Study of Substrate and Physico-Chemical Base Classification of the Rivers of Nepal

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Abstract The rivers in Nepal are classified in terms of geographical regions but a more scientific classification such as on the basis of morphology is clearly lacking. This study was done in 9 rivers namely Jhikhukhola of the Koshi system, Aandhikhola, Arungkhola, East Rapti, Karrakhola, Seti and main channel Narayani of the Gandaki system, and two independent systems within Nepal, Bagmati and Tinau. Among the morphologies, river bed or the substratum was taken as the main variable for the analysis which was categorized into 7 types as rocks, boulders, cobbles, pebbles, gravels, sand and silt. There were 23 sampling sites each with 2 stretches of around 100m in those rivers. The data were taken as a percentage, and to avoid biases it was observed visually by the same person for a complete year in every season. With 23 sites each with 2 stretches and 4 replicates corresponding to 4 seasons, there are altogether 184 observations, each termed as a case, that constitute this work. Canonical Discrimination Analysis (CDA) which is most suitable when the data pool is huge was applied to see if the rivers studied distinguish themselves in terms of its morphology. The result was remarkably successful and was close to the established regional classification of the rivers. This kind of river classification has great application in the utilization, conservation and restoration of the most important natural resource of the country.

Keywords Nepal; rivers; morphology; physico-chemical parameter; river classification

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Introduction

One of the greatest features of Nepal is its unique and unmatched physiography and corresponding biodiversity. The snow-capped mountains, gorgeous green midhills and fertile extension of the Gangetic plain interspersed with gorges and valleys, rivers and streams, and ponds and lakes make the country so diverse that it seems all of the world’s climatic regions and corresponding biota have converged in one place to make it a kind of paradise. Even within the country no two places and no two watersheds have the same characteristics.

In such background, it is very difficult to classify the rivers of Nepal, which are the country’s biggest natural resource, for the conservation, management, monitoring and restoration purpose. Being a landlocked country, Nepal only has freshwater or inland water resources. However, the country is extremely rich in water resources as will be evident from some of the forthcoming data. The inland water resource of Nepal includes natural waters such as rivers, lakes and reservoirs, and also village ponds, marginal...
swamps and irrigated paddy fields and equals 818 500 ha\cite{1}. Out of this, the network of rivers and streams, which are more than 6000 in number covers around 395000 ha of surface. There are about 1000 of them that are more than 11 km in length and as many as 100 of them that are longer than 160 km. In total, the length of rivers and their tributaries in Nepal exceeds well past 45000 km. This statistic is unique and amazing when we consider the size of the country and by any standard, the drainage density of about 0.3 km/km², is very significant.

It is not only the number and area of the rivers and streams in Nepal that highlights the richness of water resources but also the quantity of water. The total annual runoff from Nepal including catchments in Tibet is about 222 billion m³/sec with a mean runoff coefficient of 0.777 \cite{2} while the annual mean runoff of all rivers stands at 6396 m³/sec. The country is traversed by four major river systems and around 90% of the surface water is concentrated in these basins. In any case with 2.27% of the world’s freshwater \cite{3}, Nepal is regarded as the second richest country in the world in terms of water resource and the rivers play a significant role in it.

In addition, the streams and rivers are complex ecosystems that take part in physical and chemical cycles that shape our planet and allow life to sustain. Thus, rivers and streams are not just strips of water cutting their way through the hills and mountains and finding their way downhill meandering slowly toward the sea. They are much more than that. Certainly their bottom extends beneath the ground and the sides into the floodplains. Along the longitudinal course of a river, as and when the physiographic and physico-chemical conditions change the typical zone changes as a phenomenon of spatial succession.

Although rivers and streams represent only a small portion of a landscape, their state is indicative of the condition of the whole watershed. Rivers, like blood from a human, are indicative of the health of the landscape \cite{4}. Therefore, to manage the water and associated aquatic resources, it is crucial to study and understand the various aspects of the channels and their subsequent classifications.

The early systematic study on the type and classification of rivers in Nepal had been done in 1977 \cite{5} and is further enhanced and documented \cite{1, 6, 7, 8, 9}. These classifications are based on the geography and the information of the biota present in the rivers. However, these classification seems inadequate and thus, this study intends to supplement it by classifying the rivers according to their morphology in general and the substratum in particular.

In any case the morphology of Nepalese rivers is governed by the unique geophysical system and extreme climatic variation, and the river classification based on these is of utmost importance for the utilization, conservation, management and even restoration of the primary resource of the country.

