

Assessment of water quality of a tributary canal of Chittagong city using water quality index

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ABSTRACT

Water quality of a tributary canal falling into Karnafully River estuary of Chittagong, the port city of Bangladesh, has been assessed in the study. Water Quality Index (NSF-WQI) method of the National Sanitation Foundation of the United States of America was used for the assessment of the overall water quality of the canal flowing through the port city. A modified equation of water quality index (Mod-WQI) using Expert Choice (EC) software based on the Analytic Hierarchy Process (AHP) has also been proposed to effectively address the effects of different localized phenomena on the water quality of the canal. Besides experimental investigation, a physical and socio-economic survey has been performed to identify the usage and possible sources of pollution of the canal water. The survey identifies that the canal water has been conventionally used for irrigation, fishing, recreation etc. by the local community of the study area. However, the canal receives various untreated industrial toxic wastes as well as municipal wastes. The results of the study indicate that the quality of the canal water is bad according to NSF-WQI while that is of medium quality based on Mod-WQI. Therefore, it is recommended that the water of the canal, with its current quality, should not be used for irrigation, fishing, or other intended purposes. Industrial effluent must be treated before its disposal into the canal to sustain an ecological balance in the canal as well as in the river.

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I. Introduction

Surface water channels are being used as convenient sewer systems for industry and municipalities of several cities of Bangladesh. The rapid urban development has consequential economic growth through intensified industrial activities in developing countries like Bangladesh. Like other developing countries, the quality of surface water in Bangladesh is also at high risk (DoE, 2001; Hossain, 2001; Islam et al., 2011) of contamination due to unplanned urban development. The associated health and environmental problems have become acute especially in the urban areas. Chittagong, the busiest

coastal seaport in southern Bangladesh, is located on the bank of the tidal river Karnaphuli which plays a major role in the industrial and business activities of the city. The river channel and its tributary canals have been serving various water-related activities like water supply, navigation, power supply, tourism etc. However, various industries situated throughout the city corporation area discharge partially treated effluents into the canals and few industries discharge untreated effluent directly into the canal or into the Karnafully river. The effluents typically contain highly toxic and persistent inorganic substances that are ultimately being released into the canals flowing towards the Karnafully river.

The natural waste assimilation capacity of a non-tidal river has significant influences on mitigation of its pollution level. However, a significant number of studies have found that the extensive increase of pollution of the tidal river Karnafully is far exceeding its waste assimilation capacity which has already made the river water unsuitable for fisheries, irrigation, drinking purpose etc. (Ahmed et al., 2010; Hossain et al., 2006; Haider et al., 2014; Sarwar et al., 2010). Although the study on the assessment of the water quality of the Karnafully River has recently gained special attraction, the study on water quality of its tributary canals is given relatively little importance. There have been only a few studies on the assessment of water quality index (WQI) of the river and that of the tributary canals to the Karnafully river are still at rudimentary level. Water Quality Index (WQI) is a numeric expression that indicates the overall water quality at a certain location and time (Kumar and Dua, 2009; Lumb et al., 2011; Srebotnjak et al., 2012). It is an effective tool of communication to the water policymakers as well as for the stakeholders. Although a plethora of indices is being used worldwide to assess water quality, the US National Sanitation Foundation's WQI (NSF-WQI) has been most commonly used in Bangladesh and also in many countries of the world (Table 01).

Table 01. Summary of studies have been conducted in Bangladesh to assess the water quality of major rivers using methods of assessment through water quality index (WQI).

