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WATER QUALITY INDEX AS A CRITICAL TOOL FOR AN ASSESSMENT OF BIODIVERSITY OF INLAND WATER ECOSYSTEM

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ABSTRACT

The importance of brackish water lagoon, Chilika for hotspot of biodiversity in Asian continent was studied vigorously to value the water quality for conservation of biodiversity. The water quality index for biodiversity (WQIB) is the measurement tool used for assessment of biodiversity. The study covers 16 sampling locations for the selected parameters to monitor monthly during the period (2011- 2015). The individual sectors of the lagoon possess unique characteristics. The water quality of northern sector highly deteriorated compared to other sectors. Water quality of the outer channel is least infected. The study highlighted that the summer season is the best period for enrichment of biodiversity and monsoon is the worst period for the biodiversity conservation.

Keywords: Water quality index; biodiversity; coastal lagoon

INTRODUCTION

Biodiversity of coastal ecosystems is controlled by the characteristics of water quality. A number of water quality measurements have been used as an ecological indicators and substantially correlates with biodiversity. As water quality is directly correlated to biodiversity, a degradation of water quality can be expected to result in a loss of biodiversity. Only a single measure may be unable to describe the overall water quality of any water body. Whenever, a number of water quality measures fail to explain the normal, expected or ideal concentrations, in such case, composite indices are able to quantify and identify the behaviour of biodiversity of ecosystems. For safe management of aquatic ecosystems like lake, river and ocean, a well-developed tool, water quality index for biodiversity was introduced to track the changes in water quality, which adversely affect the biodiversity at monitoring stations. This method allows us to summarize complex data and compare water quality conditions across a range of inland water types. This study attentively care for development of a composite index of water quality, which strongly relates to biodiversity. A vigorous exercise was extrapolated for including selective parameters in the index, the targets or benchmarks for each parameter in assessing biodiversity.

It is difficult to specify the single answer for clarifying the definition of water quality, because a number of physical, chemical and biological parameters that can be used to measure water quality (UNEP GEMS/Water, 2006). To define water quality in terms of 'quality for life' (e.g., the quality of water needed for human consumption), 'quality for food' (e.g., the quality of water needed to sustain agricultural activities), or 'quality for nature' (e.g., the quality of water needed to support a thriving and diverse fauna and flora in a region) and the selection of parameters used to assess the quality of water depends largely on the intended use of the body of water. Regular interval of monitoring of physical and chemical properties of water quality summarily useful for possible detection of changes (both good and bad) and implement response measures to mitigate detrimental change before a situation worsens.

Monitoring data have useful concern to identify the ecological hot spots or areas, which require immediate attention; in some cases, it enables attention to be focused where it is needed the most. The set of monitoring database are useful for ecosystem manager to track the quality of water and special attention alerted for improving water quality.

Who monitors water quality?

The responsibility is shared among a number of agencies: federal, provincial, state or territorial, municipal or regional governments and they may all be responsible to monitor water quality in inland waterbody depending on the governance structure within a geopolitical region. Industrialist must also pay attention on monitoring the aquatic environment, whenever discharging industrial effluents. To find out the possible outcome for their own interest of general public, landowners, research agencies and non-governmental organizations may also take the responsibility for monitoring water quality. In some cases, the international organisation depends on national monitoring authorities to keep track on global database of water quality data of inland waters. A number of international agency working on the prospective of gathering online global database on water quality. The UNEP GEMS/Water Programme secured a unique place among them to monitor the state of inland water quality as it maintains the only global database of water quality for inland waters.

GEMStat is an online global database of water quality developed by GEMS/Water that has over two million entries for lakes, reservoirs, rivers and groundwater systems, and its over 3,000 monitoring stations include baseline (reference or non-impacted), trend (impacted) and flux (at the mouth of large rivers that discharge into the oceans) stations. Data in the GEMS/Water database date back to the 1960s.

