The Applicability of Biotic Indices and Scores in Water Quality Assessment of Nepalese Rivers

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Abstract

A number of water quality assessment methodologies, based on benthic invertebrate indicators, are herein evaluated for use in Nepalese rivers. Water quality assessment was carried out at 165 sites, covering all the major river systems of the country, between an altitude range of from 80 to 3,882m above sea level. The 'reference' water quality of the investigated sites was determined by an expert team, which followed strict definitions of the saprobic water quality classes. Based on a comprehensive sampling of the benthic invertebrate fauna, the following set of biotic scores and indices was used for methodological comparison: Trent Biotic Index (Woodiwiss 1964); Extended Trent Biotic Index (Woodiwiss 1978); Indices Biotique (Tuffery and Verneaux 1968); Belgian Biotic Index (De Pauw and Vanhooren 1983); Indices Biotique (Tuffery and Davaine, 1970); Indices Biotique Globale Normalisé (AFNOR, 1992); Family Based Index (Hilsenhoff 1988 a, b), BMWP-Score (Hellawell 1978); BMWP/ASPT (Armitage et al. 1983); Lincoln Quality Index (Extence and Ferguson 1989); Nepalese Biotic Score-NEPBIOS (Sharma 1996). The currently developed Nepalese Biotic Score, which adapted the Average Score Per Taxon (ASPT) philosophy to the local conditions, corresponds best to the observed water quality classes and is recommended for further application and development.

Aim and Objectives

The aim of the present study is to search for a suitable and simple biological method to assess water quality in Nepalese rivers. The following objectives have been fulfilled.

Investigating the saprobiological status of a river and its biotic community *in situ*; classifying water quality according to the traditional saprobic approach, which has been recently revised (ÖNORM 1995; Friedrich 1990, Moog 1996); applying various potentially suitable and presently existing biotic indices and score methods in relation to the composition and abundance of benthic macroinvertebrates; assessing methods for evaluating the water quality of Nepalese rivers; and recommending one specific assessment method as a water management tool for Nepal.

Historical review

Surface water quality assessment based on biological methods started more than one and a half centuries ago with Kolenati (1848), Hassal (1850) and Cohn (1853), who observed that organisms that occur in polluted water are different from organisms that occur in clean water. Hundreds of methods for biological water quality assessment have been developed since (Sládecék 1973a and 1973b, Pittwell 1976, Persoone and De Pauw 1979, Illies and Schmitz 1980, Rosenberg and Resh 1992, De Pauw and Hawkes 1993). It is beyond the scope of this paper to include all the assessment methods in all aquatic environments. Therefore, this study has been limited to the application of a revised saprobic system (Moog 1996), and the results obtained are compared with widely common biotic indices and score methods using macroinvertebrates as bioindicators (only in running water).

The basic principles of the saprobic system (*Saprobiensystem)* were originally proposed by the two German scientists Kolkwitz and Marsson (1902, 1908, 1909; see also Kolkwitz 1935, 1950) who jointly introduced the concept of 'biological self-purification' with distinct zones of decreasing pollution. Each saprobic zone affords optimal conditions for certain species and communities of organisms, which in turn behave as 'biological indicators of organic pollution'.

Liebmann (1959, 1960, 1962) provides a complete survey of the saprobity system in his famous handbook and has established the term *Güte-Klasse* (Liebmann 1959), indicating classes of water quality ranking from I to IV. He assigned specific colours on maps of rivers and lakes to these rankings for easy visualisation of water quality surveys. Liebmann (1959) proposed blue for Class I, green for Class II, yellow for Class III, and red for Class IV. Whatever the methods used, the system of mapping by colours is now extensively used in European countries.

The currently used saprobic methods have been summarised by Sládecék (1973a) who can be undoubtedly regarded as the father of water quality assessment philosophy in continental Europe. The saprobic system has been extensively used in Central Europe, especially in Austria and Germany. This method is gaining increased acceptance in Eastern European countries such as Hungary, Poland, Yugoslavia, Romania, Bulgaria, the Czech Republic, Slovenia, and Slovakia, as well as Western European countries such as Denmark, the Netherlands, and Switzerland.

In Austria, the saprobic system has been specified as Austrian Standards (Önorm 1995) and in Germany as DIN (Friedrich 1990). Except for DIN and the Austrian Standards, no single index or scoring method has been satisfactorily used in a particular country nationwide. The success of this system rests on the precise taxonomic determinations to the species' level, which is well known to contain the maximum amount of environmental information.

