Int. J. of GEOMATE, Dec, 2013, Vol. 5, No. 2 (Sl. No. 10), pp. 706-711
Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan

ENVIRONMENTAL CONDITION INDEX FOR ESTIMATION ON EUTROPHIC STATE OF ENCLOSED AQUIFER ECOSYSTEM

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ABSTRACT: To evaluate the effect of sediment treatment on aquifer ecosystem, a new ecological index that is composed of water quality, sediment quality and biota quantity was proposed in this study. According to ECI (Environmental Condition Index), DAF treatment (Dissolved Air Flotation) + MgO sprinkling was assessed as the most efficiency method for improvement of eutrophicated ecosystem, that is, this method can make the organic matter quantity in aquatic ecosystem minimum level in comparison with other sediment treatment method. Also, for application of this method to real field remediation such as eutrophicated lake, marsh, reservoir and so on, more detailed analysis for treatment function and optimum condition of sediment treatment was considered to be necessary.

Keywords: Environmental condition index, Aquatic ecosystem, COD, IL, Chl.a, Eutrophicated lake

1. INTRODUCTION

The countermeasure to the nutrient elution from eutrophicated sediment is necessary to be conducted with the cut of the inflow loading of nutrient from a basin area of eutrophicated lake and marsh. Furthermore, it is reported that the eluted nutrient loading from the accumulated sediment reaches 5-10 times of the inflow loading. This constant eutrophication problem is in the point that organic polluted mud is accumulated to the inflow rivers and the lake itself, it is necessary that the organic sediment, which is over quality for water quality and water livings, is taken away from the inside to the outside of the ecosystem [1]. However, the direct removal methods such as digging / boring have a risk, which disturb the lake ecosystem, and some organic matter and nutrient should be left in the sediment to preserve macrobenthos and so on. In this case, water quality purification will be expected by prevention of nutrient elution from the sediment.

In present study, DAF (Dissolved Air Flotation) treatment, MgO sprinkling and CaO sprinkling as CRM (Chemical Remediation Materials) treatment were conducted, and the effect of these treatment methods on the lake ecosystem was evaluated from the viewpoint of ecological influence. Furthermore, a new index that indicating synthetic state of ecosystem was proposed and the effect of sediment treatment on the lake ecosystem was evaluated using this index.

2. PROPOSAL OF ENVIRONMENTAL CONDITION INDEX

For evaluation and/or assessment of an environment, a variety of index, such as diversity index for biota (for example, Shannon index, Simpson's index, and so on), has been proposed and applied. Most of these indexes are based on biotic diversity, because biota, whether fauna or flora, indicates synthetic results of environmental fluctuations, that is, water and sediment condition are reflected to biota. Although the biotic index can be recognized as one of the most essential indexes to evaluate the environmental condition, it is not enough to indicate the water/sediment condition. It is recognized that water and/or sediment condition is not reflected perfectly to biotic index, and these three elements, *i.e.* water, sediment and biota, are related with one another in multiplication [2].

In this study, a new ecological index for indicating the environmental condition was calculated using the data that is obtained from the results of microcosm experiment.

The environmental condition index (ECI) was calculated by the equation (1) as described below;

$$ECI = \sqrt[3]{C_{(COD)} \times C_{(IL)} \times C_{(Chl.a)}} \qquad (1)$$

Where,

$C_{(COD)} = \sum L_{COD,\,i} / COD_{mean}$,

$C_{(IL)} = \sum L_{IL,\,i} / IL_{mean}$, and

$C_{(Chl.a)} = \sum L_{Chl.a,\,i} / Chl.a_{mean}$.

This index has no mathematical dimension. $L_{COD,i}$, $L_{IL,i}$ and $L_{Chl.a,i}$ mean the existed quantity of COD, IL and Chl.a in microcosm during the incubation period, respectively. COD_{mean}, IL_{mean} and $Chl.a_{mean}$ mean the average concentration of COD, IL and Chl.a in microcosm. This index means water condition by COD (Chemical Oxygen Demand) concentration, sediment condition by IL (Ignition Loss) concentration, and phytoplankton quantity by Chl.a (Chlorophyll a) concentration. When ECI is low value, the quantity of organic matters in the environment is low level, and when ECI is high value, the quantity of organic matters is high level in the opposite direction. The concept of ECI is indicated in Fig.1. The organic matters are recognized in general as one of main pollutant for aquatic ecosystem. This ECI can indicate the pollution level of organic matters in aquatic ecosystem, such as lake, marsh, reservoir, river, sea, and so on.

