Paleolimnology Record of Human Impact on a Lake Ecosystem: The Case of Shallow Lakes in Central Java

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Abstract. Paleolimnology approaches were used to assess human impacts on Rawapening and Warna Lakes, small lakes in Central Java, which provide an essential function for agricultural irrigation. Paleolimnology is the study of the stratigraphy of lakes where fossils are well preserved in the sediment thereby providing information about the past condition of the catchment area. However, paleolimnological studies in Indonesia have been rare. The organisms that are well preserved in the sediment are diatoms, due to their siliceous cell wall. Human’s activities were recorded in the 63 cm sediment core from Rawapening and 24 cm sediment core from Warna Lakes over the past 41 and 124 years, respectively. Human impacts on the lake ecosystems and their catchment area are highly variable in time and space. Since 1967 Rawapening Lake has been in a meso-eutrophic condition, related to releases from the nearby agricultural program. Since the 1990s Rawapening Lake experienced hypereutrophic conditions with pH > 9 that induced uncontrolled water hyacinth growth, which in turn, reduced lake function. The record showed Warna Lake to have been subject to eutrophication since 1980 likely owing to the acceleration of activities such as potato farming and deforestation for urban development in the lake’s catchment in recent decades. The trend of these past environmental changes could be used to predict the future condition; therefore, the appropriate management plans can be developed to guide interventions needed to ensure the future sustainable use of the lake.

Keywords: Paleolimnology, diatoms, human’s activity, eutrophication, Rawapening, Warna, lakes

1. Introduction
An increase in the type and number of human’s activities drive ongoing decreases in the water quality of lake ecosystems. Human has affected natural lakes by soil erosion and pollution (activities in the catchment area), habitat modification and species introductions (the anthropogenic drivers) and these impacts have been demonstrated in many case studies. Human pressures on lakes are expressed in many forms and are highly variable in time and space. However, the timing and magnitude of the first detectable human impacts on regional and continental scales as signals of human-induced change on the structure and functioning of lake functions require further research. The first human impact may not influence an aquatic ecosystem, possibly on account of the small population size, culture, or low-
level technologies. Even once technologies have evolved, some lake ecosystems may have the capacity to adapt through slow changes, when the catchment area has been modified through agricultural development [1]. When advanced technology and intensive agricultural practices were introduced more recently (e.g. within the last two centuries in Australia and New Zealand), the effects on ecosystems were far more acute, though this might also reflect the sensitivity of the systems [2-5].

The study of the physical, chemical, and biological information preserved in the lake sediments, that allows for the reconstruction of natural/anthropogenic change and the interpretation of past condition of the aquatic ecosystem, is called paleolimnology [6]. Paleolimnology approaches are useful to predict the future from past condition. Lake sediment sequences are similar to a diary book, in which it records historical activities in the catchment area. In the undisturbed sedimentation process, older layers are progressively overlain by younger material. The age of the sediment layers can be estimated by dating techniques that provide the timeline of past environmental changes. The fossils preserved in sediment, such as diatoms, indicated the water condition when the diatoms were alive. Sedimentary processes preserve diatoms, comprising planktonic, periphytic, epilithic, and epipelagic forms, and deposit them in a continuous assemblage. Diatom composition has been used to track down the evidence of environmental changes because they respond sensitively to environmental changes in lakes [7]. Diatoms are commonly used as bioindicators for the environmental condition because of their sensitivity to physical and chemical variables of water [8].

Diatoms are microorganisms widely distributed in almost all aquatic ecosystems, including lakes, rivers, oceans, and even on tree bark or in hot springs. They provide an important function in maintaining silica and carbon cycles, and they contribute 20-25% of the aquatic productivity to support aquatic life. Diatom assemblages in lake sediments have been used to reconstruct temperature [9], drought frequency [10] associated with shifting climate regimes, water total phosphorous, color, and pH [11], changes in trophic states [12], and water depth [13].