As illustrated in Figures 1, 2, and 3, the biotic indices are either formula-based or simplified to standard table form (ranking matrix). The idea of using an index in biological assessment started with Knöpp (1954). The formula-based biotic indices are close to saprobic indices in calculation procedures (Chutter 1972 Hilsenhoff 1977, Tolkamp and Gardeniers 1977, Gonzalez del Tanago and Garcia Jalon 1984, Lang et al. 1989, among others.

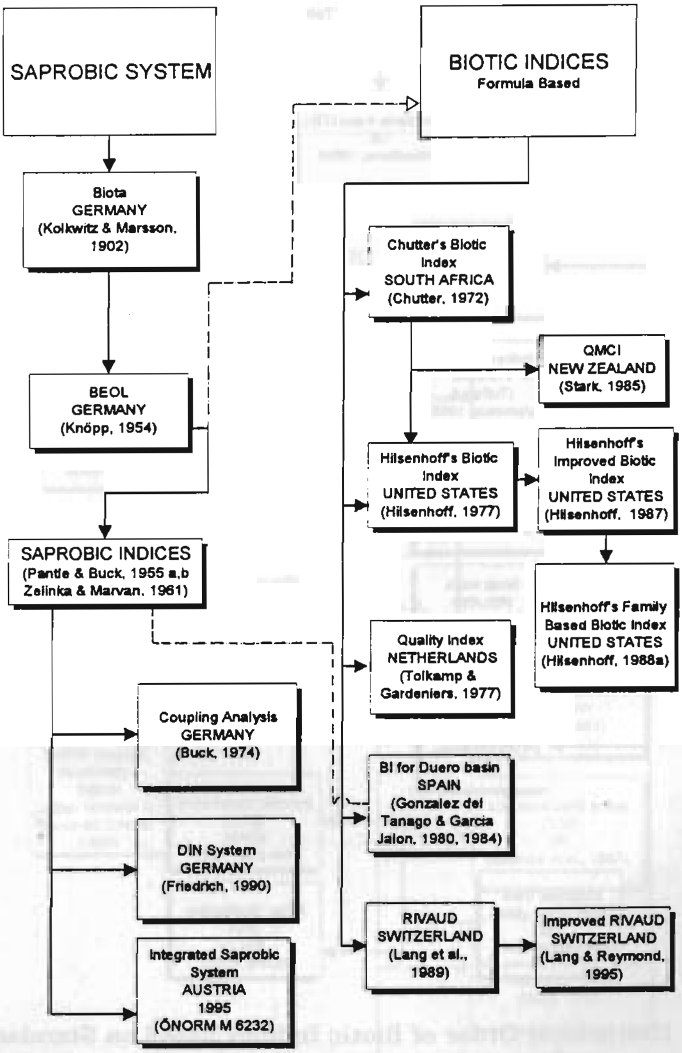

Figure 1: Hierachical Order of Formula-based Biotic Indices

The Trent biotic index (Woodiwiss 1964) is the origin of standard table-based biotic indices. All other indices, such as Graham's index (Graham 1965), the French and the Belgian *Indices Biotiques*, the Biotic Index (Flanagen and Toner 1972), and the Danish Biotic Index (Andersen et al. 1984) are modifications of the Trent Biotic Index. Later, the Trent Biotic Index was extended to provide a range of 0 to 15 in place of the 0 to 10 range in the Extended Biotic Index

(Woodiwiss 1978). The Spanish (Prat et al. 1983) and Italian modifications (Ghetti 1986) are based on this Extended Trent Biotic Index.