3. EXPERIMENTAL PROCEDURES

Water and sediment were collected from Lake Tega that locates in the northwest area of Chiba prefecture in east Japan and is well known as one of the most polluted enclosed aquifer.

3.1 Sediment Treatment

DAF treatment was conducted as follows; 50L of water was poured into 80L volume reactor, then 7kg(w.w.) of sediment was innoculated. Micro bubble was continuously injected under the sediment to water, and the poly ferric sulfate as coagulant (4L of 200mg/L) was added. Sediment with much organic matter can be divided into froth and treated sediment in this process [3], [4].

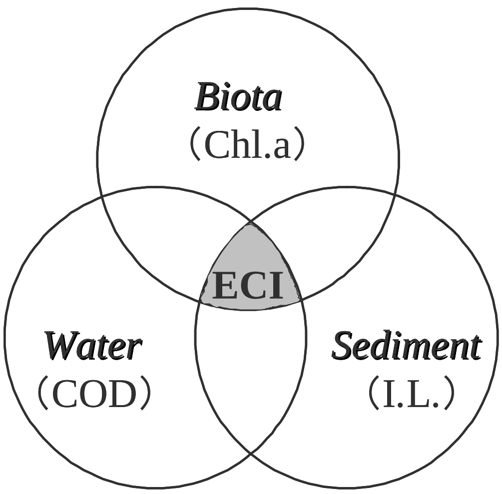

Fig.1 Concept of Environmental Condition Index (ECI)

CRM treatment was conducted as follows; MgO and CaO were prepared to sprinkle on the surface of sediment in experimental microcosm. These chemical agents are expected to control the elution of nutrient salts from sediment layer [4], [5].

3.2 Microcosm Culture

The microcosm experiment was conducted using 470ml volume glass vessel, and with 4 series culturing. Those are,

Run 1 : untreated sediment 100g(w.w.) + Lake Tega water 380mL,
Run 2 : DAF treated sediment 100g(w.w.) + Lake Tega water 380mL,
Run 3 : DAF treated sediment 100g(w.w.) +MgO 400g/m^2 + Lake Tega water 380mL,
Run 4 : DAF treated sediment 100g(w.w.) + CaO 100g/m^2 + Lake Tega water 380mL.

As described above, experimental microcosm in this study consisted of water and sediment, like natural lake ecosystem. Thus, system has a characteristic that stability and sustainability of this ecosystem are very high [6], [7]. All grass vessels were sealed up and cultured under unstirring, 20℃, bright (20,000lux) and/or dark condition. Sampling from a boundary between sediment and water was conducted at intervals of 2 days after the cultivation started. The experimental condition of microcosm culture was shown in Fig.2.

3.3 Parameters for Evaluation

COD, IL and Chl.a concentrations were measured to calculate ECI. COD is for water quality, IL is for sediment quality and Chl.a is for biota quantity, and ECI was calculated to evaluate the effect of sediment treatment to the lake ecosystem. In addition, phytoplanktonic flora, one of biotic indexes to assess the environmental condition [8], was also analyzed by microscopically observation to compare with ECI.

4. RESULTS AND DISCUSSIONS

4.1 Water Quality Assessment

Total COD quantity in each culture series were; 694.8mg/L/28days in Run 1, 480.5mg/L/28days in Run 2, 361.4mg/L/28days in