Study Area	WQI Equation Used	Findings	Reference
Turag River	WAI	<ul style="list-style-type: none"> Excessively polluted due to industrial/ domestic discharges 	Tahmina et al., 2018
Maddhapara Granite Mining Area, Dinajpur	WAI	<ul style="list-style-type: none"> Good quality for drinking and agricultural purposes 	Hawladar et al., 2017
Ground Water, Gopalganj,	WAI	<ul style="list-style-type: none"> Suitability for drinking purpose is questionable 	Rahman et al., 2017
Urban Drinking Water, Dhaka	CCME WQI	<ul style="list-style-type: none"> Good quality for drinking purpose 	Serajuddin et al., 2017
Household drinking water, Random Upazillas	WAI	<ul style="list-style-type: none"> Varied quality for drinking 	Akter et al., 2016
Groundwater, Faridpur	GWQI, HPI, HEI	<ul style="list-style-type: none"> Varied in quality for drinking pupose 	Bodrud-Doza et al., 2016
Old Brahmaputra	WQI (DOE, Malaysia)	<ul style="list-style-type: none"> Bad for public water supply, recreational, aquaculture, irrigation purposes 	Muyen et al., 2016
Goalichara Canal, Surma River	NSF-WQI, CCME WQI	<ul style="list-style-type: none"> Bad for drinking, agriculture, and aquatic life 	Ray et al., 2015
Rivers around Dhaka	IMWQI	<ul style="list-style-type: none"> Surface water quality varied with seasonal variation 	Sikder et al., 2015
Surma River	CCME-WQI	<ul style="list-style-type: none"> Bad for drinking and aquatic life 	Munna et al., 2013
Ganges and Brahmaputra River	Modified WQI	<ul style="list-style-type: none"> Bad quality for drinking good for fisheries, industrial and navigation purposes 	Tareq et al., 2013
Titas River	NSF-WQI	<ul style="list-style-type: none"> Bad quality for drinking Good for livestock, irrigation and 	Islam et al., 2011

WQI: Water Quality Index; WAI: Weighted Arithmetic Index; CCME WQI: Canadian Council of ministers of the environment WQI; GWQI: Ground Water Quality Index, HPI: Heavy Pollution Index; HEI: Heavy Metal Evaluation Index; DOE: Department of Environment; IMWQI: Integrated multi-parameter WQI; NSF-WQI: National Sanitation Foundation WQI

In this study, the water quality of Bamunshahi canal which is one of the tributary canals of the Karnafully River has been assessed to check its suitability for use in common purposes. The NSF-WQI method of US National Sanitation Foundation has been used for this purpose. In addition to the experimental study, a physical and socio-economic survey on the community settled along the canals has been performed to identify the status of current water usage, sources of pollution of the canal etc. Expert Choice (EC) software which is based on Analytic Hierarchy Process (AHP) has been used in the study to take into account the variation in basin properties, water application, pollution types etc. Consequently, a modified equation of water quality index (WQI) has been proposed to assess the water quality which was developed for better incorporating the localized phenomena in the assessment of water quality of the canal. Few suggestions are also made based on the outcome of the study which might help minimize the potential pollution of the canal and that of the river originating from disposal of untreated effluent into the natural waterways.

II. Materials and Methods

Study area and sample collection

The study was conducted to assess the water quality of the Bamunshahi canal which is originated from Oxygen circle area, a heavy industry area of the city, and ended into the Karnafully River. The canal is divided into two parts. The first part is the Shital Jharna canal, flowing from Oxygen to Dhalipara for about 5 kilometres in length, and the remaining length of the canal has been known as the Bamunshahi canal from Dhalipara to its endpoint at the confluence of Karnafully. For the convenience of discussion in the paper, the two canals together are named here as Bamunshahi canal. The details of the 11 kilometre long study area and the sampling locations are shown in [Figure 01](#). A total of 21 water samples were collected from alongside the Baminshahi canal during January 2015 to April 2016. The sampling locations were chosen at approximately equal distances (500 m) from each other to analyse variability of physical, chemical and biological parameters of water quality of the canal. Necessary precautions were taken during sample collection, and the samples were analysed in the environmental engineering laboratory of Chittagong University of Engineering and Technology following standard procedures of water quality analysis.

[Table 02](#) presents sample identifications and the sampling locations of the study.

