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Aquatic macroinvertebrate biodiversity and bio-monitoring of water quality of mining impacted streams in Bailadila Iron Ore Mine, South Bastar Dantewada district, Chhattisgarh state, India

Anish V Pachu, Sudhir Kumar, V Jeeva and V Mohan

Abstract
The aquatic macroinvertebrate biodiversity of mining impacted streams in and around Bailadila Iron Ore Mine, Kirandul Complex in South Bastar Dantewada district, Chhattisgarh state was assessed with the aim of predicting probable biological water quality by employing the macroinvertebrate water quality indices. A total number of 880 macroinvertebrates representing 27 families under 10 invertebrate orders were collected from 7 locations, which include upstream and downstream areas of Kirandul Nala and downstream area of Panchamurty Nala. Hydropsychidae were the dominant taxa among the macroinvertebrate families identified, followed by Baetidae, Chironomidae, Polycentropodidae, etc. Relatively high diversity with low dominance of taxa was noticed in Panchamurty Nala followed by locations in the u/s. of Kirandul Nala. The macroinvertebrate indices calculations revealed likely no apparent serious water quality impairment in the Kirandul Nala between upstream and downstream locations as well as that of Panchamurty Nala. The results of the indices observed to be useful in comparison with biotic metrics and diversity indices, which together give more insights into the probable water quality characteristics than alone.

Keywords: Bio-monitoring, macroinvertebrates, water quality indices, Kirandul, iron ore mining

1. Introduction

In aquatic ecosystems, biological responses to environmental pressures can be evaluated by using suitable indicator species. Monitoring the risk of ecological impacts of human activities on aquatic ecosystems forms the basis for an effective management of the ecosystems. Biological monitoring of water quality provides an integrated approach to assess the overall environmental quality of aquatic ecosystem [1] and it has become one of the most common methods for reliable assessment of anthropogenic impacts on aquatic ecosystem [2], which is complementary to the alternative method of physico-chemical evaluation of water quality. There has been enormous advancement in bio-monitoring methods and a variety of indices have been developed for the purpose of water quality assessment [3-5]. Biomonitoring of aquatic ecosystem based on macroinvertebrates has attained wide acceptance since the beginning of the twentieth century [6-8] and the method has been tested reliably in both temperate and tropical aquatic ecosystems [9-13]. Aquatic macroinvertebrates perform many important ecological functions. They are considered as central to the recycling of organic matter for making energy available to the upper trophic levels and contribute to the flow of energy along the aquatic food web and thus, are essential for maintaining overall aquatic environmental health [14, 15]. Aquatic macroinvertebrates have been used as an effective tool for bio-monitoring of aquatic ecosystems because of their varying tolerance to ambient environmental changes, relatively easy and inexpensive method of their collection and analysis and most importantly, their relatively lengthy aquatic life with all morpho-physiological and feeding adaptations [16, 17, 18, 19, 20]. They are known to possess varying degree of resistance to ecosystem pressure of both autochthonous and allochthonous in origin and show remarkably high resilience to changing environments [21]. Therefore, they are useful in identifying potential sensitive areas in aquatic ecosystems for making management decisions for conservation [22-24]. Various natural and anthropogenic factors are responsible for conditioning and shaping water quality in stream ecosystems [25]. Biodiversity of terrestrial ecosystem, demographics and land use patterns in a catchment area make impacts on the state of headwaters.

Despite being highly important, freshwater habitats are greatly disturbed world over mainly due to increased anthropogenic interferences manifested by land use and land cover changes [26, 27].

The scope of the study was to provide baseline data on biodiversity of aquatic fauna (benthic macroinvertebrates) that would serve as the basis for assessment of biological water quality of seasonal/perennial streams in and around the mining lease area of Bailadila Iron Ore Mine, Kirandul Complex, South Bastar Dantewada district, Chhattisgarh state. The study was part of a broader ecological and biodiversity assessment of the area in connection with the identification of potential impacts of iron ore mining on the environment. The study consisted of a rapid semi-quantitative field sampling of macroinvertebrates from the perennial/seasonal head water streams of the area. The main objective of the study was to analyze the abundance and richness of aquatic macrofauna of the natural water courses for biomonitoring of likely water quality characteristics by employing the biotic indices. The aquatic environment and the riparian habitat of the study area is largely influenced by landuse land cover changes on account of iron ore mining and therefore, it is pertinent to evaluate the assemblages and diversity of sensitive/indicator aquatic fauna for biomonitoring of aquatic ecosystem as well as to prose the mitigation measures for the impacts arising out of mining on the ambient environment.

The Bailadila Hills falls within Bacheli Range of Dantewada Forest Division. The area is well known for the Bailadila Iron Ore Mines (BIOM) operated by the NMDC Ltd., and well developed with rail-roads and human habitation primarily for mining and allied activities. This hill range is located at a distance of about 40 km from South Bastar Dantewada District headquarters. A total of 14 major iron ore deposits have been identified in this hill range, out of which three mines are being operated in Kirandul Complex and one of which has been commissioned since October, 1968. The area has highly undulating topography with elevation varying from 400 to 1276 m above MSL. Bailadila hill ranges are a group of hills ranging about 40 km in length and 10 km width. The lower undulating plains vary in elevation from 300 to 400 m and occasionally rise up to 600 m. The area experiences a mean annual rainfall of 1400 mm. With the moderately high rainfall, the densely forested ecosystem of the hills is quite characteristic to a mixed/ moist deciduous forest type. On the contrary, the area is reported to experience severe dry period during the post-monsoon and summer seasons.

The Bailadila hills primarily forms part of the sub-basin watersheds of the Indravati River, which is one of the major tributary of Godavari River. A relatively smaller portion of the area under Bailadila Hills towards SW is drained by Taliperu River that forms one of the tributary of the Godavari River. Both the Indravati and Taliperu Rivers are located respectively north (draining NW and entire eastern slope) and south-west of the hill ranges. The drainage pattern of the area is radial, parallel and sub-dendritic in nature. The SE slope of the hill is drained by Kirandul Nala that joins the Sankini River, which ultimately draining into the Dankini River at Dantewada. These drainages form part of the Indravati River. A relatively small stream called Madadi Nala originates at the extreme south of the hill and joins the Kirnadul Nala at its downstream near Kadampal where a small impoundment (Tailing Dam) has been constructed over an area of 296.77 acres to impound tailings generated due to wet screening operations in rainy season. It was commissioned in May 1989 and is at present submerged over an area of 173 acres. The SW slope of the hill ranges are drained by the Malinger Nala, which joins the Kolab River and further into the Taliperu River. A number of natural water courses criss-cross the ridges and meet one of the above streams.

