Research article

Characteristics of Ion Components of Clearwater Stream Watershed in an Agricultural Area with Multivariate Analysis

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Abstract Restoring the clear-stream environment that once existed in agricultural areas is one of the major challenges for the development of sustainable agriculture. Therefore, we analyzed the ionic components of the Rekifune and Satsunai River basins, which are regarded as clear-water basins in the Tokachi region of Hokkaido, using principal component analysis and cluster analysis based on surveys conducted in June and September 2014. The results showed that most of the sampling points in the Rekifune and Satsunai drainages were comparable to the average values of water quality assessed as clear-streams in Japan. However, in the tributaries of the Rekifune River, since Cl^- and Na^+ increased characteristically, the water quality was degraded by anthropogenic pollution sources such as domestic wastewater. In the Satsunai River, the water quality of the downstream tributaries was degraded due to agriculture. In addition, in one of the tributaries, deterioration of water quality was observed only in September, and the water quality of the main river immediately after the inflow of this tributary was also affected. These results indicate that the water quality in the two basins in the predominantly agricultural area is generally good. Still, it is necessary to identify the source of pollution in some areas and take countermeasures.

Keywords river water quality, agricultural area, principal component analysis, cluster analysis

INTRODUCTION

Historically, rivers flowing through rural areas in Japan had clear water and were home to various aquatic life. However, modern agricultural land-use changes and river alterations have resulted in the disappearance of the 'clear water' environment in rural areas. This water pollution caused by modern agriculture has become a global problem. We now understand the need to conserve intact rivers in agricultural areas and restore altered river ecosystems to meet the global challenge of more sustainable agriculture.

The term “clearwater stream” generally refers to uncontaminated rivers-however, no scientific definition in Japan. For example, the Japanese government publicizes river rankings based on water quality measurements, particularly biochemical oxygen demand (BOD). Therefore, any river ranked highly in the river-ranking program is defined as a clearwater stream. Also, rivers selected as “100 clearest streams in Japan” by the Ministry of the Environment are evaluated as clearwater streams.

The Tokachi region of Japan, which has an essential role in Japan’s food supply, has two clearwater streams: the Rekifune and Satsunai rivers. Both had been ranked high in the government's river-ranking program in prior years, and both had low BOD values. In a questionnaire provided to Hokkaido residents to rank clearwater streams, the Rekifune River ranked second, and the Satsunai River ranked 5th place (Shimatani et al., 1996). Therefore, it is clear that both rivers are recognized as being clearwater streams in Hokkaido. However, ever since large-scale agriculture commenced in the watershed of the Rekifune and Satsunai drainage basins, water pollution caused by these agricultural activities has become a concern. In 2008, for example, water quality studies of the Rekifune and Satsunai rivers had shown elevated nitrogen concentrations in river water caused by agricultural runoff (Yamazaki et al., 2017).

OBJECTIVE

This study evaluated ion components of river water and all water quality factors using multivariate analysis in clear stream watersheds at a large agricultural area to develop guidelines for preserving river environments.

MATERIALS AND METHODOLOGY

Study Sites

This investigation examined two clearwater stream drainages in the Tokachi region in eastern Hokkaido, Japan: the Rekifune and Satsunai drainages. Both rivers supply irrigation and tap water to the residents in the Tokachi region. Also, the Rekifune and Satsunai watersheds are geographically adjacent to one another in their headwaters. The catchment areas are similar, and the primary land use of the region is agriculture and forest.

The primary land use in the Satsunai drainage is agricultural cropland (30% of total area), including wheat, potato, sugar beet, and beans. Both chemical and organic fertilizers (livestock manure) are applied to croplands. In the Rekifune drainage, pasture and forage crops are produced, constituting 17% of the total land area.