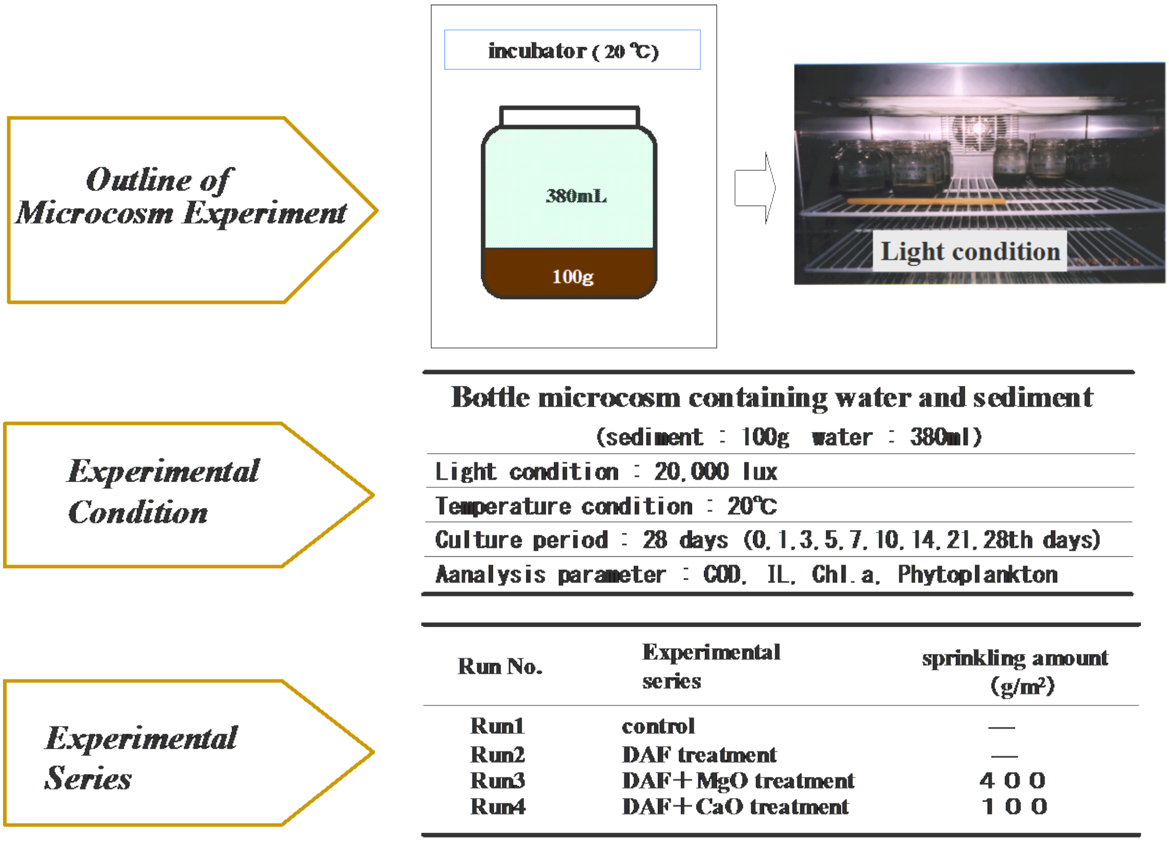

Fig.2 Experimental Condition of Microcosm Culture

Run 3, and 886.6mg/L/28days in Run 4, respectively. As shown in Fig.3, COD value increased from 3rd day after the cultivation started, and indicated the maximum value in 10th day, and decreased with gentle slope. This is because removal by DAF treatment and restraint by MgO sprinkling for the elution of nutrient salts from the sediment layer lead low growth of phytoplankton and low COD concentration in Run 3. On the other hand, CaO sprinkling made phytoplanktonic growth and COD increasing in Run 4, because of its characteristics, i.e. washing out effect of NH4-N from the sediment layer [9]. In comparison with the total COD quantity in Run 1 that is set to value 100%, 69.2% in Run 2, 52.4% in Run 3 and 127.6% in Run 4. Quantity of COD is considered as indicator of water quality, that is quantity of organic matter. From these results, Run 3, that is, DAF treated sediment + MgO sprinkling, was assessed as the most effective improvement method.

4.2 Sediment Quality Assessment

Total IL quantity in each culture series were 996mg/g/28days in Run 1, 916mg/g/28days in Run 2, 1,102mg/g/28days in Run 3, and 975mg/g/28 days in Run 4. As shown in Fig.4, IL value indicated the maximum value in 1st day, and decreased with gentle slope. This is because DAF treatment removed organic matters from the sediment layer in Run 2, and MgO sprinkling restrained the elution of nutrient salts which introduced bacterial growth in sediment layer, that means IL increasing in Run 3. CaO sprinkling made NH_4-N washed out and lead bacterial growth under nitrogen-limiting condition in Run 4. In comparison with the total IL quantity in Run 1, that was set to value 100%, 91.9% in Run 2, 110.6% in Run 3 and 97.9% in Run 4 were recognized. Quantity of IL is considered as indicator of sediment quality as quantity of organic matter. From these results, Run 2, that is, DAF treated sediment, was assessed as the most effective improvement method.

