Journal of Environmental Sciences Vol.15, No.2, pp.160—166, 2003

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2003)02-0160-07 **CLC number**: Q149 **Document code**: A

River system in Japan from a landscape ecological aspect

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Abstract: The objective of this study was to elucidate characteristics associated with rivers by classification of major rivers in Japan into several types based on riparian conditions. As the results of principal component analysis (PCA) with use of parameters reflecting forms and artificial alterations of respective rivers, four major components such as "comprehensive riparian size", "intactness of water front", "continuity of streams" and "simplicity of landform in river basin" were extracted. Subsequently, cluster analysis was performed based on principal component scores, leading to successful classification of major rivers into 6 types. These findings disclosed that (1) the extracted principal components provide effective viewpoint for classification of rivers; (2) distribution of respective classes indicates area properties; and (3) the employed quantitative procedures were found effective for classification of major rivers.

Keywords: river system; landscape ecological aspect; Japan

Introduction

It is well known that most of the rivers in Japan is characterized with their more rapid streams relative to those in counterparts in the Continents, due to geographical situations in Japan. Take rivers in the Continents for example, they have rapid flows in the upper reaches of rivers as in the same with those of Japanese rivers whereas they create the so-called delta indicative of gentle slopes in the lower reaches of rivers. In Japan, however, rivers scarcely have the delta and empty into the sea directly from the middle reaches of rivers, as if the lower reaches of them were waived(Tamai, 1993). When Japanese rivers are mutually compared, there are varieties of riparian patterns ranging from rapid flow rivers without the lower reaches to rivers with alluvial plain. Appearances of rivers also vary with some rivers meandering on a plain and some others running through urban areas.

Accordingly, it is conceivable that elucidation of specificities of each river based on their characters would play an important role in future proceedings of river management and river-use. In previous studies, to investigate specific features among different districts, mountainous areas(Okahashi, 1986) and suburban districts(Yamaba, 1996) were subjected to comparative studies by taking into account lots of variables. These studies employed classification of the targeted areas based on socio-ecological conditions as the approaching procedures to reveal area properties, followed by successful assessment of area features. By referring to these procedures, we could classify the rivers, leading to clarification of their area features.

In the current rivers, distribution patterns of riparian forests are highly associated with adjustment of flow volume and water-use(Rood, 1980; Johnson, 1994) with riparian landscapes being affected by human activities(Inoue, 2001), suggesting remarkable influences induced by human impacts. In other words, it is also important to take into account such artificial impacts upon understanding specific features of respective rivers.

Given all this, the present authors performed this study to classify major Japanese rivers based on natural and sociological conditions, thereby pursuing the characteristics of relevant rivers.

1 Methods

1.1 Study area

In the present study, major Japanese rivers(the first rank rivers) were employed as the subjects of analysis (Fig. 1). This is because these major rivers provide common variables indicative of sizes and forms.