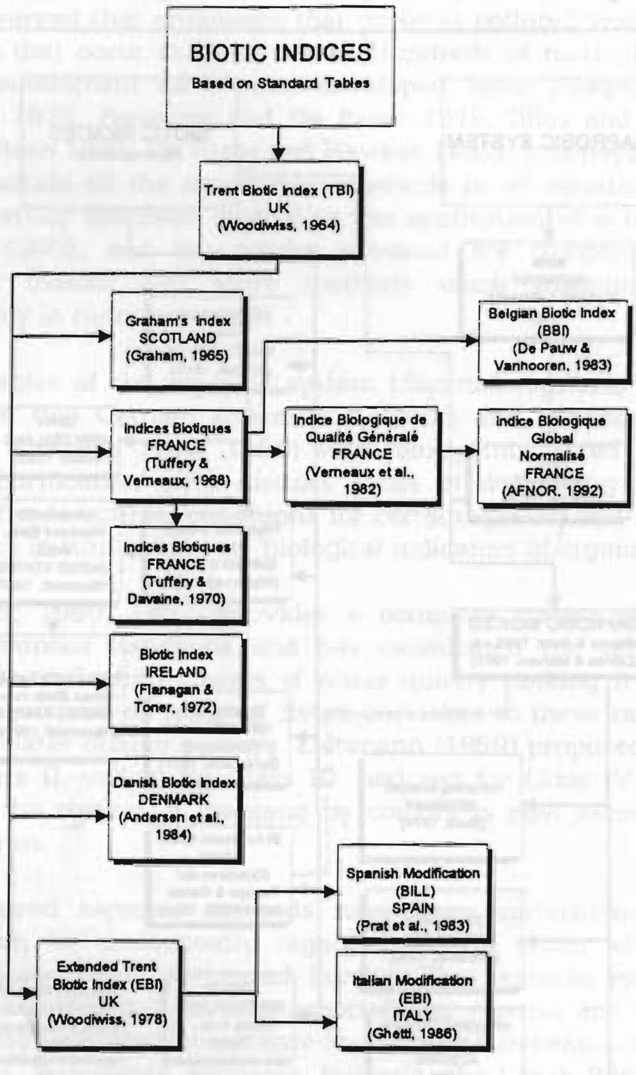

Figure 2: Hierachical Order of Biotic Indices Based on Standard Tables (ranking matrices)

The score methods were originally differentiated from index methods by involving abundance in the calculation (De Pauw and Hawkes 1993). Although this differentiation is no longer valid, the calculation procedure for score and index methods are still quite different. The origin of all score methods is Chandler's Biotic Score (Chandler 1970).

All the indices and scores have limited application, for they emphasise only the benthic fauna. The saprobic method has the advantage that it includes a large variety of abiotic characteristics and a broader range of biota (Moog 1996). Although the saprobic approach has proved to be a suitable method to characterise Nepalese rivers (Sharma 1996), even a pure biotic approach is limited in a region where no pre-existing indicator list or saprobic catalogue has been compiled. On the other hand, the ability to apply pure biotic aspects of saprobic classification is restricted to experienced experts. Guided by these premises and feeling the need for an inexpensive but reliable method to assess the biological water quality of rivers and streams in Nepal, we tested some more simple methods.

