Paleolimnological approach for management sustainable use of tropical lakes

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Abstract: Tropical aquatic resources provide ecosystem services, which are affected by human activities. Human-induced environmental change in Indonesian lakes has considerably increased since the new order in 1970. In general, many Indonesian lakes had deteriorated due to sedimentation and eutrophication, which induced the blooming of aquatic plants, mostly by water hyacinth. Water security becomes a problem, particularly in the dry seasons, but water overflow and flooding occur in many places during wet seasons. Landscape and climate changes, pollution, species diversity, preserved in lake sediment, provide long-term proof of environmental changes. This paper will discuss a paleolimnological approach to reconstruct past environmental changes. Paleolimnology is learning about stratigraphy sediment of the lakes where fossils are well preserved in the sediment and provide information about the past conditions of the catchment area. Lakes’ sediment records the changes in condition of the catchment area, like a diary book. Paleolimnology had been studied for Rawapening Lake and Telaga Warna Lake, Dieng. Reconstruction of the past environmental condition is required to predict future conditions. Reconstruction is an activity recreate past conditions by pointing the organism stored in layers of sediment, therefore, reflecting the environmental conditions based on organisms deposited, to develop the best sustainable water resources management, as in alignment with the concept of water–energy–food nexus.

1. Introduction
Indonesia uses three indicators related to SDGs documents, namely human development or human development including education and health, the environment or social small scale economic development, and a great environment or environmental development in the form of availability of environmental quality and natural resources.

Related to the environment of the lake and the catchment area, global climate change due to increased air temperature and changes in rainfall patterns are a threat to the sustainability of the functions of the lake, the loss of biodiversity of the lake, the danger of flooding, freshwater scarcity and decline in food production. Therefore, it is necessary for the development of research, including in the field of limnology to maintain, preserve, and restore the lake’s function based on the principle balance of the ecosystem and the environmental carrying capacity.

Paleolimnology is basically learning about stratigraphy sediment of the lakes, rivers, and wetland sediments where fossils are well preserved in the sediment and provide information about the past condition of the catchment area [1,2,3,4,5,6,7]. However, paleolimnological studies in Indonesia were very limited [8] particularly for Indonesian as the first author. Lakes’sediment records the changes in
condition of the catchment area, like a diary book. Reconstruction of the past environmental condition is required to predict future conditions. This can be done using the organism preserved in the sediment, such as diatoms and pollen. Diatoms are unicellular algae that are used extensively in paleoecology. The diatom assemblages in sedimentary records can make direct and indirect inferences about past environmental conditions. The palynological data on the terrestrial and aquatic ecosystem is used as an indicator of recent and paleoecological changes, particularly on the climate, history, and floral diversity. Paleolimnological analysis increasingly attention is being given to developing the technique to model human activities [6].

Reconstruction is an activity to recreate past conditions by pointing the organism stored in layers of sediment, reflecting the environmental conditions based on organisms deposited. Bioindicators for reconstruction is organisms that have cell walls that are not degraded when the organisms have died and precipitated [5].

Sustainable water management is a strategy for maintaining future water resources that include increasing water supply and managing how we use freshwater to sustain economic growth for current and future generations. However, there are too many issues concerning water resource, such as issues involving inadequate supplies to meet demands, flood damages are increasing over time, wastewater discharges by industry and households, and ahigh population. Those problems had induced an expensive value of the water [9]. Water security means “the limit of a populace to defend supportable access to satisfactory amounts of adequate quality water for managing employment, human prosperity, and financial advancement, for guaranteeing insurance against water-borne contamination and water-related catastrophes, and for saving environments in an atmosphere of peace and political steadiness” [10]. In addition to these issues, there is a water-energy-food (WEF) nexus. The water-energy-food nexus defines the very close links between these three sectors and the changes in one system can have far-reaching impacts in other systems, resulting in significant ecological, economic, social, and political consequences (Figure 1). Nexus is interpreted as a process to connect the actions of various stakeholders from different sectors for achieving sustainable development [11].

