustainable development and the quality of life of a community [13][22]. In addition, recreational lakes is also a tangible reflection of the quality of life in a given community. A major contributing factor of amenity and aesthetic values of a community livelihood especially in urban areas. Studies [4][5][7][13] have shown significant correlations to reductions in stress, lowered blood pressure, and apparent physical health to the length of stay and frequency of visits to recreational parks.

Therefore, the aim of this paper is to review all the leading constraints and barriers that hinder effective lake water quality management and proposing solution because by recognizing what are the problems, and by identifying the issues and challenges then imperative measures can be formulated to improve more effective management on lake water quality.

2. Objective, Method and Paper Outline

This paper specifically intend to discuss the existing issues and challenges faced by lake managers in the effective implementation of Integrated Lake Basin Management from the experienced of Malaysia based on the extensive reviews of government departments' and research institutions publications, scientific journals and technical reports. This paper will also highlights the most principles applied as theoretical framework in promoting sustainable management of lake water quality. This will then be followed with the debating issues of what water quality parameter that should be consistently monitored by lake managers. Finally, a concise explanation on the proactive measure taken to address on the discussed issues and challenges through the development of management support tools to facilitate lake managers in improving existing management techniques with regards to sustainable water quality management.

3. Literature Overview: Issues and Challenges of Lake Water Quality Management

The arguments and facts presented here is to illustrate the barriers in sustainable lake water quality management from the experienced lake managers in Malaysia. Although, good water resource management and sustainable development policy has been established; strong framework of Integrated Lake Basin Management has been endorsed at federal and state government; strategic planning has been deployed for short, medium and long term goal of lake management; and National Blueprint Research has been produced, effective implementation of managing lake waterbody and its watershed as one single entity is far from accomplished.

Theoretically, it is very important to understand that degradation of water quality status of lake is profoundly influenced by the intensity of anthropogenic activities, landscape alteration, rainfall distribution and population density within the lake watershed. The lake water quality status will then significantly influence the quality of life, property value and amenity value. This theoretical framework is clearly supported and in parallel with Sustainable Development theory [14], Integrated Lake Basin Management (ILBM) concept [8][23] and Driver-Pressure-Status-Impact-Response (DPSIR) framework[21].

Thus, it is quite unfortunate for Malaysia because actual solution to improve water quality and prevent pollution problems accrue from watershed activities has not actually met for lakes. Majority of the lake is still being managed in an uncoordinated and fragmented manner, leading to difficulties to achieve sound lake basin management principles[6]. Evidence in the loose implementation of ILBM on ground level indicates serious lacking of integrated management being applied. Minimal or none inclusion of both upstream and downstream stakeholders in the lake and basin management process is a solid proof of lack of inter-agencies or inter-department coordination in planning and management[6].

The fragmented and sectoral way of lakes and their various values being governed and managed did not allow comprehensive understanding of the hydrological and ecological dynamics of the lakes and the manner they changed over time and prevented the development of sustainable management regimes based on long term trends and requirements [1][23]. Most importantly is the lack of coordination and integration of data between stakeholders that has prevented the values of these lakes to be adequately quantified [4][5][11], as a consequence of which planners and managers have little understanding of the full value of the country's lake assets.

At the moment, the way data and information being managed caused numerous issues and problems among the stakeholders such as information and data overload that lead to data integrity, data accuracy and validity. Data scattering has caused incomplete data and information misleading[6]. Poor information exchange process leading to missing data and information[6]. Lack of data sharing between watershed stakeholders and lake managers has led to difficulties to have access to data and information, as well as data and information inconsistency and redundancy[6]. Lake managers and stakeholders has failed to acknowledge that updated, accurate, readily available, understood, accepted, easily access and efficiently managed data and information is vital to support any decision making related to sustainable lake water quality management. Another biggest obstacle is the ad-hoc approach adopted by lake managers of "wait until it turns bad" towards lake water quality leads to severe deterioration of resources within the lake ecosystem, causing high cost of restoration on both financial and time[2][8]. Because of its lentic nature, it will take years for lake to being restored back to its original condition[8][23]. Even if only a segmented issue such as water quality or sedimentation or algae bloom is to be regarded, the fact that lakes are close ecosystems means that a comprehensive analysis is necessary so as to include all the activities and landscape patterns within lake watershed concerned [16][20].

The major reason of why a continuous and regular monitoring of lake water quality for both dry and wet season is compulsory. Long term regular monitoring provides trends and sufficient data to be analysed in order to fathom the dominant pollution sources either point sources or non-point sources, how much nutrients coming in from the catchment activities, what are the prominent stressors (or drivers), how strong the impacts of watershed activities influence water quality status and which land use types profoundly affect lake water body[10][11][15][16][17]. Without a complete data and information, lake managers and watersheds stakeholders would not be able to comprehend or have an absolute understanding on how the driving factors would impact the water quality status which is the foundation of DPSIR principles of achieving sustainable integrated watershed-waterbodies management.

