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BIOTIC INDICES FRESHWATER ECOSYSTEMS USING AQUATIC ENTOMOFAUNA AS A BIOINDICATOR

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ABSTRACT

All living species on the planet rely on the availability of clean and fresh water. Anthropogenic activities have confined most of the water resources in raising pollution loads, which have had a significant influence on their health quality status and faunal diversity due to changes in physicochemical properties. Variability in physicochemical water properties has crucial impact on the aquatic insect distribution patterns in the water; they have different susceptibilities to pollution and environmental disturbances. Tolerance value and sensitivity of entomofauna is utilized in biotic indices to monitor condition of various water bodies. The present study highlights the importance of utilizing multiple indices for a comprehensive assessment and ecological indicators to provide better insight for water conservation and management strategies. At global landscape, multiple biological monitoring indices, namely Biological Monitoring Working Party Score System (BMWP), Average Score per Taxon (ASPT), Stream Invertebrate Grade Number-Average Level (SIGNAL), Hilsenhoff's Family Biotic Index (FBI), and Ephemeroptera, Plecoptera, and Trichoptera Index (EPT Index), are most popularly used. Since composition of entomofauna is altered in different geographical region, global applicability of these biotic indices is enhanced by employing their modified versions viz., BMWP- Thailand (BMWP-Thai), BMWP- Malaysia (BMWP-My), BMWP- Vietnam (BMWP-Viet), ASPT-Thailand (ASPT-Thai), ASPT- Vietnam (ASPT-Viet), ASPT- South Africa Score System Version 5 (ASPT-SASS5), Malaysian Family Biotic Index (MFBI) and SIGNAL version 2. Interpretation value, considering various taxonomic levels and classification systems for each index, are provided in the present study, offering a holistic understanding of water quality.

KEY WORDS: Biomonitoring, Biotic Indices, Hilsenhoff's Family Biotic Index, Entomofauna, Freshwater Ecosystem

INTRODUCTION

Water, a fundamental resource for human survival, require meticulous quality assessments. Water gets easily contaminated due to its unique carrying capacity and property of dissolving wide range of chemical compounds (Gupta *et al.,* 2013). The water ecosystem has recently undergone noticeable changes in a number of ways as a result of tremendous growth of industry and agriculture (Pathak & Mankodi, 2013).

Biomonitoring is explained as "the systematic use of the living organisms or their reactions to determine the change in the condition of the environment" (Oertel & Salanki, 2003). Markert *et al.* (2003) explained a bioindicator as "a community or an organism that contains information about the environment quality. Biomonitoring is now commonly recognized as an effective tool in the arsenal of environmentalists which reflects both current and previous conditions, whereas the chemico-physical analysis only reflects the present situation (Mandaville, 2002; Muralidharan *et al.,* 2010). The residents living in the river, lake, wetland, and stream have been used as sensitive bioindicators to establish and maintain water and environmental quality. Biomonitoring is less expensive than chemical testing and reflects the environmental balance of freshwater ecosystems. Macroinvertebrates and aquatic entomofauna are used in biomonitoring for various reasons as unlike fish; they don't move around to avoid ecological problems and thus are good indicators of localized conditions. As they have much longer life cycles than algae, they are better at depicting the effects of short-term environmental variations (Nair *et al.,* 2015).

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Traditional biomonitoring of river and stream ecosystems has relied on aquatic entomofauna to detect heavy metals (Smolders *et al.,* 2003), organic pollution (Zamora-Munoz and Alba-Tercedor, 1996), hydro-morphological degradation (Friberg *et al.,* 2009), general stressors (Doledec *et al.,* 1999), acidification (Davy-Bowker *et al.,* 2005), and nutrient enrichment (Johnson *et al.,* 2006). Aquatic entomofauna are particularly advantageous because they contribute more than half of all aquatic fauna, and their diversity enables a fine-scale analysis of habitat change (Tylianakis *et al.,* 2004). Aquatic entomofauna, with their widespread distribution, their adaptability across different habitats allows for a comprehensive understanding of environmental changes, while their behavior and life cycles enable effective monitoring of both spatial and temporal dimensions within aquatic ecosystems (Bonada *et al.*, 2006). Da Rocha *et al.* (2010) identified bioindicator entomofauna groups in aquatic environments that hold substantial significance for environmental monitoring.

The response of the aquatic entomofauna gives an early indication to contamination of the water bodies; they respond to the effects of point and non-point contaminants, as well as physical habitat alteration, throughout their life cycles. Disturbances and pollution have a negative impact on aquatic insect assemblages. As a result, they are the biological indicators that are most frequently used to monitor quality of water (Morse *et al.,* 2007). Biotic indices use numerical scores or a single index to evaluate health of river based on tolerance and sensitivity to environmental change such as pH, eutrophication, heavy metals, organic pollution, and pesticides in the community (Sumudumali & Jayawardana, 2021). The benefits of these indices are that they use easy calculations and a single stressor or metric to evaluate the health of a stream. However, biotic indices do not use the cumulative effects of many stressors in the aquatic environment (Herman & Nejadhashemi, 2015; Fierro *et al.,* 2017). The current study was attempted to compiled all the different types of biotic indices employed for evaluating freshwater ecosystems using aquatic entomofauna as a bioindicator.