![Figure 1. Water – energy – food nexus (UNU, 2013)](image)

The Nexus perspective focuses on the interdependence of water, energy, food (W-E-F) by understanding the challenges and finding opportunities. The Nexus approach recognizes the interconnectedness of W-F-E across space and time. Its objectives are: improve energy, water, and food security; address externality across sectors, and decision-making at the nexus; and support
transition to sustainability. Nexus consideration is often pursued with ‘two at one-time’ analysis. For instance, the energy-water nexus is analyzed through a two-way interaction in the use of water for energy production and the use of energy for water production. The same principles apply when studying the interactions of water-food nexus and food energy nexus [12]. Another layer of complexity is introduced with the further link of energy water to food security [13]. ‘nexus’ is interpreted as a process to connect actions of various stakeholders from different sectors for achieving sustainable development. The concept of nexus is in alignment with the concept of integrated water resource management (IWRM).

Decentralized energy-water-food systems (EWFS) propose a sustainable mechanism to improve living conditions in rural communities with the supply of electricity, water, and food using renewable resources and catalyze community welfare by investing in infrastructure for agricultural productivity [14].

Integrated Water Resources Management (IWRM) is a process that promotes coordinated development and management of water, land, and related resources, to maximize economic and social well-being in an equitable manner and without compromising, in the present or future, the sustainability of vital ecosystems. Integrated Water Resources Management aims to promote coordination and integration as a means to achieve holistic water management and improve the sustainability of water resources. As the concept of sustainability, it is not a final state to be achieved, but a continuous process to create a closer link and a better understanding of human and natural needs, and interactions between both[15]. The concept of nexus aligns with the concept of integrated water resource management (IWM) [16].

One of the processes in IWM is identify appropriate tools to develop strategy. In this part, paleolimnology is a suitable approach that connected the lakes and the catchment area, the water quality and quantity that used for increasing agriculture production, which in turn, improve food security.

2. Methods
This research was conducted at Telaga Pengilon Dieng. Coring activities using piston corer was done to collect sediment samples. Slicing is part of lab work that influences the precision of interpretation data. Sediment samples were sliced every 1 cm. Part of the sediment samples were used to analyze metal concentration by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The ICP-MS provides better sensitivity and detecting a precisely small amount of samples to perform sub-part per billion multielement measurement level [17]. Another part of every layer samples for diatom analysis. Diatoms are useful for the paleolimnological indicator. Diatoms were digested in 10% HCl and 10% H2O2 with multiple washes between stages. Naphrax was used to mount diatoms onto slides. Identification process using 1,000 magnification of the microscope until found a minimum of 300 diatom valve for paleolimnological analysis [18]. Data analysis was performed by PAST (for cluster analysis). Identification performed to species level where possible, whereas the others were identified to genus level following standard texts [19-26]. Guiry and Guiry was used for consulting taxonomy and nomenclature [27]. Clusters analysis by Bray Curtis performed using PAST (Paleontological statistics software package for education and data analysis) version 2.17c [28,29]. The species with a relative abundance of less than 1% were not included in the analysis.

3. Results and Discussion

3.1. Pengilon Lake, Dieng
Based on the ICP-MS, there was a trend of high concentration of Zinc (Zn) in the upper layers of sediment (Figure 2). Whenever compared to the clustering based on the relative abundance of diatom, the trend shows a similar pattern (Figure 2). The variation trend of Zinc concentration influences diatoms’ abundance and species composition. A sharp increase in Zinc concentration in 1-4 cm, occurred.
Figure 2. Clustering sediment layers based on diatoms (left) and concentration of Zn for 210 cm sediment samples from Pengilon Lake Dieng

Zinc is an essential trace element required by organisms and humans, distributed widely throughout the natural environment. Zinc bioavailability depends upon pH value. The higher trophic levels exhibited sensitivity to zinc as pH was reduced [30]. The sediment samples were collected in 2017 after the Sileri eruption (Figure 3).

Figure 3. Dieng eruption history
Indonesian lake ecosystems are changing due to natural or human impacts that tend to increase. Identification of an environmental problem is the first step to solving it. Ten years of environmental monitoring data are required to identify the pre-disturbance conditions, range of natural variability, or environmental change. However, environmental monitoring studies were mostly less than a one-year duration, with over 80% of studies less than three years [31]. The time scale for environmental assessments faces a problem of time series monitoring data. Reference (pre-disturbance) conditions are rarely available. Monitoring programs are rarely long enough to understand natural variability in aquatic ecosystems or to reveal conditions before significant human influence, information archived in lake sediments complements monitoring efforts, and fills data gaps [32]. Paleolimnology provided a retrospective assessment of ecosystem changes and provided the missing data that short-term monitoring programs could not capture. Effective ecosystem management needs temporal sampling with lake sediment analyzes [31,7].