The information obtained from this study has a widespread application; however, the following are some major objectives of this study:

1) To study and quantify the substratum of the selected river channels.
2) To study important physico-chemical parameters of the selected rivers.
3) To classify the rivers accordingly using the standard statistical tool.
4) To compare the result with the existing classifications.

1 Methodology

The present work was started in 2003 for an academic purpose and was completed in 2006. Altogether nine rivers from the central and western region of Nepal were studied for this work. The rivers selected were, Aandhikhola, Arungkhola, Bagmati, Jhikhukhola, Karrakhola, Narayani, East Rapti, Seti and Tinau. Except for Narayani and Seti rivers, which were included due to popular demand, all other rivers originate from midhills. The six rivers, Aandhikhola, Arungkhola, Karrakhola, Narayani, East Rapti and Seti are members of the Gandaki River system, Jhikhukhola is a tributary of the Koshi River System, and Tinau and Bagmati are independent systems \cite{5}. There were 23 sampling sites covering those nine rivers. Table 1 highlights the exact coordinates of all the sampling sites.
With 23 sites and four replicates of these corresponding to four seasons, there are altogether 92 samplings that constitute this work. As each of these 92 observations was done twice at a time, each termed as a case, there were 184 cases altogether (shown in Fig. 1). To avoid bias, all the 184 observations were made by the same individual.

The riverbanks and substrates were carefully observed and sketched in the protocol. The substrata were divided into 7 categories according to their size, namely rock, boulders, cobbles, pebbles, gravels, sand and silt. The percent composition of each of these substrate categories in each sampling sites were noted down according to visual observation. Each time digital photographs too were taken of each sampling site to verify the visual observation in the laboratory.

In addition to the substrate important physical characteristics of the rivers and the water quality such as altitude (meter above sea level), temperature (°C), dissolved oxygen (ppm), pH (0-14 scale) and conductivity (µS/cm) were also recorded by standard method and applied in the analysis.

Canonical Discrimination Analysis (CDA) was done to classify different rivers and river systems using SPSS version 11.0 software as it is one of the best tools when the number of variables and data are big. The results are produced in a numerical and graphical form to have better understanding.

Table 1  Sampled rivers, locations and the river systems

| No. | River            | Location                  | System      |
|-----|------------------|----------------------------|-------------|
| 1   | Aandhikhola      | Bayatari and Galyang (Shyangja) | Gandaki    |
| 2   | Arungkhola       | Kusunde (Nawalparasi)      | Gandaki    |
| 3   | Bagmati          | Sundarijal (Kathmandu)     | Independent|
| 4   | Jhikhukhola      | Paanchkhal (Kavre)         | Koshi      |
| 5   | Karrakhola       | Hetauda (Makawanpur)       | Gandaki    |
| 6   | Narayani         | Narayanthat (Chitwan and Nawalparasi) | Gandaki |
| 7   | East Rapti       | Hetauda and Bhandara (Makawanpur and Chitwan) | Gandaki |
| 8   | SETI             | Pokhara (Kaski)            | Gandaki    |
| 9   | TINAU            | Maniphaant, Koldanda and Butwal (Palpa and Rupandehi) | Independent |

2 Results

The data of physical and morphological factors utilized in this analysis were altitude, temperature, dissolved oxygen, pH, conductivity, and the substrates such as rock, boulder, cobbles, pebbles, gravels, silt and sand. All these factors were used as independent variables in this analysis. The table below shows the details of valid and missing variables.

Table 2  Valid and missing variables in CDA

| Unweighted cases       | N  | Percent |
|------------------------|----|---------|
| Valid                  | 184| 100.0   |
| Excluded               |    |         |
| Missing or out-of-range group codes | 0  | 0.0    |
| At least one missing discriminating variable | 0  | 0.0    |
| Both missing or out-of-range group codes and at least one missing discriminating variable | 0  | 0.0    |
| Total                  | 0  | 0.0    |
| Total                  | 184| 100.0  |

Each variable gets its own coefficients and the value of each of them is pooled together to form group matrices. The values of each variable are weighted against each other and are correlated. Three such functions are initially used, but the analysis chooses the best two functions on the basis of canonical correlation to produce results. Table 3 summarizes the canonical discriminant functions and also illustrates why the first two functions were chosen particularly based on canonical correlation.
Table 3  Summary of canonical discriminant functions

| Function | Value | % of Variance | Cumulative % Variance | Canonical Correlation |
|----------|-------|---------------|-----------------------|-----------------------|
| 1        | 6.563(a) | 77.7          | 77.7                  | 0.932                 |
| 2        | 1.608(a) | 19.0          | 96.7                  | 0.785                 |
| 3        | 0.277(a) | 3.3           | 100.0                 | 0.466                 |

The standardized canonical discriminant function coefficients for each variable in all three functions are illustrated in the Table 4.

