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SOCIO-PHYSICAL ENVIRONMENTS AND ALGAE/ WATER QUALITY PROPERTIES OF IRRIGATION PONDS: CASE STUDY IN MINAKUCHI AND OTSU, JAPAN

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ABSTRACT: Irrigation pond called ‘Tameike’ is a type of Japanese traditional rainwater harvesting facilities built to store rain and supply water to farms. It is, however, difficult to sustain a sound management of these systems due to the social changes in Japan, i.e. aging of the rural community and regression of the domestic agricultural industry. Therefore, knowledge, means and ideas are required to maintain irrigation ponds in desirable conditions. In this paper, the water quality, algae and socio-physical environments of 35 ponds in Otsu city and Minakuchi town were investigated and their relations were discussed using the statistical methods; factor analysis and cluster analysis, aiming the acquisition of knowledge for the management. Our investigations revealed that three common factors; ‘scale of the pond’, ‘development of the catchment’, and ‘cultivation in the catchment’ that explain the socio-physical environments. Based on these factors, the ponds were categorized into four types and each compared from the view of trophic levels, diversities and dominant species of algae and location of the pond. It has become apparent that the obtained factors and clusters could explain the tendencies of water quality and diversity, while the relations to dominant species of algae are still ambiguous.

Keywords: Irrigation pond, socio-physical environment, water quality, algae, categorization

INTRODUCTION

Irrigation ponds often referred to as “Tameike” are a type of Japanese traditional rainwater harvesting facilities. The number of existing irrigation ponds in Japan is about 100,000. The water storage capacity of each pond is certainly small, i.e. mostly less than 20,000 m^3, but there are a total of about 3,402 million m^3 that corresponds to about 11.4 % of the total irrigation water impoundments in Japan.

They have been constructed and managed by the regional community for hundreds of years. It is, however, often difficult to sustain their management, due to the social changes, namely, aging of farmers or rural community, development of alternative irrigation schemes, change of land-use, etc. This has resulted in water quality problems and degradation of equipments are often experienced in the irrigation ponds, especially around urban areas. In addition, the number of irrigation ponds is remarkably decreasing as the domestic agricultural industry regresses.

On the other hand, these ponds have been reevaluated not only for the impoundment of irrigation water but also for some adjunctive roles such as; 1) decrease in peak in flood runoff, 2) bio-habitat or biotope, 3) fire-fighting use, 4) recreation and 5) purification of water.

Thus, the socio-physical environment surrounding the irrigation ponds is becoming increasingly complex. It can be said that ideas, means and knowledge to assist in managing them sustainably is strongly required for the contemporary rural community.

There are various types of irrigation ponds, characterized by many variable factors, such as shapes, volume, water quality, algae, land-use of the catchment, etc. in each pond. Moreover, these factors are related either closely or slightly to each other. For example, the state of the water quality and algae in the irrigation pond should be determined by their physical and social circumstances to some extent. Therefore, it is necessary to categorize the irrigation ponds properly into diffrent types and to understand their characteristics. This could serve as an initial step towards a sustainable management of irrigation ponds.

The Ministry of Agriculture, Forestry and Fishery of Japan has collected various physical and social data and published them in the “Catalog of irrigation ponds’ in 1990. Morita and Morishita (2000) sorted and categorized the irrigation ponds in Kagawa prefecture by

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socio-physical factors of the ponds, some of which are found in the catalog, and their circumstances using principal component analysis. This work aimed mainly at supporting the maintenance of embankment and facilities. Hayashi and Takahashi (2001) also categorized irrigation ponds from the management point of view using questionnaire surveys. However, in both of these works, the impounded water and its environment were not taken into account. Therefore, they included few field data of the water quality and the habitant. In our previous works (Yanagihara et al., 2001, 2002, Yanagihara, 2003), the relation between field data and types of irrigation ponds were examined, but the conclusions arrived at were insufficient. Pertti (1993) investigated the relation between phytoplankton and environmental factors, but his work focused on a single lake and never discussed the issue of universality. Thus, little work is available to categorize or investigate irrigation ponds focusing on the relation between the impounded water and the socio-physical environments. In this research, various factors of socio-physical environments were examined and the irrigation ponds were categorized using representative common factors. Finally, the interrelations between the categories and algae/water quality properties are discussed.