Coring for collect sediment samples vertically is an important activity for the paleolimnological approach. The longer the sediment corer, the longer the time frame can be studied. Lake management requires long term data to develop management based on reference conditions to assess environmental stressors. There are many types of corer, which depend upon the location and site-specific condition. It is better to use a piston corer in the lake body with depth water 5-30 meters. Many variations of piston corer, including those that can be used on a rope. A brass messenger is then delivered down the coring line to trigger a closing mechanism that seals off the top of the coring tube (Figure 4). But, in the wet soil of the lake bank during the dry season, Russian corer is better and easy to use (Figure 5). The advantages of Russian corer are no loss of sediment, takes samples at any depth, easy to operate, suitable in flabby and very soft soils, effective for sampling young peat and sediment.

Warmer air temperatures due to climate change and local characteristics which are resulting in the warmer surface water temperatures [33], strengthened thermal stratification [34]. Variability in precipitation and increasing frequency of floods and droughts also tend to occur. The climate is considered an overriding driver of limnological change [7].

Taxonomic understanding in paleoecology such as diatoms or pollen does not mean inferring process from species composition or assemblage patterns meaningfully without understanding ecological knowledge. There is a fundamental requirement of understanding diatom seasonality, species responses to water-column mixing, habitat preferences in terms of light availability, substrate, water depth, and influences from the competition, grazing, and other food-web effects. That information is valuable to reconstruct paleolimnological interpretation and understand the long-terms diatoms’ response [35].

Early warning indicators (EWIs) are the loss of resilience or ecological value and changes ecosystem functions, such as carbon or nitrogen cycle. Therefore, EWIs should be well-established mechanisms than easily interpreted by limnologists and lake managers. The improvement of EWIs understanding can be gained from a combination of ecology and paleo-ecological methods. The paleolimnological approach addresses ecosystem function and change [35].

The advantage of paleolimnology for lake management is the ability to characterize natural variability and baseline conditions prior to recent impacts [7]. The baseline data from reference conditions can serve as useful management benchmarks [36]. These data can also be used to evaluate the achievement of the restoration target, is it an achievable or realistic target from a management perspective [7]. For example, Soeprobowati et al 2012 note that limnological changes in Rawapening Lake occur before the onset of intensive agricultural programs. By quantifying trajectories change over decades, meaningful data help distinguish eutrophication from climate change impacts [5].
**Figure 4.** Sediment core collecting from Pengilon Lake Dieng using piston corer with removable PVC, got 210 cm sediment samples

**Figure 5.** Sediment cores collected from Rawapening Lake using dissection /Russian corer
Lakes are naturally acidic or naturally increase in nutrients content. Many Indonesian lakes commonly experience water hyacinth blooms, due to eutrophication from land use activities in the catchment area. However, paleolimnological analysis in Rawapening Lakes also shows that the lake was tent to alkaline due to the tiling calcium carbonate from local communities making the fertilizer from water hyacinth [5,37]. Therefore, the lake management targets should reflect the natural baseline condition of the lake. The mitigation for eutrophication to the levels below natural conditions would reduce the nutrient input from the land-use. In the upstream area, communal waste treatment from animal farms must be built before the waste is entered the river [38]. Installation of municipal wastewater service had to be developed to prevent further phosphorous loading from the septic system and surface runoff and prevent sediment phosphorous release by capping the sediment surface or hypolimnion oxygenation [39].

The paleolimnological approach is suitable for lake management base on multiple proxies or environmental indicators to interpret past environmental conditions. A multidisciplinary approach provides a complete assessment of environmental changes that have occurred [40]. This is because the aquatic ecosystem process is a multidimensional process that involves many communities and ecosystem functions [35]. Understanding interrelation abiotic and biotic factors and resultant ecosystem resilience have to be considered for adaptive lake management [41].

4. Conclusion
Paleolimnology is a useful and complementary tool in lake management; lake sediment provides retrospective information and predict the future. The main function of lakes in tropical areas is agricultural irrigation, hydroelectricity power, fisheries, tourism, social, and religious activities. Water security is more important than food and energy security. Water is needed to generate the energy of electricity; water is needed to grow food. Lake management support SDGs number 2 (food security) through water security and sanitation (goals number 6), which has to consider climate change mitigation (SDGs number 13), terrestrial ecosystem including inland waters (goals no 15).

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