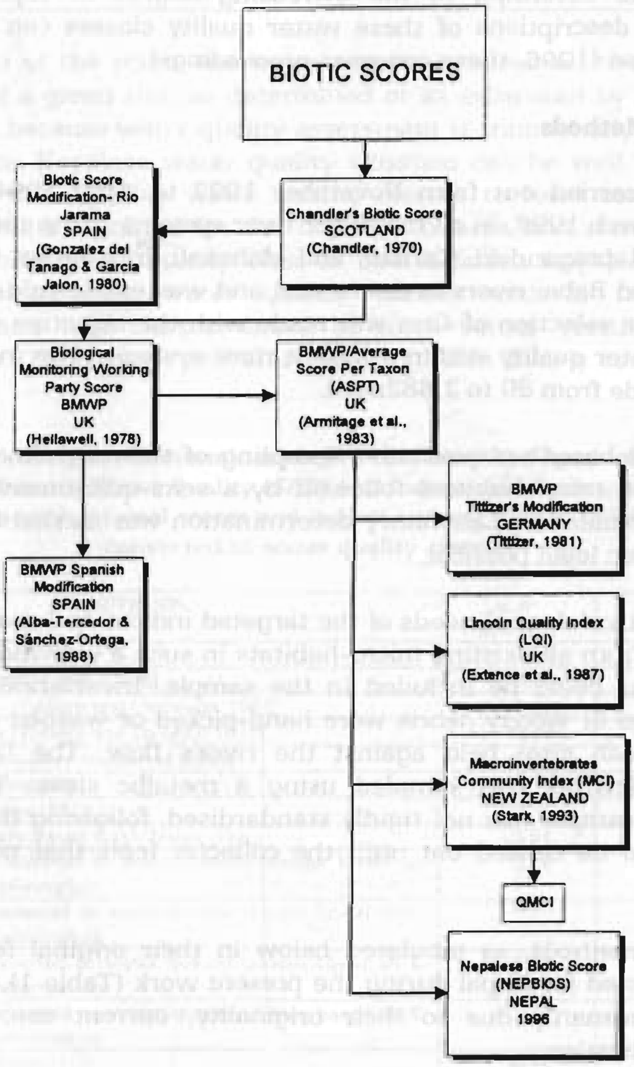

Figure 3: Hierarchical Order of Biotic Scores

In this context, the application of the saprobic system, namely producing clear definitions of the water quality classes, which requires in turn a detailed site report, was shown to be suitable to Nepal and has been adapted to the local conditions by Sharma (1996). Nepalese running waters are classified into the following four main classes and three transitional classes: I - not-to-very slightly polluted (oligosaprobic); I-II - slightly polluted (oligosaprobic to beta-mesosaprobic); II - moderately polluted (beta-mesosaprobic); II-III - critically polluted (beta-mesosaprobic to alpha-mesosaprobic); III - heavily polluted (alpha-mesosaprobic); III-IV - very heavily polluted (alpha-mesosaprobic to polysaprobic); and IV - extremely polluted (polysaprobic). These classes are designated by roman numerals and differentiated by the colours blue, green, yellow, and red, according to the increasing degree of saprobity. Detailed definitions and descriptions of these water quality classes can be obtained in Moog and Sharma (1996, these congress proceedings).

Materials and Methods

Sampling was carried out from November 1993 to April 1994, in December 1995, and in March 1996, in all the major river systems of the country, including the Saptakosi, Saptagandaki, Karnali, and Mahakali, in addition to the Bagmati, Tinau, Rapti, and Babai rivers in the central and western-to-mid-western part of the country. The selection of sites was made with the objective of including the full range of water quality within different river systems. The investigated sites ranged in altitude from 80 to 3,882masl.

This research is based on qualitative sampling of the macroinvertebrate fauna from all possible micro-habitats followed by a semi-quantitative estimation of their relative abundance. Laboratory determination was carried out to the most precise taxonomic level possible.

To fulfil the methodological needs of the targeted indices and scores the samples were collected from all existing micro-habitats in such a way that a wide variety of benthic fauna could be included in the sample. Invertebrates fixed to the surface of stones or woody debris were hand-picked or washed out into a hand net (100μm mesh size) held against the river's flow. The fauna inhabiting sediments or detritus was sampled using a metallic sieve. The time spent collecting each sample was not rigidly standardised, following the principle that sampling should be carried out until the collector feels that no more families could be found.

The following methods, as tabulated below in their original form, have been selected and tested for Nepal during the present work (Table 1). These methods were chosen primarily due to their originality, current use, and extent of geographic application.

In addition to their standard application, the following methods were also modified: the Belgian Biotic Index (BBI) and NEPBIOS with single findings included (renamed as BBI+1 and NEPBIOS/ASPT/+1 respectively) and the BMWP score with the abundance estimation included (renamed as BMWP+Ab.).

Table 1: Biotic Index and Score Methods Applied in Assessing the Water Quality of Nepalese Rivers

Biotic Index and Score Systems	Symbol Used	Reference
The BMWP Score System	BMWP	Hellawell 1978
The BMWP-Average Score Per Taxon	BMWP/ASPT	Armitage et al. 1983
Lincoln Quality Index	LQI	Extence and Ferguson 1989
Nepalese Biotic Score	NEPBIOS/ASPT	Sharma 1996
Trent Biotic Index	TBI	Woodiwiss 1964
Extended Trent Biotic Index	EBI	Woodiwiss 1978
French Biotic Index	IB'68	Tuffery and Verneaux 1968
French Biotic Index	IB'70	Tuffery and Davaine 1970
Indice Biologique Global Normalisé	IBGN	AFNOR 1992
Belgian Biotic Index	BBI	De Pauw and Vanhooren 1983
Hilsenhoff's Biotic Index by Score Methods	FBI	Hilsenhoff 1988a

The calibration of the score and index results is based on the observed water quality class of a given site, as determined or as estimated by an expert group. This was done because water quality assessment is traditionally based on quality classes, and the Nepalese water quality situation can be well described by the adaptation of the saprobic water quality classes to local conditions (Sharma 1996). The results obtained for the different indices and scores are compared with the saprobic water quality class in two different ways: 1) index or score values versus saprobic water quality classes and 2) transformed (i.e., standardised into four classes) index or score values versus saprobic water quality classes. The results are illustrated in Table 2 in a correlation analysis table.

