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AN INVESTIGATION INTO THE TEMPORAL PATTERN OF WATER QUALITY OF A NEWLY FORMED FRESHWATER LAKE

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Abstract: Cardiff Bay, one of the largest man-made freshwater lakes in Europe, was formed in April 2001 when two of the main rivers in South Wales, United Kingdom were impounded by the construction of a barrage. The water quality of Cardiff Bay has been intensively monitored, primarily due to the wetland reserve which was undergoing a fairly steady succession from the previous estuarine habitat. The present study was carried out to investigate the physical, chemical and biological quality of water in Cardiff Bay. Seven water quality parameters namely pH, biochemical oxygen demand (BOD), Ca, Mg, Cl, total hardness and total suspended solids (TSS) were analyzed for a period of five years from 2001 to 2005 to investigate their temporal variation in this study. The findings indicated that variations in water quality across Cardiff Bay were small during this period. In general, pH, BOD, Ca and hardness showed a slightly increasing trend as opposed to Cl which decreased. Mg was temporally homogeneous and TSS varied inconsistently. A comparative study was conducted against the relevant data obtained from Sasthamcotta Lake in Kerala, India in which higher values of pH, Ca and Mg were observed in Cardiff Bay. The necessity for long-term data sets was highlighted due to the observed lack of correlation among the indicators, which therefore suggests that a long-term monitoring is imperative in assessing the water quality trend as well as management strategies.

Keywords: *physico-chemical, water quality, temporal, Cardiff Bay, freshwater lake.*

1. INTRODUCTION

Water is an essential component for the survival of life on earth. Lakes and surface water reservoirs comprise one of the most important freshwater resources and provide numerous benefits. Inland lakes are immensely popular due to their various features, particularly as recreational community development. Freshwater lakes can be of natural origin (e.g., Lake Baikal) or artificially impounded (e.g., Cardiff Bay).

According to the Water Framework Directive (2000/60/EC), an 'artificial water body' is a body of surface water created by human activity in a location where no significant water body existed before and which has not been created by the direct physical alteration, movement or realignment of an existing water body [1]. Artificial water bodies are created for a range of diverse purposes. The Upper Lake (Bhojtal) of Bhopal, situated in the state capital of Madhya Pradesh, India is one of the most important sources of potable water supply for Bhopal city [1]. In Suriname, an artificial lake, Lake Brokopondo, was built after the construction of Afobaka dam on the Suriname River in 1964 [2]. The lake has been used as a source of water for hydroelectric power generation. Jim Chapman Lake, previously known as Cooper Lake, impounded on the South Sulphur River in 1991, was primarily constructed for flood control and water supply, while ancillary uses included recreational boating and fishing [3]. Lake Volta, the largest man-made lake in the world in terms of surface area and the fourth largest by water volume, was created following the construction of Akosombo dam across the Volta River in Ghana [4]. Besides storing water for the generation of electricity, the lake has been utilized as a key source of water supply for domestic, agricultural and industrial purposes. Fishing, inland navigation, tourism and recreational activities are several features associated to this lake.

Cardiff Bay is a newly formed water body which inundated the tidal mudflats at the mouth of the rivers Taff and Ely following the closure of the estuary. This bay had undergone major regeneration, including the construction of the Cardiff Bay Barrage, one of the largest civil engineering projects completed in Europe [5]. The barrage, which measures 1.1 km in length, was designed to impound freshwater from the rivers Taff and Ely to create a persistent freshwater lake. The bay was intentionally impounded with seawater in November 1999 by closing the barrage. It was then drained overnight approximately once every week until September 2000. Eventually, a freshwater inland bay with a permanent waterfront of about 13 km was created. The 200 hectares freshwater lake was introduced as the centerpiece of a vast regeneration scheme; the main vision was to transform Cardiff into a superlative maritime city onto the international map.