Water Quality Investigation

We selected fourteen water quality sampling stations in the Rekifune drainage and 21 points in the Satsunai drainage; these stations were sampled once per month in June and September 2014 during normal water levels; a total of 42 and 63 samples were collected from the Rekifune and Satsunai River drainages respectively (Fig. 1). The sampling points were located on the main stems (Stations A-F on the Rekifune River and Stations 1-11 on the Satsunai River) and downstream along tributaries (Stations G–N on the Rekifune River and Stations 12-21 on Satsunai River).

Electrical conductivity and water temperature were measured using a digital conductivity meter (DKK TOA Corporation; 592896; Japan). We analyzed the following ion components in each sample: Cl^-, NO_3^-, NO^{2-}, SO_4^{2-}, Na^+, K^+, Ca^{2+}, and Mg^{2+} using liquid chromatography.

Multivariate Aalysis

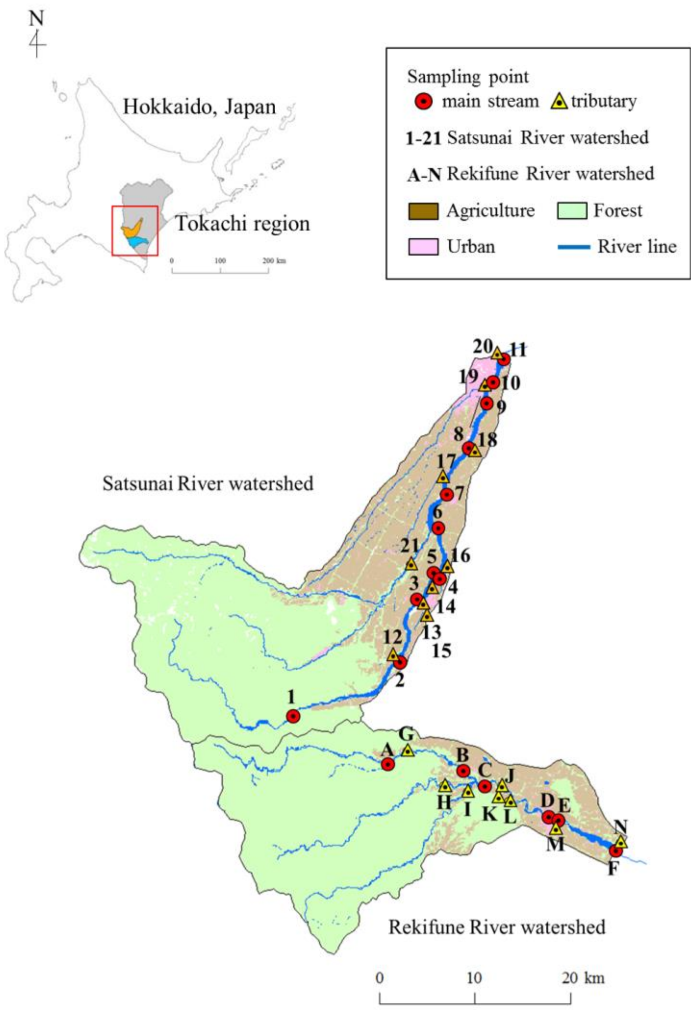

Fig. 1 Land use and sampling stations of the Rekifune and Satsunai River drainages

We used the R package (R Foundation for Statistical Computing; Ver. 3.0.3; Austria) for cluster and principal component analyses. The ion components (Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, and Mg^{2+}) were used as input variables. Cluster analysis and principal component analysis are both types of multivariate techniques. We applied Ward's method to the cluster analysis. Principal component analysis (PCA) was derived using the "princomp" algorithm of the R package.

RESULTS AND DISCUSSION

Cluster Aalysis and Pincipal Cmponent Aalysis of the Rver Water Qality

Cluster and principal component analysis using correlation matrix were carried out for seven variables: ion concentrations (Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, and Mg^{2+}) at 35 sampling stations in the Rekifune and Satsunai drainages. We compared water quality between the mean ion concentration of river water and groundwater from "100 clearest streams in Japan" of 1985 and 2008 (Yabuzaki et al., 2009) as a reference. These analyses were performed for the July and September observations in the Rekifune and Sastunai drainages, respectively.