Table 02: Sampling locations and their identifications in the study

Sampling location	Sample ID	Distance from base point (Km)	Sampling location	Sample ID	Distance from base point (Km)
Oxygen moore*	O1	0	4 no Chandgaon ward	C1	6
Shahid nagar	O2	0.5	4 no Chandgaon ward	C2	6.5
Jomader pol	O3	1.5	4 no Chandgaon ward	C3	7
Hazipara	O4	2	5 no Mohra ward	C4	7.5
Chadgaon	O5	2.5	5 no Mohra ward	C5	8
Chadmia road	O6	3	5 no Mohra ward	C6	8.5
Hazirpul	H1	3.5	5 no Mohra ward	C7	9
Dhalipara	H2	4	5 no Mohra ward	C8	9.5
Dhalipara	H3	4.5	5 no Mohra ward	C9	10
Tekbazar	H4	5	Karnaphuly river	C10	10.5
Raillarpul	H5	5.5			

*considered as base point for convenience

Physical and socio-economic survey

Once upon a time, the Bhamunshahi canal was the main source of freshwater to serve the water related services of the community living alongside the canals. Unfortunately, the water of the canal has, now-a-days, become blackish and aesthetically unacceptable as it continually receives various industrial,

municipal and agricultural discharges. Therefore, people living beside the canal are at risk of catching various water-borne diseases. Therefore, a non-structured questionnaire survey was conducted among the local community to identify potential sources of pollution, people's perception about the pollution and possible remedial measures.

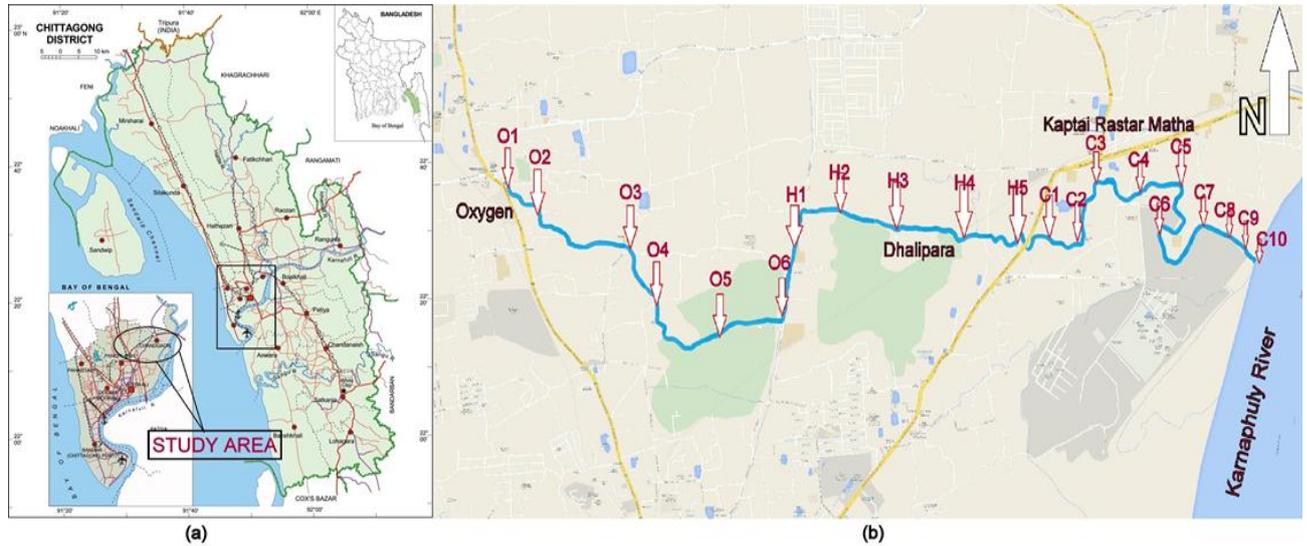


Figure 01. Study area (a) Location of study area in Chittagong city; (b) Sampling locations