Table 2: Coefficient of Determination (R^2) between the Saprobiologically-based Reference Water Quality (SAP) and Indices and Scores; a: direct comparison with original scores and indices values; b: indices and scores converted to water quality classes

METHODS	a: R^2 (n=165)	b: R^2 (n=165)
Trent Biotic Index (TBI)	0.60	0.59
Extended Trent Biotic Index (EBI)	0.57	0.55
Indices Biotiques (Tuffery and Verneaux 1968)	0.41	0.32
Indices Biotiques (Tuffery and Davaine 1970)	0.41	0.43
Indice Biologique Global Normalisé (IBGN)	0.47	0.50
Belgian Biotic Index (BBI)	0.39	0.33
Belgian Biotic Index (BBI+1)		0.48
Hilsenhoff's Family Based Biotic Index (FBI)	0.51	0.41
BMWP Scores converted to water quality classes based on AWA, 1986 transformation	0.26	0.35
BMWP Score converted to water quality classes based on C and K, 1994 transformation		**0.28**
BMWP/ASPT converted to water quality classes based on C and K, 1994 transformation	0.53	0.44
BMWP (+Ab) converted to water quality classes based on C and K, 1994 transformation		0.44
Lincoln Quality Index (LQI)	0.54	0.50
NEPBIOS converted to water quality classes based on C and K, 1994 transformation	0.86	0.79

The conversion scales for harmonisation of the methods used in changing the water quality classes to the equivalent saprobic water quality classes for the above-mentioned methods are tabulated in Tables 3 and 4. The original BMWP and BMWP/ASPT values obtained after calculation are compared by means of different transformations, either based on Coring and Küchenhoff (1994), abbreviated in the text as C and K (1994), or on Anglian Water Authority (1986) abbreviated as AWA (1986).

Table 3: A Comparison of Different Ranges of Saprobic Water Quality Classes (SWQC) with Some Biotic Index Methods Applied to Nepalese Streams (modified by Moog and Graf 1994 unpublished)

SWQC	Woodiwiss (1964) TBI	Woodiwiss (1978) EBI	Extence and Ferguson (1989) LQI	Tuffery and Verneaux (1968) IB	AFNOR (1992) IBGN	Hilsenhoff (1988a) FBI
I	10	15, 14	6.5, 7	10	20, 19	0.00 - 3.75
I - II	9	13, 12	5.5, 6	9	18, 17, 16	3.76 - 4.25
II	8, 7	11, 10	4.5, 5	8, 7	15, 14, 13	4.26 - 5.00
II - III	6, 5	9, 8, 7	3.5, 4	6, 5	12, 11, 10, 9	5.01 - 5.75
III	4, 3	6, 5	2.5, 3	4, 3	8, 7, 6	5.76 - 6.50
III - IV	2	4, 3	1.5, 2	1, 2	5, 4, 3	6.51 - 7.25
IV	1	2, 1	1	0	2, 1	7.26 - 10.00

Table 4: Transformation Scales Used in Converting the BMWP and BMWP/ASPT

Based on Anglian Water Authority 1986 (after modification)	Based on Coring and Küchenhoff 1994 (after modification)		SWQC
BMWP	BMWP	BMWP/ASPT	
> 151	> 151	8.00-10.00	I
101-150	> 151	7.00-7.90	I-II
51-100	101-150	5.50-6.90	II
26-50	51-100	4.00-5.49	II-III
7-25	26-50	2.50-3.90	III
1-6	0-25	1.01-2.49	III-IV
-	-	1	IV

The BMWP, BMWP/ASPT and NEPBIOS/ASPT values obtained are converted to water quality classes based on Table 4.

Results

Out of the 165 sites considered, the expert group classified 33 sites into water quality class I based on the saprobic system (SAP) and 12 into class IV. Table 5 illustrates the applicability of different indices and scoring methods. The original data can be obtained from the appendix section of Sharma (1996).

Discussion

The relation between the water quality of a river observed at a particular site and the calculated values obtained for each site by applying different index and score methods varied (Fig. 4). Similarly, with the conversion of each of these values to water quality classes, the correlation between the parameters either improved or was reduced. Figure 4 illustrates the relation between water quality classes as assessed by different methods.