Composite Indices of Water Quality

There is lacuna for submitting globally recognised composite index of water quality. Some countries or regions are using aggregated water quality data in the development of water quality indices. The process of normalisation, standardisation of database of water quality according to expected concentrations and interpretation of ‘good’ versus ‘bad’ concentrations classify the water quality indices. In most of the cases, the parameters are tested to fit their importance to overall water quality and the index is calculated as the weighted average of all observations of interest (Pesce and Wunderlin, 2000; Stambuk-Giljanovic, 1999; Sargaonkar and Deshpande, 2003; Liou et al., 2004; Tsegaye et al., 2006). A number of key national and international indices are shown in Table 1.

Different types of indices are used to measure their progress for different category of systems. The water quality indices used for gathering a number of information from a number of sources and combine them to shape out a clear status of the national system similar to indices of economic strength, such as Gross National Product (GNP).

Development of Indicator

It is essential to maintain a good scale of quality of inland water for conservation of biodiversity and secure the aquatic life on the point of view of safe environment. The characteristics of inland waters face a large modification to fulfil the demand to supply water for domestic, agricultural and/or industrial use to a growing population. As a result, a number of ecological imbalance growing like habitat loss, pollution, introduction of invasive species, and the manipulation of flows by the construction of dams. Ultimately, these are responsible for losses of biodiversity. The Convention on Biological Diversity (CBD) deeply analysed on this aspect and draw attention on inland water body as one of the most alarming ecosystem types and highlighted that biodiversity of fresh water ecosystems declining faster than for any other biome (CBD, 2001). It is mostly important to monitor water quality on a global basis for detaching areas, where water quality degrading in a greater rate and adopting successful techniques for the improvement of conditions of this area.

Table 1. Key National and International Indices developed for water quality

Index	Target	Method	Country	References
The scatter score index	Water quality	Assesses increases or decreases in parameters over time and/or space	Mining sites, USA	Kim and Cardone (2005)
The Wellbeing of Nations Environmental Performance Index	Human and Ecosystem Environmental health and ecosystem vitality	Assesses human indices against ecosystem indices	Globally	Prescott-Allen,2001
Index of River Water Quality	River health	Uses proximity-to-target measures for twenty five performance indicators tracked in six policy categories and combined into a final index score	Taiwan	Liou et al. (2004)
Overall Index of pollution	River health	Assessment and classification of a number of water quality parameters by comparing observations against Indian standards and/or other accepted guidelines e. g WHO	India	Sargaonkar and Deshpande (2003)
Chemical Water quality Index	Lake basin	Assesses a number of water quality parameters by standardizing each observation to the maximum concentration for each parameter	USA	Tsegaye et al. (2006)
Water Quality Index for freshwater life	Inland waters	Assesses quality of water against guidelines for freshwater life	Canada	CCME(2001)

Parameter selection

A number of parameters, which are responsible to define the definition of water quality. Out of these, a few measurements that can be measured easily. On view of global prospect, these parameters should be measured on a regular basis, and that are clearly correlated to biodiversity in aquatic environments. A strong survey on literature were exercise to find out the specific parameters, which are responsible to assess water quality. It is mostly important to review on literature deeply, to findout which water quality parameters responsible for reflective of aquatic biodiversity in both temperate and tropical rivers and lakes. The literature survey draw a concrete relationship between a number of key water quality parameters and biodiversity measures in both invertebrate and vertebrate species. A strong citation highlighted the above statement, a study carried out in the Damas River Hydrographic Basin using macroinvertebrates as indicators found that a number of parameters were significantly related to biodiversity (Figueroa et al., 2003). This study revealed a strong negative relationship in between Families Biotic Index (FBI) and dissolved oxygen (r^2=0.53). The FBI was inversely related to species richness, i.e., it was a measure of worsening biodiversity. They also observed a positive relationship between the FBI and conductivity (r^2=0.50) total phosphorus (r^2=0.71), temperature (r^2=0.66), nitrite (r^2=0.56), BOD (r^2=0.46) and total nitrogen (r^2=0.46). In a study assessing macroinvertebrate diversity and abundance in urban streams in Manaus, Amazonas, Brazil, dissolved oxygen and species abundance were found to be positively correlated (r^2=0.76) (Couceiro et al., 2007). Canonical correspondence analysis also identified that streams with few macroinvertebrate taxa were associated with high values of conductivity as well as temperature, pH and nutrients (nitrogen and phosphorus). They concluded that reduced taxon richness was closely associated with elevated nutrients in these areas.