The region is predominantly covered by three different forest types *viz*., Southern Dry Mixed Deciduous Forest (5A/C3), Moist Peninsular Low Level Sal Forest (3C/C2e (ii)) and Southern Moist Mixed Deciduous Forest (3B/C2). Although a vast area within the Forest Division fall under the category of non-forest, the mountain ridges where the iron ore mined is covered with dense forests of Southern Moist Mixed Deciduous type. The land use of area falling under Bacheli Range Forests as per the draft plan for conservation and management of wildlife in Dantewada Forest Division, prepared for NMDC, occupies mixed forests to the tune of 88.69%, followed by mining lease of 5.86%, plantation of 3.88%, etc., while the same falling under the mining lease and its 10 km buffer zone as per analysis done by IBRAD - Biodiversity Survey and Conservation Plan for Deposit 14 & 11C Mines occupies dense forest to the tune of 27.18%, open forest of 26.36%, degraded forest of 19.15%, forest blanks of 3.38%, that put together 76.06% followed by agriculture 8.35%, mining 1.03%, etc. According to ISFR, 2019 [28], the estimated area under forest cover in South Bastar Dantewada district of Chhattisgarh state amounts to 250.63 km^2 (3.02%) under Very Dense, 2305.07 km^2 (27.78%) under Moderate Dense and 1907.45 km^2 (22.99%) under Open Forest with a total of 44613.15 km^2 (53.79%) out of the total geographic area of 8298 km^2, together with a scrub forest cover of 26.34 km^2.

Material and methods

Aquatic fauna (Benthic Macroinvertebrates) comprising of lower aquatic organisms mostly of insect larvae, which are regarded as the prominent indicators of water quality and aquatic ecosystem health, were sampled from a total of 7 locations in and around the streams in Kirandul Complex, South Bastar Dantewada district, Chhattisgarh state during post-monsoon, 2017 and winter, 2018. A semi-quantitative sampling of aquatic macrofauna was performed by employing a 'D-frame' aquatic dip net having mesh size of 250 microns. In general, the benthic macro-invertebrates were collected by vigorously churning the running water in the stream bed immediately above the location where the hand held net was placed at the bottom vertically by its long handle so as to kick and dislodge the bottom substrata such as pebbles, broken logs, foliage's, etc., into the net. In case of pools, the net was towed along the bottom as well as vegetated margins. The dislodged organisms along with the debris carried by the running water to the net were then transferred into a sorting tray and after initial sorting; the samples were preserved in 70% ethyl alcohol in the field and later sorted and identified up to the maximum lowest taxonomic level possible under stereo-zoom microscope in the laboratory following standard identification manuals. Wherever possible, different kinds of habitats such as pools, riffles and cascades in a location were sampled preferably in duplicate to get a uniform representation of the aquatic fauna.

In this study, different biotic metrics and biotic indices of macroinvertebrates, which are used as measures of the structure, function and other characteristic features of their biological assemblages that show predictable responses to anthropogenic disturbances are calculated for biological monitoring of streams. For macro-invertebrates as biological indicators, lower resolution identification especially at the family level is considered rather than species level, since most studies of a similar nature have recommended family level identification as the best resolution for resolving patterns in macro-invertebrate assemblages as well as assigning the most appropriate tolerance scores for calculating the water quality index.

1) Biotic indices

In order to make easier to understand the complex biological data with regard to the indicator organisms monitored in the aquatic ecosystem, various 'biotic indices' have been developed based on the assumptions that biological communities are a product of their environment and that different kinds of organisms have different habitat preferences and pollution tolerances, which make them to respond differently to different kinds of environmental stressors. Hence, more intolerant organisms are likely to either reduce in numbers or disappear as pollution increases in a water course, while more tolerant ones increase in number.

1.1) Macroinvertebrate Water Quality Index (MWQI)

The quantitative data of macro-invertebrates recorded from the sampling locations was used for the assessment of water quality by employing the Macro-invertebrate Water Quality Index (MWQI) developed by Bhat and Pandit, 2010 [29]. As per the authors, the MWQI has the following features, which mark them superior from all the other kinds of indices used for water quality monitoring– it is simple to use and takes into account the abundance of various macroinvertebrate taxa; it shows distinct results for the samples with varying number of individuals of the same taxon; it has wide range of applicability and efficacy; it is universal and can be used for any pollution sensitivity score system at family, generic or specific level without modification and it fulfils all the criteria required from a robust biotic index for use in monitoring of water quality. The MWQI was calculated using the following formula: The MWQI was calculated using the following formula:

$$MWQI = \frac{\sum N + 1}{(\sum N + 1) + (\sum N' + 1)}$$

$N = n_i (s_i - m_s)$ & $N` = n`_i (s`_i - m_s)$

Where,

N is the multiple product of density of the *i*th taxon and the positive relative sensitivity score;

N` is the multiple product of density of the *i*th taxon and the negative relative sensitivity score;

n is the density of *i*th taxon having assigned pollution sensitivity score (s) ≥ median score (m_s) (positive score);

$n`_i$ is the density of *i*th taxon having assigned pollution sensitivity score (s) < median score (m_s) (negative score);

1 is the constant to account for samples in which taxa having pollution sensitivity score more than the median score may be absent.

Unlike other biotic indices of bio-monitoring, which generally consider the presence/absence and/or range values of different taxa, this index is a combination of both the abundance and pollution sensitivity scores of the taxa. Therefore, it is strongly influenced by the relative abundance of the taxa in a sample. Also, when compared to widely known Hilsenhoff's Family Biotic Index, this index gives distinct results for the samples with different number of individuals of the same taxa [29].