Calculation of water quality index

The water quality index (WQI) of the canal water was calculated based on the NSF-WQI method. There are nine water quality parameters in the basic NSF-WQI equation which are dissolved oxygen (DO), faecal coliform (FC), pH, 5-day biochemical oxygen demand (BOD₅), temperature change (ΔT), total phosphate (PO₄), nitrate (NO₃), turbidity (T) and total solids (TS), and the basic equation is as follows:

$$WQI = 0.17 I_{DO} + 0.16 I_{FC} + 0.11 (I_{pH} + I_{BOD}) + 0.10 (I_{\Delta T} + I_{PO_4} + I_{NO_3}) + 0.08 I_T + 0.07 I_{TS} \dots \dots \dots (\text{Eq. 1})$$

where I is the water quality sub-index value of the respective parameters which is derived from water quality index curve prescribed by Environmental Engineering and Earth Sciences, Centre of Environmental Quality, Wilkes University (EEES). However, the weighted factors used in the above equation were derived from the assessment of a total of 35 parameters after interviewing 142 scientists having expertise in this area of study (Brown et al., 1970). In this study, the analytic hierarchy process (AHP), a theory of measurement through pairwise comparisons and with reliance on the judgments of experts to derive priority scales, has additionally been applied to propose modified new weighted factors to address the localized phenomena. The basis of the pairwise comparisons is a scale of numbers is indicative of the importance or dominance of one element over another element. The adopted scale is prescribed by (Saaty, 2008). The final weights of the above mentioned parameters have been found using Expert Choice (EC) software which is designed to analyze the multi criterion decision making problems by AHP technique (Saaty, 2008).

III. Results and Discussion

Physical and socio-economic survey

During its physical survey, it was identified that most of the industries operating in the study area such as garments or tannery industries have no effluent treatment plant (ETP), and they discharge their untreated and potentially toxic wastewater into the canal. As a consequence, the water of the canal has turned blackish with time, eutrophication occurred which cause severe effects for the local community such as rusting of tin and iron products, odor pollution, respiratory diseases etc. The industries along the canal also conventionally used its water for their cooling process before which has recently been replaced by the city's water supply system. This could be a critical issue for the local community since this has created water stress in the community of the area and the Chittagong city.

However, the canal is very important to the local community to serve their water-related purposes. During public consultation, the local people informed that once upon a time Bhamunshahi canal was the main source to meet their fresh water needs. It is a matter of great concern that nowadays the color of the water is blackish and the people have stopped using the water because of the aesthetic point of view. People living beside the canal are facing various water related diseases that may be ascribed to the polluted water of the canal. According to the findings of the questionnaire survey, the canal was a good habitat for fishes, people could earn money selling fishes and also could fulfill their protein demand.

The local people informed that there are little or no fishes found in the canal now-a-days which might be due to unhealthy aquatic environment of the canal. Lands beside the canal are being used for agriculture to produce different kinds of crops, vegetables etc., and the people are using the canal water for irrigation purposes without considering its suitability for use for that purpose. Usage of contaminated water in irrigation might have long term effects on food chain which, in turn, will adversely affect the human health. The canal water is also being used for seasoning of wood of the Saw-mills located beside the canal. The canal was also a convenient means of transportation using the boat as it was wider and deeper before. The canal is found to be fluvial which is carrying water as well as sediment load. As a result, the canal has become narrower and shallower in recent days. Moreover, it was identified during the physical survey that there are illegal human settlements, silt deposition, garbage disposal especially unbiodegradable polythene dumping alongside the canal etc.. In the backdrop of all these problems, people are avoiding the canal route for transportation and are using instead more expensive road transportation.

Experimental Investigation

Physical, chemical and biological parameters of the water samples collected from the study area were analysed to assess their quality for intended uses of the local community. The results obtained from experimental investigation were also compared with the guideline values of Bangladesh Standards (BECR'1997) of water quality parameters. The experimental observation along with the results of different water quality parameters of the canal water are discussed in details in (Zuthi et al., 2016). However, basic statistics of water quality parameters of the water samples collected from the canal have been presented in Table 03. The concentration of different parameters present in the water sample indicates that the water is not suitable for irrigation, fishing and recreation according to BECR, (1997). The value of dissolved oxygen (DO) of the water is generally found to be considerably higher than that of Bangladesh standard for fishing. Nevertheless, the very high BOD₅, COD contents of the water are indicative of the possible presence of toxic organic wastes which may ultimately hamper the DO content and make the water unsuitable for different specific purposes.

