⚿ OPEN ACCESS

Assessing Seasonal Water Quality Variations in River Water Using Water Quality Index (WQI): A Case Study

Md. Serajuddin[1*], Md. Aktarul Islam Chowdhury[1], Md. Ehteshamul Haque[2]

[1]Department of Civil & Environmental Engg (CEE), Shahjalal University of Science & Technology (SUST), Sylhet 3114, Bangladesh
[2]Department of Microbiology, University of Chittagong, Chittagong 4331, Bangladesh

Abstract	Original Research Article

Over the last 20-30 years, most of the rivers around Dhaka city including Sitalakhya have become increasingly threatened due to indiscriminate anthropogenic pollution. The erratic and uneven rainfall over time and space, a prolonged dry period due to climate change phenomenon has been worsening the situation. Abrupt changes are observed in the raw water quality of this river on a seasonal basis. Thus the seasonal water quality information is becoming essential as to take important decisions on drinking water pursuit and beyond. Assessment of the quality status & the seasonal trend of the Sitalakhya river water quality in Bangladesh is made in terms of water quality index (WQI), a numerical value to express its quality, based on physical, chemical and biological measurements using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). Water samples were analyzed for quality parameters as recommended in the Bangladesh Standard (ECR 1997) on the 'best practice based classification for drinking water supply after conventional treatment' and the compliance level is compared with the limits as stated in the guideline. Out of the four seasons in a year, in the dry season (winter, December to February) and the hot summer season (pre-monsoon, March to May) of this study period, WQI values varies from 40 to 45(out of 100), reflecting poor water quality as per ratings attributed to WQI. In the monsoon season (June to September) the WQI varies in between 49 to 64(Marginal to fair) and autumn (October to November) it varies in between 47 to 63 (Marginal to fair) indicating comparatively fair water quality. In comparison, in the monsoon season, the water is the best available water in the river. An alarming message is that the water quality has been deteriorating very fast.
Keywords: Guidelines for river water quality, seasonal river water quality variations, Sitalakhya river raw water, Water Quality Index.

INTRODUCTION

Water existed on this planet long before life evolved. All the complex chemical processes involved in the development & maintenance of living organisms are sensitively attuned to the physical properties of water. Consequently water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations. It is central to the production and preservation of the core of benefits and services for people. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society and the environment. Indeed, without proper water governance, there is likely to be increased competition for water among sectors and an escalation of water crises of various kinds, triggering emergencies in a range of water-dependent sectors.

Water supply for domestic purposes, sanitation, agriculture, industry and energy are interlinked and all generate wastewater and cause pollution. Water resources must be managed sustainably if supplies are to be maintained for people and economic uses. In many basins, the wasteful use of water and its pollution are already imposing immense costs and damage that amount to serious environmental degradation and which compromise the benefits of water services, particularly to the poor and vulnerable. Over 1.7 billion people are currently living in river basins where water use exceeds recharge, leading to the desiccation of rivers, depletion of groundwater and the degradation of ecosystems and the services they provide. The fact that, on some estimates, over 80% of wastewater is discharged without treatment makes this

situation worse. Protecting water quality from all sources of wastewater pollution, domestic, industrial or agricultural, is a prerequisite for sustainable development, human well-being and ecosystem health - as was clearly expressed at Rio+20 and now in SDG [1, 2].

Hence the 'quality' of water is the vital element in any water pursuits which has an extremely broad spectrum of meanings. Good water quality resources depends on a large number of Physicochemical parameters and the magnitude and source of any pollution load; and to assess that, monitoring of these parameters is essential [3-5]. It is well established that the rainfall is changing on both the global and the regional scales due to global warming. The implications of these changes are particularly significant for Bangladesh [6].

The conventional approaches for assessing water quality and advocating are mainly based on the comparison of experimentally determined parameters with the local or international standards. However, in many cases, managers and the general public have neither the inclination nor the training to study these reports in detail. Rather, they require statements concerning the general health or status of the system of concern. Thus the need for a more simple 'criteria' for describing the water quality is felt especially by the service providers on the operational aspects of the treatment plant as well as policymakers and the public representatives to convince the general mass of people regarding their role to preserve this valuable resource [7].