Different Types of Biotic Indices

Numerous biotic indices have been used as an alternative to traditional methods, which were very tedious and time-consuming. The Trent Biotic Index, which was formulated in England by Woodiwiss (1964), served as the foundation for many other indices. The majority of biotic indices have been developed in response to national and are region specific, viz., Indice Biotique France, 1968 (France), Chandler's Score, 1970 (Scotland,), Belgian Biotic Index, 1983 (Belgium), BalKaN Biotic Index, 1999 (Serbia), Nepalese Biotic Index, 1996 (Nepal), BMWP- Thailand, 2002 (Thailand), BMWP-Vietnam, 2009 (Vietnam), Singapore Biotic Index, 2010 (Singapore), Malaysia Biotic Index, 2015 (Malaysia), National Sanitation Foundation Water Quality Index and Nepalese Biotic Score (India) (Sharma *et al.,*2006), Biological Monitoring Working Party score and Trent Biotic Index (United Kingdom) (Hooda *et al.,* 2000), South African Scoring System (South Africa), Namibian Scoring System (Namibia), Zambian Invertebrate Scoring System (Zambia) (Zakaria & Mohamed, 2019), Belgian Rivers (Belgian Biotic Index), Okavango Delta, Botswana (Okavango Assessment System) and Tanzanian rivers (Tanzanian River Scoring System) (Shimba & Jonah, 2016). Although numerous biotic indices have been created for specific locations, many of them may be utilized in other global areas with some modification. Among all the aforesaid biotic indices, BMWP scores are widely employed in the global region (Kumar *et al.,* 2013; Romero *et al.,* 2017; Varnosfaderany *et al.,* 2010; Uherek & Pinto Gouveia, 2014).

1. Biological monitoring working party (BMWP):

BMWP gives a single value for the pollution tolerance capacity of an organism at the family level. For determining the BMWP score, all the individual tolerance scores of participating families were added. Individual family score values represent pollution tolerance (Mandaville, 2002; De Lorme, 2012).

BMWP = ∑ tolerance scores of the families present in the site

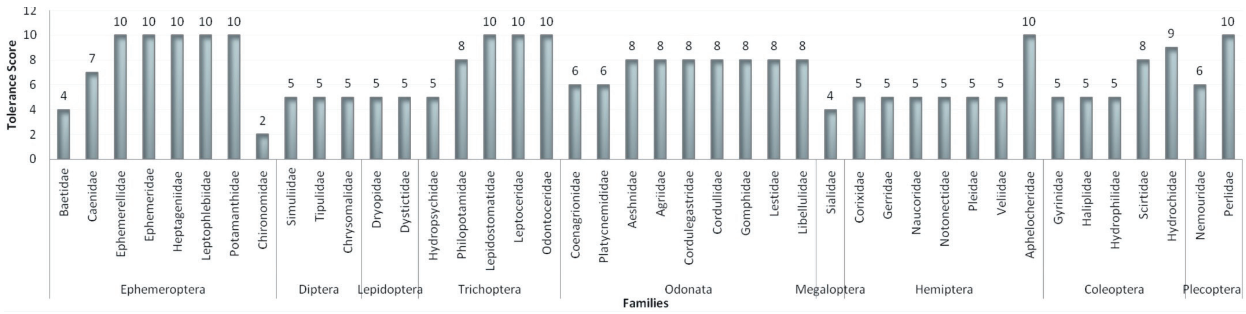

Fig. 1: Tolerance Value of various families according to BMWP (Armitage *et al.,* 1983)

Table 1: Interpretation Value for BMWP, ASPT, SIGNAL, FBI

BMWP (Chesters, 1980)		ASPT (Mandaville,2002)		SIGNAL (Chessman, 1995)		FBI (Hilsenhoff, 1988)		
Range of Score	Water Quality	Range of Score	Water Quality	Range of Score	Water Quality	Range of Score	Water Quality	Degree of Organic Pollution
0-16	Poor water quality	<4	Probable severe pollution	< 4	Severe pollution	0.00-3.75	Excellent	Organic pollution
17-50	Moderate water quality	4-5	Probable moderate	4-5	Moderate pollution	3.76-4.25	Very good	Possible slight organic pollution
51-100	Good water quality	5-6	Doubtful Quality	5-6	Mild pollution	4.26-5.00	Good	Some organic pollution
101-150	Highly good water quality	>6	Clean water	> 6	Clean water	5.01-5.75	Fair	Fairly substantial pollution
151+	Very high good water quality					5.76-6.50	Fairly poor	Substantial pollution
						6.51-7.25	Poor	Very substantial pollution
						7.26-10.0	Very poor	Severe organic pollution

The tolerance values for the families of Ephemeroptera, Diptera, Lepidoptera, Trichoptera, Odonata, Megaloptera, Plecoptera, Hemiptera, and Coleoptera are shown in Fig. 1. The range of tolerance values is from the lowest (0) to the highest (10).

As shown in Fig. 1, the Chironomidae family has a tolerance value of 2, whereas the Hydrochidae and Caenidae families have tolerance values of 9 and 7, respectively. Nine families have an 8-point tolerance value, ten families have a 10-point tolerance value, and fifteen families have a 5-point score. The Baetidae and Sialidae families have a tolerance score of 4, whereas the Nemouridae, Coenagrionidae, and Platycnemididae families have a tolerance score of 6.