Table 03: Basic statistics of water quality parameters of the water samples of the studied canal

Water Quality Parameter	Unit	Minimum	Maximum	Average	Median	Std. Dev.
pH	---	6	8	7	7	0.45
Temperature	°C	26	29	27	28	0.88
Color	PCU	15	100	62	60	27.87
Turbidity	NTU	5	106	54	47	31.45
DO	mg/L	6	10	8	8	1.21
BOD ₅	mg/L	10	50	29	30	10.27
EC	µS/cm	148	1685	1321	1353	312.27
Alkalinity	mg/L (as CaCO ₃)	20	55	39	42	11.54
Total Hardness	mg/L (as CaCO ₃)	33	60	45	42	9.42
COD	mg/L	90	400	167	150	73.44
TDS	mg/L	140	1360	648	640	329.82
TS	mg/L	660	1980	1142	1040	347.21
Nitrate	mg/L	0	177	129	133	31.03
Phosphate	mg/L	4	5	5	5	0.22

Assessment of water quality using WQI

NSF-WQI method: Based on the experimental results of analysis of water quality parameters, sub-index values of the parameters used in NSF-WQI equation were obtained from the index curve (EEES) which is shown in Table 04. According to NSF-WQI method, the water quality index relates the water quality of a water source to a scale ranging from 0 (worst) to 100 (best). Based on the obtained WQI from the scale, the water is classified as very bad to excellent. In this study, the NSF-WQI is observed from 37.68 to 50.32. The water taken from all the stations except station C10 (location is shown in Figure 01) is of bad quality. Although the water of station C10 (WQI 50.32) are of medium quality (Table 05), it is within the lower range of scale. The location of C10 is at the confluence of Karnafully River which might have resulted in a relatively better of water in this section due to the dilution of wastewater along the course of the canal. As the water quality of the canal generally falls under bad quality, it is not suitable for its intended uses without proper treatment.

Table 04. Water quality sub-index value for different parameters

Sampling Stations	Sub-index value for different parameters							
	DO	Temperature	pH	Turbidity	BOD ₅	TS	NO ₃ ⁻	PO ₄ ⁻
O1	93	93	92	77	2	20	1	13
O2	85	83	93	50	2	20	1	13
O3	99	93	93	66	12	20	1	13
O4	93	85	93	87	2	20	1	13
O5	99	89	93	5	2	20	1	13
O6	99	85	92	27	5	20	1	13
H1	97	89	92	32	12	20	1	13
H2	96	85	75	36	7	20	1	13
H3	95	81	79	41	5	20	1	13
H4	85	81	68	24	2	20	1	13
H5	99	81	72	27	12	20	1	13
C1	83	89	79	56	2	20	1	13
C2	83	89	68	52	5	20	1	13
C3	99	89	72	51	12	20	1	13
C4	83	89	72	52	8	20	1	13
C5	95	89	79	52	5	20	1	13
C6	95	89	75	43	2	20	1	13
C7	99	87	75	27	2	20	1	13
C8	95	85	72	22	5	20	1	13
C9	99	85	83	5	34	20	1	13
C10	83	85	87	20	34	20	97	17

Mod-WQI using analytical software: It is mentioned in the earlier section that the analytic hierarchy process (AHP) has been applied to propose modified new weighted factors to take into account the effects of local phenomena on to the water quality of the canal. The AHP is based on the judgments of experts to derive priority scales and the weighted factors are derived from measurements through pairwise comparison. In the NSF-WQI equation, FC is one of nine water quality parameters. However, the water samples studied in the study contain no FC content and therefore, modified new weighting factors need to be incorporated into the scale to account for this phenomenon. In the modified new equation, eight water parameters have been taken into consideration, and new weights of the parameters have been found using AHP process and EC software (Equation 2).