Under this backdrop, modern techniques such as water quality index (WQI) have been developed which provides a single value that expresses overall water quality by integrating different water quality variables [8]. Numerous water quality indices have been formulated all over the world. These indices are based on the comparison of the water quality parameters to the standards and give a single value for the water quality of a certain source [9]. The WQI summarizes a large quantity of water quality data in a comprehensive manner into a single number [10, 11], into a simple term e.g. excellent, good, bad, etc [9], to transmit the information concerning water quality to the public in general [9-12], water distributors, planners, managers, and policy makers [13].

A large number of water quality indices viz. Weighted Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) etc. have been formulated by several national and international organizations. These WQI have been applied for evaluation of water quality in a particular area [8].

Four distinct seasons can be recognized in Bangladesh from the climatic point of view: (1) the dry winter season from December to February, (2) the pre-monsoon hot summer season from March to May, (3) the rainy monsoon season from June to September and (4) the post-monsoon autumn season which lasts from October to November. Rainfall variability in space and time is one of the most relevant characteristics of the climate of Bangladesh. Rainfall in Bangladesh varies from 1400 mm in the west to more than 4300 mm in the east of the country. Rainfall in Bangladesh mostly occurs in monsoon, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds [6].

The Sitalakhya river in Bangladesh plays a fundamental role in Dhaka city, as a source of drinking & irrigation water, and also as a sink for wastewater. In fact, it is the prime source of domestic water supply through surface water treatment plant for the millions of citizens of the capital city. Thus the water quality of this river has a tremendous effect on the economy & social wellbeing of the entire nation [14].

The water quality of this river is being deteriorated over the last three decades making any water pursuit very difficult. The climate change scenario has made the situation graver. The erratic and uneven rainfall over time and space, a prolonged dry period has been worsening the situation. Abrupt changes are observed physically in the raw water quality of this river on a seasonal basis. Thus the seasonal water quality information is essential as to take the important decision on the extent of treatment measures at the largest treatment plant in the country which is drawing raw water from this river. Sometimes addition or subtraction or modifications in some of the treatment units and or chemical feeding might be needed depending on the quality status of the water. In such circumstances, the seasonal raw water quality variation data helps the treatment plant manager immensely to decide upon [14].

Although several reports on the assessment of water quality based on physicochemical and bacteriological distributions in the Sitalakhya river have been published by several researchers [15-17] but the parameters selected were not in line with the numbers and specific quality parameters as per ECR, the duration was limited only in a part of the year without the scope to identify seasonal variation. Besides, WQI has not been used for this river to categories water quality status. With this background, an investigation was initiated, whose primary objective was to examine the seasonal water quality variation as well as the trend over a period of sixty months continuously of the raw water of the Sitalakhya. The physicochemical parameters were compared with the national river water quality standards in order to quantify the seasonal variation of the water quality condition of this major

river of Dhaka. An attempt has been made to assess the seasonal variation of this river water quality in terms of WQI using four distinct water quality parameters as is recommended as standard for surface water in the national water quality standards of Bangladesh [18].

Trustworthy information on the characteristics of water quality is direly needed so as to control pollution effectively and manage sustainable water resources. The present baseline information on the seasonal variation of the physicochemical properties of this river water would be a useful tool for the plant operators and also for further ecological assessment and monitoring of the river quality and to demonstrate to all stakeholders regarding our unabated atrocity in polluting this valuable water source and make them aware of the probable disaster in near future.

Objective of the Study

The main objective of this study is to assess the status & the trend of the Sitalakhya river water quality at the intake of the largest drinking water treatment plant in Bangladesh and to show the seasonal variations of the raw water in terms of WQI which is developed on four water quality parameters, namely pH, DO, BOD_5 & total coliform and the compliance level is compared with the limits as stated in the ECR for the best practice surface water to be extracted for its ultimate use as potable water.

MATERIALS AND METHODS
Study Area, Sample Collection & Analysis

The study area is Dhaka the capital city of Bangladesh with a population of more than fifteen million located in the central part of Bangladesh. Dhaka has a distinct monsoonal season, with an annual average temperature of 26°C (79°F) and monthly means varying between 19°C (66°F) in January and 29°C (84°F) in May , sometimes reaching to 40 degrees Celsius. Approximately 87% of the annual average rainfall of 2,123 millimeters (83.6 inches) occurs between May and October. Dhaka is located at 23°42′N 90°22′E, on the banks of the Buriganga river and surrounded by other peripheral rivers. Tropical vegetation and moist soils characterize the land, which is flat and close to sea level [14].