Table 4  Standardized canonical discriminant function coefficients

| Function | 1 | 2 | 3 |
|----------|---|---|---|
| Altitude | −1.287 | 0.320 | −0.110 |
| Boulder  | −0.458 | −0.002 | 0.951 |
| Pebbles  | 1.053 | 0.765 | 1.177 |
| Cobbles  | −0.271 | −0.749 | 0.588 |
| Rock     | 1.548 | 0.769 | 0.659 |
| Silt     | −0.341 | −0.267 | 0.181 |
| Oxygen   | 0.169 | −0.054 | −0.226 |
| Conductivity | 0.006 | 0.114 | −0.315 |
| Temperature | 0.194 | 0.107 | −0.709 |
| Sand     | 0.352 | 0.450 | 1.458 |
| Ph       | 0.167 | 0.110 | −0.560 |

When all these standardized canonical discriminant functions were pooled together within the groups to derive correlations between discriminating variables, an interesting result was obtained (Table 5). In function 1, the variables having the largest absolute correlation were found to be altitude and two morphological features, boulders and pebbles. The same in function 2 were found to be some additional morphological features such as cobbles, rock and silt, and two physico-chemical parameters, dissolved oxygen (DO) and conductivity. The function 3 had temperature, sand, pH and gravels having some correlation, though the last variable is not used in the further analysis.

With these functions and correlations of the variables, the classification of the river systems were done using all 184 cases and all the cases were used in both ways, weighted and unweighted in the analysis. Among the cases used, Bagmati had 16 cases, Gandaki had 104 cases, Koshi had 16 cases and Tinau had 48 cases (Table 6). The results of the classification of the river system were amazing, perfectly matching the regional differences of the country. This indicated that the group of abiotic factors such as morphological and physico-chemical features was able to discriminate among themselves to represent the regional and physico-geographic group of the rivers and river systems of Nepal.

Table 5  Correlation details of the discriminant variables (structure matrix)

| Function | 1 | 2 | 3 |
|----------|---|---|---|
| Altitude | −0.583(*) | 0.556 | −0.178 |
| Boulder  | −0.155(*) | 0.016 | 0.016 |
| Pebbles  | 0.104(*) | −0.072 | −0.021 |
| Cobbles  | −0.060 | −0.651(*) | −0.129 |
| Rock     | −0.014 | 0.326(*) | −0.109 |
| Silt     | 0.027 | −0.259(*) | 0.121 |
| Oxygen   | 0.015 | −0.149(*) | −0.122 |
| Conductivity | 0.048 | −0.118(*) | −0.061 |
| Temperature | 0.160 | −0.038 | −0.476(*) |
| Sand     | 0.113 | 0.173 | 0.390(*) |
| Ph       | 0.060 | 0.008 | −0.292(*) |
| Gravels(a) | 0.058 | 0.050 | −0.081(*) |

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions variables ordered by absolute size of correlation within function.

(*) Largest absolute correlation between each variable and any discriminant function (a) This variable is not used in the analysis.

Table 6  Prior probabilities for groups

| River system | Prior | Cases used in analysis |
|--------------|-------|-----------------------|
|              |       | Unweighted | Weighted |
| Bagmati      | 0.087 | 16         | 16.000   |
| Gandaki      | 0.565 | 104        | 104.000  |
| Koshi        | 0.087 | 16         | 16.000   |
| Tinau        | 0.261 | 48         | 48.000   |
| Total        | 1.000 | 184        | 184.000  |

Fig.2 shows how the different variables in each rivers and river systems discriminated each other and how close they are to their group centroids, which are remarkably apart from each other and distinct. In Bagmati, the variables were found to be 100% distinct and totally discriminated the variables of other rivers (Table 7). Similarly in the Gandaki system, the variables were 98.1% distinct whereas only 1.9 % of them were not distinct and that too from only one
river system, Koshi. The Koshi system on the other hand showed 100% distinct variables completely discriminating the group of variables from other systems. Finally, Tinau River showed 83.3% distinct variables and all those variables, which were not able to discriminate the system, were found to be mixed with the variables of the Gandaki system only.