Natural lakes and artificially constructed impoundments should be considered separately. Impounding fundamentally alters the dynamics of estuaries with consequences in terms of sedimentation rates, pattern and water quality [6]. Cardiff Bay is a unique water body, however, little known in context of the aquatic species assemblages and interactions, water quality trends, and the effects of water chemistry parameters on aquatic life. Opportunities were created from extensive water quality monitoring data that was collected over the first five year period since the bay was converted into a freshwater environment. The objective of this present study was to examine the effects of water quality through various parameters and to assess whether the existing data was adequate enough to detect any changes in temporal patterns, which might be of significant importance to the aquatic life exist in the bay.

2. MATERIALS AND METHODOLOGY

A. Study Area

The study area, Cardiff Bay, is located in the south of Cardiff, the capital of Wales having latitude 51°27′28″N and longitude 3°08′24″W (Fig. 1). This shallow freshwater lake has a surface area of 2 km^2 (200 hectares) with a mean depth of 4 m. Water quality of the bay had been a huge concern as it received a large amount of organic matter from two urban rivers, the Taff and Ely. Owing to the prediction of excessive algal growth due to very high concentration of total phosphorus and chlorophyll-a, Cardiff Bay was designated as a sensitive area (Eutrophic) under the Urban Wastewater Treatment Directive [7]. The occurrence of toxic algae can potentially poison fish and other wildlife within the lake and thereby pose a threat to public health.

Fig. 1. Cardiff Bay [8]

B. Data Collection

Cardiff harbor authority (CHA) is the main body responsible for collecting and monitoring data to maintain water quality within the bay. A comprehensive water quality monitoring program has been implemented in adjacent water. The main features of this program were continuous monitoring of water quality at six locations using probes suspended from buoys which collect data every 15 minutes and transmit to a harbor authority computer in an hourly basis; regular monitoring of water quality using mobile equipment deployed from the water vessel; and regular retrieval of water samples for laboratory analysis [1]. The data analyzed for this study were collected from CHA through Catchment Research Group, Cardiff University.

C. Data Analysis

The present study attempted to observe the trend of water quality in Cardiff Bay following its impoundment for a period of five years (2001-2005). The original data set had information on date and site for the respective parameters. The data was categorized into yearly basis. Seven water quality parameters were considered for this study (Table I) which was selected on the basis of their impact on lake ecosystem. Standard statistical tool was applied to analyze the data, identify any significant temporal variation for different parameters and possibly comment on the observations made.

Table I. Physico-chemical parameters that were analyzed during this study

Parameter	Abbreviation	Unit
pH	pH	Unit less
Biochemical Oxygen Demand	BOD	mg/l
Calcium ion	Ca	mg/l
Magnesium ion	Mg	mg/l
Chloride ion	Cl	mg/l
Total Hardness	Hardness	mg/l
Total Suspended Solids	TSS	mg/l

D. Temporal Variation

Temporal variation of chemical quality of artificial water bodies can be described by studying concentrations or by determining factors such as settling rates, biodegradation rates or transport rates. Temporal variability can occur to one of the following reasons [9]:

- Diel variability (24 hour variations) limited to biological cycles

- Days-to-months variability mostly in connection with climatic factors and to pollution sources
- Seasonal hydrological and biological cycles
- Year-to-year trends, mostly due to human and hydrological influences

Variation of different water chemistry parameters due to seasonal changes is a common feature for freshwater environment. Parameters like pH and suspended solids may vary significantly in the respective receiving water bodies.

3. RESULTS AND DISCUSSION

A. pH

The acidic or alkaline condition of water is expressed by pH which is a basic water quality parameter. The pH of water determines the solubility (amount that can be dissolved in water), biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, carbon) and heavy metals (lead, cadmium, copper etc.) [1]. The pH ranging from 6-9 is suitable for the existence of most biological life [10]. A general increasing trend in the magnitude of pH was observed for temporal pattern; however the variation was not of much significance. The rate of increase from year 2001 to 2002 was only 1.6%, which was by far the highest difference among five years. Mean pH was found to be the highest in 2005 at 8.11. An explanation for the increase in pH of the lake water might be due to the growth of excessive algae or phytoplankton that uptakes CO_2 for photosynthesis.