The largest surface water treatment plant of the country is situated beside the river Sitalakhya in the eastern periphery of Dhaka city at Latitude N 23° 43'

11.25" & Longitude E 90° 26' 14.25". This plant & the raw water from the intake of this plant from the Sitalakhya river is respectively the plant & surface water of concern of the present study (Fig-1) [14].

The raw water from the intake of this plant was collected and taken to the laboratory, by following the precautions laid by standard methods [19]. Each of the water samples was analyzed for four parameters. The test results were categorized into four seasons as discussed earlier. The list of parameters tested, methods, equipment, and standards of testing are given in Table-1. The experimental values were compared with the limits as stated in the Bangladeshi guidelines [18] 'best practice base classification' for the surface water to be extracted for its ultimate use as potable water (Table-1). For adapting with ECR the BOD values were transformed to COD with the help of a correlation chart developed earlier [20]. Besides, instead of total coliform the E.coli concentration value obtained was used in index calculation.
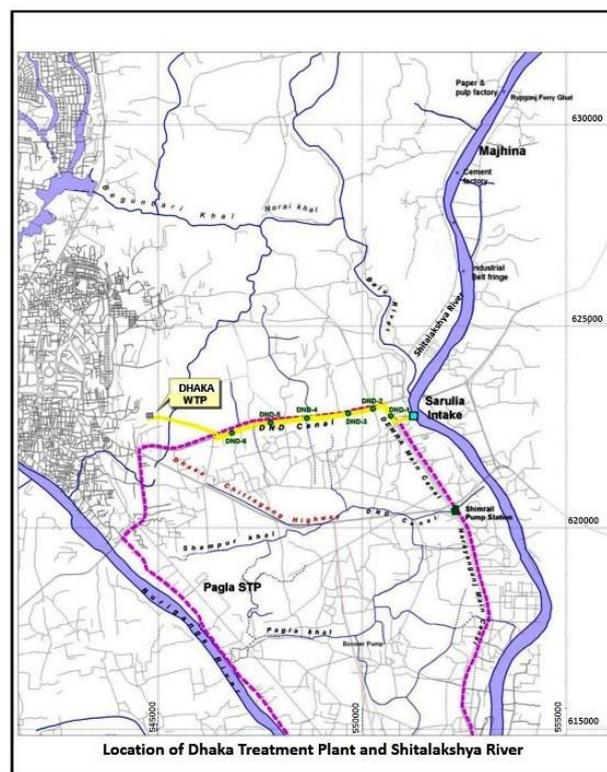

Fig-1: Raw water source from Sitalakhya River to Water treatment plant [20]

Table- 1: List of Water Quality Parameters tested with name of the Equipment, Methods utilized, and targeted raw & treated water quality

Sl. No	Parameters tested	Unit	Frequency of test	Targeted raw water quality	Targeted treated water quality	Equipment utilized	Methods used	Method no
01	COD	mg/L	Daily	14	<4	HACH DR890 Colorimeter,	Reactor Digestion Method	8000
02	DO	mg/L	Daily	≥ 6.0	≥ 6.0	HACH DRB200 COD reactor	Electrometric Method	-
03	pH	-	Daily	6.5-8.5	6.5-8.5	HACH Probe LDO101, Multimeter HQd40	Electrometric Method	-
04	E.coli	CFU/100ml	Daily	5000	0	HACH Probe PHC101, Multimeter HQd40	Membrane Filtration(m-TEC)	8367

The calculation of WQI in this study was done by using Canadian guidelines for WQI CCMEWQI with minor modification. CCME WQI provides a consistent method, which was formulated by Canadian jurisdictions to convey the water quality information for both management and the public [7, 21].

The WQI of the Canadian Council of Ministers of the Environment (CCME WQI) [7] is an index used in many countries in addition to Canada [21]. The CCME WQI model is a simple yet robust way of reporting water quality issues [7], and provides a simplified way of interpreting water quality parameters

so that they are easily understood by policy makers and the general public.

General description of the Index

The index is based on a combination of three factors: the number of variables whose objectives are not met, (Scope) F1, the frequency with which the objectives are not met, (Frequency) F2 and the amount by which the objectives are not met, (Amplitude) F3. These are combined to produce a single value (between 0 and 100) that describes water quality, as shown below.