SITE AND OBSERVATIONS

Eighteen ponds in Otsu, city and seventeen ones in Minakuchi town were selected as research targets. Otsu, the capital city of Shiga prefecture, is located in its southwestern part with a population of about 300,000. It is roughly categorized as an urban area. On the other hand, Minakuchi is a small town where agriculture is quite a major industry. Moreover, suburbanization is proceeding around the area due to a recent foray of factories. It is located in the southeastern part of Shiga prefecture, which is roughly categorized as a rural area (Fig. 1). The ratios of farm households to the whole households in Otsu and Minakuchi are 3.3 % and 10.0%, respectively.

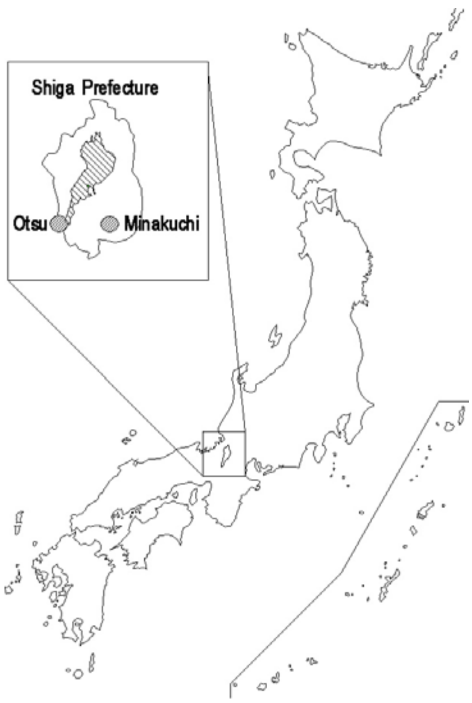

Fig. 1 Study areas

On those study sites, water quality (T-N (total nitrogen), NO_3-N, NH_4-N, T-P (total phosphorus), PO_4-P, DO (dissolved oxygen), water temperature, EC and pH) and algae (Chlorophyll-a and species) were observed three times in a year at each outlet. Observations for Minakuchi town were carried out in 2001 and those for Otsu city were in 2002. In addition, socio-physical environments were investigated through the public records mentioned in the above catalog and field survey.

CATEGORIZATION

Methods

The socio-physical environments are the most convenient indices in the categorization of irrigation ponds. Some important parameters were selected among the given ones and cast into the factor analysis to obtain common factors, because some of the given parameters have little relation with the rest of the parameters and there are no common factors among them.

Next, the irrigation ponds were categorized by the resultant factors using cluster analysis. In the analysis, the similarity of the irrigation ponds were defined by squared Euclidean distance and the distance within the clusters was computed by the Ward method.

Analyses

Table 1 shows the major socio-physical and environmental parameters and their values. The command area, the impoundment and the water depth were obtained from the catalog of the irrigation ponds. The area of the water surface and the ratio of land-use type were estimated from the maps (1:3000 or 1:12500) and GIS data prepared by Shiga prefectural office.

In the factor analysis, factors were extracted by the principal component analysis and obtained factors were rotated by the quartimax method. The resultant commonalities that indicate the extent to which the common factors could reveal the parameters, are shown in Table 2.