In Table 1, the interpretation values for BMWP are delineated across five distinct groups, ranging from 0 to 151 and more. Each group corresponds to a specific quality of water, spanning from poor to very high good water quality. This classification system provides a comprehensive evaluation of water quality based on the BMWP, allowing for a clear understanding of the ecological conditions associated with different numerical ranges.

Modified Forms of BMWP:

The BMWP index is widely used as a standardized technique for biological assessment in numerous countries. Adaptations of this index have been employed in European nations, Spain (Alba-Tercedor & Sanchez-Ortega, 1988) and Poland (Czerniawska-Kusza, 2005), as well as in South American countries such as Costa Rica (Astorga *et al.,* 1997), Colombia (Roldan, 2003), Brazil (Baptista *et al.,* 2007), and Ecuador (Jacobsen, 1998). In Asian countries, modifications of the BMWP index have been employed, such as BMWP-My for the Malaysian region by Khoo (2004) and BMWP- Thai for Thailand by Mustow (2002). The BMWP-Viet score system was adapted for Vietnamese water bodies (Nguyen *et al.,* 2004). It was also modified in countries such as India (De Zwart & Trivedi, 1994) and Indonesia (Trihadiningrum *et al.,* 1996).

The Nepalese Biotic Score (NEPBIOS), modified form of BMWP, has been utilized for the evaluation of highland water bodies like streams and rivers in Nepal (Sharma & Moog, 1996). Subsequent developments include the Hindu Kush-Himalayan biotic index (HKHbios), applicable in a vast geographical area encompassing Pakistan, India, Nepal, Bangladesh, and Bhutan (Ofenbock *et al.,* 2010). In Nepal, various biotic indices have been developed for river systems, including NEPBIOS, NEPBIOS-BRS, GRSbios, and NEPBIOS-extended, addressing aspects of physico-chemical and bacteriological parameters (Sharma, 1996; Pradhan, 1998; Nesemann, 2006; Sharma *et al.,* 2009). Despite the success in assessing running water systems, there was a gap for the biotic index for stagnant water bodies in Nepal. Consequently, the Nepal Lake Biotic Index (NLBI) was introduced as a score-based method for monitoring water quality of lakes and reservoirs in Nepal.

2. Average score per taxon (ASPT):

ASPT is the average tolerance score of all taxa (Sivaramakrishnan, 1992; Mandaville, 2002) calculated by dividing the BMWP score with total number of scoring families. The following formula is used to calculate the ASPT:

$$ASPT = \frac{\sum BMWP\ Score\ of\ the\ site}{Total\ no.\ of\ Scoring\ families}$$

Table 1 outlines the interpretation values for ASPT, categorizing them into four distinct ranges ranging from less than 4 to more than 6. These ranges are indicative of the quality of water, spanning from probable severe pollution (scores below 4) to clean water (scores exceeding 6). The ASPT values serve as a important tool for assessing the ecological health of water bodies, providing a clear and concise framework to gauge water quality based on the specified score ranges.

Modification of ASPT: Mustow (2002) modified ASPT-Thai for Thailand. Nguyen *et al.* (2004) reported that the ASPT-Viet score system was modified to account for the natural conditions in Vietnam.

3. Stream Invertebrate Grade Number Average Level (SIGNAL):

The SIGNAL, scoring system for macroinvertebrates is a valuable tool in assessing water quality. It was developed by Chessman in 1995 and employed in Australian water bodies. This family-level water pollution index relies on the tolerances score of aquatic macroinvertebrate families to different pollutants. The methodology involves identifying macroinvertebrates to the family-level classification, where each family is assigned a grade between 1 and 10 based on their tolerance to common pollutants, where higher grade values indicate lower levels of tolerance. To determine the overall water quality, each species is then assessed for abundance using a 4-point scale. The scores for each type are subsequently calculated by multiplying the assigned grade by the abundance.

$$\text{SIGNAL} = \frac{\sum \text{(Signal Grade of each family} \times \text{Weight factor of each family)}}{\sum \text{(Weight factor of the site)}}$$

Table 2: Transformation of abundance into weight classes to calculate SIGNAL

SIGNAL Class (Chessman, 1995)	
Number of Individuals	Weight Factor (abundance classes)
1-2	1
3-5	2
6-10	3
11-20	4
>20	5

Table 2 outlines the transformation of abundance into the weight factor for calculating SIGNAL in the samples.

Fig. 2, depicts the tolerance values of various insect families concerning SIGNAL. Notably, the Notonectidae, Philopotamidae, and Glossosomatidae families exhibit tolerance values of 1, 8, and 9, respectively. Another group of six families, including Hydrophilidae, Curculionoidae, Dytiscidae, Mesoveliidae, Naucoridae, and Corixidae, demonstrates a tolerance score of 2. Three families, Chironomidae, Vellidae, and Nepidae have tolerance score of 3. Five families, Hydroptilidae, Noteridae, Gyrinidae, Gerridae, and Libellulidae, are characterized by a tolerance