Table 1 shows the cluster analysis results and PCA score of PC1 and PC2 of the July and the September observations, respectively. First, the "100 clearest streams in Japan" of 1985 and 2008 were classified as Cluster1 and Cluster2, respectively, in the July observation data. Also, twenty-eight sampling stations (11 stations of the Rekifune and 17 stations in the Satsunai) were classified into Cluster1 and Cluster2. Therefore, most of the main stems and the tributaries of the Rekifune and the Satsunai drainages have the same level of water quality concentration as the “100 clearest streams in Japan”. However, three tributaries of the Rekifune and four of Satsunai drainages, classified as Cluster3 to Cluster5, show a different trend from the “100 clearest streams in Japan”.

Next, in the September observation data, the “100 clearest streams in Japan” of 1985 and 2008 were classified as Cluster1. Also, twenty-four sampling stations (11 stations of the Rekifune and 13 stations in the Satsunai) were classified into Cluster1. The results of the Rekifune River were like those of the July cluster analysis, while the Satsunai River showed a different trend. Particularly, Stations 5 and 14 in the Satsunai River were classified as Cluster5.

Table 1 Results of cluster analysis and PCA score

ID	June			September			ID	June			September		
	PC1	PC2	Cluster ID	PC1	PC2	Cluster ID		PC1	PC2	Cluster ID	PC1	PC2	Cluster ID
1985	-0.53	0.07	Cluster 1	-0.77	0.21	Cluster 1	1	-1.81	0.22	Cluster 1	-1.98	0.21	Cluster 1
2008	0.37	-0.54	Cluster 2	0.04	-0.30	Cluster 1	2	-1.73	0.23	Cluster 1	-1.83	0.17	Cluster 1
							3	-1.37	0.20	Cluster 1	-1.40	0.04	Cluster 1
A	-1.56	0.15	Cluster 1	-1.69	0.07	Cluster 1	4	-1.36	0.22	Cluster 1	-1.44	0.04	Cluster 1
B	-1.12	-0.02	Cluster 1	-1.37	-0.08	Cluster 1	5	-1.07	0.30	Cluster 1	3.99	0.79	Clsuter 5
C	-1.15	0.04	Cluster 1	-1.39	0.02	Cluster 1	6	-1.17	0.33	Cluster 1	-0.75	0.27	Cluster 1
D	-0.91	-0.01	Cluster 1	-1.17	-0.05	Cluster 1	7	-0.93	0.09	Cluster 1	-0.99	0.01	Cluster 1
E	-0.87	0.00	Cluster 1	-1.17	-0.05	Cluster 1	8	-0.78	0.03	Cluster 1	-0.76	-0.13	Cluster 1
F	-0.68	0.05	Cluster 1	-0.96	-0.01	Cluster 1	9	-0.60	-0.02	Cluster 1	-0.72	-0.14	Cluster 1
G	-0.71	-0.26	Cluster 1	-1.18	-0.09	Cluster 1	10	-0.61	0.01	Cluster 1	-0.72	-0.13	Cluster 1
H	-1.32	0.11	Cluster 1	-1.52	0.04	Cluster 1	11	-0.35	-0.10	Cluster 1	-0.36	-0.26	Cluster 1
I	-1.31	0.09	Cluster 1	-1.56	0.15	Cluster 1	12	-1.01	0.07	Cluster 1	-1.36	0.17	Cluster 1
J	0.84	-0.56	Clsuter 4	0.86	-0.17	Clsuter 3	13	-0.95	0.02	Cluster 1	-0.40	-0.38	Clsuter 3
K	0.80	-0.63	Cluster 2	-0.08	-0.13	Cluster 1	14	-0.63	0.51	Cluster 1	5.86	1.44	Clsuter 5
L	0.11	-0.48	Cluster 2	-0.59	-0.08	Cluster 1	15	-1.44	0.23	Cluster 1	-1.51	0.04	Cluster 1
M	5.51	8.13	Cluster 5	3.15	5.73	Cluster 4	16	-0.28	0.05	Cluster 1	-0.34	-0.24	Clsuter 3
N	2.37	-1.14	Clsuter 4	2.10	-0.72	Clsuter 3	17	-0.90	-0.17	Cluster 1	-1.29	-0.03	Cluster 1
							18	5.74	-3.57	Cluster 3	4.54	-2.92	Cluster 2
							19	3.80	-1.49	Cluster 3	3.20	-1.51	Cluster 2
							20	5.41	-2.14	Cluster 3	4.49	-1.99	Cluster 2
							21	2.19	-0.02	Clsuter 4	1.08	0.03	Clsuter 3