$$\text{Mod-WQI} = 0.223 \text{IDO} + 0.284 \text{IpH} + 0.205 \text{IBOD} + 0.054(\text{I}\Delta\text{T} + \text{IPO4} + \text{INO3}) + 0.090 \text{IT} + 0.034 \text{ITS} \dots \text{Eq.2}$$

A comparison between NSF-WQI and Mod-WQI have been presented in Table 05. It is observed that there are some deviations between NSF-WQI and modified WQI. Biological oxygen demand (BOD), dissolved oxygen (DO), pH and turbidity have gained increased weights in the new equation while temperature, total phosphate, nitrate and total solids have reduced weights. The changes in the priorities of the many factors seem rational due to the importance of their role in water quality (Karbassi et al., 2011). A higher weight in any parameter critically influences the overall water quality.

It is found from the physical survey that the Bamunshahi canal receives municipal sewage as well as effluents from food industries, garments and tanneries. A high level of metabolic waste concentration in the tanks of food industries may produce pollution in a closed aquatic environment and thus affecting the receiving bodies (Karbassi et al., 2011; Taseli, 2009) which justifies an increased weight for BOD. The NSF-WQI results give a general view of water quality but the modified WQI is useful to study on the specific usage of water or any other qualitative problem. Mod-WQI is in the range of 46.65 to 63.41 which indicates the water quality is in medium quality except the locations H4 and C2 (locations shown in Figure 01). The water quality of these stations is of bad quality.

Table 05. NSF-WQI and Mod-WQI for different sampling point with their relative weights

Sample point	Distance from base point (Km)	NSF-WQI	Mod-WQI	WQI Weights		
				Parameter	NSF	Modified
O1	0	44.41	60.67			
O2	0.5	40.00	56.20			
O3	1.5	45.76	63.35	DO	0.17	0.223
O4	2	44.52	61.42			
O5	2.5	39.38	55.59			
O6	3	40.96	57.69	FC	0.16	----
H1	3.5	42.19	59.34			
H2	4	39.52	53.41	pH	0.11	0.284
H3	4.5	39.57	54.15			
H4	5	34.97	46.65	BOD	0.11	0.205
H5	5.5	39.13	53.23			
C1	6	39.20	52.64	ΔT	0.10	0.054
C2	6.5	38.00	49.77			
C3	7	41.85	55.82	PO ₄	0.10	0.054
C4	7.5	38.77	51.52			
C5	8	41.25	55.57	NO ₃	0.10	0.054
C6	8.5	39.76	53.01			
C7	9	38.96	52.35	T	0.08	0.090
C8	9.5	37.68	50.66	TS	0.07	0.034
C9	10	41.40	59.10			
C10	10.5	50.32	63.41			

Figure 02 shows a comparison of water quality using the two equations (Eq. 1 and Eq. 2). According to the guidelines of the Department of Environment of Malaysia (DoE, 1986 and 1990), the quality of water is very polluted as per NSF-WQI (WQI: 0-59). The water quality of the canal as assessed through mod-WQI indicate that most of the water collected from the study area is very polluted except at three locations. The water of the three locations (O1, O4, C10 stations as shown in Figure 01) is slightly polluted. The water can be generally categorized as of quality Class IV (DoE, 1986 and 1990) which implies that it is not suitable for drinking, fisheries but can be used for irrigation. Water from a few locations is in Class III for which it is not suitable for drinking purposes without treatment and also is not suitable for livestock, irrigation, recreation etc. The variation in the two methods might be due to exclusion of FC content in the Mod-WQI. Although most of the water samples are in medium quality, special attention must be paid to eliminate further deterioration of the water quality through sewage disposal in the canal. A few hanging toilets were observed alongside the canal which poses significant risks in this regard. If the canal becomes encroached for development of new human habitat and gets silted in near future, the water of the canal may be at risk of serious pollution with a significant amount of FC. The situation may worsen shortly which would critically affect the conventional water usage from the canal, and as a result, the water of the Karnafully River may ultimately become suitable for various water usages.

