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Paleolimnological approach infers past environmental changes archived in lake sediments of Bukit Merah Reservoir, Malaysia.

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Abstract Human activities in the watershed of Bukit Merah Reservoir, have significantly increased, placing unprecedented pressure on this important system. However, long-term records of the ecological effects are scarce. Thus, this research aims to examine the impact of human-induced environmental change on the reservoir using a paleolimnological approach. Two 25 cm sediment cores were extracted from the reservoir using a Uwitech corer, and analysed for ^{210}Pb, elemental geochemistry, and diatom remains. Using ^{210}Pb and the Constant rate of Supply Model (CRS) the oldest sediments (22.5-24.5 cm) were dated to AD 1985 ± 34 years. The mean concentration of metals (As, Cd, Cu, Pb, and Zn), total nitrogen (TN), total organic carbon (TOC), and total phosphorus (TP) increased from the bottom of the core and fluctuated to the top. This may be ascribed to increasing usage of agrochemicals, tourism, industry contributions, sand excavation, and inputs from small and medium-scale companies in the catchment area. In this study, the dominance of diatom species (*Aulacoseira granulata*, *Aulacoseira ambigua*, *Discostella stelligera*, and *Cyclotella meneghiniana*) throughout the length of the core, indicates high productivity of the reservoir due to continuous human impacts. As a result, immediate action is needed to further ameliorate the degradation of the reservoir.

Keywords: Paleolimnology, sediment core, diatom, geochemical, human impact

1. Introduction

Human impacts on inland water bodies and their catchments are common in the Anthropocene epoch. Long-term monitoring is crucial to indicate that impacted aquatic ecosystem functions are compromised by human activities (Smol and Douglas, 2007). Such data on environmental change are particularly valuable for determining the reference conditions of an ecosystem in the absence of significant human impacts, which can be used to estimate the timing and severity of anthropogenic disturbance. Identifying this perceptible shift enables the setting of management targets and advances scientific knowledge on the intricate interaction between individuals, climate, and environment (Bennion et al., 2011)

Lakes are natural accumulators of large and diverse organic, chemical, and lithic materials which are sensitive to abiotic and biotic environmental changes. The breakdown of nutrients and materials derived from the lake basin including watersheds (terrestrial input) and airsheds (atmospheric input) are conserved in a chronological sequence in lake sediments (Smol and Douglas, 2007). A sediment profile that accumulates in relatively undisturbed conditions can thus be used to reconstruct and infer past biota and environmental conditions through paleolimnology approach. Paleolimnological is a multidisciplinary science that deals with the study of biological, chemical, and physical indicators conserved in sedimentary profiles (Smol and Douglas, 2007). Specifically, the study of sedimentary diatom remains and preserved geochemical constituents archived in lake sediments allows for reconstructing common anthropogenic environmental impacts on the freshwater ecosystem through time (Bennion et al., 2011). It can also allow for the determination of the source of such pollutants, whether they be atmospheric contaminants, point source pollution from agriculture, aquaculture, or impacts of climate change.

Bukit Merah Reservoir (BMR) is the oldest man-made reservoir in Peninsular Malaysia. The reservoir is hugely important to regional potable and agricultural water supply, however, its surrounding catchment areas have been experiencing heavy pressure from agricultural activities, tourism, and other land use forms (JPBD, 2017). In addition, the human population around the catchments has increased significantly in recent decades due to expanding economic activities. These activities have been shown to affect the ecological balance of this reservoir, nevertheless, the management of these impacts on this important reservoir is difficult in the absence of long-term data. Thus, this study was conducted to determine the environmental change through the study of geochemical and diatom signatures preserved in the sediment of BMR.

2. Materials and Methods

2.1 Study area and sample collection

The Bukit Merah Reservoir (Figure 1) is situated at 05°01′35.42″ N, 100°39′42.92″ E, in Kerian district of Perak State, Northern Malaysia. It is a modified homogenous dam that was constructed in 1902 and began operating in 1906. The reservoir has a surface area of about 40 km^2 and a mean depth of 2.5 m, fed mainly by water supplies from the Sungai Karau and Merah of the catchment area.