A grading of eight index values between 0 and 1 are used to denote the distinct water quality classes with the minimum and maximum representing both the extremes of the defined water quality criteria as detailed in the table below:

Table 1: MWQI ranges and details of water quality characteristics assigned

Index range	Water quality	Degree of organic pollution
≥ 0.9000	Excellent	No apparent pollution
≥ 0.7000 - < 0.9000	Very good	Slight organic pollution
≥ 0.6000 - < 0.7000	Good	Some organic pollution
≥ 0.5000 - < 0.6000	Fair	Significant pollution
≥ 0.4000 - < 0.5000	Fairly poor	Significant organic pollution
≥ 0.3000 - < 0.4000	Poor	Very Significant pollution
≥ 0.2000 - < 0.3000	Very poor	High organic pollution
< 0.2000	Worst	Severe pollution

(Source: Bhat and Pandit, 2010)

Macroinvertebrate based tolerance score systems have been used to calculate water quality indices world over. Most biomonitoring methods of water quality in streams and rivers involve Tolerance Score (TS) for benthic macroinvertebrates based on their pollution sensitivity [30]. It provides single values ranges from 0-10 for the family level representative of the organism's tolerance to pollution. The TSs will be high for pollution intolerant organisms and lower for the tolerant ones.

For the calculation of MWQI, modified Tolerance Scores for the macro-invertebrates taxa (identified up the family level) that adopted from similar kinds of tolerance scores employed for biomonitoring in different geographic regions mainly Asian countries *viz.*, Malaysia, Singapore, Thailand and Vietnam as well as Australia as indicated in the Table below and detailed as Annexure 1 was used.

Table 2: Indicative references of Tolerance Scores referred for the present study

Sl. No.	Geographic Area	Tolerance Scores	References
1	Thailand	BMWP-Thai	Mustow, 2002 [31]
2	Australia	SIGNAL2	Chessman, 2003 [32]
3	Vietnam	BMWP-Viet	Nguyen *et al*., 2004 [33]
4	Lower Gangetic Plains	HKH Bios	Ofenbock *et al*., 2010 [34]
5	Singapore	Sign-Score	Blakely *et al*., 2014 [35]
6	Malaysia	BMWP-My	Zakaria & Mohamed, 2019 [36]

1.2) Taxa Tolerance Score (TTS)

The Tolerance scores of the individual taxa are summed up to obtain the Taxa Tolerance Score of the sampling location. The index is akin to the BMWP Score commonly used as a measure for biological monitoring of water quality. However, in this case, instead of the tolerance score as in BMWP, the scores adopted from similar scoring system as indicated above were used for calculating water quality index. The scale of criteria for water quality characteristics based on the Total Tolerance Sore is given as under:

Total Tolerance Score	Category	Interpretation
>120	Excellent	No apparent contamination
101-120	Good	Slightly contaminated
61-100	Moderate	Moderately contaminated
36-60	Poor	Contaminated
16-35	Very poor	Highly contaminated
<15	Extremely poor	Extremely contaminated

1.3) average score per taxon (ASPT)
The average Tolerance Score of all taxa within the community was calculated by dividing the tolerance scores by the number of families represented in the sample [9, 37, 38]. The resultant average value of a particular sapling location is matched with the range matrix of the index (detailed below) for assessment of probable water quality characteristics.

ASPT Range	Water Quality
> 5.4	Excellent
4.8 - 5.4	Very Good
4.3 - 4.8	Good
3.6 - 4.3	Moderate
3.0 - 3.6	Poor

For assessing water quality, the ASPT was also taken into consideration. This is to reduce the effects of sample size, sampling effort and sampling efficiency on the results obtained by TTS alone as the taxa richness (number of taxa present) is indicative of the diversity of the community. In general, a TTS greater than 100, together with an ASPT value greater than 4 would indicate a good quality water source.

2) Biotic Metrics
The most common biotic metrics such as numerical abundance i.e., total number of macroinvertebrate organisms present in a sample and richness i.e., the number of types of macroinvertebrate taxa present in a sample were calculated. Apart from this, community metrics that include abundance of richness of EPT Taxa (Ephemroptera, Plecoptera and Trichoptera), which are used as a measure for identifying the disturbances due to pollution in freshwater aquatic ecosystems were also calculated.

3) Diversity Indices
The diversity indices such as Shannon (*H*), Simpson (1-D), Dominance (D) and Evenness (e^H/S) of macroinvertebrates in different sampling locations were analyzed by employing a standard software programme (PAST, ver. 2.17c).

4) Functional feeding groups (FFGs)
The Functional Feeding Groups (FFG) of the macroinvertebrate taxa were assessed following Ramirez and Gutierrez-Fonseca (2014), Meixler and Bain (2015) and Cummins (2018) [39, 40, 41] to understand the functional feeding adaptations of macroinvertebrate community and thereby insights into the probable impairment in functional ecosystem of the area.

Results
Seven locations in the perennial/seasonal streams originating/passing through the mine lease areas of BIOM, Kirandul Complex were sampled for aquatic macroinvertebrates during post-monsoon (November, 2017) and winter (January, 2018) seasons (Table 1). A total number of 880 macroinvertebrates representing 27 families under 10 invertebrate orders were collected during both the sampling period (Table 2). The relative abundance of macroinvertebrates of both the seasons varied from 2.73% at location 1 (Kirandul Nala u/s.) to 34.89% at location 4 (Kirandul Nala d/s.). However, the Kirandul Nala u/s. (locations 1-3) and Panchmurty Nala (location 7) were less abundant in macroinvertebrates than that of the Kirandul Nala d/s. (locations 4-6). The richness of macroinvertebrate taxa varied from 6 to 14 respectively at locations falling within the Kadampal tailing dam and downstream of it (Figure 1).