The assessment of paleolimnology in Indonesia using diatoms is very limited [14]. The application of diatoms was an alternative approach for biostratigraphy in the olistostrome (the mixed material of older and younger sediment) in Karangsambung Paleogene stratigraphy analysis. The soft fraction of the sediment is laminated and represents the low regime part of olistostrome suspension deposition phase. However, the application of diatom biostratigraphy in the olistostrome deposit was difficult, due to a lack of references [15]. This study is one of very few studies and it aimed to assess the impact of human’s activities by comparing the diatom assemblages down sediment cores from Rawapening [16] and Warna [17] Lakes.

Rawapening Lake is a semi-natural lake located at 7° 4’ - 7° 30’ S and 110° 24’46” - 110° 49’06” E at altitudes between 455 - 465 meters above sea level. The catchment area of Rawapening Lake covers 89.53% of the Semarang Regency, and 9.31% of Salatiga and 1.2% of the Magelang Regency [18]. Rawapening was dammed in 1936 by the Dutch East Indies Government, to create a maximum water surface area of 2,667 Ha in the rainy season (November-April) and 1,650 ha during the drought season (May-October) [19-20]. The tidal area depends on the rainfall intensity. From 2012 to 2016, the lake surface area increased from 1,693 Ha to 1,720 Ha [21]. During May and December 2016, the landcover change was triggered by a high precipitation in December and a rapid-uncontrolled growth of water hyacinth in May [22]. Rawapening Lake is heavily polluted with values of TSS, BOD, COD, total phosphorous, Cd, Pb, and H2S all being more than the standard [23].

Warna is a small crater lake situated on the highland plateau of Dieng, at 4°37’ – 5°15’ S, 106°32’ – 106°52’ E, and at an altitude of 2,000 meters above sea level. Warna Lake is in a volcanic province and lies within a crater created from volcanic eruptions. In 2007, 63.22% of the Dieng region was dominated by non-forest areas and this case increased to 66.1% by 2010 [24]. The catchment area of Warna Lake changed, mainly for potato farming. Warna is connected to the deeper Pengilon Lake. Nowadays, the Dieng region is a national center for potato cultivation with a harvest frequency of two to three times a year [25]. The agricultural practices lead to soil erosion which contributes sediment to the lakes, and decreases the water volume. The excess use of fertilizer for agricultural practices leads to eutrophication [26].
2. Methods
There were two shallow lakes from Central Java, which are Rawapening and Warna Lakes that have already been studied with respect to their paleolimnology. The first study area was located in Rawapening Lake [16] with cores spanning 29-63 cm in sediment length from 4 sites. The sites were chosen for long sediment core collection with a view to maximizing spatial and environmental gradients, for accessibility, and suitability for coring. The second study area was in Warna Lake Dieng [17] with up to 24 cm sediment core length extracted from 2 sites which are representative of the local habitats with an abundance of vegetation cover yet dominated with by trees and and undergrowth flora of Poaceae. Long cores of sediment were taken from an anchored boat using a modified gravity corer using methods that recover the very loose uncompacted sediment surface without disturbance. Sediment cores were extruded at 1 cm increments. Sediment samples were subsampled for diatom analysis and 210Pb dating.

Diatoms were prepared by placing 1 gram of sediment sample in a glass vial and adding a 10% solution of HCl to dissolve carbonates. Organic materials were then oxidized by treating the sediment with 10% H2O2 for 4 hours under heat. After allowing the treated sediment to settle for 24 hours, the acid above was aspirated and the residual rinsed several times at 6 hours intervals until the suspension reached neutral pH. Two aliquots of each sample were pipetted onto coverslips, which were dried by heating on a warming plate. They were then mounted with Naphrax® onto glass microscope slides. Diatoms were identified and counted under microscope at 1,000 x magnification. 300 diatom valves were enumerated per slide. Diatoms were identified to the species level, using standard taxonomic literatures.