4.3 Biota Quantity Assessment

Total Chl.a quantity in each culture series were 0.512mg/L/28days in Run 1, 0.192mg/L/28days in Run 2, 0.088mg/L/28days in Run 3, and 0.222mg/L/28days in Run 4. Succession of Chl.a concentration in each culture series was shown in Fig.5

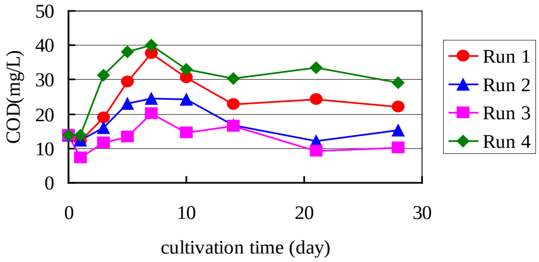

Fig.3 Succession of COD concentration in water

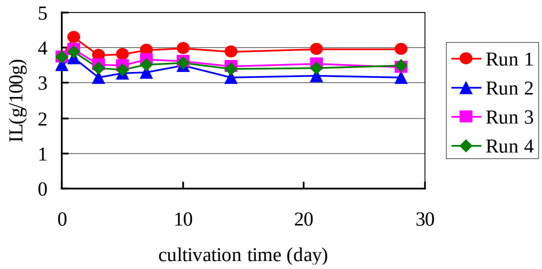

Fig.4 Succession of IL concentration in sediment

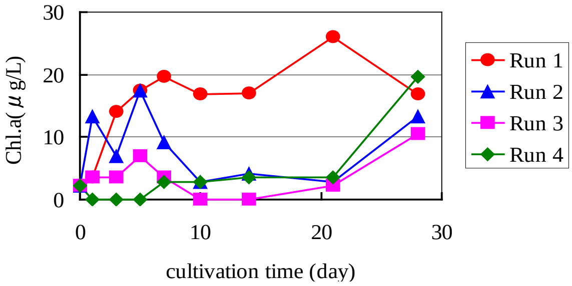

Fig.5 Succession of Chl.a concentration in phyto-plankton

The dominant species in each microcosm culture series were cyanophyceae and bacillariophyceae in Run 1, bacillariophyceae in Run 2, bacillariophyceae, chlorophyceae and phytoflagellata in Run 3, and bacillariophyceae in Run 4. This is because these sediment treatments lead the difference of T-N/T-P mass ratio in water. Composition of phytoplanktonic flora is much effected by T-N/T-P mass ratio in water [10]. DAF treatment removes nitrogen peculiarly, and T-N/T-P mass ratio becomes lower, where cyanophyceae cannot grow in Run 2. MgO sprinkling leads higher T-N/T-P mass ratio, because it has effect to restrain phosphorus. From this, the hybrid treatment of DAF treatment and MgO sprinkling can make nutrient salts concentration lower with keeping T-N/T-P mass ratio properly, like Run 3. CaO sprinkling lead much higher T-N/T-P mass ratio because of its washing out effect on NH_4-N, even after DAF treatment in Run 4. Concluding these characteristics, DAF treatment lead lower T-N/T-P mass ratio, hybrid treatment, DAF treatment and MgO sprinkling keep proper T-N/T-P mass ratio with low nutrient salts concentration, and hybrid treatment of DAF treatment and CaO sprinkling introduce high T-N/T-P mass ratio to an extreme. In comparison with the total Chl.a quantity in Run 1, that was set to value 100%, 37.6% in Run 2, 17.2% in Run 3 and 43.3% in Run 4 were recognized. Quantity of Chl.a is considered as indicator of biological quantity, i.e. quantity of phytoplankton. From these results, Run 3, that is, DAF treated sediment + MgO sprinkling, was assessed as the most effective improvement method.

4.4 Ecological Estimation from Environmental Condition Index (ECI)

ECI value in each culture series were 1.69 in Run 1, 1.22 in Run 2, 0.87 in Run 3, and 1.45 in Run 4. From these results, Run 3, that is, DAF treated sediment + MgO sprinkling, was assessed as the most effective improvement method. Comparison of each index in experimental culture was shown in Table 1.

In comparison with an analysis of phytoplanktonic flora as biotic indicator using microscopic observation, ECI can explain the difference of phytoplanktonic succession in each culture series. Biomass rate of each phytoplankton species, *i.e.* cyanophyceae, bacillariophyceae, chlorophyceae and phytoflagellata in each treatment condition were shown in Fig.6.

