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APPLICATION OF CCME WATER QUALITY INDEX IN EVALUATING THE WATER QUALITY STATUS IN LIMESTONE MINING AREA OF MEGHALAYA, INDIA

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ABSTRACT

The water quality indices reflect the overall quality status of the water and give simplified understanding to the general public about the health status of water bodies. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was computed to reveal the overall water quality scenario in the limestone mining area of Meghalaya. The CCME WQI value ranges between 0 to 100 indicating poor to excellent water quality and has been widely used by the researchers for quality assessment. Data of pH, EC, turbidity, total alkalinity, total hardness, calcium, magnesium, sulphate, chloride and BOD from 5 sampling sites in the vicinity of limestone mining and cement plants in East Jaintia Hills, Meghalaya were used to compute the CCME WQI. The CCME WQI were found 91.83 (Station 1), 66.04 (Station 2) and 62.60 (Station 3) indicating water quality varying from marginal to good categories in the limestone mining area. However, water samples collected from cement plant areas revealed CCME WQI 33.34 (Station 4) and 30.34 (Station 5) exhibiting poor quality of water which can be attributed to elevated levels of EC, turbidity sulphate, total hardness and calcium. The activities at cement plants were found having more impact on water quality deterioration than the limestone mining.

KEY WORDS
Water Quality
CCME WQI
Limestone Mining
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INTRODUCTION

Change in quality of water can be detected by monitoring its various physical, chemical and biological variables (Sargaonkar and Deshpande, 2003; Duran and Suicmez, 2007). However, the data generated distinctively does not depict the overall water quality status. Therefore, use of water quality index (WQI) is an effective alternative available as it summarizes the overall water quality based on various physico-chemical parameters studied. This method simplifies the results into a single and understandable value representing and describing the quality status of the water bodies (Tiwari and Mishra 1985; Kankal *et al.*, 2012). The use of water quality index was initially proposed by Horton (1965). Since then, multiple methods have been developed and employed in water quality assessment. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for evaluating the quality status of water has been used worldwide (Sharma and Kansal, 2011; Al-Janabi *et al.*, 2012; Manii, 2013; Munna *et al.,* 2013; Rakesh and Ammini, 2013; Damo and Icka, 2013; Gyamfi *et al.*, 2013; Salman *et al.,* 2015).

Meghalaya is one of the seven North-Eastern states of India. The state is blessed with abundant renewable and non renewable resources. Important minerals found are coal, limestone, sillimanite, granite, uranium etc. Limestone is the second most important mineral extracted in the state after coal. It constitutes about 9% of the country total limestone reserves and mostly distributed on the southern fringe of the state (IBM, 2012). Currently, more than eight cement plants are operational in the East Jaintia Hills, Meghalaya. As a result, extensive excavation and extraction of limestone rocks starting from Nongsning village up to Lumshnong village are taking place in order to satisfy the raw material requirements of these cement plants. Impact of mining on the environment has been widely observed. Several studies on physico-chemical analysis of water in Jaintia Hills, Meghalaya have been done (Swer and Singh, 2004a, b; Lamare and Singh, 2014a, b, c; Lamare and Singh, 2015). In this paper, we summarise the effect of limestone mining and cement plants on water quality in East Jaintia Hills, Meghalaya based on physico-chemical analyses and computation of CCME WQI.

MATERIALS AND METHODS

Sampling collection

Sampling was done, during winter, pre monsoon and post monsoon seasons of 2014, from five different sites of limestone mines and cement plant of East Jaintia Hills, Meghalaya. Grab sampling method was adopted for water samples collection. The collected samples were stored in a pre-cleaned jerican (previously washed with 10% nitric acid and cleansed with distilled water) and were then transported to the laboratory for analysis of various physico-chemical parameters (APHA, 2005).A brief description of each sampling location is given below and its corresponding location is displayed in Fig. 1.

Station 1

It is situated in Nongsning Village adjacent to one of the limestone quarrying site. Locally knows as 'Mihchariang'. Siltation of the stream bed is seen during rainy season whereas algal growth on the stream bed was observed during winter seasons. However, this is one of the main source of drinking water supply to the nearby locality and adjacent villages.

Station 2

Locally called as 'Wah- Rkhiang'. It is situated inside the natural vegetation area of Mynkree village and located downstream to one of the active limestone quarrying sites. Thick sand deposition on stream bed is evident along its route.