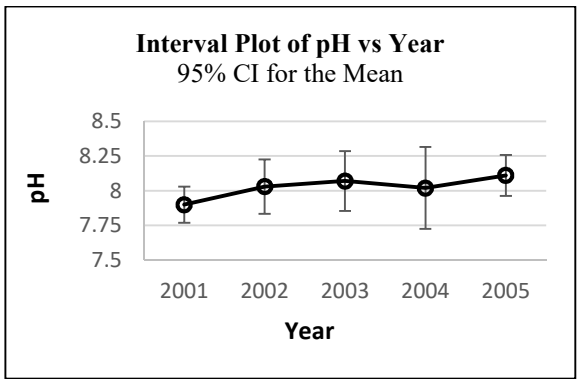

Fig. 2. Temporal variation of pH

B. BOD

The BOD_5 is a measure of the amount of oxygen that bacteria will consume in five days at 20°C while decomposing organic matter under aerobic conditions [11]. Oxygen required during first five days is usually considered as standard BOD. Unpolluted waters typically have BOD values of 2 mg/l or less [9]. In this present study, BOD values ranged from 1.06 mg/l to 1.34 mg/L. Generally, the pattern showed an increasing trend where the highest value was recorded in 2004. If BOD loading increases and subsequently depletes the oxygen level, certain species of fish and bottom-dwelling organisms might die. An extensive aeration system was embedded in the lakebed so that oxygen level is kept above a statutory 5 mg/l at all times within the bay [7]. Regular skimming was carried out to remove debris and algal scum from the lake surface.

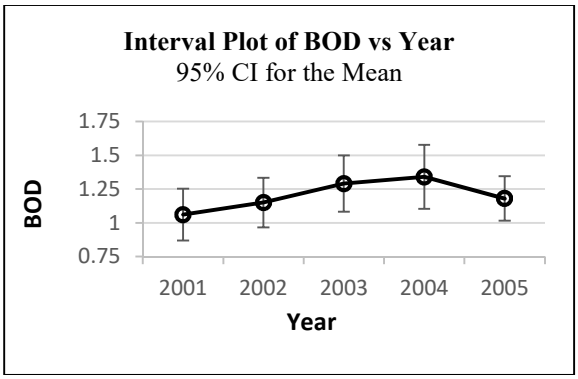

Fig. 3. Temporal variation of BOD

C. Ca and Mg

The chemical composition of a lake is fundamentally a function of its climate which affects hydrology and basin geology. The major cations in lake systems are calcium, magnesium, sodium and potassium. Major anions are bicarbonate, carbonate, sulfate and chloride. Lakes with high concentrations of calcium and magnesium ions are called hardwater lakes, while those with low concentrations of these ions are called softwater lakes. The ionic concentration influences the ability to assimilate pollutants and maintain nutrients in the lake.

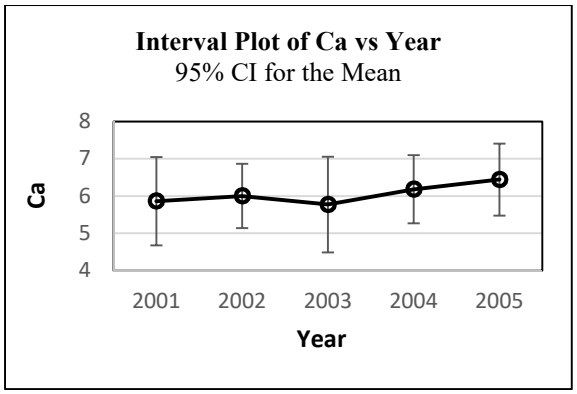

Fig. 4. Temporal variation of Ca

Calcium is an important nutrient for aquatic organism and it is commonly present in all water bodies [12].

The concentration of Ca varies greatly in natural waters depending upon the basin [13]. Magnesium is often associated with calcium in all kind of water but it usually occurs in lesser concentration than calcium due to the fact that the dissolution of magnesium rich minerals is a slow process [14]. Magnesium is essential for chlorophyll growth and acts as a limiting factor for growth of phytoplankton [15]. Mean Ca was found to be the highest in 2005 (6.44 mg/l) where as Mg was 3.42 mg/l in 2001. The variation was noteworthy in case of Ca where an upward trend was observed from 2003 onwards. The variation was not significant in case of Mg as the values followed a similar trend apart from the value in 2001.