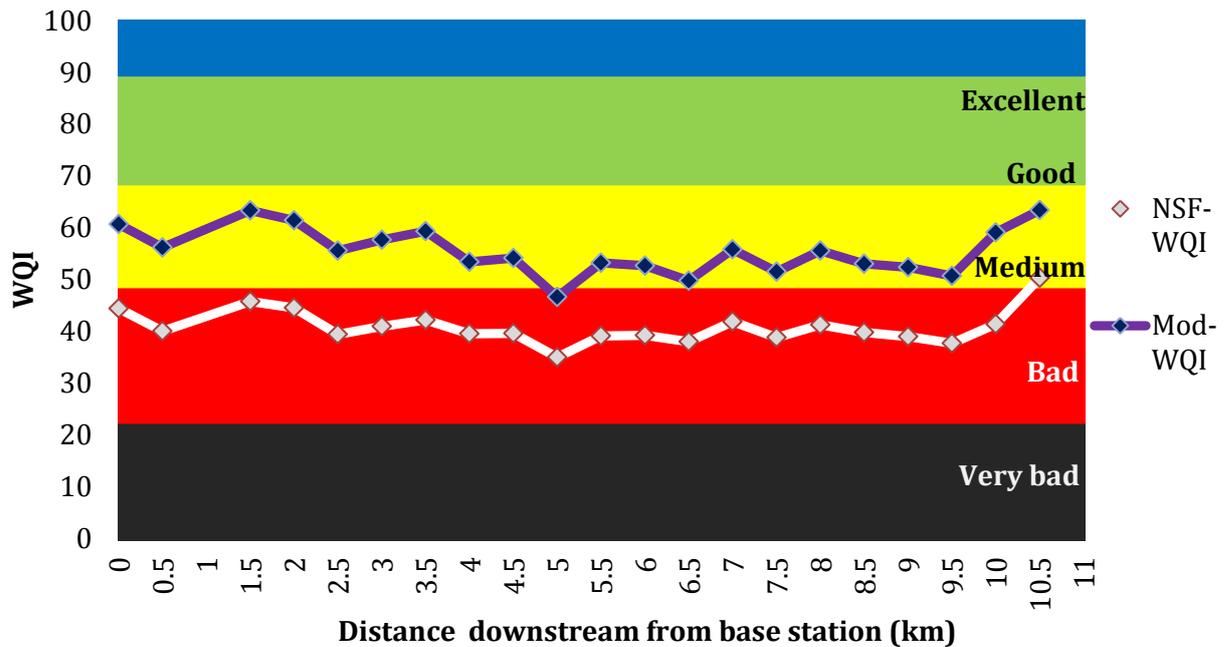


Figure 02. Variation of water quality index and its quality along studied canal length

IV. Conclusion

The analysis indicates that water quality of the Bamunshahi canal is in bad quality based on NSF-WQI and is in medium quality based on mod-WQI. The quality of the canal water generally falls in quality Class-IV assessment done with mod-WQI. The water of the canal should be considered not suitable for drinking, fishing and recreation but still can be used for irrigation. There are high risks that the level of water pollution of the Bamunshahi canal will increase unless proper actions are taken to stop current trends of untreated waste disposal into the canal. The major causes of water pollution of the canal have been identified to be disposal of untreated or partially treated effluent from industry, garments, tannery etc. These can be mitigated through legal enforcements for installing and launching effluent treatment plant (ETP) in each industry or to install a CETP (central ETP) for the industries operating within the study area. Awareness raising and strict monitoring programs should be run by the local authorities to ensure a healthy aquatic environment of the Bamunshahi canal and also that of the Karnafully river.

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Conflict of Interest

The authors declare that they have no conflict of interest

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