Station 3

It is situated immediately near the limestone quarrying site of Mynkree village. It is locally known as 'Wah-Pom-Pa'. The stream is characterised with rugged bed, stone and gravel of different sizes deposited all over the stream bed and even over its bank. Water level is usually high during rainy season but reduce drastically during dry seasons.

Station 4

It is known as 'Wah Jynrong' and located in Wahiajer-Narpuh village approximately 1 to 1.5 Km south from one of the Cement plants. Minimal disturbance from human activity was observed. This water body was once the source of water supply to the local community but nowadays it has been affected and contaminated by the cement plants. Visibly water was body was turbid with thick sand deposition on its bed.

Station 5

It is about 0.5 to 1 Km away from another cement plant. It is known as 'Umjri' in Lumshnong Village. It is located deep within the thick vegetation cover of the village. Before the existence of the cement plants, local people derived drinking water from this source. At present, the water is totally contaminated. However, due to unavailability of water during dry season people still use this water for drinking and other domestic uses. The appearance of water body was dull and turbid.

Physico-Chemical Parameters Analysed

The methods of analysis for various water quality parameters were summarised in Table 1 following the procedures described in APHA, 2005; Maiti, 2001 and Trivedi and Goel, 1986.

CCME-WQI Computation (CCME, 2001)

CCME-WQI consists of three main elements: scope (F1), frequency (F2) and amplitude (F3). In this study, BIS (1991) and ICMR (1975) standards were adopted for obtaining the objectives of various physico-chemical parameters involved. To obtain the data of various elements in this method, the results from the analysis of various parameters studied were incorporated in the equation given below:

F1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration ("failed variables"), relative to the total number of variables measured:

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100$$

F2 (Frequency) represents the percentage of individual tests that do not meet objectives ("failed tests"):

$$F2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) \times 100$$

F3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F3 is calculated in three steps.

Step-1

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows. When the test value must not exceed the objective:

$$\text{Excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_i}\right) - 1$$

For the cases in which the test value must not fall below the objective

$$\text{Excursion}_i = \left(\frac{\text{Objective}_i}{\text{Failed test value}_i}\right) - 1$$

Step-2

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (*nse*) is calculated as

$$nse = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Total number of tests}}$$

Step-3

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100.

$$F3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors. The sum of the squares of each factor is therefore equal to the square of the index. This approach treats the index as a three-dimensional space defined by each factor along one axis. With this model, the index changes in direct proportion to changes in all three factors.

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality. From Table

2, the computed CCME WQI values obtained for each sampling stations were than compared and ranked accordingly based on their corresponding individual index value.

RESULTS AND DISCUSSION

Quality of water in limestone mining area

To determine the quality status of surface water in limestone mining area, ten various physico-chemical parameters were analysed seasonally from five different sampling locations. The results obtained were discussed below and are graphically presented in Fig. 2, 3 and **4.**

pH

Throughout the sampling period**,** the level of pH was found alkaline in nature with values ranging from 7.3 to 8.2. This may be due to dissolution of calcium carbonate, the main constituent of limestone rocks, which when comes in contact with water generate alkalinity. pH of water in other limestone mining area has also been reported to be alkaline (Mishra, 2010).

Electrical conductivity (EC)

The EC of water in the limestone mining area (*i.e.* Stations 1, 2 and 3) was found within the standard limit throughout the sampling period except during winter season for Station 2 (471.33 μS/cm) and station 3 (305.33μS/cm). However, water samples collected near the cement plants (i.e. stations 4 and 5) showed an elevated EC level with values exceeding the standard limit at all seasons. The EC values varied from 375.33μS/cm to 626.33μS/cm. This could be due to increasing amount of contamination drained in the water body from the cement plants leading to elevated amount of dissolved ions in

Table 1: Summary of method followed for evaluation of various physico-chemical water parameters