Two sediment cores (BMR1 and BMR2) were taken from the reservoir in 2018, at a depth of 2.65 cm, using a UWITEC gravity corer with a 9 cm diameter and 120 cm length. The cores were transported to the laboratory, sectioned into intervals of 1 cm each, and stored in a whirl-pak® following analysis in the laboratory. Sediment cores (BMRI) were used for radiometric and diatom analyses. While sediment core (BMR2) was used for trace metal, and nutrients (total nitrogen, total carbon, and total phosphorus) analysis.

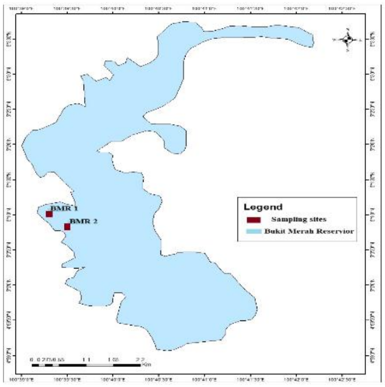

Figure 1: Study area map showing the sampling points

2.2. Sediment chronology

For dating, ^{210}Pb concentration in the sediment core was determined by gamma particle spectrometry (Appleby, 2008). The samples were placed into plastic tubes, sealed with 2-Ton Epoxy®, and allowed to rest for about three weeks to ensure radioactive equilibrium between ^{226}Ra and ^{210}Pb. Sedimentation rate and sediment age were computed using the Constant Rate of Supply (CRS) dating model (Appleby, 2008), by linear regression between excess ^{210}Pb and core depth.

2.3. Geochemical analysis

For metal analysis, about 0.5 mg of freeze-dried sediment was placed in Teflon tubes, and aqua regia mixture in a ratio of 7HNO$_3$: 3 HCL was poured into the sample and placed in a microwave digester for sample digestion for 4 hours at a temperature of between 200 ºC to 300 ºC. Digested samples were passed through a 0.45µm filter paper and made up to 50 cm^3 volume with distilled water. ICP-OES (Agilent Technologies 700 series) was used to analysed Pb, As, Cu, Cd and Zn in the filtered samples.

For nutrient analysis, sediment samples were grounded to a fine powder with the aid of a pestle and mortar and treated with 10% HCL to remove carbonates. Treated samples were analysed for percentage total nitrogen (% TN) and percentage total organic carbon (% TOC) by simple combustion in the Perkin Elmer 2400 Series II CHN Elemental Analyser (Perkin Elmer). Total phosphorus was determined by the molybdenum blue method of Murphy and Riley (1962).

2.4 Diatom analysis

A modified method of Renberg (1990) for diatom preparation was used, which involved the treatment of freeze-dried sediments with 20 % HCl to remove carbonates and 30 % hydrogen peroxide to remove organic materials. The samples were placed in the water bath at 90 °C till the organic materials had been removed. Naphrax was used to mount the cleaned samples onto microscope slides. Olympus light microscope (Model BX53F, Olympus, Japan) x 1000 magnification was used to identify and enumerate diatom to species levels if possible and a minimum of 300 valves were counted per sample. Diatom identification was based on the taxonomic keys of Krammer and Lange-Bertalot (1986).

2.5 Numerical analyses

Geochemical and diatoms zones were delineated by Bray Curtis Clustering analysis using PAST (Paleontological statistics software package for education and data analysis)

3. Results and Discussions

3.1 Sediment core chronology

The constant rate of supply model (CRS) dating model (Appleby, 1998) was employed to derive the sediment accumulation rates and chronologies of the sediment core from BMR, as relatively low unsupported ^{210}Pb activity was detected at 12 cm which may be due to increased sedimentation rate at the depth to the bottom of the core. The CRS model dated the oldest sediments (22.5 – 24.5 cm) to AD 1985 ± 34 years . The sedimentation rates in this core fluctuate with an average of 0.23 g cm^{-2} yr^{-1}, and the highest rate of 0.47 g cm^{-2} yr^{-1} in the 1990s, which is indeed high compared to most reservoirs studied in southeast Asia (Anjum et al., 2018). Details on the activities of ^{210}Pb and ^{137}Cs in the core of BMR have been described in the study of Akogwu et al. (2023).