3. Results and Discussion
Central Java is under considerable environmental pressure from a large population, and, as a result intensive water resource use and intensive agriculture. Meanwhile, the tropical climate does not usually lead to water shortages, high mountains on a small island dictate steep slopes and so a vulnerability to landscape change. As a result, the water volume of the lakes fluctuates; in the wet season, the lake has a high volume and in the dry season the volume reduce sharply. This year, the water depth in Rawapening and Warna Lakes reduced by 2 meters (Figure 1-2).

![Figure 1. Rawapening Lake in wet (left) and dry (right) seasons](image-url)
Rawapening has 16 tributaries and is a key feature in the Semarang River system. It is a shallow lake with intensive aquacultural activities and is suffering from the invasion of water hyacinth. It is a flow through lake yet is surrounded by intensive agriculture and settlements. The lakes of the Dieng Plateau are closed crater lakes, some with unusual volcanic geochemistry. All Dieng lakes are either used as sources of water or are impacted by water use within their catchments. They are surrounded by steep crater walls which are cultivated or settled by townships (Figure 3).

Figure 2. Warna Lake in wet (left) and dry (right) seasons

Figure 3. Lowland developed for agriculture to the edge of waterways (a) and the cooler uplands of Dieng surrounded by stepcrater walls (b) which are mostly cultivated by potatoes irrigated by pumping water from lake (c)
Central Java landscapes support intensive agricultural industries and associated communities. These are in part based on subsistence agriculture and in part a production system that provides for the food needs of regional towns and cities. The development of catchments is greatly decentralised and a legacy of past neglect is uncontrolled landscape development and negligible attendance to the catchment or water way management. As a consequence, land is developed for agriculture to the edge of waterways (Figure 4), surface water is over abstracted, urban and road development is uncontrolled, the waste management is limited, rubbish is widely scattered, and a complex array of chemicals is applied with little control.

![Figure 4](image_url)  
**Figure 4.** Diatom assemblages from the Asinan Site of Rawapening Lake [17]

Both Rawapening and Warna Lakes receive high sediment and nutrient loads and are eutrophic, suffering from bottom water anoxia. The Dieng lakes are particularly vulnerable as they are internal drainage systems and are subject to high levels of water abstraction. Both systems host urban and agricultural communities that are distributed across the catchments and are closely dependent on production for their existence.

Rawapening is in period of environmental change as the data provided on the current and past aquatic ecosystem in this lake show it to have been degraded by anthropogenic pressures which have affected the water quality through eutrophication. The past condition of Rawapening has been explained using diatom analysis. The diatom stratigraphy in the Rawapening sediment was summarized in a journal paper [16] to integrate monitoring data about diatoms and water quality within the periods time (Figure 4). Based on the biostratigraphy and chronostratigraphy approaches, 1967 saw the highest abundance of *Synedra* indicating that the Rawapening environment had been fresh and the quality status was close to mesothropic. Since 1990, the pH abruptly changed to alkaline (pH > 9) and hyperthrophic conditions ensued as indicated by the high abundance of *A. granulata* (Ehrenberg) Simonsen and, ultimately, *Aulacoseira ambiguia* (Grunow) Simonsen. The changes of pH could have been a consequence of the eutrophication effect. Eutrophication is the main problem in Rawapening Lake and arise from a complex of interacting factors. Meanwhile, Rawapening Lake retains an important role for hydroelectricity power generation, and agricultural and fishery production. Aquaculture net cage production has been increased by about 50, 4% in the Tuntang district (ME, 2011a). Recent studies indicated that factors driving most environmental stress in Rawapening Lake are phosphorous, nitrogen and calcium loading from the Parat, Torong and Kedungtingin Rivers.