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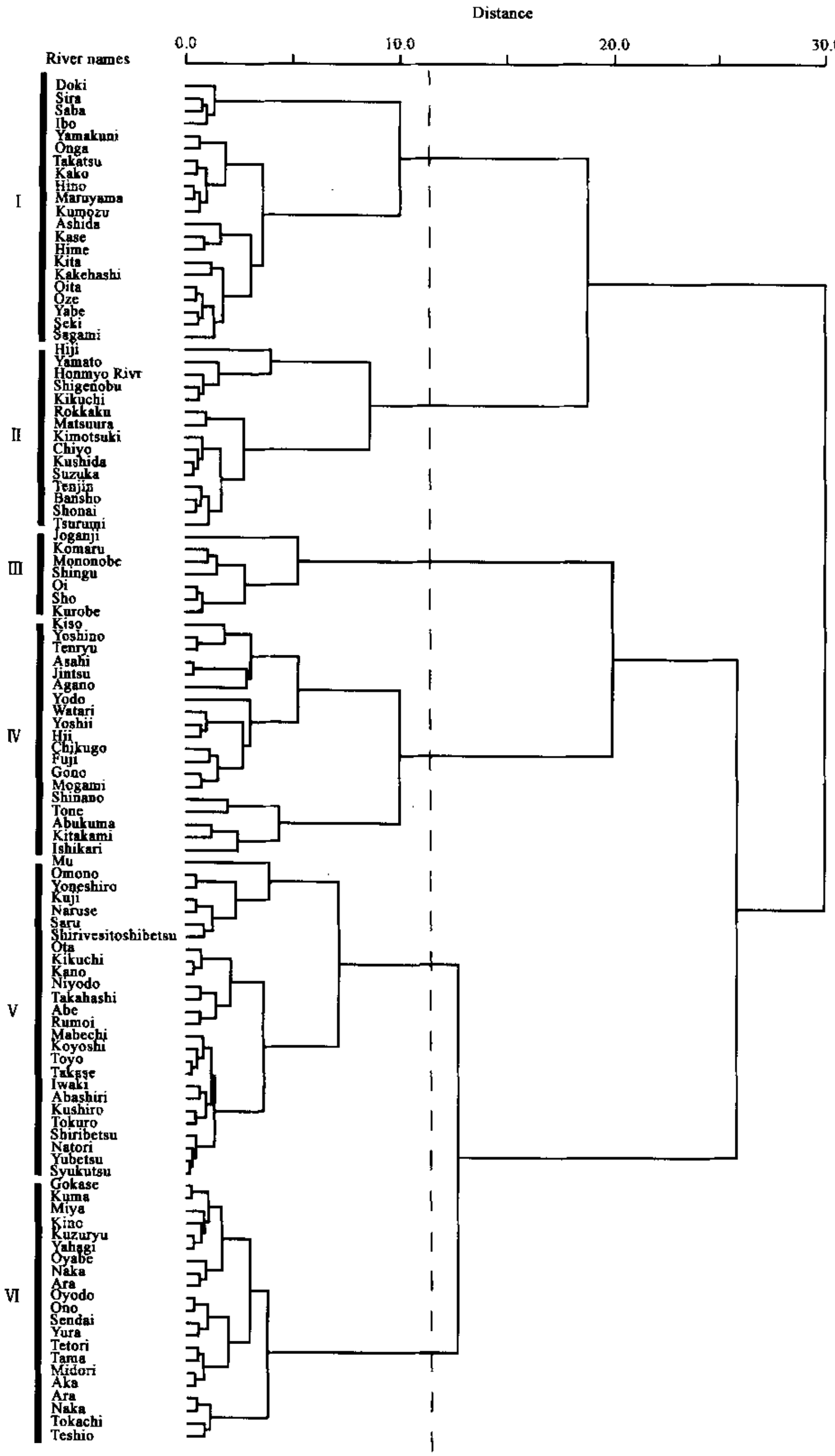

Fig. 1 Dendrogram made from the cluster analysis

The total number of the first rank rivers amounted to 109 rivers.

1.2 Analytical procedures

For the purpose of elucidating characteristics of rivers by using 109 major rivers as the unit for analysis, multivariate analysis was used. With the objective to achieve pattern classification by using lots of possibly correlated variables as would be selected in the present study, it would appear likely that principal component analysis(PCA) is effective because PCA permits both discovery of major variables resulting from intervariable correlations and summarization of mutually uncorrelated major variables(Okahashi, 1986). Furthermore, to divide the targeted rivers into some types objectively, cluster analysis was employed following calculation of principal component scores which are obtained from PCA.

1.3 Variables for analysis

Table 1 shows names and definitions of the variables to be used in the analysis. Variables indicating landform around the rivers include "number of streams", "length of main stream (km)", "total length of streams" and "basin area (km^2)" (Survey Society of Land Development, 1998). The mean values of these variables in the targeted rivers were 127.8 streams, 107.7 km and 2201.4 km^2, respectively. By using these variables, we calculated "the ratio of the number of streams per basin area (number/km^2)". As the variables reflecting the rearrangement including installments of artificial structures in rivers, "artificial water front (%)", "number of river structures", "number of dams (height > 15 m)" and "number of water-use structures" were selected (Environment Agency of Japan, 1989). The mean values of variables for the targeted rivers were 19.6 in the number of river structures, 0.04 in the number of water-use structures and 1.3 in the number of dams. Based on these mean values, "number of river structures per total length of streams", "number of water-use structures per total length of streams" and "number of dams per total length of streams" were additionally calculated to be used as the variables.