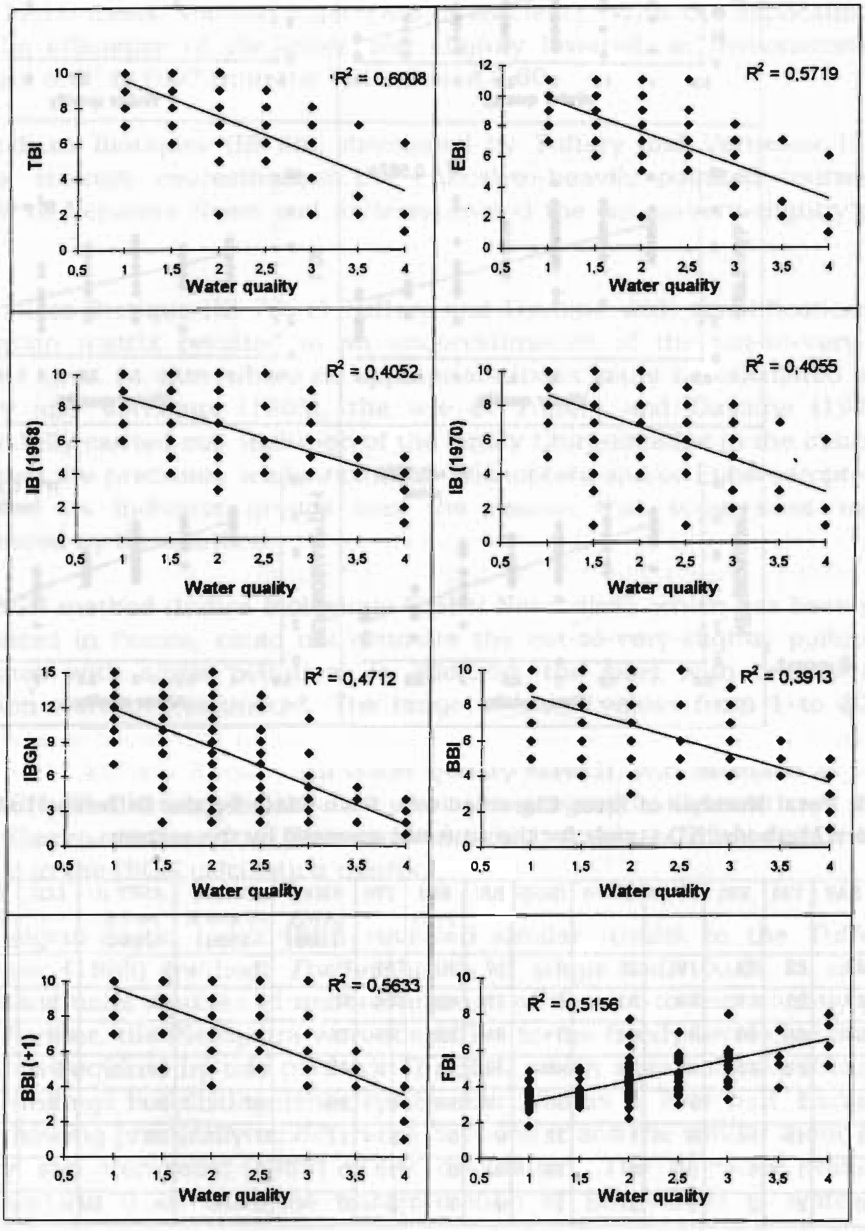

Figure 4: Relation between Water Quality Classes as Assessed by Different Methods