Fig. 2 shows the eigenvector of PC1 and PC2, also Fig. 3 shows the results of the principal component analysis, color-coded into clusters 1 to 5 as described above. The x-axis is the first principal component (PC1), and the y-axis is the second principal component (PC2).

The cumulative contribution of the principal component analysis was 95% and 82% from the first to the second principal components in July and September observations, respectively, indicating that the characteristics of river water quality in the Rekifune and Satsunai River drainages can be summarized by two principal components. The eigenvectors of the first and second principal components showed a similar trend in both July and September. First, the eigenvectors of PC1 were positive for all items. PC1 indicates the overall characteristics of the river water quality, and the larger the positive value of PC1 is, the worse the river water quality is. The eigenvectors of PC2 showed positive values for Cl^-, Na^+, and K^+, and negative values for NO_3^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+}. The negative values of PC2 indicate that the components are contained in fertilizer, so it can be inferred that when PC2 is large with negative values, the influence of agriculture is significant. On the other hand, for the item with a positive PC2, the increase in Cl^-, and Na^+ concentrations in river water due to the inflow of domestic wastewater was reported in the suburbs of urban areas (Taniguchi et al., 2004; Hirata et al., 1999), which may reflect anthropogenic influences other than agriculture.

Cluster1 and Cluster2 in July, and Cluster1 in September, show the range of -1.9 to 0.8 for PC1 and the content of -0.6 to 0.5 for PC2. The main stems and most of the tributaries of the Rekifune and Satsunai Rivers are comparable to those of the “100 clearest streams in Japan”.

On the other hand, the three sites in the tributaries of the Satsunai River, classified as Cluster3 in July and Cluster2 in September, showed positively large values of PC1 and negative values of PC2 in both July and September. The tributaries located in the lower reaches of the Satsunai River are affected by agriculture. Although the water quality is worse than "100 clearest streams in Japan", it does not significantly affect the water quality of the main river of the Satsunai River.

In addition, Cluster4 in July and Cluster3 in September have a larger PC1 than the "100 clearest streams in Japan". Therefore, the water quality tends to deteriorate, although not as markedly as the tributaries in the lower reaches of the Satsunai River.

One tributary station of the Rekifune River, classified as Cluster5 in July and Cluster4 in September, showed large positive results for both PC1 and PC2. The water quality at station M of the Rekifune River is degraded by anthropogenic influences other than agricultural influences in the period of July to September at least.

Finally, one station in the main stem of the Satsunai River and one station in a tributary classified as Cluster 5 in September were both classified as Cluster 1 in July, and the river water quality in July was good. However, in September, PC1 became larger with positive values, and the water quality deteriorated. On the other hand, PC2 is positive, ranging from 0.8 to 1.4. Therefore, although it is not as pronounced as station M in the Rekifune River, it is considered that the river is affected by anthropogenic factors other than agriculture only in September. Since station 5 of the main stem of the Satsunai River is just after the inflow of the tributary of station14, it is considered that there is a pollution source around station 14, which deteriorates the river water quality of the main stem around station5.