Parameters	Abbreviation	units	Methods	Instrument Used	Standard(BIS/ICMR)
pH	-	-	In-situ measurement	EUTECH PCTestr 35	6.5 -8.5
Electrical Conductivity	EC	μS/cm	In-situ measuremen	EUTECH PCTestr 35	300
Turbidity	-	NTU	In-situ measurement	Turbidimeter TN-100	5
Total Alkalinity	TA	mg/l	Titrimetric	Titration	200
Total Hardness	TH	mg/l	Titrimetric	Titration	300
Calcium	Ca	mg/l	Titrimetric	Titration	75
Magnesium	Mg	mg/l	Titrimetric	Titration	30
Sulphate	SO_4	mg/l	Turbidimetric method using $BaCl_2$	UV- VIS Spectro 118 photometer	200
Chloride	Cl	mg/l	Argentometric method	Titration	250
Biological Oxygen Demand	BOD	mg/l	Direct Method (5 days incubation)	Titration	5

Table 2: CCME WQI based water quality categorization

CCME WQI	Ranking	Water Quality Characteristics
95 -100	Excellent	Water quality is protected with a virtual absence of threat; condition very close to natural and pristine levels
80 - 94	Good	Water quality is protected with only a minor degree of threat or impairment; Conditions rarely depart from desirable levels
65 - 79	Fair	Water quality is usually protected but occasionally threatened or impair; Conditions sometimes depart from desirable levels
45 - 64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
0 - 44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Table 3: Computed CCME WQI of water samples collected from limestone mining area of Meghalaya

CCME WQI Element	Station 1	Station 2	Station 3	Station 4	Station 5
Number of failed variables	1	3	4	5	5
Total number of variables studied	10	10	10	10	10
Total number of test	30	30	30	30	30
Total number of failed test	1	3	4	13	14
Excursion	0.066	13.85	10.21	40.77	47.41
nse	0.0022	0.461	0.34	1.35	1.85
F1	10	30	40	50	50
F2	3.33	10	13.33	43.33	46.66
F3	2.15	13.85	25.40	57.60	61.24
CCME Water Quality Index	91.83	66.04	62.60	33.34	30.34
Category	Good	Fair	Marginal	Poor	Poor

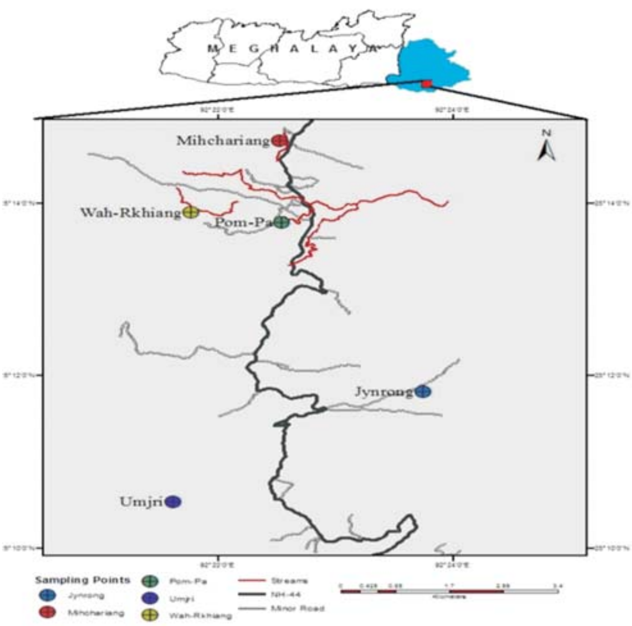

Figure 1: Location map of the study area

it. Seasonally, level of EC was recorded maximum during winter > post monsoon > pre monsoon seasons. This indicates the role played by surface runoff in deteriorating the water quality.

Turbidity

The measured level of turbidity in Stations 1, 2 and 3 (limestone mining sites) was found minimum and maximum during winter and pre monsoon seasons with values varied between 0.78 NTU to 4.50 NTU and 5.33 NTU to 55.77NTU, respectively. Flow of muddy water attributed by monsoon rain and soil disturbances caused by mining activities lead to the increased in the level of turbidity in vicinity of mining area. However, the turbidity values in stations 4 and 5 varied from 1.38NTU to 16.48 NTU, 30.63 NTU to 46.73 NTU and 2.78 NTU to 6.05 NTU during winter, pre monsoon and post monsoon, respectively. Increased in levels of turbidity with values exceeding the recommended limit (BIS: 5NTU) were observed in water samples collected near cement plants except during winter and post monsoon in station 4.