Table 3: Location details of aquatic macroinvertebrate sampling from the streams in BIOM, Kirandul Complex

Sl. No.	Sampling Locations	Lat. (N)	Long. (E)	Alt. (m)
1	Kirandul Nala u/s. (near waterfall)	18°37’12.21’’	81°14’32.95’’	888
2	Kirandul Nala u/s. (near water testing lab)	18°37’47.09’’	81°14’51.95’’	747
3	Kirandul Nala u/s. (near pump house)	18°37’21.32’’	81°14’59.04’’	699
4	Kirandul Nala d/s. (near Nala diversion)	18°38’39.85’’	81°16’43.96’’	582
5	Kadampal tailing dam (within)	18°38’46.37’’	81°16’57.81’’	576
6	Kadampal tailing dam d/s.	18°39’39.23’’	81°17’31.15’’	560
7	Panchamurty Nala	18°39’51.74’’	81°14’54.45’’	611

Table 4: Total abundance & richness and the Functional Feeding Groups (FFG) of macroinvertebrate taxa from the streams in BIOM, Kirandul Complex

Sl. No.	Order/Class	Family/Taxa	Genera/Taxa	Abundance	FFG
1	Arhynchopdellida	Erpobdellidae		3	--
2	Oligochaeta	Oligochaeta		2	cg
3	Diptera	Athericidae		9	pr
4	Diptera	Ceratopogonidae		4	pr
5	Diptera	Chironomidae		51	cg
6	Diptera	Culicidae		1	cg
7	Diptera	Simuliidae		15	cf
8	Diptera	Tabanidae		5	pr
9	Diptera	Tipulidae	*Hexatoma* sp.	4	sh
10	Coleoptera	Curculionidae	*Blosyrus* sp.	1	sh
11	Coleoptera	Dytiscidae	*Hydaticus* sp.	1	pr

12	Coleoptera	Gyrinidae		3	pr
13	Ephemeroptera	Baetidae		89	cg
14	Ephemeroptera	Caenidae		2	cg
15	Plecoptera	Perlidae		2	pr
16	Trichoptera	Hydropsychidae		612	cf
17	Trichoptera	Philopotamidae		8	cf
18	Trichoptera	Polycentropodidae		25	cf
19	Trichoptera	Rhyacophilidae		5	pr
20	Hemiptera	Gerridae	*Tenagogonus* sp.	5	pr
21	Hemiptera	Naucoridae	*Naucoris* sp.	2	pr
22	Odonata	Coenagrionidae		1	pr
23	Odonata	Corduliidae		1	pr
24	Odonata	Gomphidae		6	pr
25	Odonata	Libellulidae		7	pr
26	Decapoda	Gecarcinucidae	*Barytelphusa cunicularis*	11	sh
27	Decapoda	Palaemonidae	*Macrobrachium* sp.	5	sh
Total Abundance				880	
Total Richness				27	

Cg=collectors-gatherers, Pr=predators, cf=collectors-filterers, Sh=shredders

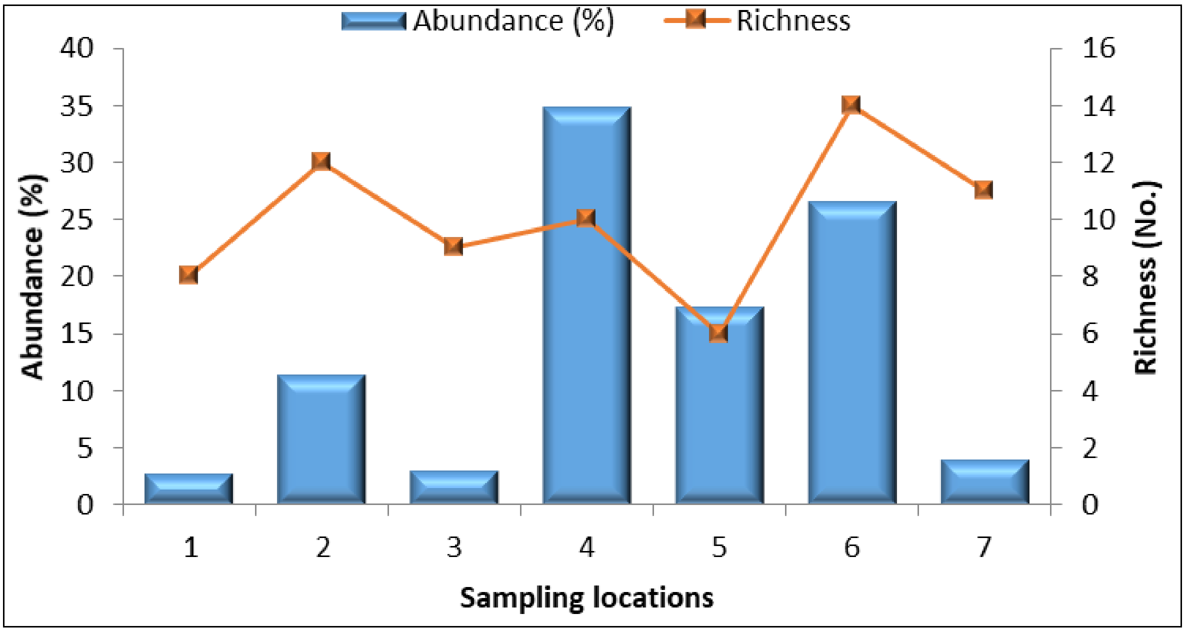

Fig 1: Total spatial abundance (%) and richness (No.) of (Biotic metrics) macroinvertebrates from sampling locations in the streams in BIOM, Kirandul Complex