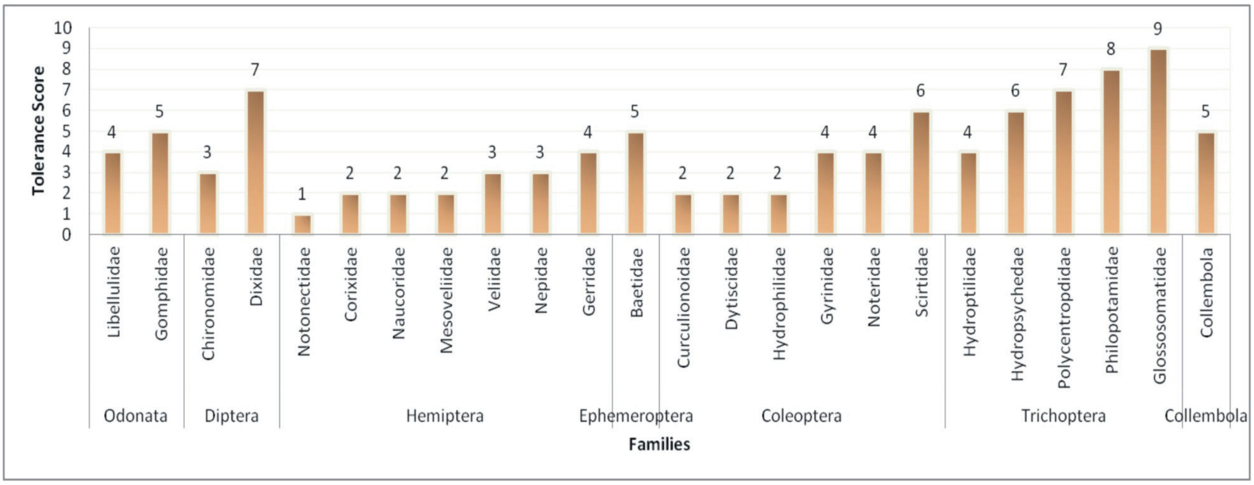

Fig. 2: Tolerance Value of various families according to SIGNAL (Chessman, 1995)

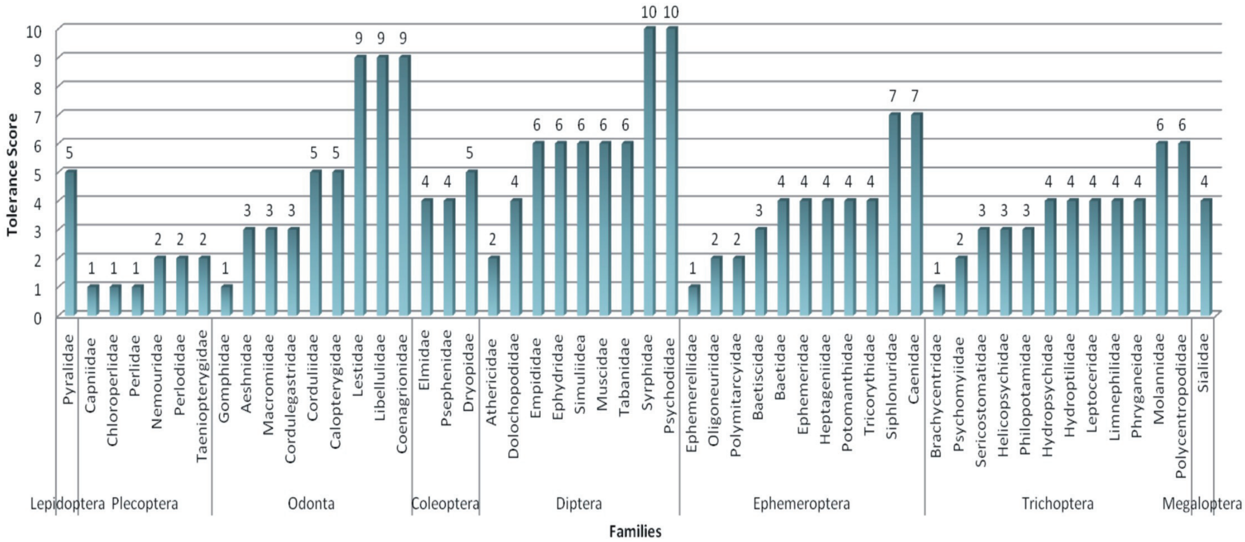

Fig. 3: Tolerance Values of various families according to FBI (Mandaville, 2002)

score of 4. Two families, namely Baetidae and Gomphidae, and sub class Collembola have a tolerance score of 5. Families such as Hydropsychidae and Scirtidae display a tolerance score of 6, while the Polycentropodidae and Dixidae families exhibit a tolerance value of 7. In Table 1, the interpretation values for the SIGNAL were delineated into four distinct ranges, ranging from less than 4 to more than 6. Each range corresponds to a specific quality of water, providing a comprehensive assessment of water conditions. Scores below 4 suggest probable severe pollution, while scores exceeding 6 indicate clean water. This scoring system serves as a valuable tool for evaluating the ecological health of streams, offering a clear and concise water quality classification based on the specified score ranges.

4. Family biotic index (FBI):

The FBI was created by Hilsenhoff in 1982 and provides a single tolerance value that represents the arithmetic mean of all species tolerance values in the benthic arthropod community. The FBI was calculated in the following manner:

$$FBI = \frac{\sum x_i t_i}{n}$$

Where x_i = Total count of individuals of a family, t_i = Taxons tolerance value, and n = sum of all collected specimens.