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1{}^2 + F_2{}^2 + F_3{}^2}}{1.732} \right)$$

Thus, in the CCME WQI a value of 100 is the best possible index score and a value of 0 is the worst possible. Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories: Excellent: (CCME WQI Value 95-100) Good: (CCME WQI Value 80-94), Fair: (CCME WQI Value 65-79) Marginal: (CCME WQI Value 45-64) Poor: (CCME WQI Value 0-44). The assignment of CCME WQI values to these categories is termed "categorization" and represents a critical but somewhat subjective process. The categorization is based on the best available information, expert judgment, and the general public's expectations of water quality.

In our study, the 'categorization' has been a bit modified and reassigned. The minor change that is made in the rating of water quality in this study is based

on the fact that Canada being one of the leading developed countries of the world the water available over there are bound to be very good nearly close to the quality of natural water and the probability of achievement of utmost good quality water is much easier than Bangladesh, a developing country of the east wherein the present context availability of a marginal good quality surface water is difficult. As such instead of five categories of water quality rating as in Canadian CCME WQI total six number of categorization have been assigned against six sets of WQI values.

The original rating of water quality as per CCME WQI values are described in Table 2 whereas the modified WQI used in this study with modified rating of water quality against WQI values are shown in Table 3.

Table-2: Water quality ratings as per CCME WQI

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

Table-3: Water quality ratings used in this study - a bit modified CCME WQI

WQI Value	Rating of Water Quality	Comments
91 – 100	Excellent water quality	Water quality is ensured with a virtual absence of threat or impairment; conditions very close to cent percent of desired levels.
81 – 90	Very Good water quality	Water quality is ensured with only a negligible degree of threat or impairment; conditions rarely depart from desirable levels.
71 - 80	Good water quality	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from desirable levels.
55 – 70	Fair water quality	Water quality is usually ensured but occasionally threatened or impaired; conditions sometimes depart from desirable levels.
45 – 54	Marginal water quality	water quality is frequently threatened or impaired; conditions often depart from desirable levels
0 - 44	Poor water quality	Water quality is almost always threatened or impaired; conditions usually depart from desirable levels.

RESULTS AND DISCUSSIONS

The global numbers of the sample tested in this study period is 5353, comprising 867, 1048, 1146, 1145 and 1147 numbers in 2013 through 2017 respectively. Globally 48.5% of samples were found in compliance with the targeted value and the WQI is 47.It is revealed from Fig.2 that among the four seasons the dry (winter) and the hot summer (pre-monsoon) seasons are the critical seasons in terms of WQI. In the dry & pre-monsoon seasons of this study period of five years, WQI varies between 40 to 45 WQI, & during four years below 44 reflecting poor water quality & one particular year slightly higher than 45 indicating marginal water quality as per the water ratings mentioned in Table-3. In the monsoon season the WQI varies mostly between 49 to 64 except 2013, & during four years below 55 reflecting marginal water quality & one particular year slightly higher than 80 indicating good water quality and in autumn it varies between 47 to 63 where during the four years below 55 reflecting marginal water quality & one particular year slightly higher than 63 indicating fair water quality. In comparison, in the monsoon season, the water is the best available water at the intake of the plant though it could not reach the good quality index.
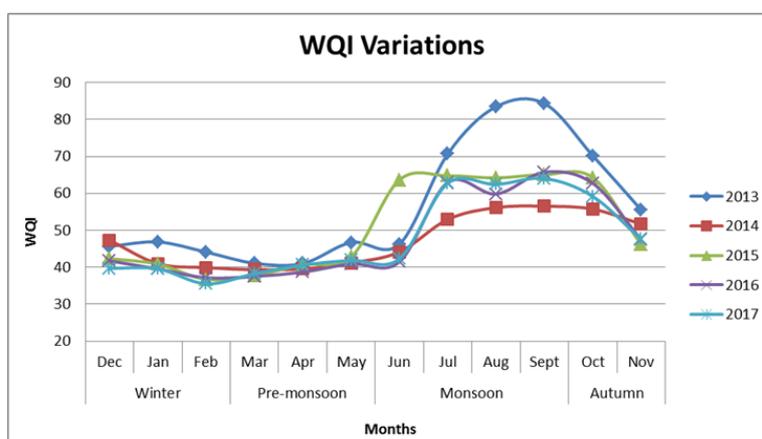

Fig-2: WQI variations with seasons

Observing the monthly WQI values it is seen that in every year February & March is the most critical time of the year in terms of water quality and similar trends are extended both ways, up to December in one direction and up to May in the other direction. That is in each year from December to May is the critical season with respect to water quality. The WQI oscillates during this time from 35.5 to 47.5 indicating poor to marginal water quality.