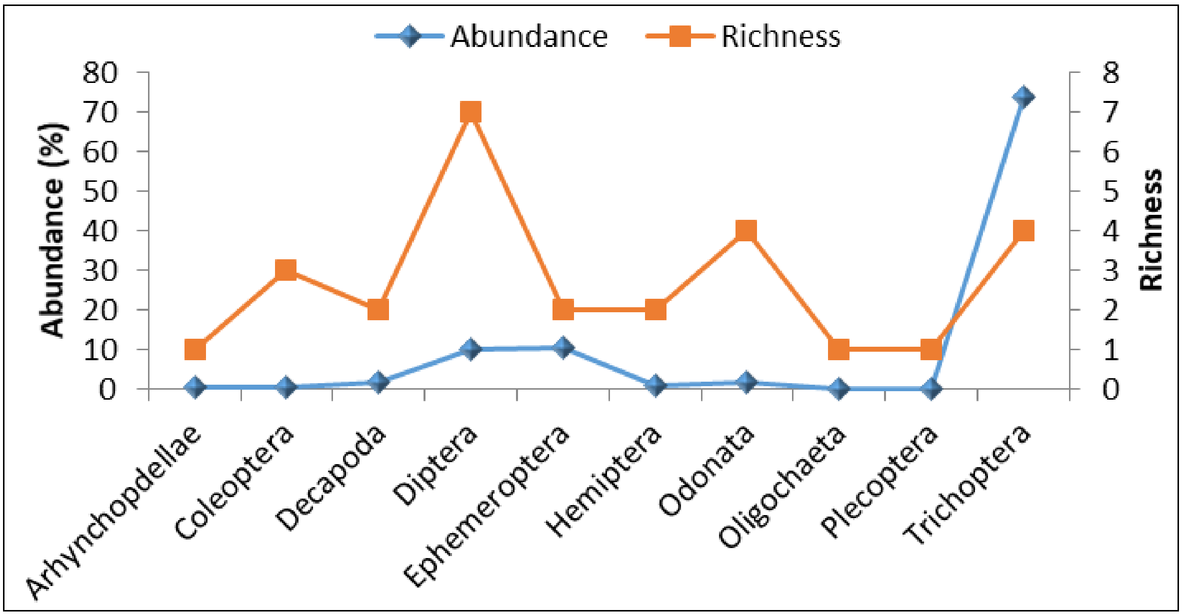

Fig 2: Abundance (%) & richness of organisms, grouped under macroinvertebrate orders, recorded from the streams in BIOM, Kirandul Complex

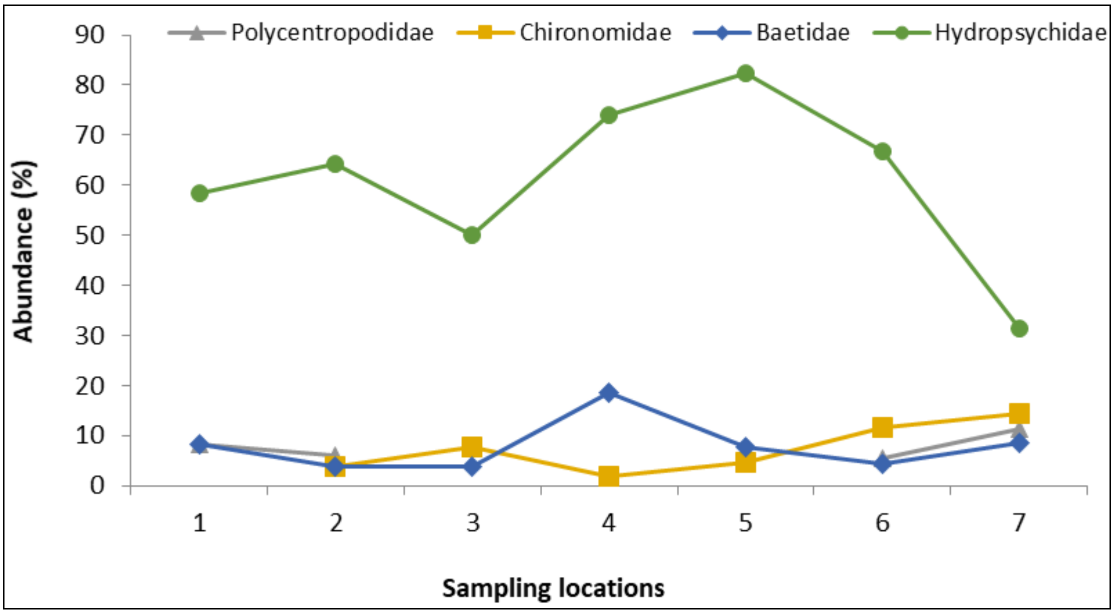

Fig 3: Total spatial abundance of dominant macroinvertebrate taxa (family) recorded from the streams in BIOM, Kirandul Complex

Among aquatic macroinvertebrate Orders, Trichoptera with a relative abundance of 73.86% was the most abundant taxa followed by Ephemeroptera (10.34%), Diptera (10.11%), etc. The richness, among invertebrate orders, was highest in Diptera (7) followed by Odonata and Trichoptera (4 each), Coleoptera (3), etc., (Figure 2). The most abundant macroinvertebrate family was Hydropsychidae with a total relative abundance of 69.55% (varied from 31.43 to 82.35%) followed by Baetidae (10.11%), Chironomidae (5.80%) and Polycentropodidae (2.84%) (Figure 3). The EPT taxa together account for more than half of the total numerical abundance (84.43%) of the organisms and was represented by 2 families under Ephemeroptera, only 1 family i.e., Perlidae under Plecoptera and 4 families under Trichoptera. The diversity indices of macroinvertebrates calculated for the sampling locations varied from 0.14 to 0.69 in case of dominance, from 0.24 to 0.63 in evenness and from 0.68 to 1.94 in Shannon (Figure 4). Dominance index was high in d/s. location of Kirandul nala than that of its u/s. locations (except location No.1). Shannon index was highest in Panchamurty Nala d/s. location and relatively high in Kirandul Nala u/s. locations.