Table 1 Definition of variation of river system in Japan

Variable	Average	Definition
Number of streams*	127.84	Total number of main stream and tributaries
Length of main stream, km*	107.76	Length of main stream
Total length of streams, km*	802.03	Total length of main stream and tributaries
Basin area, km^2*	2201.39	Area of basin
Number of streams /basin area	0.07	Number of streams/basin area
Artificial water front, %**	24.33	Proportion of artificial water front
Number of river structures**	19.62	Total number of river structures
River structures/total length	15.58	River structure/total length of main stream and tributaries
Number of dams, h > 15 m**	1.34	Total number of dams
Dams/total length	0.06	Dams/total length of main streams and tributaries
Number of water-use structures**	0.04	Total number of water-use structures
Water-uses/total length	0.00	Water-use structures/total length of main stream and tributaries

* Survey Society of Land Development, 1988; ** Environment Agency of Japan, 1989

1.4 Procedures of analysis

Procedures of analysis are as follows: (1) Data matrix is prepared with use of 109 first rank rivers as the row and 12 variables as column. (2) Because of handling variables each having different units, respective normalize scores are obtained followed by preparation of the data matrix based on normalize scores. (3) The data matrix of normalize scores is subjected to PCA and principal components ($\geqq$1.0 as eigen value) are extracted, thereby calculating respective eigen vectors for principal components and principal component scores. (4) According to the results obtained by the above-stated principal component analysis, interpretation of principal components and distribution patterns of principal component scores are investigated. (5) Cluster analysis is conducted on the major principal component scores indicative of the highly ranked ratio of contribution, whereby the targeted rivers are to be classified.

2 Results

2.1 Interpretation of principal components

As the result of principal component analysis, four principal components (≧1.0 as eigen value) were extracted. The ratio of contribution by these four principal components accounted for 79.4% against the whole variations attributable to 12 variables (Table 2). Followings are our interpretation about four principal components (≧ 1.0 as eigen value).

Table 2 Results of principal component analysis

Principal component	PC1	PC2	PC3	PC4
Eigen value	4.291	2.413	1.590	1.240
Ration of contribution, %	35.755	20.108	13.246	10.330
Cumulative ratio of contribution, %	35.755	55.863	69.109	79.439
Number of streams	0.846	−0.332	0.042	−0.234
Length of main stream, km	0.905	0.050	−0.088	0.092
Total length of streams, km	0.934	−0.246	0.010	−0.048
Basin area, km^2	0.934	−0.158	−0.017	0.078
Number of streams/basin area	−0.168	−0.477	0.103	−0.701
Artificial water front, %	−0.292	−0.600	0.190	−0.334
Number of river structures	−0.073	−0.726	−0.410	−0.081
River structures/total length	0.472	−0.558	−0.251	0.396
Number of dams, h > 15m	−0.476	−0.426	−0.391	0.481
Dams/total length	−0.098	0.466	−0.744	−0.270
Number of water-use structures	0.381	0.394	−0.669	−0.312
Water-uses/total length	−0.537	−0.485	−0.385	0.000

The principal component 1 (PC1) can explain 35.8% of the whole variations, disclosing that PC1 possesses predominant importance relative to other principal components including the principal component 2. PC1 has remarkably positive correlation with "number of streams", "length of main stream", "total length of streams" and "basin area", thereby allowing us to consider that PC1 presents "comprehensive river sizes".

The principal component 2 (PC2) shows highly negative correlation with "artificial water front", "number of river structures" and "number of river structures per total length of streams". Accordingly, it is conceivable that PC2 indicates the conditions with less weight of artificial water front and limited installment of artificial structures including river structures. In other words, PC2 is characterized as the principal component representing "intactness of water front".

The principal component 3 (PC3) demonstrated highly negative correlation with "number of dams per total length of streams" and "number of water-use structures". Therefore, PC3 is considered to present the condition with fewer installments of water-use and dams in rivers, as well as preserved continuity of streams. Taking into consideration these features, PC3 is regarded as the principal component representing "continuity of streams".