| River system | Predicted group membership | Total |
|--------------|----------------------------|-------|
|              | Bagmati            | Gandaki | Koshi | Tinau |       |
| Count        | 16                 | 0       | 0     | 0     | 16    |
| Gandaki      | 0                  | 102     | 2     | 0     | 104   |
| Koshi        | 0                  | 0       | 16    | 0     | 16    |
| Tinau        | 0                  | 8       | 0     | 40    | 48    |
| Bagmati %    | 100.0              | 0.0     | 0.0   | 0.0   | 100.0 |
| Gandaki %    | 0.0                | 98.1    | 1.9   | 0.0   | 100.0 |
| Koshi %      | 0.0                | 0.0     | 100.0 | 0.0   | 100.0 |
| Tinau %      | 0.0                | 16.7    | 0.0   | 83.3  | 100.0 |

Thus, the morphological features and the physico-chemical parameters of different rivers and river system studied in this work were found to be very good variables, which were able to classify the rivers and river systems of Nepal. The result of the classification showed that it is very much in terms with the age-old classification of the Nepalese rivers \(^{5, 8}\) in terms of region, origin and geology.

In the cross validation of the above grouping where each case was classified by the functions derived all cases other than that case, the group variable for Bagmati River and Koshi system were again found to be 100% distinct. On the other hand, 96.2% in the Gandaki system and 83.3% in Tinau were able to discriminate the respective river and system. Here too even when they were did not discriminate one hundred percent, the group variables were mixed with only one other river or system. The classification system was found to be so accurate that 94.6% originally grouped cases and 93.5% of cross-validated grouped cases were classified correctly.

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3 Discussion

The use of classification of various ecological entities for better management and conservation is a common process practice these days in all parts of the world. There are several examples of these kinds of works in the field of river ecology as well. Nepal consists of 4 main drainage basins of Koshi, Gandaki, Karnali and Mahakali representing different regions of the country. In addition to these, there is a network of southern rivers and Mahabharat rivers in each region\(^8\). The rivers are classified according to origin and location but hardly with their biological and physical characteristics. The result as could be seen was amazing as it is exactly the copy of the classification from origin and region.

The application of Canonical Discrimination Analysis (CDA) is increasing rapidly in all sectors to classify or group any set of entities. It is especially common when there is a huge pool of data and high number of variables. Pitkanen\(^{10}\) in the work on the classification of biodiversity in a managed forest used this analysis to determine the variables that best describe the classes. Similarly, Lu et al.\(^{11}\) used CDA to differentiate successional stages and to identify the best forest stand parameters to distinguish these stages.

The CDA was found to be used in classifying the species from different regions too. Silva A.\(^{12}\) in her study in sardine population of two regions used this technique and found that the two groups of sardine were significantly separated by this method. There are many applications of this analysis in river and stream ecology as well. Legleiter\(^{13}\) worked on stream habitat mapping and used this analysis in conjunction with remotely sensed data. Singh et al.\(^{14}\) in their work on spatial and temporal variations in water quality of Gomti River have applied discriminant analysis and found that it showed best results for data reduction and pattern recognition during both temporal and spatial analysis.

The present work used this analysis to classify the different rivers and river systems of Nepal on the basis of morphological and physico-chemical characteristics of rivers and water. Altogether, twelve variables were used from each of the 184 cases spread over nine rivers and four seasons. This made it a huge pool of data normally useful in CDA. The best discriminant variables in Nepalese rivers were found to be altitude, substrata such as boulders, pebbles rock and silt, and other characteristics such as dissolved oxygen (DO) and conductivity.

The variables discriminated themselves making four distinct groups corresponding to the classification available for the Nepalese rivers, Bagmati, Gandaki, Koshi and Tinau. 94.6% correct case for the original group and 93.5% correct case for the cross-validated group indicated that the classification based on those variables are very near the reality. This also suggested that this method could be extended to other rivers and river systems in different regions once enough data are collected. In addition, the discrimination analysis for classification helps in the management and conservation of water resource, fisheries resource and restoration of depleted resources.

4 Conclusion

The results to classify the rivers and river systems based on morphological and physico-chemical parameters were found to be very impressive as the method classified the rivers into natural regional groups. This indicated that the abiotic factors are efficient in discriminating each other to form natural groups. The classification was found to be absolutely matching with the reality and the age-old classification of Nepalese rivers. Thus, this kind of classification and grouping will be very helpful in managing water and fisheries resources on a larger scale.

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