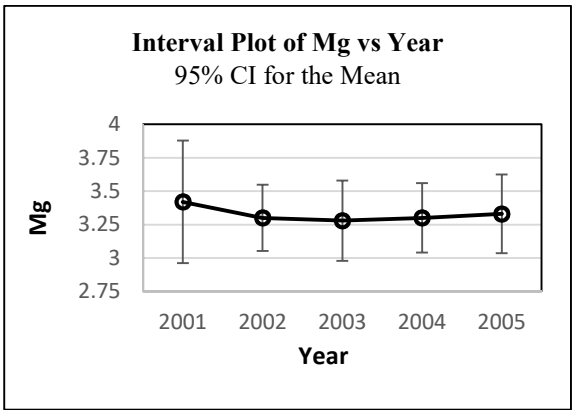

Fig. 5. Temporal variation of Mg

D. Cl

Chloride is one of the major inorganic anions in water. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff and saline intrusion [13]. A chloride concentration in Cardiff Bay was noticed between 3.27 mg/l to 3.77 mg/L. A decreasing trend of Cl was noteworthy from year 2001 to 2002, in which mean Cl significantly dropped around 40%. The reason might be due to the dilution of lake water by heavy rain. Cl might also affect BOD measurement by killing or inhibiting the microorganisms that decompose organic matter in water. An increasing trend of BOD in Cardiff Bay validated the statement.

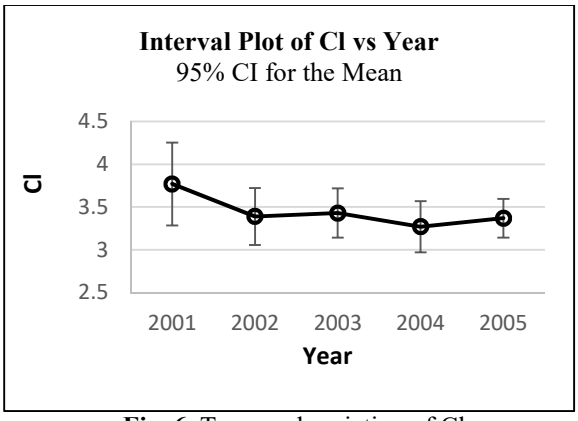

Fig. 6. Temporal variation of Cl

E. Hardness

The total hardness of water is not a specific constituent but is a variable and complex mixture of cations and anions [15]. Freshwater rich in sodium chloride can have a very low hardness. Mean total hardness value was found to be in the range between 11.45 mg/l to 12.07 mg/l in this study. A general increasing trend was observed, although marginal, where the maximum value was recorded in 2005. The lower values of hardness might occur due to the presence of low concentration of Ca and Mg in lake water.

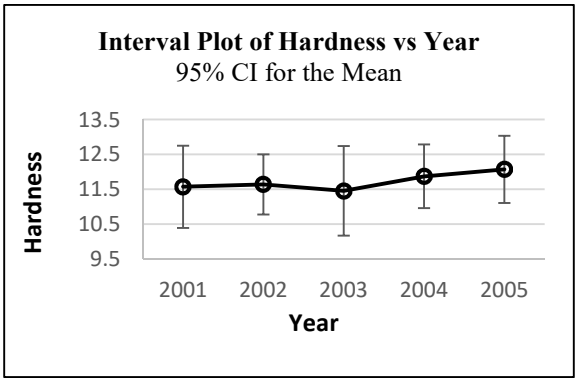

Fig. 7. Temporal variation of hardness

F. TSS

Total suspended solids are organic and inorganic solid materials, generally larger than two microns, which remain suspended in water. They include silt, planktonic algae, agricultural runoff, industrial wastes, fine debris and other particulate matter. There was no clear pattern observed in this study as TSS showed an incoherent trend with respect to time. Mean TSS was found to be lower in 2002 and 2003 as compared to 2001 and then increased in 2004 where the highest value was noticed 3.11 mg/l. The bed of Cardiff Bay is mostly composed of soft sediments, e.g., mud and silt and banks are made of cemented

pebbles [16]. The aquatic environment and organisms within the bay could be affected by increasing value of TSS.