Table 1 Physical-environmental parameters for irrigation ponds

Name of Ponds	Location	Command Area (ha)	Water Surface Area (m^2)	Impoundment (m^3)	Water Depth (m)	Ratio of Land Use Type (%)		
						Forest	Paddy/ Upland Field	Urban Area
Urakaido	Otsu	1.0	1360	2000	1.5	61.9	27.9	10.2
Iba	Otsu	3.0	2320	4000	1.7	9.1	24.5	66.4
Yamanobo	Otsu	1.0	2340	1200	0.5	88.9	0.9	10.2
Sendai	Otsu	0.7	3480	2160	0.6	100.0	0.0	0.0
Tsuru	Otsu	3.5	15480	34700	2.2	88.4	3.7	7.9
Shin(F)	Otsu	3.5	11280	31700	2.8	88.4	3.7	7.9
Beppomitsu	Otsu	5.8	3140	4320	1.4	50.1	29.5	20.3
Shin(B)	Otsu	5.8	8300	11520	1.4	50.1	29.5	20.3
Mago	Otsu	6.2	32220	37900	1.2	50.6	6.5	42.9
Terabe	Otsu	15.0	22880	20000	0.9	83.7	0.0	16.3
Ishikura	Otsu	20.0	4800	16100	3.4	100.0	0.0	0.0
Sanbonmatsu	Otsu	5.0	1940	1400	0.7	95.4	3.2	1.4
Teranomae	Otsu	0.2	3880	1000	0.3	43.0	20.0	37.0
Furu	Otsu	0.3	2960	4320	1.5	63.2	0.0	36.8
Shin(H)	Otsu	1.1	9480	19000	2.0	75.0	0.0	25.0
Ko(O)	Otsu	0.1	1600	640	0.4	75.0	0.0	25.0
Miyanomae1	Otsu	6.0	3200	7200	2.3	100.0	0.0	0.0
Miyanomae2	Otsu	10.0	4640	4900	1.1	100.0	0.0	0.0
Higashi	Minakuchi	5.0	3060	2500	0.8	87.5	12.5	0.0
Momoki1	Minakuchi	5.0	5000	10000	2.0	100.0	0.0	0.0
Momoki2	Minakuchi	5.0	2000	2000	1.0	100.0	0.0	0.0
Otani(K)	Minakuchi	20.0	22656	137000	6.0	100.0	0.0	0.0
Yoshi	Minakuchi	3.0	1172	5000	4.3	0.0	0.0	100.0
Iwatani	Minakuchi	5.0	10013	52000	5.2	59.4	40.6	0.0
Isegai	Minakuchi	5.0	2453	12000	4.9	100.0	0.0	0.0
Oo(U)	Minakuchi	34.0	7875	16000	2.0	100.0	0.0	0.0
Benten(U)	Minakuchi	34.0	7830	13000	1.7	100.0	0.0	0.0
Tokoji	Minakuchi	2.0	2925	5000	1.7	82.5	17.5	0.0
Asoda	Minakuchi	28.0	5198	4000	0.8	50.0	41.7	8.3
Benten(N)	Minakuchi	18.0	15720	41400	2.6	62.5	37.5	0.0
Ima	Minakuchi	1.5	2835	5000	1.8	62.5	37.5	0.0
Oo(K)	Minakuchi	11.0	12690	45000	3.5	100.0	0.0	0.0
Kusazawa	Minakuchi	0.5	3994	12000	3.0	100.0	0.0	0.0
Ootani(M)	Minakuchi	2.0	2790	6000	2.2	100.0	0.0	0.0
Nishi	Minakuchi	5.0	1665	2400	1.4	62.5	37.5	0.0

In the next stage, the number of the valid common factors was decided by the accumulated contributing rates that are computed from the eigenvalue of each common factor. In this research, the criterion for the accumulated contributing rate was set at 70%, where the selected factors were assumed to include enough information. Resultantly, the number of factors became three as shown in Table 3.

Table 4 shows the computed factor loads for the selected parameters. The load of impoundment became nearly unity for factor 1 and largest among all of the parameters and those of water surface area and water depth were large, while those of land-uses are very small. The load of forest and urban area for factor 2 were located in opposite positions with respect to the origin. The load of paddy/upland field was estimated large only for factor 3. As a result, factor 1 is defined as “a scale of

Table 2 Commonality of parameters

Parameters	Value
Command Area	0.513
Water Surface Area	0.616
Impoundment	0.895
Water Depth	0.561
Forest	0.993
Paddy/ Upland Field	0.903
Urban Area	0.903

Table 3 Accumulated contributing rate

Factor	Contributing rate	Accumulated contributing rate
Factor 1	31.656%	31.656%
Factor 2	26.965%	58.621%
Factor 3	18.273%	76.894%

Table 4 Factor loads

Parameter	Factor 1	Factor 2	Factor 3
Command Area	0.408	0.498	0.313
Water Surface Area	0.784	0.021	0.028
Impoundment	0.939	0.115	-0.017
Water Depth	0.737	-0.053	-0.121
Forest	0.043	0.843	-0.530
Paddy/ Upland Field	-0.092	-0.098	0.941
Urban Area	0.012	-0.950	-0.006

irrigation pond". Similarly, factors 2 and 3 are defined as "development of the catchment" and "extent of cultivation in the catchment", respectively. Factor loads for each pond are shown in Table 5.