It is also important to be aware that most changes happened in lake water quality is unobservable to the eye. In contrast to the air quality pollutants that is visible such as haze and smog. Low dissolved oxygen, high total coliform, increase of water acidity of alkalinity, high concentration heavy metals such as lead, mercury, zinc and copper, and high nutrients loads can never be detected through visible eye view. Only when high pollutants concentrations combine with other factors causing

algal blooms or fish kills or appearance of colour or turbid water, will physical evidence is noticed. The severity of pollutants concentrations in lake water quality can only be determined through measurement with specific scientific equipment. Further, the value of pollutants reading must comply with standard water quality index before the actual condition of lake water quality is known.

Hence, referring to standard developed specifically for river or industrial effluent is not accurate. Water quality parameters of lakes is more intricate compared to river or marine because of its lentic nature. A combination of trophic state index parameters such as chlorophyll a and total phosphorus; physical parameters such as pH, and dissolved oxygen; chemical parameters such as biochemical oxygen demand and chemical oxygen demand; and biological parameters of E.Coli and Total Coliform will provide a good representative of lake water quality status.

4. Corresponding to the Issues and Challenges

According to [4],[5] and [7] by understanding how the landuse change and intensity of watershed activities influences water quality of the lake within that particular watershed itself, lake managers, planners, stakeholders and policy makers were able to plan sustainably and avoid the undesirable effects of urbanization and development.

Having discussed the most prominent issues and challenges, water quality prediction model is an essential tool to achieve sustainable lake water quality management. The model will allow understanding of parameters that affect lake water quality, expansion of quantitative relationships between all the variables, fingerprint and combine the physical, chemical and biological environmental factors [18]. The model also integrates all factors within watershed activities to be able to measure alteration in lake water quality and forecast the water quality changes with changes of the watershed variables. In addition, they may provide data for environmental planning studies, on which funding decisions are made, providing prioritisation of research grant allocation as well as avoiding spending unnecessarily towards one particular lake [2][3][14].

At the regional level of ASEAN countries, Laguna De Bay of Phillipines[2] and Tonle Sap of Cambodia[3] are excellent showcase of regional success in developing specific model that meet the countries' lakes need instead of just relying on using commercial model. The purpose of developing water quality prediction model that tailored to the Malaysia's need is to help us to better reflect on our understanding of lake water quality interactions and their behavior, and we can improve from the current traditional management practice. In a long run, we would be able to share knowledge gained from our own experiences with other lake managers at regional scale.

The GIS-based lake water quality prediction model is a management supporting tool to facilitate lake managers and planners not merely diagnosing water quality problems effectively and managing lake and its catchment as one single entity but most importantly the knowledge of how lake ecosystems correspond to changes and activities within the lake catchment. The model integrates statistical and spatial linear regression analysis in shared geo-database. The spatial data consists of land-use types, population density, river network, lake catchment area, rainfall distribution, and pollution sources (Figure??). The selected lake water quality parameters of pH, temperature, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Phosphorus, Total Nitrogen, Turbidity, Suspended Solids, E.Coli and Total Coliform is collected in both dry and wet season. The linear regression equation of y=mx+c will be the foundation of model calculation (equation 1). Arc-GIS 10.3 software is used in model development.

$$LHS = f\ (S + W + P)$$
$$\text{LHS} = \text{Lake Health Status}$$
$$\text{f} = \text{Coefficient}$$
$$\text{S} = \text{Social Factor}$$
$$\text{W} = \text{Water Quality Factor}$$
$$\text{P} = \text{Physical Factor} \qquad (1)$$

GIS is chosen to develope the propose water quality prediction model because of its ability to store, retrieve, manage and analyse spatially and temporally varied data [12]. The system provides the best platform to integrate both spatial and non-spatial data into decision support system. Its ability to perform interpolation and extrapolation at large spatial scales is also a huge advantage [14][17].

Once the lake managers and stakeholders are enlightened about the medium to long term hazards of lake mismanagement to the whole lake ecosystem health and well-being, they likely would form a strong pressure groups to

facilitate the implementation of established policies and strategic planning. Through this model they would also be able to make a responsive decision.

5. Conclusion

The integrating nature of lakes, long retention time, and complex response dynamics mean that continuous water quality monitoring, excellent data management and good information is particularly valuable in the decision-making process because the cost of a mistake (can be very high. Hence, issues and challenges that hinder effective lake water quality management must be appropriately addressed. This can be done by recognizing and understanding the drivers that significantly impacting the lake water quality status.

Establishing good policies, drawing excellent strategic planning and publishing a concrete integrated management blueprint is a waste if the key issue of watershed and water quality still remain separately manage or manageable but with minimal coordination. The imperative measure is to integrate upstream activities with lake water quality management. Focusing on the watershed as the basic planning unit is more effective in enabling the lake managers to become more aware of their immediate environments. It helps them to better relate to the lake water quality problems directly and indirectly affecting them, which eventually facilitates the process of developing a shared vision for the watershed and lake waterbody. The developed water quality prediction model is a tool that bridge communication barrier and knowledge gap between results of scientific findings to the planner, lake managers, and policy makers. It is time to actively engage science data in decision making related to lake water quality, because the prolong practice of relying on vague information and ambiguous data to make important decision has lead to severity of lake water quality condition.