Total alkalinity (TA)

TA of surface water was found within the permissible limit (BIS: 200mg/l) throughout the sampling seasons. However, it was found that water samples from the study area showed methyl orange alkalinity only and zero phenolphthalein alkalinity. This indicates the presence of bicarbonate only and no carbonated and hydroxide ions. Similar finding has also been reported earlier (Ahmed *et al.*, 2007). It was observed that TA concentration in water varied from 76.33mg/L (at station 2, minimum) to 173.33 mg/L (at station 3, maximum).

Total hardness (TH)

Concentration of TH was found <300mg/l (*i.e.* within the standard limit) in stations 1, 2 and 3 in all sampling seasons. The minimum and maximum TH concentration values were 67.33mg/L and 298.67mg/L in station 2, respectively. This indicated that the sample possesses soft to hard water type in nature, based on water hardness classification. However, water samples collected from stations 4 and 5 showed TH concentration varied between 304 mg/L to 477.33mgl/ and 238mg/L to 482mg/L, respectively. This showed the concentrations was exceeding the standard limit and exhibited a very hard water type at all sampling seasons except during pre monsoon season in station 5. Hardness of water may be attributed by the presence of calcium bicarbonate and magnesium. Similar type of results was also reported by Ravikumar and Somashekar (2010).

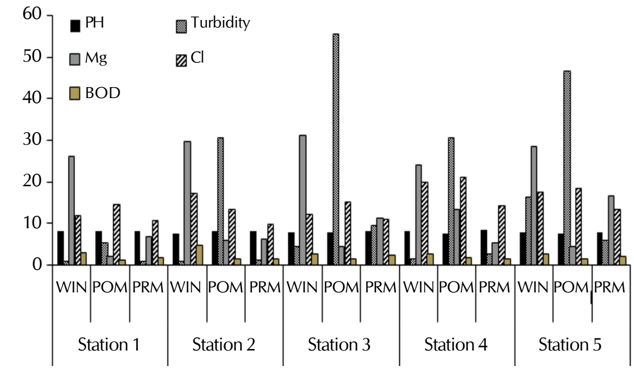

Figure 2: Graphical representation of water parameters all expressed in mg/L except pH and Turbidity (NTU)

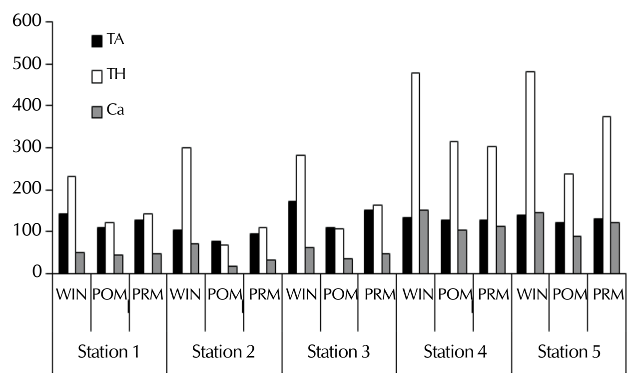

Figure 3: Graphical representation of different water parameters all expressed in mg/L

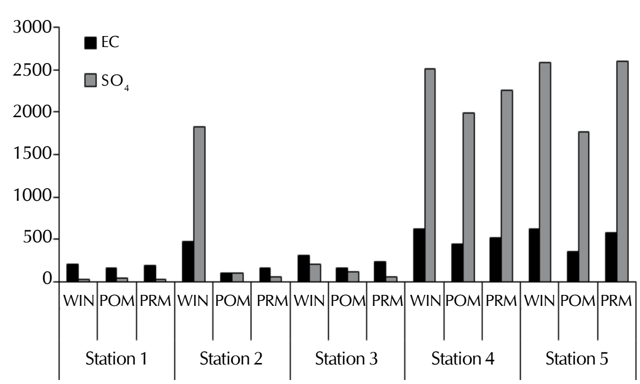

Figure 4: Graphical representation of different water parameters all expressed in mg/L except EC (μS/cm

Calcium

Concentration of calcium was found exceeding the limit and ranged from 104.29mg/L to 151.67mg/L in station 4 and 88.03mg/L to 146.06 in station 5. The significantly high level of calcium may be attributed by waste generated and drained from cement plants into the water body of the area. However, it was found within the permissible limit in stations 1, 2 and 3 in all sampling seasons. In these stations, the calcium concentration varied from 17.38 mg/L to 70.65mg/L.