Using the obtained factors, the irrigation ponds could be categorized with the cluster analysis. In this case, the number of the clusters was set to four. The result is illustrated in Table 5 and in Fig.2 as a dendrogram. In the figure, the vertically drawn straight line divides the irrigation ponds into four clusters. It can be considered that the irrigation ponds that belong to the same cluster have some similarities.

Averaged factor loads for each cluster are shown as a scattergram in Fig.3, which roughly indicates the followings. Irrigation ponds of cluster A are small and their catchments are less developed and less cultivated. They are likely to be small irrigation ponds in hill areas. Similarly, those of cluster B, C and D are large ponds in alluvial slopes, middle-size ponds near urban areas and middle-size ponds in agricultural zones.

Table 5 Factor load for each pond

Name of Pond	Factor1	Factor2	Factor3	Cluster
Iba	-0.31382	-2.36703	0.91007	C
Urakaido	-0.78645	-0.18847	0.82973	D
Tsuru	0.68805	0.02224	-0.58994	B
Sin(F)	0.57474	0.00337	-0.6529	B
Beppomitsu	-0.55054	-0.45321	1.16344	D
Shin(B)	-0.16955	-0.48885	1.1842	D
Mago	1.57029	-1.34113	-0.03193	C
Sendai	-0.94684	0.48984	-0.88294	A
Yamanobo	-0.98502	0.09967	-0.77077	A
Teranomae	-0.83605	-1.14782	0.52156	D
Sanbonmatsu	-0.93713	0.5537	-0.53446	A
Shin(H)	0.12865	-0.65148	-0.84883	C
Ko	-0.98965	-0.50244	-0.79448	A
Furu	-0.51903	-1.0638	-0.81848	C
Terabe	0.72414	0.15557	-0.23705	B
Ishikura	0.35922	0.89407	-0.38247	B
Miyanomae1	-0.36948	0.53198	-0.82003	A
Miyanomae2	-0.56846	0.74907	-0.57463	A
Higashi	-0.84951	0.51845	0.03685	A
Nishi	-0.78508	0.28043	1.54214	D
Momoki1	-0.32216	0.50978	-0.82621	A
Momoki2	-0.8556	0.6099	-0.76134	A
Imai	-0.63977	0.12544	1.38714	D
Benten(U)	-0.64212	0.3093	0.16793	B
Yoshi	0.48492	-3.71093	-0.68458	C
Isegai	0.30161	0.29949	-1.06073	A
Oo(U)	0.39134	1.44513	0.25308	B
Kusazawa	-0.16401	0.28915	-1.07291	A
Otani(M)	3.93831	0.52723	-0.49315	B
Asoda	-0.31468	0.69655	2.74438	D
Benten(N)	1.08614	0.51027	1.98783	D
Oo(K)	1.12272	0.52738	-0.68609	B
Tokoji	-0.64212	0.3093	0.16793	A
Iwatani	1.4102	-0.11388	1.4812	D

Attributes

Following the success in categorization, it is required to discuss what the clusters or categories mean in the field and with which phenomenon or condition of the