Fig. 3 depicts the tolerance values for the families, Plecoptera, Odonata, Coleoptera, Lepidoptera, Diptera, Ephemeroptera, Trichoptera, and Megaloptera. Notably, six families exhibit a tolerance value as one, including Capniidae, Chloroperlidae, Perlidae, Gomphidae, Ephemerellidae, and Brachycentridae. Seven families possess tolerance values as two, such as Nemouridae, Perlodidae, Taeniopterygidae, Athericidae, Oligoneuriidae, Polymitarcyidae, and Psychomyiidae. Another set of seven families are characterized by tolerance values as three, namely Aeshnidae, Cordulegastridae, Macromiidae, Baetiscidae, Helicopsychidae, Philopotamidae, and Sericostomatidae. Fourteen families demonstrate tolerance values as four, including Sialidae, Elmidae, Psephenidae, Dolochopodidae, Baetidae, Ephemeridae, Heptageniidae, Potomanthidae, Tricorythidae, Hydropsychidae, Hydroptilidae, Leptoceridae, Limnephilidae, and Phryganeidae. Additionally, four families have tolerance values as five: Calopterygidae, Corduliidae, Dryopidae, and Pyralidae, while seven families exhibit tolerance values as six: Empididae, Ephydridae, Simuliidea, Muscidae, Tabanidae, Molannidae, and Polycentropodidae. Notably, two families, Caenidae and Siphlonuridae, boast tolerance values as seven. On the higher end, families like Psychodidae and Syrphidae have a tolerance value of 10, while Coenagrionidae, Lestidae, and Libellulidae fall into the category of nine tolerance values.

In Table 1, interpretation values for the FBI are outlined across seven categories, ranging from 0 to 10. Each category corresponds to a specific water quality classification, spanning from excellent to very poor. Additionally, these categories offer insights into the degree of organic pollution, ranging from minimal organic pollution to severe organic pollution. The range of scores from 0 to 3.75 indicates excellent water quality and unlikely organic pollution, while the range of scores from 7.26 to 10.0 indicates very poor water quality and severe organic pollution. The FBI serves as a valuable metric for assessing water quality, providing a comprehensive understanding of both the overall quality and the extent of organic pollution in a given water body based on the specified score categories.

5. Ephemeroptera, Plecoptera, and Trichoptera Index (EPT Index):

The EPT Index (Ephemeroptera, Plecoptera, and Trichoptera) serves a valuable method for assessing the water condition in benthic macroinvertebrate communities. This index operates on the premise that high-quality streams typically exhibit greater species richness, as many aquatic entomofauna species within these orders are intolerant of pollutants. This method involves rapid sampling for assessing water quality differences at different sites and was also used to evaluate the impacts of spills and unusual discharges in the water bodies. Benthic macroinvertebrates, being sensitive indicators of environmental stress, respond to both natural and human-induced changes. EPT Index is the total number of different taxa within these groups. This index is compared to values in an EPT rating table; a higher EPT value indicates improved quality of water with a greater number of EPT insect taxa in cleaner water. Beside it, the EPT Biotic Index (Schmidt-Kloiber & Nijboer, 2004) is based upon the sensitivity of the taxa to respond to changes in the condition of water quality (Lenat, 1998), and assigns the water quality and level of impact is calculated by the following formula:

$$\textbf{\textit{EPT Biotic Index}} = \frac{\sum (TV) * d}{D}$$

Where, TV = the tolerance values of the families within the EPT group, d = density of each family, and D = total amount of densities.

Fig. 4 illustrates tolerance values for specific insect families associated with the EPT index, focusing on Plecoptera, Ephemeroptera, and Trichoptera. Notably, Molannidae and Polycentropodidae families exhibit a tolerance value of 6, while Caenidae and Siphlonuridae have a tolerance score of 7. Families such as Ephemerellidae, Capniidae, Chloroperlidae, Perlidae, Brachycentridae, and Lepidostomatidae demonstrate a tolerance value of 1. Additionally, families including Baetiscidae, Philopotamidae, Calamoceratidae, Helicopsychidae, Sericostomatidae, and Uenoidae have a tolerance value of 3. Furthermore, a group of 10 families, namely Baetidae, Ephemeridae, Heptageniidae, Potomanthidae, Tricorythidae, Hydropsychidae, Hydroptilidae, Leptoceridae, Limnephilidae, and Phryganeidae, share a tolerance score of 4. This concise overview provides a clear understanding of the tolerance levels within these families in relation to the EPT index.