The maximum monthly WQI = 84.3 is found in September 2013 and minimum monthly WQI =35.5 is found in February 2017. The minimum & maximum average concentration value for the studied water quality parameters are found as follows: COD (max.)= 76.3 mg/L [Feb.2017], COD (min.) =3.2 mg/L [Aug-Sep. 2013], DO (max.)=5.4 mg/L [July 2013], DO (min) =0.2 mg/L [March 2016], Ecoli (max) =3, 02,500 CFU/100ml [Feb.2017], Ecoli (min) =475CFU/100ml [Sep.-Oct. 2014].Not a single DO sample could meet the compliance level throughout this long five years. Out of 1714 COD samples only 35% COD samples globally can meet the compliance level. In winter and pre-monsoon season the compliance level for COD are respectively 10% and 2.65%.Similarly for E-coli only 43% of the global sample complied and they are mostly in monsoon season. Interestingly all the sample tested for pH throughout the study period met the compliance level indicating the strong buffer capacity of the water till date. In another study with the same source of water, it is seen that the level variation of COD is heavily correlated with the variation of ammonia [20]. So the bad WQI indicates the presence of other vulnerable pollutants in the water also, especially in the dry season. It is very difficult to treat such water only with the conventional treatment process. In practice, this has been proved at Dhaka where special additional treatment process and unit has been installed to treat the water in order to cater the drinking water need of the citizens of the capital city [20].

In analyzing the reasons of very poor WQI values in dry and pre-monsoon season it is observed that the most important chemical water quality parameter COD in the dry seasons during the study period have an average values of 34, 27, 23, 23, 45(all in mg/L) respectively in 2013 through 2017. Similarly the physical water quality parameter DO has an average value of 1.2, 1.06, 0.81, 0.48, 0.69 (all in mg/L) respectively during the same period. In pre-monsoon season during the same period the average concentration of COD & DO was found respectively 46, 52,42,50,41, and 0.9, 0.9, 1.0, 0.60, 1.1(all in mg/L). When we compare these values with the WQI table the reasons for such week WQI is evident. When out of four testing parameters three parameters fail to comply the F_1 value in the WQI equation become 75 wherein cent percent ideal case of unpolluted water it could be zero. This F_1= 75 exerts a tremendous negative effect in obtaining a good WQI value. Similarly when the number of failed test with respect total test done are high for example in case of COD it was >97% and for DO this was 100% in the pre-monsoon season. These deviations made the F_2 value very high contributing sharply to reduce the WQI values.
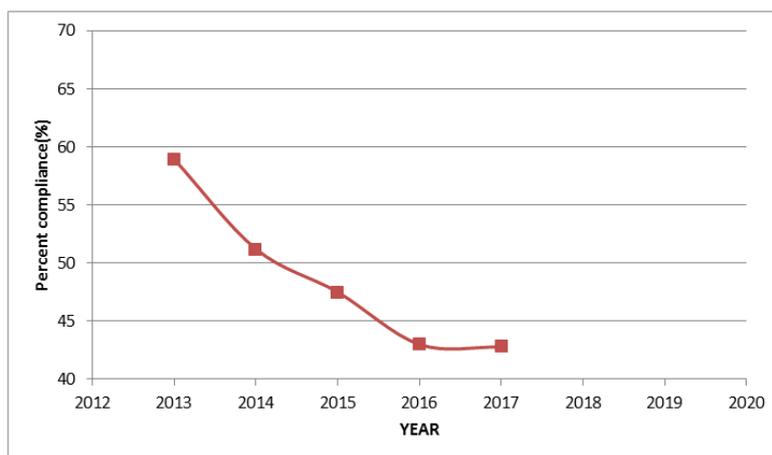

Fig-3: Compliance status in reaching water quality target over the years

When we consider the year wise performance it is seen that in 2013 through 2017 the percentage of compliance are respectively 59,51,47.5,43,and 42.76 indicating a gradual declination and also indicating more deterioration of pollution level in the raw water. This matter is authenticated in the recent raw water studies of the same river [14]. The results warrants that this is high time to take necessary measures to protect the raw water from the man-made pollution activities by the influential stake holders otherwise we have to face an unpleasant situation in near future.