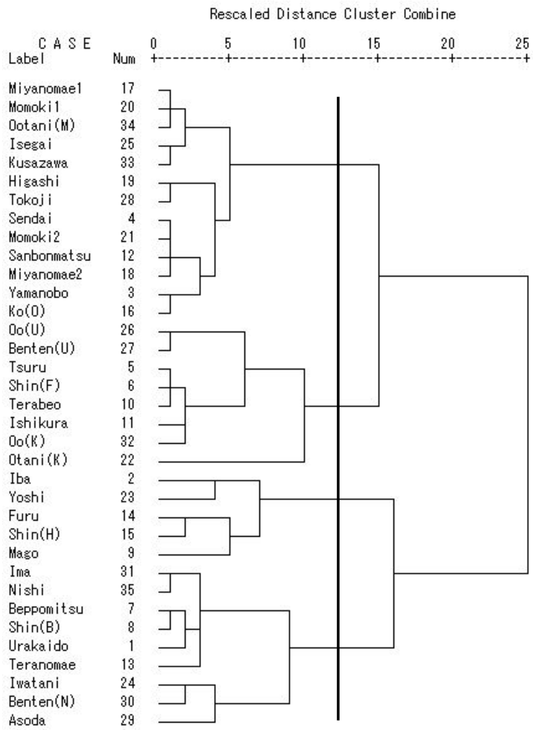

Fig. 2 Dendrogram by Cluster Analysis

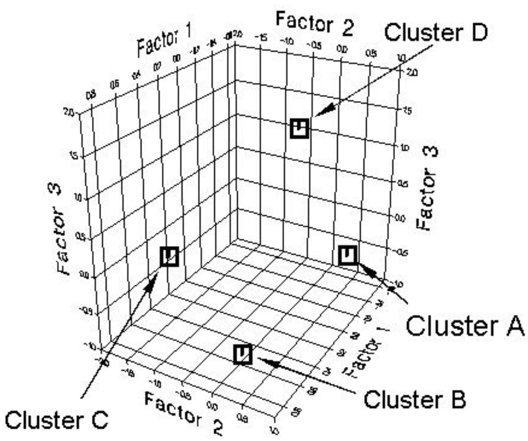

Fig. 3 Position of Clusters

irrigation ponds they are related. This is referred to as 'attributes'. In this research, algae diversity, algae dominant species, trophic level, Chlorophyll-a and location were chosen among observed data as indices of the attribute.

Algae diversity H is estimated using Shannon-Weaver's formula as;

$$H = -\sum \frac{n_i}{N} \log_2 \frac{n_i}{N} \qquad (1)$$

$$N = \sum n_i \qquad (2)$$

Table 6 Trophic Level of Water (Okino, 2002)

Level	T-P (mg/L)	T-N (mg/L)
Extreme Oligotrophy (EO)	<0.005	<0.2
Oligo-Mesotrophy (OM)	0.005-0.01	0.2-0.35
Mesotrophy (MT)	0.01-0.03	0.35-0.575
Meso-Eutrophy (ME)	0.03-0.1	0.575-1.5
Eutrophy (ET)	0.1<	1.5<

where n_i shows the i-th density of population. They were classified into 2 levels as 'H >=2.0' and 'H <2.0'. Algae dominant species were classified into 4 species as 'CHLORO- PHYCEAE', 'DIATOM', 'CYANOPHYCEAE' and 'EUGLENOPHYCEAE'.

Trophic level is the classification of water quality based on T-P (total phosphorus) and T-N(total nitrogen) level by (slightly modified) Vollenweider's approach, which is shown in Table 6. Chlorophyll-a was also classified into 2 levels as 'more than 8 (Chl-a>8)' that roughly indicates eutrophy and 'less than 8 (Chl-a<8)' that roughly indicates oligotrophy. Location indicates the place of the irrigation pond, i.e., Otsu or Minakuchi.

Table 7 indicates the factor scores for each attribute. Regarding Factors 1 and 2, 'H>2.0' and 'H<2.0' stood in contrast with respect to the origin. This implies that the degree of development in the catchments is high and the scale of the irrigation pond is large for 'H<2.0'. For 'H>2.0', the opposite result was obtained. It may be interpreted that the biodiversity of algae was small in ponds of cluster C and large in those of cluster A. When 'scale' was small and 'degree of cultivation' was high, Chlorophyll–a tended to be large. The higher 'development' and 'cultivation' were, the higher the trophic level became. In addition, the trophic level depended also on the 'scale' to a certain extent. The results also show that 'DIATOM' became dominant when factors 1 and 2 were small, 'CHLOROPHYCEAE' was dominant when factor 1 was small, 'CYANOPHYCEAE was dominant when factor 2 was large and 'EUGLENOPHYCEAE' was dominant when factors 1 and 3 were large. However, these relations of the species of algae are still ambiguous. Finally, 'Otsu' and 'Minakuchi' stood in opposite positions with respect to the origin for all the factors. Ponds in Otsu were comparatively smaller than those at Minakuchi were. Contrary to the Minakuchi, the level of development was high and the cultivation was low in Otsu, which clearly shows the characteristics of the two different locations.