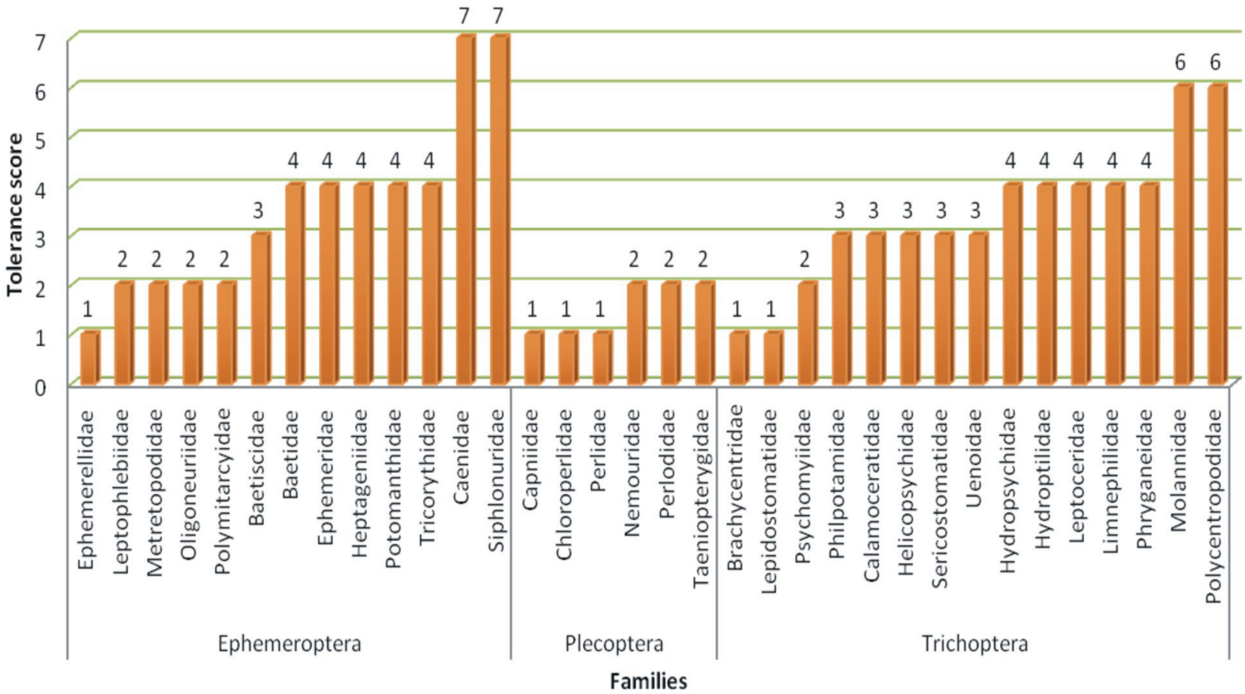

Fig. 4: Tolerance Value of various families according to EPT Index (Bode *et al.,* 1996)

Table 3: EPT rating table based on the number of EPT-families (Bode *et al.,* 1996; Bode *et al.,* 1997)

No. EPT-families	Water quality	Level of impact	EPT Biotic Index	Water quality
< 2	Poor	Impacted	0-3.75	No impact
2-5	Good	Moderated impact	3.75-6.50	Moderated impact
6-10	Very good	Fair impact	>6.50	Impacted
>10	Excellent	No impact		

Table 3 shows the parameters for classifying the water quality according to the total EPT families and the EPT Biotic Index. When the count is below 2, it signifies poor water quality, with an associated impact level of being impacted. Conversely, having more than 10 EPT families indicates excellent water quality, with the impact level categorized as no impact. EPT Biotic Index is presented in three categories, ranging from 0 to over 6.50, reflecting the spectrum of water quality from no impact to impact.

Global Perspectives: Reviewed Insights on Biotic Indices Worldwide

Due to the unavailability of taxonomic knowledge for Iranian macro benthic invertebrates at the species level, the family level biotic indices viz. BMWP and revised BMWP were utilized (Varnosfaderany *et al.,* 2010). However, the Tabanidae and Empididae families were not present in the original BMWP list; their score calculation was on the basis of reappraisal methodologies provided by Walley & Hawkes (1996), considering their scores from another modified version of BMWP (Ofenböck *et al.,* 2008). Since Gomphidae family did not have revised scores (Walley & Hawkes, 1996), the original scores were used (Armitage *et al.,* 1983). Notably, revised BMWP and ASPT scores were found generally higher than their original counterparts, suggesting that families in the Zayandeh Rud River in Iran often had greater pollution tolerance. This indicates that the utilizing of the revised BMWP score system could be a valuable tool for assessing quality of water in the River Zayandeh Rud.

Likewise, Alba-Tercedor and Sanchez Ortega (1988) revised the original BMWP table by increasing the number of taxa but using the original scores. Based on the study by Armitage *et al.* (1983), Alba-Tercedor (1996) upgraded the taxonomic groups and scores as well as the category and the interpretation of results.

The composition of aquatic insect communities can vary geographically, and tropical regions may have species absent in other regions; therefore, Zakaria & Mohamed (2019), for assessment of water quality at Sg. Bantang, Johor, and modified BMWP as BMWP-My (BMWP-Malaysia). BMWP which was originally developed in UK. had limitations in reflecting the health of the stream as many aquatic entomofauna relevant to the Malaysian region were not included in BMWP tolerance values. BMWP-My proved to be the most accurate in reflecting stream health, as it accounted for the majority of aquatic insects found in the sampling sites. This specificity and inclusivity made BMWP-My more reliable biotic index for water quality assessment in Malaysian river systems compared to other indices. Likewise, BMWP-Thai was developed in Thailand, incorporating families not found in the UK. (Mustow, 2002), which might be crucial for water quality indicators in the Malaysian context.