References

[1] ASM and NAHRIM, "Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Brief Report Series 1," 2010.

[2] O. B. Barbosa, E. C. Hernandez, and A. Santos-Borja, "Decision Support System and GIS as Tools for Integrated Management of the Laguna De Bay Basin," in *Proceedings of Taal 2007: The 12th World Lake Conference*, pp. 2212-2219, 2007.

[3] R. Chea, C. Guo, G. Grenouillet, and S. Lek, "Toward an ecological understanding of a flood-pulse system lake in a tropical ecosystem: Food web structure and ecosystem health," *Ecological Modelling*, vol. 323, pp.1-11, 2016.

[4] J. A. Dunalska, J. Grochowska, G. Wiśniewski, and A. Napiórkowska-Krzebietke, "Can we restore badly degraded urban lakes?" *Ecological Engineering*, no. 82, pp. 432-441, 2015.

[5] I. C. Duggan, "Urban planning provides potential for lake restoration through catchment re-vegetation," *Urban Forestry & Urban Greening*, no. 11, pp. 95– 99, 2012.

[6] M. Evers, "An analysis of the requirements for DSS on integrated river basin management," *Management of Environmental Quality: An International Journal*, vol. 19, no. 1, pp. 37-53, 2008.

[7] A. Erol and T. O. Randhir, "Watershed ecosystem modeling of land-use impacts on water quality," *Ecological Modelling*, no. 270, pp. 54-63, 2013.

[8] International Lake Environment Committee Foundation (ILEC), "Managing Lakes and their Basins for Sustainable Use: A Report for Lake Basin Managers and Stakeholders," Technical Report, pp. 12-13, 2005.

[9] J. M. Kandulu, J. D. Connor, and D. H. MacDonald, "Ecosystem services in urban water investment," *Journal of Environmental Management*, no. 145, pp. 43-53, 2014.

[10] T. G. Kazi, M. B. Arain, M. K. Jamali, N. Jalbani, H. I. Afridi, R. A. Sarfraz, J. A. Baig, and A. Q. Shah, "Assessment of water quality of polluted lake using multivariate statistical techniques: A case study," *Ecotoxicology and Environmental Safety*, no. 72, pp. 301-309, 2009.

[11] J. Kibena, I. Nhapi, and W. Gumindoga, "Assessing the relationship between water quality parameters and changes in landuse patterns in the Upper Manyame River, Zimbabwe," *Physics and Chemistry of the Earth*, no. 67, pp.153–163, 2014.

[12] J. Kim, J. Noh, K. Son, and I. Kim, "Impacts of GIS data quality on determination of runoff and suspended sediments in the Imha watershed in Korea", *Geosciences Journal*, vol. 2, no. 16, pp. 181-192. 2012.

[13] E. K. Larsona and C. Perrings, "The value of water-related amenities in an arid city: The case of the Phoenix metropolitan area," *Landscape and Urban Planning*, no.109, 2013.

[14] K. S. Lee and E.-S. Chung, "Development of integrated watershed management schemes for an intensively urbanized region in Korea," *Journal of Hydro-environment Research*, no. 1, pp. 95-109, 2007.
[15] J. Leon-Munoz, C. Echeverria, R. Marce, W. Riss, B. Sherman, J. L. Iriarte, "The combined impact of land use change and aquaculture on sediment and water environmental quality in oligotrophic Lake Rupanco," *J. Environ. Manag*, no. 128, pp. 283–291, 2013.
[16] B. Lin, X. Chen, H. Yao, Y. Chen, M. Liu, L. Gao, and A. James, "Analyses of landuse change impacts on catchment runoff using different time indicators based on SWAT model," *Ecological Indicators*, no. 58, pp. 55-63, 2015.
[17] Y. Liu, H. Long, T. Li, and S. Tu, "Land use transitions and their effects on water environment in Huang-Huai-Hai Plain, China," *Land Use Policy*, no. 47, pp. 293 – 301, 2015.
[18] E. Lytras, "Developing models for lake management," *Desalination*, no. 213, pp. 129-134, 2007.
[19] NAHRIM and NRE, "A Desk Study on the Status of Eutrophication of Lakes in Malaysia," Technical Report, pp. 85–90, 2005.
[20] R. G. Niswonger, K. K. Allander, and A. E. Jeton, "Collaborative modelling and integrated decision support system analysis of a developed terminal lake basin," *Journal of Hydrology*, no. 517, pp. 521-537, 2014.
[21] Y. Tsuzuki, "Relationships between pollutant discharge and water quality in the rivers from "better" to "worse" water quality," *Ecological Indicators*, no. 52, pp. 256-269, 2015.
[22] C. M. Tuttle and M. D. Heintzelman, "A loon on every lake: A hedonic analysis of lake water quality in the Adirondacks," *Journal of Environmental Economics and Management*, vol. 1, no. 57, pp.21-44, 2014.
[23] World Lake Vision Action Report Committee, *Implementing the World Lake Vision for the Sustainable Use of Lakes and Reservoirs*. International Lake Environment Committee (ILEC), 2007.