Table 8 shows the average values of water quality and diversity of algae for each cluster. It can be said that those values are reasonable for the explanation of each cluster. However, the ranges of Chl-a, T-N and T-P were

Table 7 Factor score for each attribute

Factor	July			October			December			Average		
	1	2	3	1	2	3	1	2	3	1	2	3
H>2	-0.089	0.060	-0.056	-0.106	0.102	0.094	-0.588	0.310	0.137	-0.261	0.158	0.059
H<2	0.285	-0.456	0.336	0.136	-0.219	-0.099	0.587	0.144	0.318	0.336	-0.177	0.185
ET (T-P)	0.391	-0.073	1.101	-0.786	-0.188	0.830	-0.679	-0.667	0.402	-0.358	-0.310	0.777
ME (T-P)	-0.141	-0.234	-0.088	-0.238	-0.105	0.335	-0.361	-0.047	0.354	-0.246	-0.129	0.200
MT (T-P)	-0.074	0.039	-0.261	0.400	-0.051	-0.291	0.476	0.195	-0.164	0.267	0.061	-0.239
OM (T-P)	0.019	0.702	-0.604	-0.589	0.560	-0.794	0.359	0.894	-0.382	-0.070	0.719	-0.594
EO (T-P)	-	-	-	-	-	-	-	-	-	-	-	-
ET (T-N)	-0.033	-0.444	0.868	-0.471	-0.138	0.481	-0.706	-0.430	0.687	-0.403	-0.337	0.678
ME (T-N)	-0.030	0.050	-0.030	0.293	-0.090	0.231	0.020	-0.049	0.507	0.094	-0.030	0.236
MT (T-N)	-0.071	-0.110	-0.341	0.084	0.308	-0.262	0.101	0.068	-0.228	0.038	0.089	-0.277
OM (T-N)	0.162	0.148	-0.055	-0.125	0.053	-0.077	0.134	0.571	-0.296	0.057	0.257	-0.143
EO (T-N)	-	-	-	0.081	-1.600	-0.756	0.600	-0.405	-0.426	0.341	-1.003	-0.591
DI	-0.291	-0.079	0.230	-0.247	-0.199	-0.288	0.462	-0.266	0.349	-0.025	-0.182	0.097
CH	-0.335	-0.387	-0.129	0.276	0.289	0.186	-0.194	0.591	-0.495	-0.084	0.164	-0.146
CY	-0.022	0.340	-0.088	-0.310	0.012	0.153	0.404	0.612	1.029	0.024	0.321	0.365
EU	1.570	0.180	0.792	1.490	-0.728	0.725				1.530	-0.274	0.758
Chl-a >8	-0.048	-0.020	0.060	-0.048	-0.020	0.060	-0.383	-0.282	0.213	-0.159	-0.107	0.111
Chl-a <8	0.053	-0.095	-0.039	0.053	-0.095	-0.039	0.394	0.297	0.108	0.167	0.036	0.010
Otsu	-	-	-	-	-	-	-	-	-	-0.218	-0.261	-0.185
Mina-kuchi	-	-	-	-	-	-	-	-	-	0.220	0.196	0.161

Note: DI=,'DIATOM', CH='CHLOROPHYCEAE', CY='CYANOPHYCEAE' and EU='EUGLENOPHYCEAE'.

quite large as shown in Figs. 4-6, which indicates that the borders of clusters exist not crisply but fuzzily. In addition, the range of the diversity for each cluster overlaps with each other in such a way that it is difficult to find any distinction.