Hui & Fikri (2021) compared EPT, Hilsenholf's FBI, original BMWP, original ASPT, Thailand's BMWP (BMWP-Thai), Thailand's ASPT (ASPT-Thai), Vietnam's BMWP (BMWP-Viet), Vietnam's ASPT (ASPT-Viet), South Africa Score System Version 5 (SASS5), ASPT of South Africa Score System Version 5 (ASPT-SASS5), SIGNAL2, Singapore's Biotic Index (SingScore), Malaysian Family Biotic Index (MFBI), and Malaysian BMWP (BMWP-My) in tropical streams in Ranau-Telupid districts, Sabah, Malaysia, aiming to distinguish reference and disturbed sites. EPT, BMWP-Viet, and BMWP-My effectively discriminated reference from disturbed sites and correlated significantly with habitat quality and nutrient gradient. BMWP-Viet exhibited a strong association with phosphate concentrations, though weaker ties to habitat scores. BMWP-My surpassed other Malaysian indices, demonstrating sensitivity, responsiveness, and seasonal stability. Conversely, SingScore and BMWP-Thai, from neighboring countries, exhibited lesser performance, potentially due to designations and modifications. Indices incorporating relative abundances, such as the FBI and MFBI, displayed poor performance. Correspondingly, Saha and Gupta (2015) focused Oxbow lakes in Assam, Northeast India, using BMWP-THAI scores, ASPT-THAI, and the Nepal Lake Biotic Index (NLBI). Using BMWP-THAI scores, and revealed varying water quality across the lakes during different seasons.

Likewise, Choudhury & Gupta (2017) conducted a rapid assessment of water quality in Deepor Beel, Assam, India, using original BMWP and BMWP-THAI, SIGNAL, ASPT, and ASPT-THAI. As per SIGNAL scores, Deepor Beel exhibited severely polluted water. Despite moderate water quality being indicated by the BMWP scores for all sites, the average THAI score demonstrated good water quality of Site 1. However, the ASPT score for all sites, along with the average THAI score, suggested probable moderate pollution of the water. Another study by Chakravarty & Gupta (2021) BMWPTHAI, ASPTTHAI, EPT, FBI (Family Biotic index), and SIGNAL 2 were utilized for the study of the Jatinga River in North East India. BMWPTHAI revealed 'moderate' water conditions in the midstream and 'poor' conditions downstream across different seasons; the midstream displayed 'clean water' pre-monsoon, while the downstream showed 'severe pollution.' ASPTTHAI scores suggested 'clean water' during the monsoon but 'doubtful' midstream quality and 'probable moderate pollution' downstream in the post-monsoon and winter. The SIGNAL2 scores indicated a 'healthy habitat' midstream and 'severe pollution' downstream during the monsoon and post-monsoon, with 'moderate' and 'severe pollution' in winter and pre-monsoon. EPT percentages signaled 'moderate' conditions in midstream during the monsoon and post-monsoon, contrasting with 'poor' conditions downstream. The FBI recorded 'good' water in quality in midstream during the monsoon and post-monsoon but 'fairly poor' and 'poor' downstream. Overall, the consistent trend in biotic indices suggested relatively better water quality in the midstream, potentially influenced by anthropogenic activities like sand mining and local practices.

Uherek & Pinto Gouveia (2014), in Maroaga Stream, Amazon, Brazil, utilized the BMWP Score System to assess water quality. Regardless in an Environmental Protection Area, the stream's water did not qualify as "very clean," possibly due to the presence of bat *Guano* from the near Maroaga Cave, altering water properties and impacting the macroinvertebrate community. Similarly, Nzovwe Stream's water quality was interpreted as moderately polluted based on the composition of the macro-invertebrate community and the BMWP score (Ojija & Laizer, 2016).

Sarma & Baruah (2017) introduced the Bio-sensitivity Assessment (BSA) index, combining both bio-sensitivity and diversity indices. By employing the BMWP score and BSA index, the study underscored the valuable role of aquatic insects as bio-indicators in assessing and monitoring water pollution in the Bahini River.

In addition to the BMWP Score System, ASPT and SIGNAL Score were also used by Barman & Gupta (2015) in the study of water quality assessment of Bakuamari stream in Chakrashila Wildlife Sanctuary, Assam, India. SIGNAL score indicated a moderate system, whereas BMWP scores indicated moderate water quality, and ASPT scores indicated good quality of system.

However, the BMWP scores indicated poor to moderate water quality, the ASPT scores suggested polluted to doubtful water quality, and SIGNAL scores indicated severe to moderate pollution levels in the Brahmaputra River, Dibru Saikhowa National Park, Assam, India, by Gogoi & Gupta (2017). Similarly, Hazarika (2023) recorded BMWP, ASPT, and SIGNAL-2 scores indicating a moderately polluted perennial pond in Assam, Northeast India.

The SIGNAL method was also applied by Gupta *et al.,* (2013) to assess the pond water quality surrounding two cement factories in Assam and found a moderately polluted nature of the water. Boruah & Gupta (2016) conducted an analysis of the ecosystem health of two ponds in Cachar District, Assam, India, utilizing EPT and SIGNAL 2. EPT suggested good water quality in both systems. However, SIGNAL 2 revealed the stressed condition of these two water bodies.

In addition to the BMWP and ASPT index, the FBI was also used by Nasirian (2014) to assess water quality and organic pollution in the Shadegan and Hawr Al Azim wetlands of Khuzistan Province, south-western Iran. BMWP, ASPT, and FBI indicated polluted, severe pollution, and severe organic pollution, respectively. Similarly, Pahari *et al.,* (2021) conducted a comparative study of natural pond (NP) and brick embankment pond (BEP) by using diversity, equitability, SIGNAL, BMWP, ASPT and FBI. The habitat in NP appeared to be more compatible and stable than that in BEP, as per the scales proposed by Wright *et al.* (1993), Chessman (1995), and Kazanci *et al.* (2010).