3.2 Geochemical stratification

The geochemical variation in the sediment core was interpreted by environmental change and the characteristics of human activities in the watershed delineated from cluster analysis as shown in zone 1 to 3

Zone 1 (24-18.5 cm). The concentrations of metals were minimal in this zone, with As, Cd, Cu, Pb, and Zn recorded concentrations of 8.45mg/kg (1985), 0.39 mg/kg (1987), 0.98mg/kg (1986), 11.50mg/kg (1989), and 20.45 mg/kg (1988) respectively (Figure 2). This period marks the early commencement of agricultural projects before urbanisation and the increasing impacts of land use activities in the 1990s. As such, there seems to be no clear input of metal pollution from the catchment of BMR in the 1980s. The concentration of TOC, TN, and TP was relatively low with mean values of 0.52 %, 0.51 %, and 0.25 mg/kg respectively, implying low primary productivity of the reservoir. Furthermore, the C/N ratio used to identify the nutrient source was in the range of 11-13 in this zone, indicating the influence of external sources of sediment organic matter in the reservoir. In zone 2 (18.5- 9.8 cm), metal concentrations increased generally with Cu, As and Zn recording a high concentration of 1.78mg/kg ,10.38mg/kg, and 22.5mg/kg, in 1995, 1991, and 1993 respectively. Increasing usage of agrochemicals to boost oil palm and other agricultural products, grey water from hotels adjacent to the reservoir may be a source of metals. The peaks of Cd (1.1mg/kg) and Pb (16.5 mg/kg) recorded in this zone may be related to oil spills from motorised boats (JPBD, 2017). There was a rapid increase in the values of TOC, TN, and TP with an average value of 1.25 % 0.56 %, and 0.46 mg/kg respectively. The breakdown of the remains of aquatic vegetation covering over 4000 acres that were cleared in the 1990s may have influenced the upward increase of TOC. TN and TP were strongly influenced by exogenous inputs from fertilizer usage. Likewise, the C/N values increased with an average value of 21.5 suggesting that terrestrial vascular plants were a significant source of organic matter. In Zone 3 (9.8-0.5 cm), the metal concentration steadily increased to the top of the core with Cu, As, and Zn reaching peak concentrations of 2.62mg/kg, 12.5mg/kg, and 35.6mg/kg in 2010, 2018, and 2017 respectively, Whereas Pb and Cd fluctuated to the top of the core recording high concentrations of 15.88 mg/kg and 0.88 mg/kg in 2012 and 2006. Increasing urbanization, rapid growth, and expansion in small-scale industries, sand excavation is evidence of the heavier burden of metals in the reservoir since the 2000s. Similarly, the TOC, TN, and TP fluctuated to the top of the core (Figure 2), recording a high mean concentration of 1.26%, 0.54%, and 0.91mg/kg in 2012, 2010, and 2016 respectively. Inputs from the large establishment of goat and chicken farms, oil palm mill manufacturing activities, and agricultural runoff from heavily fertilized farming activities amongst the communities covering over 45.49 km^2 of the catchment area could accelerate nutrients into the reservoir (JPBD, 2017).

3.3 Diatom stratigraphy

In Zone 1 (24-18.5 cm), our result showed the dominance of *Aulacoseira ambigua*, *Aulacoseira granulate,* and *Discostella stelligera*, with a relative abundance of 48.50%, 41.40%, and 30.15% respectively (Figure 3). These species are commonly found in highly disturbed aquatic ecosystems and thrive in mesotrophic to eutrophic conditions (Van Dam et al., 1994). Dredging activities of the reservoir in the 1980s, stimulated further buildup of silts and pollutants that have settled at the reservior bottom , thus elicited the dominance of these species in response to changing environmental conditions. In Zone 2 (18.5- 9.8 cm), diatom assemblage remains predominated by *A. granulata*, *A. ambigua*, and *D. stelligera,* although other species such as *Stephanodiscus hantzschii*, *Cyclotella meneghiniana, Frustulia saxonica,* and *Pinnularia gibba* which are associated with mesotrophic to highly eutrophic water (Van Dam et al., 1994), significantly increased in their relative abundance accounting for 6.8%, 20.45%, 8.60%, and 18.90%, respectively, indicates a deteriorating water condition due to continuous nutrient input largely from the catchment area. In Zone 3 (9.8-0.5 cm), *Amphora pediculus* and *Brachysira brebissonii* were poorly represented in the zone because they are known to thrive in nutrient-poor water (Van Dam et al., 1994).The unprecedented increase in *Nitzschia palea* indicated high metal richness of the reservoir (Chen et al., 2014). Similarly, *S. hantzchii* and *C. meneghiniana* increased steadily to the top of the core; thus, confirming that the reservoir is currently undergoing eutrophication (Van Dam et al., 1994).