The principal component 4 (PC4) shows remarkably positive correlation with "number of streams per basin area". Less number of streams per basin area indicates limited changes of landform within basin. Given these features, PC4 is interpreted to reflect "simplicity of landform in basin".

2.2 Classification by cluster analysis

By using scores of four principal components (≧1.0 as eigen value) extracted by the above-stated principal component analysis, cluster

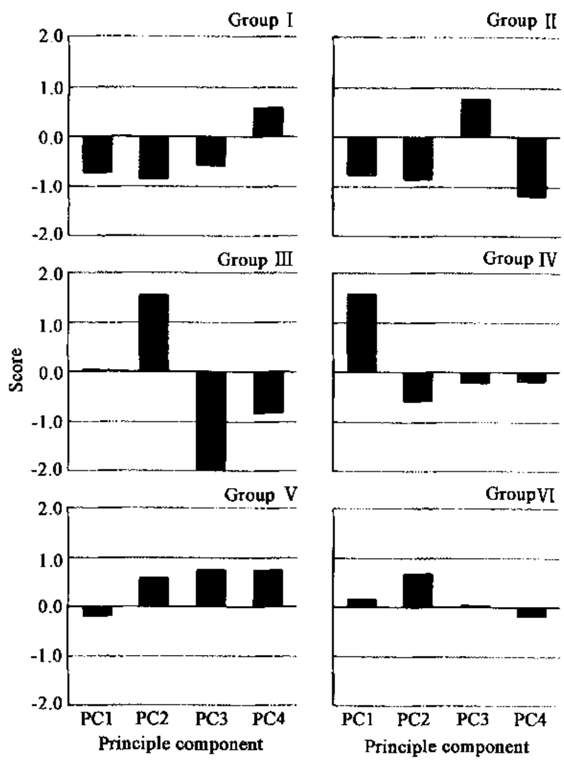

Fig.2 Mean scores of 4 principle components in 6 groups

analysis was performed on 109 rivers. Ward's method was employed for cluster analysis. As the coupling stage to induce significant alterations in distance revision among clusters, cleavage was made by Euclidean distance 11 as the coupling distance, leading to classification into 6 groups (Fig. 2). These groups were named as Type Ⅰ, Type Ⅱ, Type Ⅲ, Type Ⅳ, Type Ⅴ and Type Ⅵ in the downward order, respectively

Type Ⅰ represents the group comprising Ashida River, Doki River, Kako River, Kose River and Sagami River. Type Ⅰ is characterized with lower contribution of PC1 (comprehensive river size) and PC2 (intactness of water front), together with lower value of PC3 (continuity of streams) (Fig. 2). From the view point of variables for analysis, Type Ⅰ shows minimum values both in number of streams and total length of streams among six types (Table 3). Based on these findings, Type Ⅰ can be classified as river group with small river sizes. The artificial water front was ranked second following Type Ⅱ while the number of river structures showed the highest values among six types. Given all this, Type Ⅰ can be positioned as the group undergoing remarkable alterations and land-uses.

Type Ⅱ is the group consisting of Yamato River, Shigenobu River, Suzuka River and Tsurumi River. Although Type Ⅱ was similar to Type Ⅰ in terms of lower contribution of PC1 and PC2, higher values of PC3 was evidenced. Minimum values in length of main stream and basin area among six types indicate that Type Ⅱ represents rivers with small river sizes as in the same with Type Ⅰ. Type Ⅱ also shows the highest values in artificial water front, indicating that this group is featured to have the highest degrees in water front alterations whereas this type has less number of water-use structures, suggesting that water-use is inadequately achieved.

Table 3 Average of variables in each similarity type

Variable	Average	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ
Number of streams	127.84	53.05	89.07	80.63	395.17	55.77	108.43
Length of main stream, km	107.76	64.29	51.20	120.75	199.39	97.62	120.71
Total length of streams, km	802.03	309.01	329.45	515.29	2437.96	447.89	778.08
Basin area, km^2	2201.39	755.38	561.67	1492.75	6450.17	1611.42	2177.24
Number of streams/basin area	0.07	0.07	0.15	0.06	0.07	0.04	0.06
Artificial water front, %	24.33	32.74	54.28	8.06	21.62	14.35	15.41
Number of river structures	19.62	32.67	23.07	12.75	26.78	8.77	14.05
River structures/total length	15.58	21.19	9.67	7.88	29.67	11.65	9.90
Number of dams, h > 15 m	1.34	0.62	0.07	4.88	2.33	0.19	2.19
Dams/total length	0.06	0.15	0.10	0.06	0.02	0.02	0.03
Number of water-use structures	0.04	0.08	0.03	0.03	0.01	0.03	0.02
Water-uses/total length	0.00	0.00	0.00	0.02	0.00	0.00	0.00