Magnesium

In all sampling seasons, the concentration of magnesium was found to be insignificant. The maximum concentration of magnesium was found during winter season, having values which varied from 23.98mg/l (station 4) to 31.12mg/L (station 3).

Sulphate (SO_4)

When SO_4 level in water is beyond 200mg/L, it is consider unsuitable for drinking purposes. In this study, its concentration in station 1 varied from 30.48mg/l to 40mg/l, station 2 from 60.48mg/l to 1828.57mg/l, station 3 from 55.71mg/l to 201.43mg/l, station 4 from 1982.86mg/l to 2515.71mg/l and 1771.90mg/l to 2602.38mg/l in station 5. It was observed that a surplus amount of SO_4 content was detected in water samples collected near the cement plants. This could be due to the discharge of waste water or AMD water released from the cement plants due to use of coal, a main source of energy for all cement plants. However, the unexpected rise in SO_4 at station 2 during winter season could be due to mixing of waste water or discharge from the newly operational cement plant in this area.

Chloride (Cl^-)

In this investigation, chloride concentration was found insignificant and within the standard limit in all sampling seasons. Its concentration varied from 9.86mg/l to 21.25mg/l. the minimum level of Cl^- was found in station 2 during post monsoon season while station 4 possesses the maximum during pre monsoon season.This indicate that the area is relatively free of Cl^- contamination.

Biological oxygen demand (BOD)

BOD concentration in stations 1, 2, 3, 4 and 5 varied between 1.14mg/l to 2.95mg/l, 1.41mg/l to 4.90mg/l, 1.84mg/l to 2.68mg/l, 1.44mg/l to 2.62mg/l and 1.40mg/l to 2.82mg/l respectively. The level of BOD in all sampling stations and sites are within the prescribed limit (BIS: 5mg/l).This level of BOD indicates that the water body of the area has relatively low organic pollution.

CCME WQI assessment

To further simplified the above physico-chemical data for better understanding of the general public. The data of various water parameters (pH, EC, turbidity, total alkalinity, total hardness, calcium, magnesium, sulphate, chloride and BOD) analysed were incorporated in the CCME WQI equation by following the methods as described earlier. The overall CCME WQI values obtained for different water samples of the study area are presented in Table 3.

The table showed that total numbers of variables studied were 10. Overall total numbers of test involved were 30. The number of failed variables at stations 1, 2, 3, 4 and 5 not meeting their objectives were 1,3,4,5 and 5, respectively. This indicates that more is the disturbances more will be the effect on quality of water. Sampling stations 4 and 5 displayed variables with maximum failing data. The total number of failed test deviating from their objective values (out of 30 times being tested) at all sampling stations increases drastically from 1, 3 and 4 at limestone mining vicinity to 13 and 14 near cement plant. Increasing number of failed test in water samples collected near cement plant may be due to addition of waste material into the water leading to the change in variations of it physico-chemical characteristics. The sampling station with highest Normalises Sum Excursion (*nse*) values was monitored at Station 4 and Station 5 with corresponding values of 1.35 and 1.85, respectively. This clearly indicates that cement plants contribute more towards water contamination as compared to that from limestone mining. The calculated F1, F2 and F3 values for all sampling stations showed the following sequence: station 5 > station 4 > station 3 > station 2 > station 1.

Based on application of CCME WQI in water quality assessment, it revealed that water samples collected near the cement plants i.e. Station 4 and Station 5 exhibit poor water quality (index value between 0 - 44). Hence, water is always threatened or impaired due to some ongoing activities and in this case it could be the cement plants. This poor quality of water with low WQI may be attributed by elevated level of EC and turbidity along with high concentration of sulphate, total hardness and calcium. The number of failed variables and tests which do not meet their objectives was found maximum at these stations. The CCME WQI ranking of water quality for samples collected from limestone mining vicinity (i.e. stations 1, 2 and 3) were found to vary from good to marginal category. The computed index value recorded were 91.83 (Station 1), 66.04 (Station 2) and 62.60 (Station 3). Turbidity is the only parameter showing maximum failed tested data in the limestone mining area. The percentage of failed test which does not meet the given objectives values in these stations includes EC, turbidity, magnesium and sulphate leading to the occasional and frequent impaired or threatened condition of the water quality. Since these stations are located in the vicinity of limestone mining, the probable caused for deterioration could be the limestone mining activity carried out in the area.

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