CONCLUSIONS

Three common factors that can be considered as scale of irrigation ponds, development of the catchments and extent of cultivation in the catchments were extracted from several socio-physical parameters. Using the resultant factors, irrigation ponds were categorized into four clusters, i.e., (A) small irrigation ponds in hill areas, (B) large ponds in alluvial slopes, (C) middle-size ponds near urban areas and (D) middle-size ponds in agricultural zones.

In the next step, attributes that are indices of water quality, algae and location were analyzed using the common factors. Based on the analysis, it became apparent that diversity of algae, Chlorophyll-a and trophic level by T-P and T-N could be explained by those factors. Especially, the result that T-P and T-N had a close relation with 'development' and 'cultivation', respectively, coincides with the results of previously published technical reports, e.g. Takahashi *et al.* (1999). Thus, it would be possible to predict water quality properties from the socio-physical environments.

It is also expected that ponds of each cluster have their own characteristics in algae and water qualities and the characteristics of ponds of the same cluster will resemble each other. It was, however, valid only for the average results, because the deviation of water quality and algae properties for each cluster was considerably large, even though they inherently include large dispersion. Therefore, the relation between clusters and

Table 8 Averaged water quality and algae properties

Cluster	Chl-a (μg /L)	T-N (mg/L)	T-P (mg/L)	*H*
A	14.5	0.819	0.0463	2.43
B	10.4	0.478	0.0346	2.16
C	32.1	1.022	0.0506	2.25
D	27.6	1.166	0.1042	2.28

attributes was limited only to the average condition and could not refer to individual ponds.

At present, the amount of obtained data is rather limited and therefore there may be some assumptions in the conclusions, but this work is a first step towards better management and evaluation of irrigation ponds.

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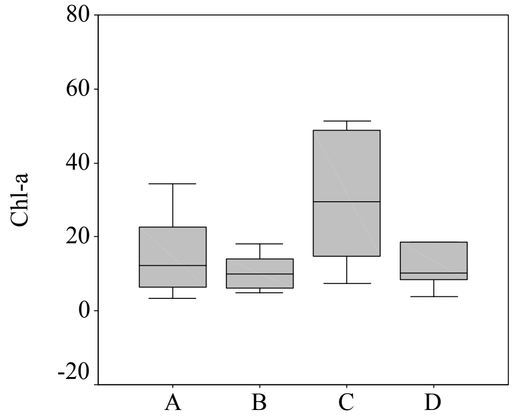

Fig.4 Distribution of Chl-a for each cluster (unit of Chl-a=μg/L)

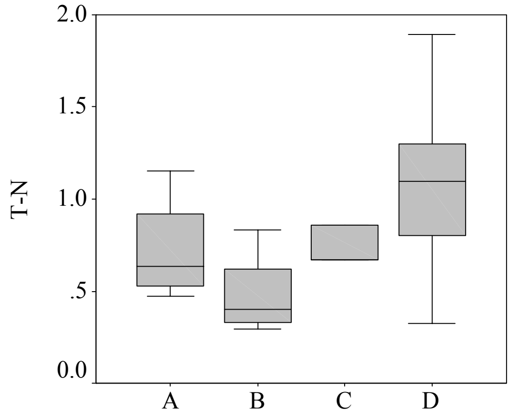

Fig.5 Distribution of T-N for each cluster (unit of T-N=mg/L)

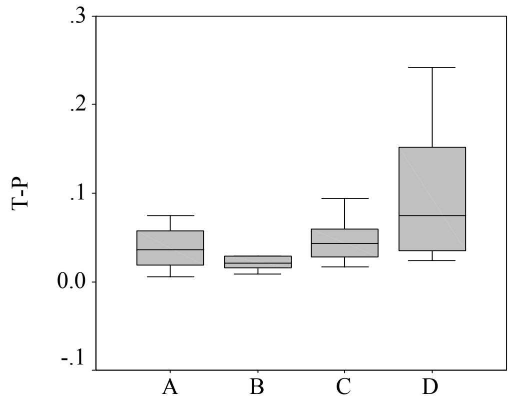

Fig.6 Distribution of T-P for each cluster (unit of T-P=mg/L)