CONCLUSION

This study emphasized that the single value of WQI has higher sensitivity to classify the surface water quality than a long list of values of a large variety of

parameters. This tool can be utilized by the policymakers and utility personnel to classify promptly as first judgment regarding the acceptability of the raw water for harnessing drinking water from it. The results of this research could be applicable to similar situations in Bangladesh even worldwide. This study concluded that 51.5 % of all the water samples tested were found to be beyond the targeted limits of acceptance to be the most desirable raw water for drinking water treatment. Out of four parameters, three were beyond the limit. The pre monsoon season provides the worst raw water in terms of pollution, containing the highest concentration values of COD. The quality of water available in the monsoon season also fluctuates with the amount of rainfall which is erratic in recent years. All the stakeholders should be aware that if the man-made pollution is continued in a similar way like today, in the near future uncertainty would prevail regarding the successful treatment of drinking water from this raw water.

ACKNOWLEDGEMENTS

REFERENCES

1. Serajuddin M. Water Treatment at Saidabad Plant: State – of - the Art. Engineering News, Institution of Engineers, Bangladesh (IEB). 2002; 28(4): 4-9.
2. UN Water. A Post-2015 Global Goal for Water: Synthesis of key findings and recommendations from UN-Water. UN, USA, 2014
3. Reddi KR, Jayaraju N, Suryakumar I, Sreenivas K. Tidal fluctuations in relation to certain physic-chemical parameters in Swarnamukhi river estuary, east coast of India. Indian Journal Marine Science. 1993;22:222-234.
4. Waeles M, Riso RD, Le Corre P. Seasonal variations of dissolved and particulate copper species in estuarine waters. Estuarine, Coastal and Shelf Science. 2005 Jan 1;62(1-2):313-323.
5. USEPA (United States Environmental Protection Agency). Sampling handling and preservation. In: Metals for Chemical Analysis of Water and Wastes, EPA 600/4-79-020. Cinnati, Ohio, USA, 1983, 58-61.
6. Shamsuddin S. Recent trends in the climate of Bangladesh. Climate research, 2010; 42: 185-193.
7. CCME. Canadian environmental quality guidelines for the protection of aquatic life, CCME water quality index: technical report, 1.0. Canada, 2001.
8. Tyagi S, Sharma B, Singh P, Dobhal R. Water quality assessment in terms of water quality index.

American Journal of Water Resources. 2013 Aug;1(3):34-38.
9. Katyal D. Water quality indices used for surface water vulnerability assessment. International journal of environmental sciences. 2011 Sep 11;2(1): 154-173.
10. Sharma D, Kansal A. Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). Applied water science. 2011 Dec 1;1(3-4):147-57.
11. Reza R, Singh G. Assessment of ground water quality status by using water quality index method in Orissa, India. World Applied Sciences Journal. 2010;9(12):1392-1397.
12. Al-Heety EA, Turki AM, Al-Othman EM. Assessment of the water quality index of Euphrates River between Heet and Ramadi cities, Iraq. Inter. J. of Basic & Applied Sciences. 2011;11(6): 38-47.
13. Lumb A, Halliwell D, Sharma T. Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River basin, Canada. Environmental Monitoring and Assessment. 2006 Feb 1;113(1-3):411-29.
14. Serajuddin M, Islam A. Surface water quality susceptibility in drinking water treatment at Dhaka, Bangladesh. Journal of Biodiversity and Environmental Sciences (JBES). 2017; 11(1): 123-133.
15. Alam MN, Elahi F, Didar-UL-Alam MD. Risk and water quality assessment over view of River Sitalakhya in Bangladesh. Academic Open Internet Journal. 2006;19: 1-9.
16. Jahidul MI. Water pollution of Shitalakshya River and its impacts on Human health of Bandar, Narayanganj. A technical report. J.U. Dhaka, Bangladesh, 2013.
17. Sikder M, Yasuda M, Syawal SM, Saito T, Tanaka S, Kurasaki M. Comparative assessment of water quality in the major rivers of Dhaka and West Java. International Journal of Environmental Protection. 2012 Apr 18;2(4):8-13.
18. ECR. Environmental Conservation Rules, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, 1997.
19. APHA. Standard methods for the examination of water and waste water, 21st edn. American Public Health Association, Washington, DC, USA, 2005.
20. Serajuddin M, Chowdhury MAI, Ferdous T. Correlation among some global parameters describing organic pollutants in river water: a case study. International Journal of Research – Granthaalayah. 2018; 6(7): 278-289.
21. Lumb A, Halliwell D, Sharma T. Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River basin, Canada. Environmental Monitoring and Assessment. 2006 Feb 1;113(1-3):411-29.