As a comparison, the biostratigraphy of diatom assemblages in Warna Lake showed a contrasting composition, with Eunotia and Pinnularia mostly dominating the diatom assemblages owing to the acid pH. *Frustulia crassinervia* (Brebisson ex W. Smith) Ross, *Gomphonema parvulum* (Kutzing)
Kutzing, *Pinnularia valdetolerans* Mayama & H. Kobayasi, and *P. viridis* (Nitzsch) Ehrenberg dominated around 1935-1954. (Figure 5). The presence of *Gomphonema parvulum* (Kutzing) indicated that the condition was relatively clean and free of metal contamination. The highest sedimentation rate occurred at site 1 (cf site 2) because it is located closer to agriculture areas and so is more greatly impacted by agricultural runoff [17]. Around Warna Lake, the agricultural activity increased rapidly since the 1970s [24]. The total abundance of diatoms in Warna Lake was lower than that of Rawapening Lake because of the characteristic of acidity and high concentrations of sulphate in Warna Lake.

These upper changes in the diatom assemblage closely followed the timing of the recent increase in primary production based on spectrally inferred imagery on Figure 5. The subfossil diatom response of decreasing *Gomphonema* and *Eunotia* also increasing *Pinnularia* species, especially *P. viridis* and *P. viridiformis* has recently been observed in response to climate warming in Warna Lake especially at site 2, as well as in other Indonesian lakes. Despite these subtle warming-related changes, the relatively low diatom assemblages recorded since the 1901s suggest that volcanic activity occurred regularly and influenced the sedimentary diatom flora. The main driver of these modest assemblage changes was likely increasing vegetation around the lake and, from the 1970s, the input of nutrient loads causing eutrophic conditions that induced an increase in the eutraphentic form *Sellaphora seminulum* [17].

![Figure 5. Diatom stratigraphy from the 2 sites from Warna Lake [17]](image)

The paleolimnological data from Rawapening and Warna Lakes cannot explain all the historical changes. Prior to the new phase of agricultural intensification, the lakes were oligo – meso-trophic. After a sharp increase in agricultural activities, the lakes became eutrophic with the situation worsening after the application of inorganic fertilizers. As the demand for protein increased due to the
rise of human populations, livestock farming also sharply increased exacerbating to the eutrophication of the lakes. This condition was clearly evident at Rawapening Lake.

Paleolimnological data are crucial for the effective application of aquatic management and to complement long-term monitoring because it provides data about past environmental conditions. The record of sensitive biological indicators (diatoms) over a long period enables the lake response to historic catchment changes to be recovered and used to identify the time and causes of water quality degradation. Coupled with ongoing monitoring, this trajectory of change from this record of the past allow managers to forecast future change and so implement measures in a timely and proportionate manner [6, 26].

Since the nineteenth century, paleolimnological study using diatoms as a bioindicator has applied these reconstruction techniques, revealed changes in diatom assemblages, both the temporal variability and directional change. Thus, the approach has been established and represents a valuable tool for any environmental assessment program and framework. Today, around the world, diatom-based approaches for lake condition reconstruction are being compared to historical records of the catchment development and the ecological condition of aquatic systems to better understand the responsiveness of these critical systems to human impacts [27-28].

The drivers of change in both the Rawapening and Dieng systems are drawn from evidence of the intensive catchment development over a long history. This case, and the low level of catchment governance arrangements, make the management challenge considerable and precludes short term, imposed solutions. Critical to the investment of a management solution is a co-ordinated program of community education and project engagement. Strong involvement of the community will allow the introduction of remediation measures and the co-ownership of infrastructure ensuring the longevity, and sustainable use, of these natural assets.

4. Conclusion
Human’s activities in the catchment area have influenced the water quality of the lakes. The use of fertilizers for agricultural practices and livestock farming in the catchment areas has led to the eutrophic state on the lakes. This case was well described by the preserved diatom assemblages preserved in the sediments of Rawapening and Warna Lakes. Both lake systems suffered from multiple, diffuse inputs of a diverse suite of pollutants and the trajectories of change warn of a risk to the sustainable use of the lakes.

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