Dyer et al. (2003) conducted a study looking at the influence of untreated wastewater to aquatic communities (algae, invertebrates and fish) in the Balatuin River, The Philippines. Taxon richness and abundance of macroinvertebrates were influenced by wastewater discharge. Specifically, decreased DO and increased BOD were associated with the wastewater discharge and sites dominated by pollution-tolerant species, e.g., oligochaete worms and chironomids. Ammonia was also identified as a causal factor of poor colonization and recovery of species in areas affected by the discharge. In an earlier study, Dyer et al. (2000) also identified ammonia as a negative, moderating factor for an index of biotic integrity and fish taxa richness in a study of fish communities within the state of Ohio, USA.

Azrina et al. (2006) measured macroinvertebrate richness and diversity indices along the Langat River, Malaysia to assess the influence of anthropogenic impacts on biodiversity. They found that both richness and diversity indices were generally influenced by conductivity, temperature and total suspended solids. Pathiratne and Weerasundara (2004) looked at organic pollution status in three inland water bodies in Sri Lanka. They found that benthic oligochaete species richness and abundance were consistently higher in the highly eutrophic and organically polluted Lake Beira. Oligochaetes are used to assess organic pollution and trophic status, an increase in richness and abundance is indicative of organic pollution. They found that the structure of the oligochaete communities was influenced by conductivity, nitrate and BOD.

Growns et al. (1992) assessed macroinvertebrates, zooplankton and water quality variables in wetlands near Perth, Australia. They found that in the most nutrient enriched wetlands species richness decreased and numbers of tolerant species increased. In a study assessing Odonata distribution in a lowland river catchment in eastern England, phosphate concentrations, BOD and low velocity were found to influence larval assemblages (Hoffmann and Mason, 2005). Adult populations were found to respond indirectly to BOD and ammonia concentrations. Nutrient enrichment and its effects on periphytic communities were assessed by Marcus (1980). The study found that nitrogen concentration was the only stream physiochemical parameter which correlated with periphytic variations. It was suggested that ammonia was the primary factor influencing periphytic growth. The distribution of epilithic diatoms in the Nairobi River, Kenya were assessed with regards to environmental conditions (Ndiritu et al., 2006).

It was found that diatom assemblages responded to concentrations of nitrate, nitrite, phosphate, conductivity, TDS, alkalinity and temperature. Diatom richness was also found to be significantly related to temperature, altitude, BOD, conductivity, calcium, alkalinity, organic nitrogen and phosphorus in a study conducted in the La Trobe River, Australia (Chessman, 1986). Baldigo and Lawrence (2000) investigated the direct effects of acidification on fish community composition in the Neversink River, New York. They found that species richness and total density of fish were adversely affected at strongly to severely acidified sites. Regression analysis revealed that pH, along with Ca^{2+}, Al, K^{+} and temperature accounted for 75 to 80% of variability in species richness; pH having a positive relationship ($r = 0.86$). They concluded that species distributions and species richness were most strongly affected by stream acidification. A number of water quality variables were also found to be correlated with macroinvertebrate species richness and abundance in a study conducted in farm dams in New South Wales, Australia (Brainwood and Burgin, 2006). Conductivity was one of the most closely correlated water quality variables related to community composition. Townsend et al. (1983) assessed the influence of physical and chemical factors on invertebrate and fish community structures in streams in Southern England. They found that the structure of communities was strongly related to variation in stream pH, temperature and stream discharge; where acidified sites had low species richness (r^2=0.73).

Multivariate analysis also showed that annual mean temperature, conductivity and maximum discharge were important factors in explaining species composition between sites. These studies clearly show a strong relationship between a number of key water quality parameters and biodiversity measures in both invertebrate and vertebrate species. The predominant parameters showing strong consistent correlations were pH, temperature, dissolved oxygen, nutrients (nitrogen and phosphorus) and conductivity. These primary parameters are outlined in Table 2. Variations of parameters are included within some of these categories as they have demonstrated strong relationships; for example, nitrate, nitrite and ammonia are listed under nitrogen, phosphates and dissolved inorganic phosphorus are listed under phosphorus and salinity and TDS are listed under conductivity. In addition to these a number of other parameters also demonstrated significant relationships to some measure of biodiversity but were not included in this list either because a) there were only one or two studies demonstrating the relationship or b) they were strongly related to parameters already selected, e.g., alkalinity (pH) and biochemical oxygen demand (dissolved oxygen).