Type Ⅲ is the group comprising Jyoganji River, Shingu River, Ooi River, Shingu River and Kurobe River. Despite of higher contribution of PC2, PC3 was extremely low. Type Ⅲ is characteristic of remarkably large number of dams, while demonstrating lower artificial water front compared with those in other types. Accordingly, Type Ⅲ represents the group consisting of rapid streams, whereby sand guard works have been frequently conducted so far.

Type Ⅳ represents the group consisting of Kiso River, Yoshino River, Yoshii River, Asahi River, Shinano River, Tone River and Ishikari River. PC1 was much higher than those in other types. Type Ⅳ showed the largest values respectively in terms of number of streams, length of main stream, total length of streams and basin area among six types. All of these findings suggest that Type Ⅳ is the group consisting of big rivers with large river sizes.

Type Ⅴ is the group comprising not only rivers in Hokkaido Island such as Abashiri River, Kushiro River and Wakubetu River, but also Niyodo River, Takanasi River and Abe River. Both PC3 and PC4 were found positive. Out of six groups, Type V has the smallest number of river structures while artificial water front was second lowest following Type Ⅲ among six types. These findings suggest that Type V is the group undergoing relatively less artificial changes.

Type Ⅵ represents the group consisting of Kinokawa River, Kuzuryuu River, Yura River, Tama

River, Naka River and Tokachi River. Despite of relatively higher values in PC2, other components were close to zero. These features allowed us to conclude that Type VI retains higher intactness but represents average type among first rank rivers.

2.3 Area distribution of respective types

Fig. 3 illustrates area distribution of each type from Type Ⅰ to Type Ⅵ. Although Type Ⅰ is distributed to the middle part of Japan, distribution center is located in Chugoku area and Kyushu area, indicating that this is centered on Western Japan district. As in the same with Type Ⅰ, Type Ⅱ is distributed mainly in Western Japan, with the trend that Type Ⅱ is not observed at least in the Eastern Japan area. Type Ⅲ includes seven rivers; however, 4 out of 7 rivers are situated in the middle part of Japan.

There is a trend that Types Ⅳ, Ⅴ and Ⅵ are distributed relatively nation widely. However, once our attention is focused on local districts, most of the rivers in Hokkaido and Tohoku (Northern East Japan) belong to either of these types, without rivers classified into Types Ⅰ, Ⅱ and Ⅲ.

3 Discussion

As the results of principal component analysis (PCA) by using variables indicative of forms of rivers and degrees of artificial changes, four principal components such as "comprehensive river sizes",