4.0 Conclusion

Bukit Merah Reservoir is a multi-stressor environment, and several human-related changes in the watershed of the reservoir have been documented in the last 34 years. Geochemical concentrations indicate the impacts of changing land use activities, especially due to urbanisation agriculture, and tourism. Diatom shifted more profoundly due to anthropogenic stressors having a significant impact on the productivity of the reservoir, indicative of a continually enriched system. Urgent attention is needed to address the current deteriorating state of the reservoir

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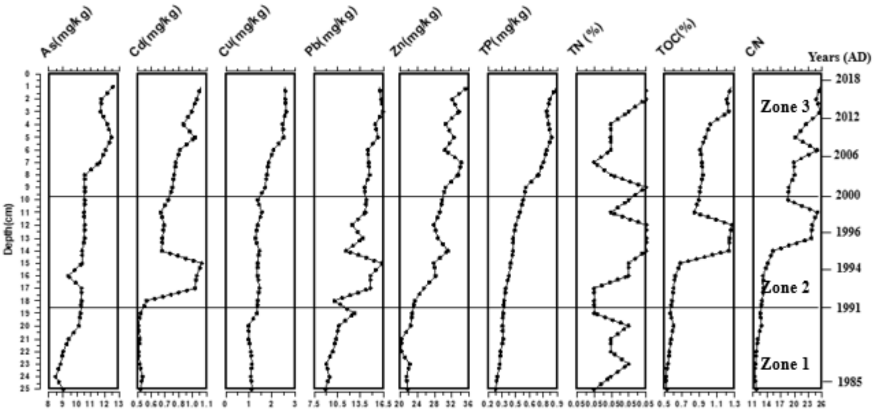

Figure 2: *Geochemical stratigraphy of core BMRI from Bukit Merah Reservoir*. Redrawn from Akogwu et al.(2023)

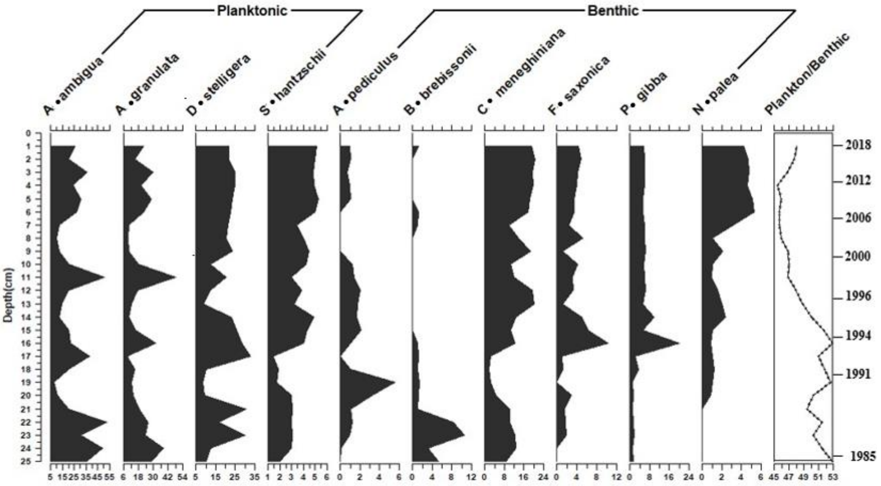

Figure 3: Diatom stratigraphy of core BMR2 from Bukit Merah Reservoir

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