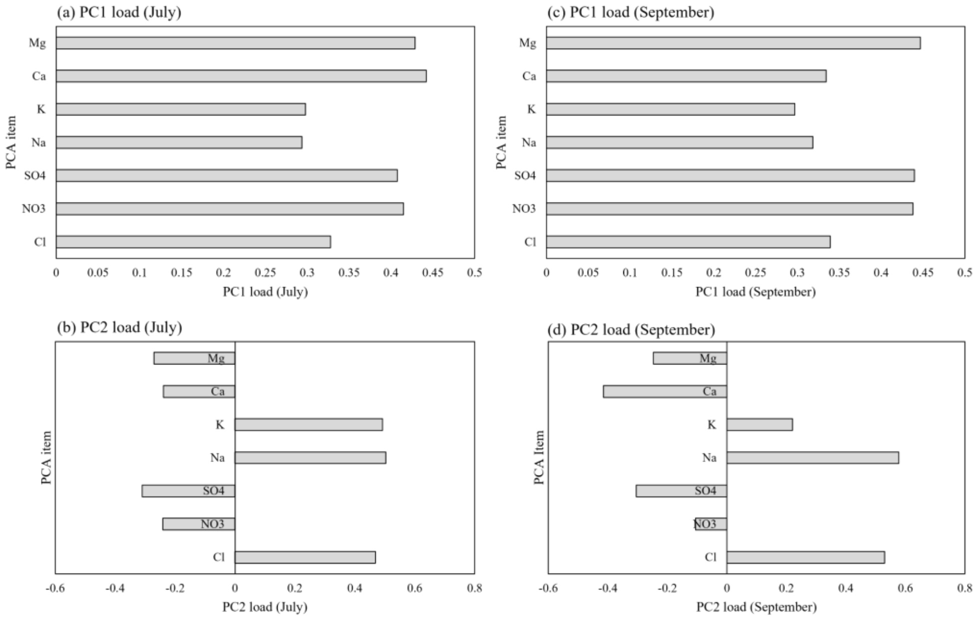

Fig. 2 Eigenvector of PC1 and PC2

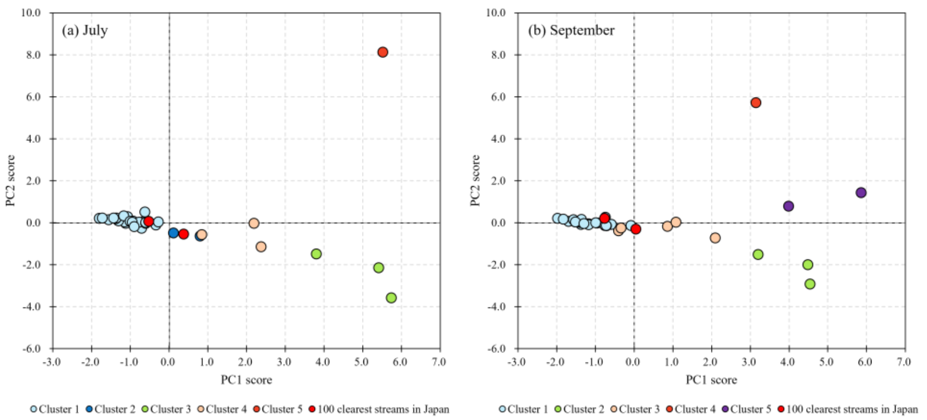

Fig. 3 Relationships between PC1 and PC2

CONCLUSION

In this study, we investigated the water quality of the Rekifune and the Satsunai drainages, which are in a large agricultural area and are regarded as clear streams. We compared them with the "100 clearest streams in Japan" results using multivariate analysis. As a result, the water quality of both rivers is comparable to that of the "100 clearest streams in Japan" and can be evaluated as a good water quality environment. However, the Rekifune River deteriorated at one station due to anthropogenic influences such as domestic wastewater. Furthermore, there is a concern about pollution sources operating at different times in the Satsunai River. Although the effects of these pollution sources have not had a significant impact on the main rivers of both the Rekifune and the Satsunai Rivers, it is necessary to identify these pollution sources and take measures to ensure sustainable conservation in the future.

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