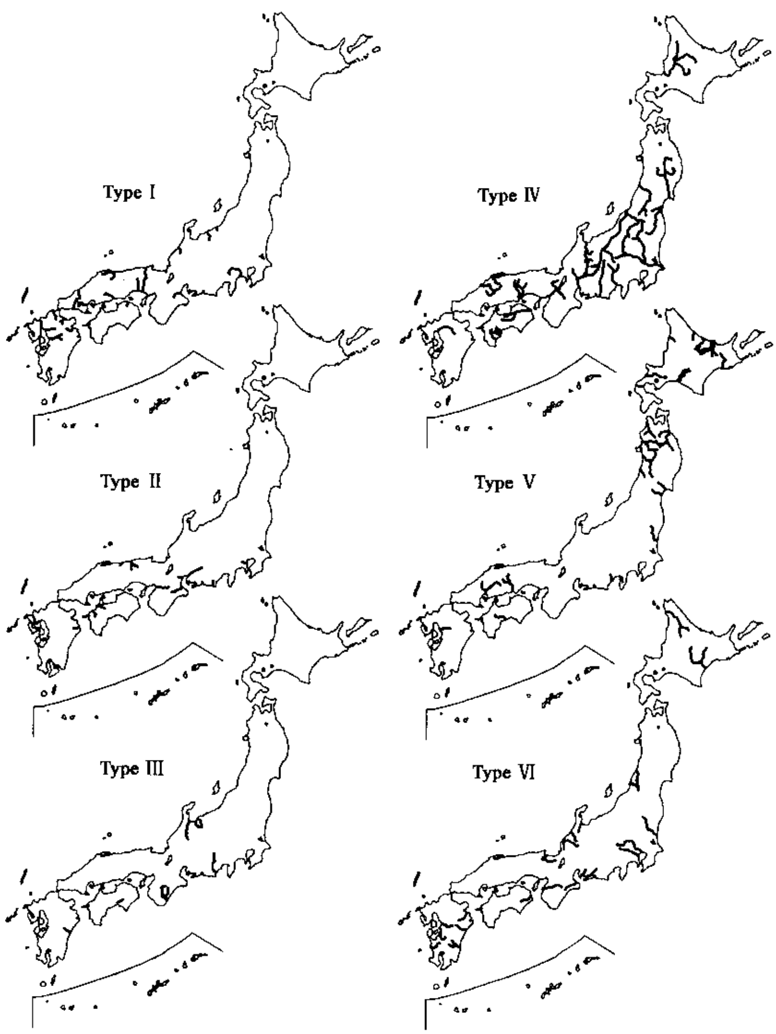

Fig.3 Distribution of six groups of rivers in Japan

"intactness of water front", "continuity of streams" and "simplicity of forms in basin" were extracted. In particular, "comprehensive river sizes" (principal component 1) and "intactness of water front" (principal component 2) demonstrated higher ratio of contribution as 35.7% and 20.1%, respectively, indicating that these components play important roles in classification of Japanese rivers into groups. "comprehensive river sizes" is the significant component highly correlated with variables indicative of geographical features of rivers such as total length of streams and basin area. Since this component was evidenced to have the highest contribution ratio among the components, which were analyzed in this study, it was disclosed that forms of rivers play important roles in comparison of rivers.

Principal component 2 (PC2) presenting intactness of water front tended to be higher in Type Ⅰ and Type Ⅱ. Distribution of Type Ⅰ and Type Ⅱ was centered on Western Japan including Chugoku and Kyushu districts. Incidentally, these Western Japan areas are well known to have histologically advanced development of basin from ancient eras. Generally speaking, once development is advanced in basin, river-embanking works should be conducted to prevent rivers from flood. Consequently, higher artificial water front ratio has ensued. On the other hand, Type Ⅴ includes lots of rivers located in Hokkaido. Specific features of this Type exist in positive correlation with "intactness of water front" and "continuity of rivers". Development in the reaches of rivers in Hokkaido has been progressed to less extent relative to those in other districts. Thanks to such intactness, these rivers retaining the most natural environments among Japanese archipelagoes still persist in Hokkaido. In other words, these rivers can be positioned as the river types still retaining favorable river ecosystem. Such insights of respective districts through their features might enable our conclusion that the intactness of water front extracted as the principal component 2 could be an index suggestive of residual degrees of river ecosystem.

As stated above, taking into consideration the successful extraction of indices indicative of features of Japanese rivers, quantitative classification of rivers by using respective variables representing characters of each river is considered to be a useful procedure to emboss features of rivers. Additionally, area distribution of types also facilitates putting similar profiles of rivers in order in each district.

In the present study, we could obtain clearly interpreted principal components, by using variables related to forms of rivers and human impacts within rivers. On the contrary, no one can deny the fact that available variables were restricted. Whenever development was densely performed, rivers are relatively highly affected by sociological factors in basin (Takahashi, 1990). For example, basin sizes are one of the factors deciding rainfall amount, which controls river flows whereas correlation between rainfall and river flows is also influenced by land-use in the basin. In the present study, we could not afford to use indices related to land-use; however, addition of these variables in future studies would enable us to obtain other features which could not be interpreted in the present study.

Acknowledgement: The authors thank Prof. Kunito Nehira of Hiroshima University for his kind advice and encouragement.

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