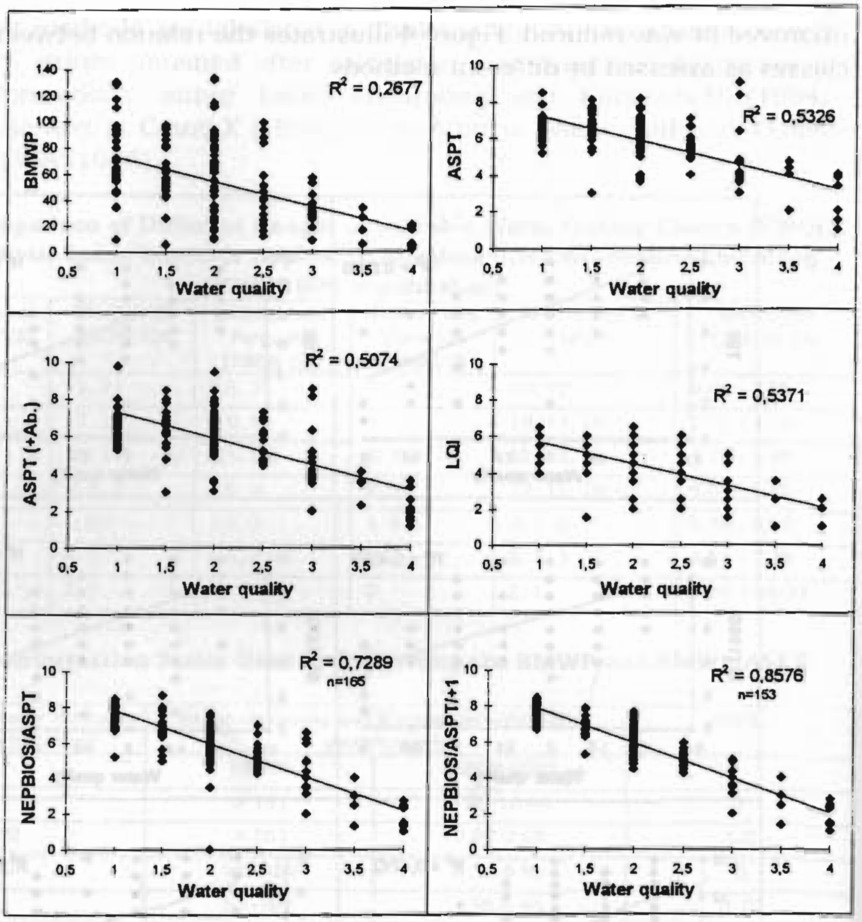

Figure 4 cont.

Table 5: Total Number of Sites Classified into Each Class by the Different Indices and Score Methods; ND stands for the sites not assessed by the system

Water Quality Classes	SAP	TBI	EBI	IB'68	IB'70	IBGN	BBI	BBI (+1)	FBI	BMWP (AWA, 1986)	BMWP (C and K, 1994)	ASPT (C and K, 1994)	LQI	NEP-BIOS
I	33	22	33	18	15	0	17	30	74	0	0	5	3	14
I-II	27	35	24	29	31	0	29	43	24	9	0	25	51	31
II	57	68	68	44	61	34	44	39	29	75	9	83	56	67
II-III	18	20	20	44	31	46	46	32	15	44	76	33	25	32
III	14	2	2	20	8	36	19	14	5	26	43	9	14	8
III-IV	4	15	14	6	17	32	6	6	5	11	37	10	5	7
IV	12	1	1	0	0	16	0	0	10	0	0	0	11	5
ND*	0	2	2	4	2	1	4	1	3	0	0	0	0	1

The Trent Biotic Index (TBI), although developed originally for the river Trent by the Trent River Board, yielded comparatively satisfactory results when applied to assess the water quality of Nepalese rivers. Sites with slight pollution were overestimated and not-to-very slightly polluted courses were underestimated. The results showed that this index is very much affected by river type. Not only were there several taxonomic shortcomings, but a very uniform or homogenous habitat, current velocity, depth (in large rivers), and geographically restricted indicator taxa, resulted in the underestimation of the water quality.

The Extended Trent Biotic Index (EBI), which is basically an elaboration on the Trent Biotic Index, showed a decrease in efficiency. With the application of the EBI, the efficiency of the index was slightly lowered, as demonstrated by a decrease of R^2 to 0.57 from the TBI value of 0.60.

The Indices Biotiques (IB 68), developed by Tuffery and Verneaux (1968) in France, strongly overestimated the critical-to-heavily polluted courses when applied to Nepalese rivers and underestimated the not-to-very-slightly polluted sites.

The Indices Biotique (IB 70) of Tuffery and Davaine with simplifications in the calculation matrix resulted in an underestimation of the not-to-very-slightly polluted sites. At sites where no appropriate index could be calculated by using Tuffery and Verneaux (1968), the use of Tuffery and Davaine (1970) was successfully carried out. Inclusion of the family Chironomidae in the indicator list improved the precision, while including Trichoptera and/or Ephemeroptera (only *Baetidae*) as indicator groups was the reason that some sites were left unassessed by this method.

The IBGN method (Indice Biologique Global Normalisé), which has been recently introduced in France, could not estimate the not-to-very-slightly polluted sites and sites with slight pollution. In addition, the sites with critical-to-heavy pollution were overestimated. The range of index values from 1 to 20 in the IBGN was so broad that no site had an index value of more than 15. Surprisingly, one site (Muktinath *Khola*) with water quality class II, was assessed as IV under the IBGN. The reason for this was that the geographically-restricted indicator taxon *Gammarus lacustris* (Gammaridae), which dominated this site, is listed as group 2 in the IBGN calculation matrix.