Table 1 Comparison of each index in each experimental series

Run No.	Sediment treatment	total COD	total IL	total Chl.a	ECI	Saprobic index	dominant species of phytoplankton
Run 1	no treat	100	100	100	1.69	ps	cyanophyceae, bacillariophyceae
Run 2	DAF	69.2	91.9	37.6	1.22	ms	bacillariophyceae
Run 3	DAF + MgO	52.1	110.6	17.2	0.87	os	bacillariophyceae, chlorophyceae
Run 4	DAF + CaO	127.6	97.9	43.3	1.45	ms	bacillariophyceae

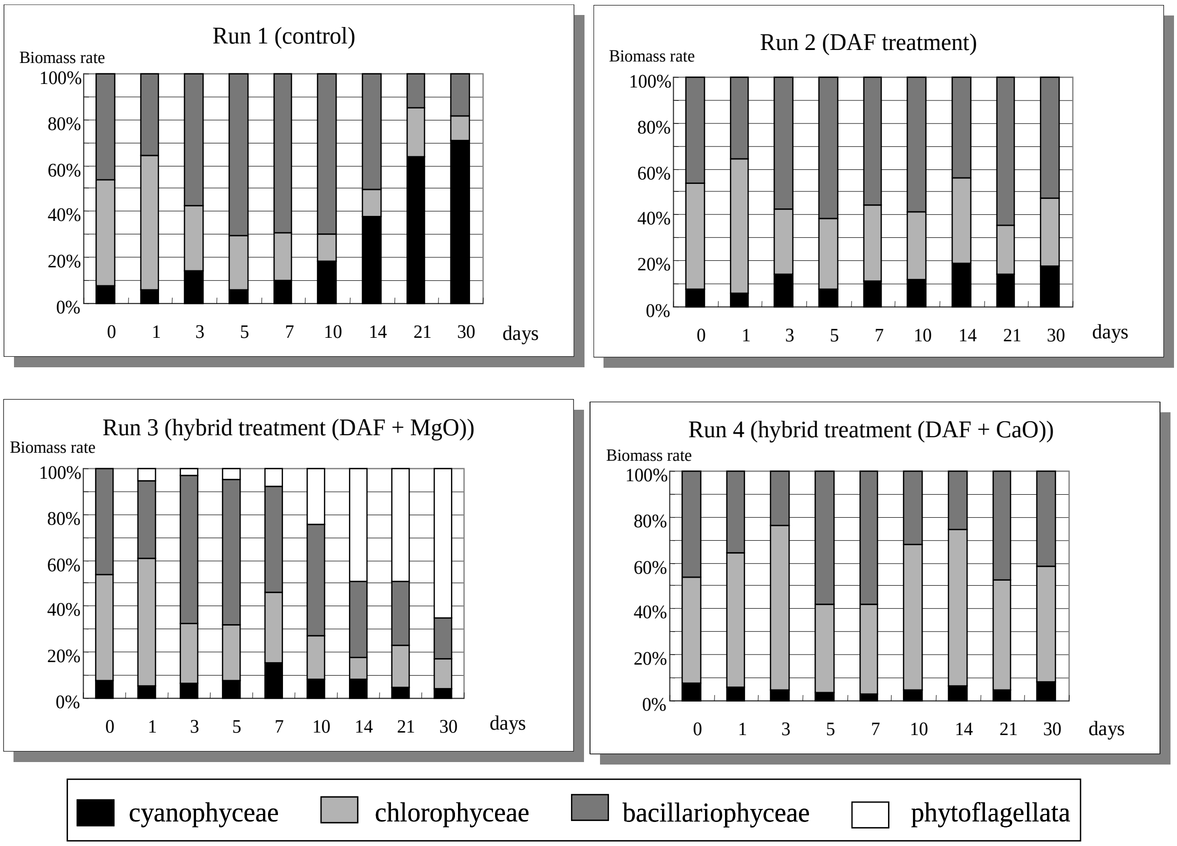

Fig.6 Biomass rate of each phytoplankton species on each experimental series

The dominant species of phytoplankton in each culture series were Microcystis aeruginosa, Anabaena spiroides (cyanophyceae) and Melosira granulata (bacillariophyceae) in Run 1, M.granulata and Nitzschia acicularis (bacillariophyceae) in Run 2, M.granulata (bacillariophyceae), Scenedesmus quadricauda (chlorophyceae) and Chlamydomonas spp. (phytoflagellata) in Run 3, and M.granulata and N.acicularis (bacillriophyceae) in Run 4. These species are recognized as biotic indicator for eutrophication and organic pollution of water environment [11]. According to the Saprophilous classification, Run 1, Run 2, Run 3 and Run 4 are under the state of ps, β-ms, os and α-ms respectively. This means Run 1 is the most polluted / eutrophicated state and Run 3 is the most purified / oligotrophic state.