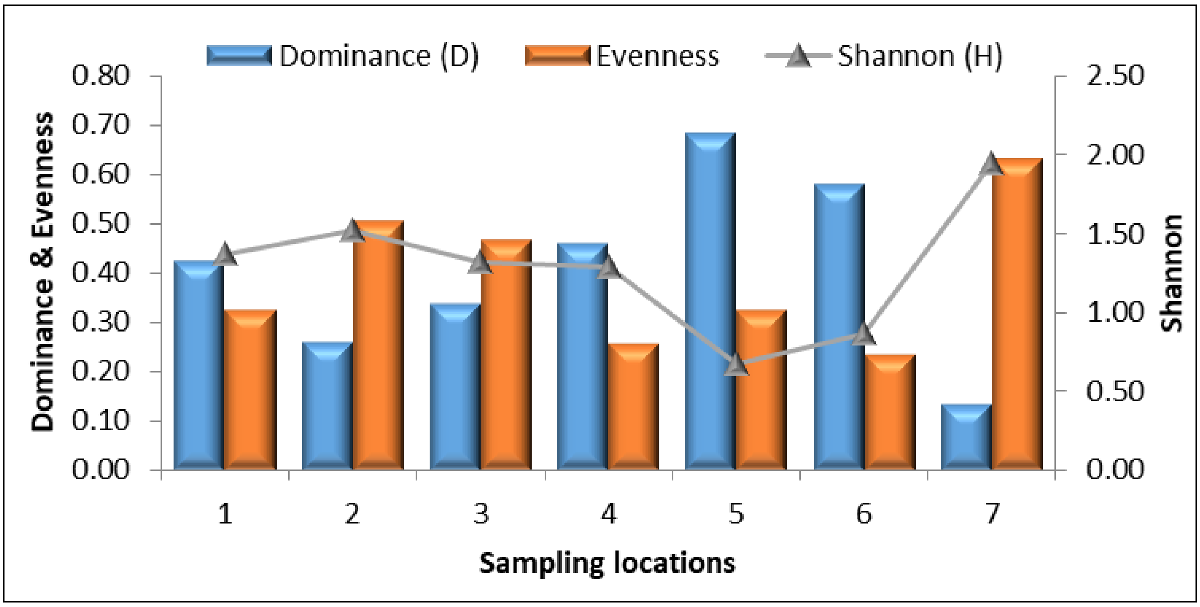

Fig 4: Diversity indices of macroinvertebrate taxa recorded from sampling locations in the streams in BIOM, Kirandul Complex

Table 5: TTS of sampling locations from the streams in BIOM, Kirandul Complex

Location Sl. No.	Sampling Period	Taxa Tolerance Score	Category	Interpretation
1	Post-monsoon	**50**	**Poor**	**Contaminated**
2	Post-monsoon	49	Poor	Contaminated
	Winter	34	Very poor	Highly contaminated
	Total	54	Poor	Contaminated
3	Post-monsoon	25	Very poor	Highly contaminated
	Winter	23	Very poor	Highly contaminated
	Total	36	Poor	Contaminated
4	Post-monsoon	26	Very poor	Highly contaminated
	Winter	36	Poor	Contaminated
	Total	40	Poor	Contaminated
5	Post-monsoon	25	Very poor	Highly contaminated
6	Post-monsoon	34	Very poor	Highly contaminated
	Winter	43	Poor	Contaminated
	Total	58	Poor	Contaminated
7	Post-monsoon	54	Poor	Contaminated

Table 6: ASPT of sampling locations from the streams in BIOM, Kirandul Complex

Location Sl. No.	Sampling Period	ASPT	Water Quality
1	Post-monsoon	**6.25**	**Excellent**
2	Post-monsoon	4.45	Good
	Winter	5.67	Excellent
	Total	4.50	Good
3	Post-monsoon	4.17	Moderate
	Winter	3.83	Moderate
	Total	4.00	Moderate
4	Post-monsoon	3.71	Moderate
	Winter	4.50	Good
	Total	4.00	Moderate
5	Post-monsoon	4.17	Moderate
6	Post-monsoon	3.40	Poor
	Winter	4.78	Good
	Total	4.14	Moderate
7	Post-monsoon	4.91	Very good

Table 7: MWQI of sampling locations from the streams in BIOM, Kirandul Complex

Location Sl. No.	Sampling Period	MWQI Range	Water Quality	Degree of Organic Pollution
1	Post-monsoon	0.3889	Poor	Very significant pollution
2	Post-monsoon	0.8763	Very good	Slight organic pollution
	Winter	0.7273	Very good	Slight organic pollution
	Total	0.7751	Very good	Slight organic pollution
3	Post-monsoon	0.6400	Good	Some organic pollution
	Winter	0.3810	Poor	Very significant pollution
	Total	0.7500	Very good	Slight organic pollution
4	Post-monsoon	0.8910	Excellent	No apparent pollution
	Winter	0.0200	Worst	Severe pollution
	Total	0.9249	Excellent	No apparent pollution
5	Post-monsoon	0.7290	Very good	Slight organic pollution
6	Post-monsoon	0.5783	Fair	Significant pollution
	Winter	0.3626	Poor	Very significant pollution
	Total	0.7536	Very good	Slight organic pollution
7	Post-monsoon	0.8036	Very good	Slight organic pollution

The TTS of the sampling locations, among the biotic indices of macroinvertebrates calculated for the prediction of probable biological water quality characteristics, observed to range from '*very poor*' with '*highly contaminated*' (23 - 34) to '*poor*' with '*contaminated*' (36 - 58) water quality (Table 3); the ASPT ranged from '*poor*' (3.40) to '*excellent*' water quality (6.25) through '*moderate*' (3.71 - 4.17), '*good*' (4.45 - 4.78) and '*very good*' (4.91) water quality (Table 4) and the MWQI of the sampling locations observed to range from '*worst*' water quality with '*severe pollution*' (0.0200) to '*excellent*' water quality with '*no apparent pollution*' (0.9249) through '*poor*' water quality with '*very significant pollution*', '*fair*' water quality with '*significant pollution*', '*good*' water quality with '*some organic pollution*' and '*very good*' water quality with '*slight organic pollution*' (Table 5).