The choice of parameters to be included in the computation of a composite index of water quality was based on 1) the presence of a relationship between the water quality parameter and biodiversity and 2) the availability of monitoring data for the parameter in international water quality monitoring databases such as UNEP GEMS/Water's GEMStat database and the European Environment Agency's Water Base database. With these two factors in mind, the following parameters were chosen for inclusion within the WQIB: Dissolved Oxygen, Electrical Conductivity, pH, Temperature, Nitrogen, and Phosphorus. Beyond being good correlates of biodiversity, the parameters chosen for the development of a water quality index for biodiversity were selected for an additional reasons that is, they are good indicators of specific issues that are relevant on a global basis (eutrophication, nutrient pollution, acidification, salinization, climate change).

Targets

To interpret water quality data, it is required to assign a benchmark or target for a parameter against which individual observations may be compared. In some cases, a target may be a human or ecological threshold beyond which life is impaired. In other cases, a target may be a historical value or a natural background concentration that can serve as a goal for water quality management programmes to reach through intervention and protection of water resources. Setting realistic targets for water quality is essential to identifying areas of concern as well as to working towards improving water quality on a station by station and country by country basis. Probably the most widely recognized international targets for water quality are the World Health Organization's Drinking Water Quality Guidelines (WHO, 2004) and although these are an excellent resource for ensuring safe drinking water quality and protecting human health, they do not address issues of environmental degradation of aquatic biological resources.

By comparison, there are a number of baseline, threshold, guideline or standard values for different water quality parameters that have been set or proposed at the national and regional levels for the protection of ecosystem health (UNEP GEMS/Water, 2006). These guidelines have been established by nations or regions that have comprehensive monitoring programmes such as Australia and New Zealand (The Australian and New Zealand Environment and Conservation Council), the European Union (The Water Framework Directive), the United Kingdom (Environment Agency), the USA (Environmental Protection Agency) and Canada (Environment Canada). Guidelines and standards differ according to required uses of a body of water (e.g., for human consumption, recreation, protection of aquatic life, agriculture) and the actual values may vary according to natural background conditions of the systems and what is considered 'ideal' for different parts of the world.

In some cases, even national targets do not exist for the parameters used in the index described here. This typically occurs when a parameter is not toxic at naturally occurring concentrations and/or when natural background concentrations are highly variable and, therefore, a reasonable target in one region might be impractical in another region. The Table 2 describe each parameter used in the water quality index and the targets used as a basis against which observations can be compared.

Table 2. Summary of targets for water quality parameters included in water quality index.

Parameter	Target	Details
Dissolved oxygen	6 mgL^{-1}	DO must not be less than target when average water temperatures are 20 °C
pH	6.5-8.5	pH must fall within target range
Conductivity	500	Conductivity must not exceed target
Total Nitrogen	1 mg L^{-1}	Total nitrogen must not exceed target
Total Phosphorus	0.05 mgL^{-1}	Total phosphorus must not exceed target
Temperature	Latitude dependent	Temperature must not exceed modelled temperature

Temperature target

The identification of a general target for water temperature is difficult because natural variations occur with climate and season. However, increases in temperatures that may occur due to climate change have the potential to result in shifts in species composition and loss of endemic species. Relationships between latitude and mean summer water temperature were used to compute a guideline for water temperature. Summer temperature data from the GEMStat database were used to assess trends by latitude. Summer averages were calculated for May to October at Latitudes 0 and above (northern hemisphere) and November to April at latitudes 0 and below (southern hemisphere).