The experimental results from batch culturing series, were considered to satisfy the theological hypothesis that the hybrid treatment can control nutrient elution from the sediment more effective than DAF and/or no treatment, because water bloom which observed generally in Lake Tega in summer was not observed in grass vessel. Thus, efficiency of this hybrid treatment system of DAF treatment and MgO sprinkling for sediment remediation, possibility of artificial control on phytoplanktonic flora and necessity to establish environmental assessment method on ecosystem level such as ECI proposed in this study were indicated. And to make these treatment methods be applied to real field such as eutrophicated lake and marsh, more detailed analysis for treatment function and optimum condition of sediment treatment was considered to be necessary.

5. CONCLUSIONS

To evaluate the effect of sediment treatment on aquifer ecosystem, a new ecological index that is composed of water quality, sediment quality and biota quantity was proposed in this study. According to this ECI (Environmental Condition Index), DAF treatment + MgO sprinkling was assessed as the most efficiency method, that is, this method can make the organic matter quantity in aquatic ecosystem minimum level in comparison with other sediment treatment method. More detailed analysis for treatment function and optimum condition of sediment treatment was considered to be necessary to make these treatment methods be applied to real field remediation such as eutrophicated lake, marsh, reservoir and so on.

6. ACKNOWLEDGEMENTS

This work is partially supported by the Grant-in-Aid for Scientific Research (24651029) of Japan Society for the Promotion of Science (JSPS).

7. REFERENCES

[1] Inamori Y, Jin X, Park J, and Xu K, Guideline on the Management for Establishment of Eco-Sound Watershed Environment of Lakes and Marshes. Tokyo: The Industrial Water Institute, 2007.

[2] Wetzel RG, Limnology, Third Edition: Lake and River Ecosystems, Academic Press, 2001.

[3] Agatsuma S, Murakami K, Gomyo M and Amano Y, "Shell Fragment Application as Regional Unused Resources for Nutrients Elution Control from Eutophicated Sediment", in Proc. 5th IWA-ASPIRE Conf. Exhib., 2013, CD-ROM.

[4] Agatsuma S, Murakami K, Gomyo M and Amano Y, "Water Quality Purification in the Seaside Park Pond using Shell Fragment as Regional Unused Resources", in Proc. Wat. Environ. Technol. Conf. 2013 (WET2013), 2013.

[5] Amano Y, Taki K, Murakami K, Ishii T and Matsushima H, "Sediment Remediation for Ecosystem in Eutrophicated Lakes", The Scientific World, Vol.2, 2002, pp.885-891.

[6] Odum E P, Ecology, New York: Springer-Verlag, 1963.

[7] Beyers R J, and Odum H T, Ecological Microcosms, New York: Springer-Verlag, 1993.

[8] Murakami K, Ishii T, Taki K, Matsushima H, "Internal Production Control by Sediment Treatment in Eutrophicated Lakes using Experimental Mesocosm System", Papers on Environmental Information Science, No.22, 2008, pp.487-492.

[9] Muto T, Saito T, Matsushima H, Tanaka K, Murakami K, Taki K, "NO2-N Accumulation through Denitrification Reaction with Lake Sediment", Proc. 2nd IWA Int. Sympo. on Sequencing Batch Reacter Technology (SBRT-2), 2000, CD-ROM.

[10] Fujimoto N, Fukushima T, Inamori Y, Sudo R, "Analytical Evaluation of Relationship between Dominance of Cyanobacteria and Aquatic Environmental Factors in Japanese Lakes", J. of Wat. Environ., Vol.18, No.11, 1995, pp.901-908.

[11] Watanabe T, Asai K, Houki A, Tanaka S, and Hizuka T, "Saprophilous and Eurysaprobic Diatom Taxa to Organic Water Pollution and Diatom Assemblage Index (DAIpo)", Diatom, Vol.2, 1986, pp.23-73.

Int. J. of GEOMATE, Dec, 2013, Vol. 5, No. 2 (Sl. No. 10), pp. 706-711.
MS No. 3352 received on June 14, 2013 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in the Dec. 2014 if the discussion is received by June, 2014.
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