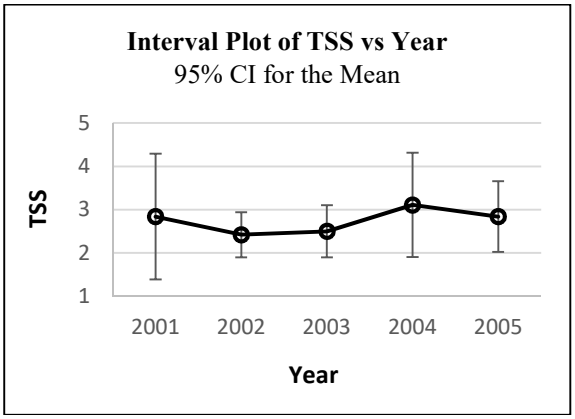

Fig. 8. Temporal variation of TSS

G. Comparison with similar literature

A comparison was made for selected parameters between Cardiff Bay and Sasthamcotta Lake, the largest natural freshwater lake in Kerala, India. In addition to being one of the major tourist attraction places, Sasthamcotta Lake is a drinking water source for about 700,000 residents in Kollam district [17]. Inland navigation and fishing are the major economic activities that take place in this lake. In a recent study, several water quality parameters were analyzed from November 2017 to February 2018 of this lake [17]. Comparing the mean values of selected water quality parameters, it was found that water in Cardiff Bay was slightly alkaline as opposed to Sasthamcotta Lake which was highly acidic. The variation was found to be insignificant when mean BOD and hardness values were compared. Higher values of mean Ca and Mg in Cardiff Bay were observed.

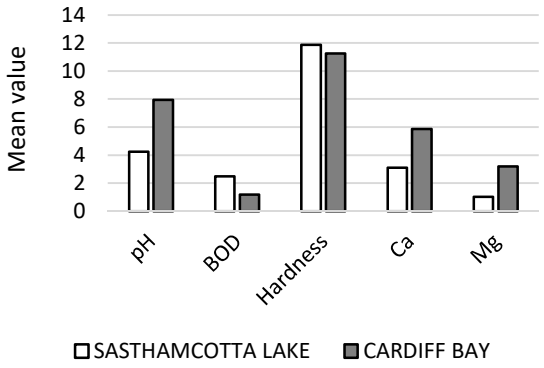

Fig. 9. Comparative study between two lakes for five water quality parameters

4. CONCLUSION

The results obtained from the present study indicated that water quality in Cardiff Bay varied from little to moderately during five years of the study. Generally, a number of parameters such as pH, BOD, Ca and hardness showed a marginal increase. This revealed that the bay water was mildly alkaline and relatively soft with respect to time within the study period [7; 18]. Mg was temporally homogeneous throughout the lake system. Cl showed a decreasing pattern where as TSS had inconclusive trend. More detailed investigation of temporal trends (e.g., summer, winter or quarterly in each year) in chemical and nutrient concentration and further analysis of such trends would have been advantageous. Spatial distribution of water chemistry variables across the bay including the rivers Taff and Ely were not covered in this research. Development of any correlation among the physico-chemical parameters are another aspect that needs to be included in future studies.

Short-term predictions are necessary for tactical control of sudden escalating impacts on freshwater quality such as harmful algal blooms or toxic contamination. However, long-term predictions are needed for strategic management of gradual escalating impacts on freshwater quality such as eutrophication or acidification [1]. Long-term data are invaluable for detecting environmental trends since many environmental characteristics are intrinsically highly valuable [19]. Cardiff Bay is a relatively recent formation in comparison to the other artificial impoundments considered in this study. Continuation of further investigation of the data is required to predict seasonal trend, correlation and future direction with better accuracy. The control of lake water quality is based on sound management practice in relation to the required water uses and a detailed knowledge of these processes is of significant interest.

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