Dissolved oxygen target

The lowest acceptable dissolved oxygen concentration for aquatic life, as set by the Canadian Council of Ministers of the Environment (CCME, 1999), ranges from 6 mg L^{-1} in warm water to 9.5 mg L^{-1} in cold water for the protection of early life stages of fish. These targets were derived from the US Environmental Protection Agency's "slight production impairment" estimates (CCME, 1999).The target is in agreement with the Australian guidelines for protection of freshwater ecosystems and the Brazilian guideline for Class 1 waters, that recommend DO be greater than 6 mg L^{-1} (ANZECC, 1992, Brazil, 1986). Dissolved oxygen targets were assigned on a station by station basis, based on their predicted summer average temperature (Figure 2). A guideline of 6 mg L^{-1} was applied to those stations whose predicted summer average temperature was greater than or equal to 20 ^{o}C. A guideline of 9.5 mg L^{-1} was applied to those stations whose predicted summer average temperature was below 20 ^{o}C.

pH target

The Canadian Council of Ministers of the Environment (CCME, 1999) set a guideline of pH 6.5 – 9.0 for the protection of aquatic life. That is, pH should not measure below 6.5 or above 9.0. This target is in agreement with the US EPA (US EPA, 2006), Australian water quality guidelines (ANZECC, 1992) and the European Union (EEA, 2006). In addition, WHO (2004) suggest an optimum pH range of 6.5-9.5 for drinking water; if the pH was out of this range, the suitability of the water for drinking would be markedly impaired. Brazilian water quality guidelines for Class 1 waters recommend that pH be between 6.0 and 9.0 (Brazil 1986). The target range for pH used in the global index of water quality developed here is pH = 6.5 to 8.5.

Conductivity target

The mean salinity of the world's rivers is approximately 120 mg L^{-1} total dissolved solids (TDS) which corresponds to an electrical conductivity of approximately 220 µS cm^{-1} (Weber-Scannell and Duffy, 2007). However, conductivities in fresh waters can range between 10 and 1,000 µS cm^{-1} and in highly polluted rivers conductivities can exceed 1000 µs cm^{-1} (Chapman, 1996). A number of studies have identified the effects of TDS on aquatic organisms. These include reduced egg survival and fertilization rates in fish (Peterka, 1972) as well as reduced productivity and growth in algae (LeBlond and Duffy 2001, Sorensen *et al.*, 1977) at concentrations above 275 mg L^{-1} TDS (approximately 500 µs cm^{-1}). Derry *et al.* (2003) found that when TDS increased from 270 to 1170 mg L^{-1} (approximately 500 to 1500 µS cm^{-1}), populations of the aquatic plants *Ceratophyllum demersum* and *Typha* sp. were nearly eliminated. There are no globally agreed upon guidelines or targets for TDS or conductivity.

Australia and New Zealand have set guidelines for salinity that include a conversion to conductivity (ANZECC, 1992). Default trigger values (which refer to slightly to moderately disturbed rivers) for conductivities for upland and lowland rivers nationally in Australia range between 120 and 300 µs cm^{-1}. Brazil (1986) recommends that TDS not exceed 500 mg L^{-1} (~ 780 µS cm^{-1}) for Class 1 fresh waters, used for the protection of aquatic life, irrigation of crops, and recreation. Based on this information a conductivity target of 500 µS cm^{-1} was chosen.

Nitrogen and Phosphorus targets

In a global scale, it has been less research study conducted to mark benchmarks for 'good' nutrient concentrations in inland waters, The background concentration of available nutrients present in nature that are toxic to aquatic systems, which makes difficult to set global water quality targets (UNEP GEMS/Water 2006; Dodds et al., 1998; Dodds 2002; Wetzel 2001). Thus, nitrogen and phosphorus targets for the derivation of a global water quality index were chosen to reflect the average boundary concentration between mesotrophic and eutrophic/hypereutrophic systems (Table 3).