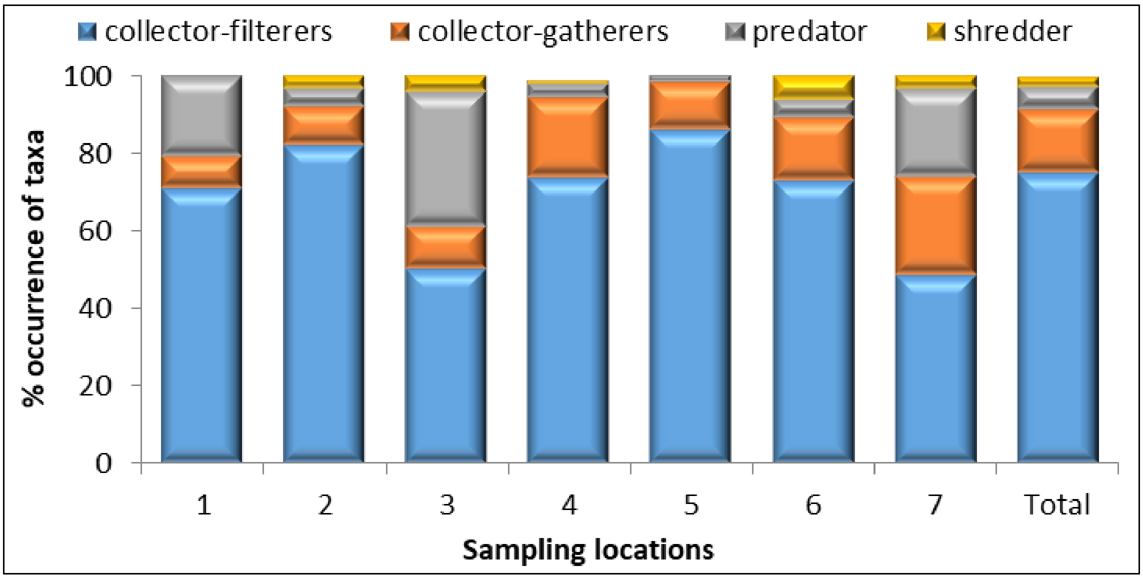

Fig 5: Composition of FFGs of macroinvertebrates in the sampling locations from the streams in BIOM, Kirandul Complex

The FFGs of the macroinvertebrates observed to dominate by collector-filterers (86.27 - 48.57%) followed by collector-gatherers (8.33 - 25.71%), predators (1.31 - 34.62%) and shredders (0.98 - 5.98%) across the sampling locations (Figure 5). Both collector-filterers and shredders were represented by 4 taxa each, collector-gatherers by 5 taxa, while predators dominated in the collection by 13 taxa.

Discussions

Among the seven sampling locations, three (1-3) are falling in the upstream of Kirandul Nala, while the other three locations (4-6) at its downstream, including the two (5-6) respectively within the Kadampal tailing dam and d/s. of it. Some extent of the Kirandul Nala, from the infrastructure area of the mine up to near u/s. of the Kadampal tailing dam, is diverted along a closed RCC square tunnel, in order, to maintain the required flow towards d/s. as well as to avoid contamination of the water from the pollutants in the ore handling area. Sampling location 4 is located at the water course d/s. of this stream diversion channel. Location 7 is falling in the downstream of Panchamurty Nala, which is evidently influenced by wash off from waste dumps within the mine lease area during rainy seasons. The sampling for macroinvertebrate was performed during the end of post-monsoon (Nov., 2017) and winter (Jan., 2018) seasons, both of which are characterized by lean flow in the streams devoid of much of the impacts of erosion and wash off from the mining areas. Nevertheless, water flow during rainy season is reported to be influenced by wash-off containing silt and sediments from mining areas locally termed as '*Laal Paani*', which is a very serious concern both in terms of aquatic ecosystem health as well as access to clean water by the general public and their agriculture and domestic activities.

Although the forests and its biotic resources are rich and varied, relevant scientific studies of qualitative and quantitative in nature are seldom carried out and because of this, there is much gap in the knowledge of these valuable bio-resources in the area. Studies conducted for documentation of aquatic invertebrate fauna pertinent to bio-monitoring of water quality are not reported from the region, despite the aquatic resources (forested streams) of the area are continuously being impacted due to on-going mining and allied activities. A study of the impacts of mining on forests and biodiversity in three iron ore mining leases *viz*., 14, 14NMZ, 11B and their buffer areas of the Kirandul complex by Biswas and Biswas (2018) [42] is the only prominent work of its kind carried out from the area with detailed vegetation, invertebrate and animal diversity. Details of the odonata (dragon flies and damsel flies) from within the region and its adjoining locations are mentioned in the literature by Tiple (2012) [43], Tiple and Chandra (2013) [44], Dawn and Chandra (2014) [45], Kol and Meshram (2015) [46], etc. The other relevant literature with regard to the subject includes; fauna of Indravati Tiger Reserve by Ghose (1995) [47], biodiversity strategy and action plan for Bastar detailing the flora and fauna of the region by Gode (2003) [48], aquatic and semi-aquatic bugs of Chhattisgarh by Jehamalar and Chandra (2013) [49], aquatic beetle of Chhattisgarh by Ghosh *et al.* (2014) [50], etc.

Moderate to high abundance of macroinvertebrates especially Hydropsychidae of the order Trichoptera together with relatively less diversity and high dominance at three d/s. locations of Kirandul Nala (4-6) indicates probable impairment in water quality. These locations are reported as highly polluted because of being affected mainly by tailing deposits in the Kadampal tailing dam as well as wash off directly from the active mining locations including ore handling areas during rainy season. The observed changes in macroinvertebrate abundance and diversity characteristic may be attributed to factors directly related to mining/land use land cover changes associated with mining on surface water courses. On the contrary, relatively low abundance and corresponding high diversity of macroinvertebrates with low dominance (except location 1) reported in the sampling locations from Kirandul Nala u/s. (2-3) and Panchamuty Nala (7) indicates probable absence of external disturbances on the water courses. Nevertheless, evident disturbances due to silt and sediment wash off from waste dumps in the mining areas are reported in Panchamurty Nala during rainy seasons. Unlike other d/s. locations of the Kirandul Nala, the Kadamplal tailing dam d/s. is surrounded by more riparian vegetation and is having varied bottom substratum that is relatively more akin to the u/s. locations in the stream, except the disturbances in terms of spread of more agriculture areas. In case of Panchamurty Nala, although known for heavy silt laden water during rainy season, its riparian zone on the hill slopes is surrounded by relatively dense vegetation cover. Moreover, flow variation is also quite evident in this stream. Biswas and Biswas (2018) [42] reported that mining in Bailadila forest area has aggravated degradation/loss/fragmentation of habitats leading to large scale loss of biodiversity and further, the anthropogenic factors other than mining that influence loss of biodiversity includes biotic interference, grazing, pollution and introduction of exotics, etc.