In Bundu Tuhan, Sabah, Fikri *et al.* (2013) utilized EPT in addition to FBI, BMWP, and ASPT to evaluate pristine and altered streams and record decreased water quality. Dutta *et al.* (2014) focused on the Tail Race of the Dikhow River in Assam, India, employing the FBI, and assessed very poor quality of water. According to Wahizatul *et al.* (2011) on Sungai Peres and Sungai Bubu streams of Terengganu, Peninsular Malaysia, despite receiving pollutants from anthropogenic activities, FBI, BMWP, ASPT, and EPT indices consistently categorized both streams as having clean-to-excellent water quality. FBI, BMWP, ASPT, and EPT indices in a study by Vian *et al.* (2018) in Crocker Range National Park, Sabah, Malaysia, also consistently supported Kimanis River status as a non-impacted and unpolluted aquatic ecosystem. The study highlighted the river's highwater integrity, with the upstream strata exhibiting better water conditions compared to the downstream. However, the study by Ab. Hamid & Normi (2018) in recreational rivers of Kedah & Penang, Peninsular Malaysia, FBI indicated moderately good in both the BSH (before school holiday) and ASH (after school holiday) seasons, whereas the DSH (during school holiday) season it indicated moderate water quality. In contrast, other biological indices, including BMWP, ASPT, and EPT, presented a more optimistic evaluation of quality of water for all seasons, describing it as very good, good, and not impacted, respectively. These diverse assessments from different indices emphasize the importance of considering multiple indicators when evaluating water quality, as different indices may provide varying perspectives on the health of the aquatic ecosystem.

The FBI revealed varying pollution levels across different sites, with the Kaliyikkal site showing elevated pollution levels and the Main Kallar site exhibiting good water quality conditions during the study by Priyanka & Prasad (2022) in Western Ghat streams. Thus, demonstrating the sensitivity of the FBI in detecting and differentiating pollution levels within a region.

Kubendran & Ramesh (2016) conducted a study in the Southern Western Ghats, India, focusing on EPT, ASPT, and BMWP, which indicated high water quality for both streams, Kurangani and Valiparai. The EPT Index revealed higher richness in Kurangani. Correspondingly, Shafie *et al.* (2017) employed EPT, BMWP, and ASPT during a study on the Liwagu River in Sabah, Malaysia, suggested moderate water quality, synonymous with some level of pollution, and emphasized the importance of implementing a rigorous and effective biological water quality monitoring program in the River Liwagu, Sabah. The BMWP and ASPT scores calculated by Marwein & Gupta (2018) in a small stream at Shillong, Meghalaya, indicated the impact of physical disturbance on aquatic organisms and water quality. Sabha *et al.* (2022) conducted a hydrobiological assessment in the Dagwan Stream, Kashmir Himalaya, using BMWP, ASPT, and Hindu Kush-Himalayan Biotic Score (HKHbios) at all study sites, except Near Duck Park, and suggested good water quality according to criteria set by Mason (2002) & Chapman (1996). The Hindu Kush-Himalayan Biotic Score exhibited a decreasing trend downstream, indicating very good water quality conditions upstream and moderate water quality downstream. Other indices, such as the Shannon-Weiner Diversity Index (H) and the Simpson Index, further supported the clear division of upstream and downstream conditions.

The contrasting approaches and variations in the values of the three indices, namely EPT, SWRC, and FBI, offer researchers a valuable insight into both sensitive and tolerant components of the ecosystem, enhancing the overall understanding of water quality dynamics (Pepa *et al.,* 2012). Similarly, Jyothylakshmi *et al.* (2021) conducted a study on the River Killiyar in Thiruvananthapuram, Kerala, India, focusing on EPT and FBI. EPT was found to dominate the river, indicating clean and well-oxygenated water conditions, and the FBI revealed variations in water quality along the river. The values at its origin, indicated excellent water quality whereas, at downstream, there was a noticeable increase in FBI, suggesting a decline in water quality.

CONCLUSION

Biomonitoring, particularly through the use of aquatic entomofauna, has shown to be a reliable and cost-effective technique for assessing the condition of the environment. Unlike chemical analysis, biomonitoring captures the dynamic interactions within freshwater ecosystems, providing a more holistic understanding of their health. The reviewed insights from worldwide studies underscore the adaptability and effectiveness of biotic indices in assessing water quality.

Original biotic indices, BMWP, ASPT, FBI, SIGNAL, and EPT serve as quantitative tools to evaluate water quality based on the tolerance and sensitivity of entomofauna to environmental changes. These indices offer a practical and efficient means of assessing the impact of pollutants, habitat alterations, and other stressors on aquatic ecosystems. Moreover, modified biotic indices from various regions as per the diverse geographical conditions, BMWP-Thai, BMWP-Viet, BMWP-My, ASPT Viet, ASPT-Thai, ASPT SASS5, SASS5, MFBI, FBI, and SIGNAL 2 highlighted the global applicability of these tools.

However, evaluation of diverse biotic indices and variations in their interpretation are needed to be addressed by a long-term monitoring program, which will influence government policies for the conservation of small streams in both protected and unprotected areas. Further, comprehensive investigations to validate the application of various biotic indices are essential. The contrasting approaches of biotic indices offer insights into both sensitive and tolerant components of the aquatic ecosystem, enhancing the overall understanding of water quality dynamics and providing valuable insights for water resource management and policy formation.

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DECLARATION OF INTEREST

The authors state that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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