Table 3. Nitrogen and phosphorus concentrations corresponding to intermediate (mesotrophic) to highly productive (hypereutrophic) trophic states in inland waters

Parameter	Mesotrophic	Eutrophic	Hypereutrophic	Type of water body	Source
Total Phosphorus (mgL^{-1})	0.011-0.035 0.027 0.010-0.030	0.035–.100 0.084 0.030–.100	> 0.100 > 0.100	Lakes Lakes and Reservoirs Lakes	OECD (1982) Wetzel (2001) Nurnberg (1996)
Total Nitrogen (mgL^{-1})	0.350-0.650 0.753	0.650–1.20 1.875	>1.20	Lakes Lakes and Reservoirs	Nurnberg (1996) Wetzel (2001)

Dissolved nutrient forms, which tend to cycle very rapidly through aquatic environments, can range from <1 to nearly 100 % of total nutrient concentrations across a broad range of aquatic environments, making it difficult to set boundary concentrations for dissolved forms (Dodds, 2003). However, generally strong relationships exist between annual average total and dissolved concentrations of both nitrogen and phosphorus, making it possible to predict average total concentrations based on average dissolved concentrations (Table 4). In cases where dissolved forms of nitrogen or phosphorus were reported instead of total forms, the total form was imputed based on the dissolved concentrations.

A total of 28% and 7% of the nitrogen records were imputed based on dissolved inorganic nitrogen and NO_3+NO_2, respectively, whereas 19% and 2% of the phosphorus records were imputed based on orthophosphate and total dissolved phosphorus, respectively. To reduce the effect of extreme outliers on model results, linear models were developed by excluding values that were greater than the 95th percentile of both the dependent and independent variables.

Index Calculation

The specification of water quality index for certain category like for biodiversity is a proximity-to-target (PTT) is an index calculated on a station by station manner using measured concentration of the parameters as outlined above (temperature, dissolved oxygen, pH, electrical conductivity, total nitrogen, and total phosphorus).

Table 4. Regression models predicting total nitrogen and phosphorus based on dissolved forms of the same nutrient.

Nutrient (total number of records with real data)	Model	Model r^2	Residual variance	N to build model	Number of records where Total N was imputed
Total nitrogen	0.474+1.135*(Dissolved inorganic nitrogen) 0.614+1.205*(NO_3+NO_2)	0.88 0.78	0.351 0.702	27,615 23,226	17,851 4,222
Total Phosphorus	0.034+1.307*(Orthophosphate) 0.0232+1.1832*(Total dissolved phosphorus)	0.72 0.63	0.0036 0.0034	39,458 373	11,768 544

The criteria for determination of PTT scores for each parameter were manipulated from exceedances of annual average concentrations from targets, following winsorization of the exceedance data at the upper 95th percentile. The difference in between observed values and the target divided by the range between the worst observed value and the target provides the PTT score. In general, this score varied in between 100 (targets met) and 0 (most extreme failure to meet targets). The WQIB was calculated by optimising the average PTT scores for the variables at a location in one year. The PTT score of 100 represent the WQIB is good symptoms, wherever, this value progress through declining trend, it highlighted the detonation condition of water quality. Table. 5 presented the status of WQIB. The nutrient parameters (nitrogen and phosphorus) failed to meet targets and the nutrient PTT scores were the most strongly correlated to the WQIB. WQIB scores ranged from 0 to 100, and averaged 83.2 with a median of 90.8 (Table 5).

Table 5. Summarisation of qualifying target score for water quality index for biodiversity

Parameter	Avg. ± SD	Median	N	% of records falling to meet target	Pearson's r
Conductivity	91.2±25.0	100	23,996	13.5	0.58
Nitrogen (N)	76.4 ±31.7	92.8	65,876	61.2	0.78
Dissolved oxygen (DO)	85.6 ±28.6	100	53,185	31.0	0.61
pH	92.3±24.5	100	54,326	12.1	0.24
Phosphorus (P)	81.1± 29.5	95.9	64,521	59.6	0.80
Temperature	85± 29.0	100	7,922	31.1	0.45
WQIB	83.2 (20.4)	90.8	73,655	76.0	1.00

CONCLUSIONS

The better biodiversity conditions of any ecosystems act as a measurement key to present better health conditions of any ecosystems. For qualitative representations of biodiversity, calculation of water quality index of that ecosystem is most prier assignment. The present study highlights sector wise biodiversity conditions of a largest brackish water lagoon, Chilika by analysing water quality index of different sectors. Northen sector of the lagoon secure very critical biodiversity loss due to effect of detoriated water quality of that particular sector. The study significantly draw the attention of Lake Management authority for encouraging developing a special monitoring tool for this particular sector.

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