The four types of FFGs with dominance of C-Fs and C-Gs, which is predominantly contributed by Hydropsychidae and Baetidae respectively, are typical pattern found in tropical forest stream ecosystems. A similar result of high relative abundance of C-Fs in the EPT assemblages was reported in streams in Southern Eastern Ghats in Tamil Nadu indicating probable presence of fine particulate organic matter as well as decomposing activities by microbial communities in the sampling locations [51].

Although limited sampling, the water quality characteristics based on the three macroinvertebrate indices *viz*., Taxa Tolerance Score, ASPT and MWQI revealed striking observations about the probable impairment in water quality of the sampling stations, which is more or less in conformity with the general observations on the state of the study area (Table 3, 4 & 5). The water quality characteristics based on TTS (total) of both the u/s. and d/s. locations in the Kirandul Nala (except one location within the Kadampal dam) as well as that of Panchamurty Nala observed as '*poor*' with '*contaminated*' water quality is perhaps due to relatively low abundance of pollution sensitive taxa as it is evident from that of EPT where only relatively more tolerant taxa such as Hydropsychidae and Baetidae dominated over the others. The results of ASPT observed to vary from '*moderate*' to '*excellent*' through '*good*' in u/s. locations as well as '*moderate*' and '*very good*' in both d/s. locations and Panchamurty Nala respectively. The variations in ASPT from generally observed 'moderate' water quality to higher ranges is probably due to presence of more sensitive taxa such as Perlidae, Polycentropodidae, Philopotamidae, Rhyacophilidae, etc., over the others in some sampling locations. The MWQI of the Kirandul Nala u/s. sampling locations observed to vary from '*poor*' to '*very good*', the d/s. locations vary from '*very good*' to '*excellent*' and that of the Panchamurty Nala observed as '*very good*'. Although, d/s. locations in Kirandul Nala are generally regarded as more polluted than the u/s. locations, so also the d/s. locations of Panchamurty Nala, mainly due to reasons attributable to land use land cover changes and related disturbances arising out of mining establishments, the water quality characteristics of both the locations in this study are observed to be at par with each other based on MWQI. The results of the three indices of this study, therefore, are observed as complementary to each other, though some of the sampling locations showed contrasting water quality characteristics among the indices.

Nevertheless, visibility of water in the d/s. sampling stations of Kirnadul Nala was observed to be influenced by deposition of tailings and was not as good as that of the other u/s. stations. Influence of catchment area vegetations and land use land cover changes due to mining on water quality has been reported from a river network in central Indian forests quite similar to this environment by Pachu *et al.* (2017) [52]. Profound influence of the silt/sediment already deposited on the visible water quality of the Kirandul Nala up to the Kadampal Tailing Dam was noticed and that might act as a potential source of water pollution by surface erosion and cause increased sediment pollution to the water downstream. The water quality impairment might also be due to the silt/sediment wash off from the active mining areas including the infrastructure like ore handling plant at the downstream of downhill conveyor system during rainy season.

Conclusion

The biodiversity of aquatic macroinvertebrates in the perennial/seasonal streams in and around the Bailadila Iron Ore Mine, Kirandul Complex and the biological water quality employing the macroinvertebrate water quality indices *viz*., Taxa Tolerance Score, ASPT and MWQI indicated likely no apparent impairment in water quality in the d/s. locations of the Kirandul Nala compared to that of the u/s. locations. Though Panchamurty Nala is reported as relatively much polluted stream owing to mining influence, the results of the three indices indicated likely no serious impairment in water quality. However, studies of this kind are highly recommended periodically to understand much about the impacts of developmental changes on water quality. Overall, the results of the indices are useful in comparison with biotic metrics and diversity indices and these attributes together observed to give more insights into the probable water quality characteristics than alone.

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Annexure 1: A list of tolerance values of macroinvertebrate taxa used for calculating biotic indices in different geographic regions together with the values used at present

Sl. No.	Order/Taxa	Family/Taxa	Tolerance Values Referred						Values used for Present Study
			1	2	3	4	5	6	
1	Arhynchobdellida	Erpobdellidae	3	1	3	--	1	--	3
2	Oligochaeta	Oligochaeta	1	--	1	2	2	--	1
3	Diptera	Athericidae	--	8	--	9	10	5	5
4	Diptera	Ceratopogonidae	--	4	--	2	3	6	4
5	Diptera	Chironomidae	2	3	2	1	2	1	2
6	Diptera	Culicidae	--	1	--	--	1	--	1
7	Diptera	Simuliidae	5	5	5	7	4	5	4
8	Diptera	Tabanidae	--	3	--	7	--	5	5

9	Diptera	Tipulidae	5	5	5	8	3	6	5
10	Coleoptera	Curculionidae	5	2	5	5	--	--	5
11	Coleoptera	Dytiscidae	5	2	5	--	5	6	2
12	Coleoptera	Gyrinidae	5	4	5	7	--	5	4
13	Ephemeroptera	Baetidae	4	5	4	--	7	6	4
14	Ephemeroptera	Caenidae	7	4	7	7	7	4	4
15	Plecoptera	Perlidae	10		10	8	9	6	10
16	Trichoptera	Hydropsychidae	5	6	5	9	7	5	5
17	Trichoptera	Philopotamidae	8	8	8	7	8	6	8
18	Trichoptera	Polycentropodidae	7	7	--	--	9	5	7
19	Trichoptera	Rhyacophilidae	7	--	--	8	--	--	7
20	Hemiptera	Gerridae	5	4	5	--	5	5	4
21	Hemiptera	Naucoridae	5	2	5	7	7	6	5
22	Odonata	Coenagrionidae	6	2	4	5	3	5	4
23	Odonata	Cordulidae	6	5	4	5	5	6	5
24	Odonata	Gomphidae	6	5	6	--	8	5	5
25	Odonata	Libellulidae	6	4	4	6	4	5	4
26	Decapoda	Gecarcinucidae*	3	3	3	6	9	--	3
27	Decapoda	Palaemonidae	8	4	3	6	7	--	4

* used different names as per the latest classifications
1. Thailand: BMWP-Thai [31]; 2. Australia: Signal2 [32]; 3. Vietnam: BMWP-Viet [33]; 4. Lower Gangetic Plains: HKH Bios[34]; 5. Singapore: Sign-Score [35]; 6. Malaysia: BMWP-My [36]

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