The Belgian Biotic Index (BBI) revealed similar results to the Tuffery and Verneaux (1968) method. The exclusion of single individuals in calculating systematic units resulted in underestimation of the not-to-very slightly polluted sites. Further, the Plecoptera were identified to the family level only and not to genus, as required by this method. The BBI, which does not take into account single findings but distinguishes systematic units as 1, 2 or $\geq$ 2, had an R^2 of 0.39, showing practically no difference between it and the similar Biotic Index of Tuffery and Verneaux (1968) in its calculation. The R^2 value was slightly decreased, to 0.33, with the transformation of BBI values to water quality classes.

With the inclusion of single findings in calculating the Belgian Biotic Index (BBI+1), the correlation of determination between the calculated (predicted) and observed water quality classes improved from 0.33 to 0.48. Similarly, while only 39 per cent of the variability in the index values could be explained by the BBI, the inclusion of single findings raised this value up to 56 per cent. However, it is clear that the efficiency is reduced when the BBI+1-index values calculated are converted to the equivalent seven water quality classes. Additionally, it is important to note that the inclusion of a single finding is methodologically dangerous and may lead to misinterpretations.

Hilsenhoff's Family-based Biotic Index (FBI), an average of the tolerance values of all arthropod families in a sample as developed by Hilsenhoff, strongly overestimated the not-to-very-slightly polluted sites. This overestimation is mainly due to the index range. The fluctuations are, however, lower in assessing the not-to-very-slightly polluted sites to slightly polluted sites than the moderately polluted sites. Some of the moderately polluted sites, all of which are from typical lowland streams, were assessed as very heavily polluted. The reason for this was the high tolerance values assigned to the odonates and the exclusion of Hemiptera and some Coleoptera (except Dryopidae, Elmidae and Psephenidae) in calculations.

The BMWP score and BMWP/ASPT values, when compared with the observed water quality, showed a correlation of $R^2 = 0.26$ and 0.53, respectively. With the conversion of the values obtained by these two methods to water quality classes the correlation with BMWP (AWA, 1986 transformation) improved to 0.35, and with the modified C and K-based transformation the correlation remained at 0.28. Similarly, BMWP/ASPT values converted to water quality classes based on the modified method of Coring and Küchenhoff (1994) reduced the R^2 value to 0.44.

The range of differences between BMWP scores and observed water quality classes is quite broad as compared to ASPT, except for water quality class IV, where the span is greater with the latter.

The majority of BMWP scores in unpolluted river sections were between 45 and 100, with ASPT values of from 5.5 to 7.5. This is in contrast to Armitage et al. (1983), who reported BMWP scores of 100 to 150 with corresponding ASPT values 5.01 to 6.00. The highest BMWP score obtained was 133 in a middle reach of the stream Chudi *Khola,* which by the saprobic system was classified under water quality II. At this site, an ASPT value of 6.33 was obtained. This seriously underestimated the unpolluted sites, for none of the sites could attain a BMWP Score >151, the score needed for water quality class I as proposed by AWA (1986). A majority of the sites, although unpolluted, could not attain a high BMWP score because many sensitive taxa of local occurrence are not included in the BMWP score list and hence were excluded from calculation. Similarly, a high range of differences in the value of the ASPT within the same water quality class was either due to the influence of marginal taxa or physiographic influences (data from Sharma 1996).

The Lincoln Quality Index (LQI), which is based on the BMWP score and the Average Score Per Taxon (ASPT) method, strongly underestimated the not-to-very-slightly polluted sites (WQC I).

Most of the traditional scores and indices used were considered unfit for Nepal in their present form. Because of their coarse taxonomic level - mostly to order - they seem to be unadaptable to Nepalese conditions. Instead, the BMWP/ASPT method seems promising when adapted and modified with Nepalese taxa. The newly developed NEPBIOS/ASPT overcomes many of the problems mentioned, because it contains: a higher number of family-level indicator organisms (Nepalese families were added), modified score values of the family-level indicator organisms, and a higher taxonomic precision, obtained by including genera and species.

The Nepalese Biotic Score showed an overall correlation of $R^2 = 0.73$ with the observed saprobic water quality classes (165 sites). With the exclusion of impoundments and sections influenced by toxic chemicals, the correlation between the observed and calculated water quality increased to $R^2 = 0.86$, and after transformation of the ASPT values to water quality classes, to $R^2 = 0.79$.

Regarding the need for an inexpensive, simple, and reliable method to assess the biological water quality of rivers and streams in Nepal, the Nepalese development and improvement of the ASPT seems to fulfill the demands of modern water management. Although the applicability of this local assessment method has been shown, the necessity for further improvement of the system and its environmental sensitivity is obvious.

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