

Modelling of Surface Water Quality Parameters from Damodar River at Slag Disposal Site: A Case Study

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ABSTRACT

The work aims at assessing the Water Quality Index (WQI) of surface water of river Damodar, Dharampur, West Bengal, India, by monitoring six sampling locations within the positioning at Damodar river namely (viz., Control Pond (CP), River Upstream (RU), Effluent Discharge Site (EDS), River Downstream (RD), Sewage Fed Pond 1 (SP1) and Sewage Fed Pond 2 (SP2)) for a period of 1 year. For calculating the WQI, 14 parameters, namely, pH, dissolved oxygen, total dissolved solids, total suspended solids, biological oxygen demand, chemical oxygen demand, hardness, alkalinity, chloride, nitrite, nitrate, iron, copper, and coliform were considered. The WQI value ranges from 30.11 to 177.11 (summer season), 24.30 to 392.61 (rainy season) and 25.38 to 261.74 (during winter season) falls under the excellent, good, poor, very poor to unsuitable to be used category. The present study revealed that the water of river Damodar at Dharampur, West Bengal, India is polluted (due to surface run-off, bathing activities, agriculture run-off, effluents from upstream from surrounding industrial and garden area, the immersion of idols of God and Goddess during festival season), and is unsuitable for human consumption, and also for the survival of life forms unless treated properly.

Key words: Physicochemical Parameters, Water Quality Index, Damodar river, Dharampur, West Bengal

Mathematics Subject Classification: 62H25

Journal of Economic Literature (JEL) Classification : I18, Q25, Q53, Q57

1. INTRODUCTION

Water is necessary for all living plants and animals to maintain their life. Surface water quality is influenced by complex anthropogenic activities and natural processes (Jarvie et al. 1998; Ravichandran

2003; Khatri and Tyagi 2015; Malvi et al. 2005; Barkwith et al. 2015). The overuse of surface and groundwater is jeopardizing numerous resources due to the reduction of the available quantities and also the deterioration of their quality (Jarvie et al. 1998; Ravichandran, 2003; Pophare et al. 2014). The deteriorated quality of surface water is becoming a significant issue in many countries (Malvi et al. 2005; Qin et al. 2014). Thus, recently developing countries have intensified efforts to judge the standard of rivers (Kannel et al. 2007). Water Quality Index (WQI) helps us to study the detailed about score of each variable. The target of the WQI is to classify the waters relative to biological, chemical, and physical characteristics defining their possible uses and managing their allocations (Liou et al., 2004; Boyacioglu, 2007; Khalil et al., 2011). The aim of the present study was to identify the water quality status of the river Damodar, near Dharampur, West Bengal, India using the physicochemical parameters of the water around Dharampur and adjoining areas. This study also helps in the assessment and periodic monitoring of water quality for proper management strategies to minimize the water pollution level.

2. METHODOLOGY

2.1. Study Area

The river Damodar basin is the main repository of 46% of coal reserves in India and lies between latitudes 22°45'N and 29°30'N and longitudes 84°45'E and 88°30'E. The river Damodar originates from the Chotanagpur plateau in Bihar and traverses about 500 km through the states of Bihar and West Bengal where it joins Hooghly. The valley receives rainfall limited to the 4 months, i.e., June to September. Dharampur is situated between latitude 23°40' North and longitude 86°55'.

2.2. Sample collection and analysis

Water samples from six sites (Control Pond (CP), River Upstream (RU), Effluent Discharge Site (EDS), River Downstream (RD), Sewage Fed Pond 1 (SP1), and Sewage Fed Pond 2 (SP2)) located in the open water were collected at a depth of 0.5 m seasonally [Summer season – (March –June); Rainy season –(July- October); and Winter season-(November-February)] during 2019-2020 from river Damodar at Dharampur, West Bengal. Sample in triplicates was collected at each site randomly. Water samples were preserved in pre rinsed 2l polyethylene terephthalate bottles at 4°C. Each container was marked with the name and date of collection. Data analysis was done following the standard protocol of APHA (2012) and guidelines provided in the manual: water and wastewater analysis (CPCB). Various physicochemical parameters such as pH, Hardness, and TDS were measured in situ using a water analyzer kit. The methodologies adopted for the determination of water quality parameters of the collected samples were presented in Table 1.

Table 1. Analytical methods used during study

Parameters	Unit	Analytical Methods
pH	°C	Digital thermometer
TDS	mg/l	Electrometric
TSS	mg/l	Gravimetric analysis
DO	mg/l	Winkler method
BOD	mg/l	Dichromate method
COD	mg/l	Winkler's azide method
Hardness	mg/l	Titrimetric
Alkalinity	mg/l	Digital titrator
Nitrite	mg/l	Spectrophotometric
Nitrate	mg/l	Spectrophotometric
Chloride	mg/l	Argentometric Titration
Iron	µg/l	Anodic Stripping Voltammetry
Copper	µg/l	Anodic Stripping Voltammetry
Coliform	CFU in 100 ml water	MPN method

2.3. Water Quality Index

Fourteen parameters were selected namely: pH, dissolved oxygen, total dissolved solids, total suspended solids, biological oxygen demand, chemical oxygen demand, hardness, alkalinity, chloride, nitrite, nitrate, iron, copper, and coliform. The values used are the mean values. The standard used in this study was the recommended according to guidelines for drinking water ICMR (1975), WHO (2004) and BIS 2012 (Indian Standard Specification for Drinking Water) (Table 2).

Table 2. Standard values and their recommended agency

Parameters	Standard values	Recommended Agency
pH	6.5	ICMR/BIS
TDS	500	ICMR/BIS
TSS	500	ICMR/BIS
DO	5	ICMR/BIS
BOD	5	ICMR
COD	20	ICMR
Hardness	200	ICMR/BIS
Alkalinity	600	ICMR
Nitrite	3	ICMR
Nitrate	10	ICMR
Chloride	250	ICMR
Iron	1	ICMR
Copper	2	ICMR
Coliform	1	ICMR

WQI is a method or tool to express water quality that offers a simple reproducible unit of measure (Singh et al. 2013). The weights for various parameters of water are assumed to be inversely proportional to the recommended standards for the corresponding parameters. WQI rates the health of water quality with numbers (Brown et al. 1970). The indices help general awareness of people and policymakers in water quality management. Water quality scale as suggested by different authors is presented in Table 3.

Table 3. Water quality Scale

Water Quality	WQI (Yadav et al. 2010)	WQI (Ramakrishnaiah et al. 2009)	WQI (Mohanty 2004)
Excellent	0-25	<50	<50
Good	26-50	50-100	50-100
Poor	51-75	100-200	100-200
Very Poor	76-100	200-300	200-300
Unsuitable	Above 100	>300	>300

2.4. Parameter Weightage Determination

For water quality index calculation, the weightage of each of the parameters is to be identified. Parameters having higher permissible limits are less harmful. The weightage of tested parameters has an inverse relationship with its permissible limits. Therefore

$$W_n = 1/S_n,$$

Where;

W_n = Unit weight of the different parameters tested

S_n = Standard values of parameters

2.5. Quality Rating or Sub Index of Selected Parameters

A rating scale was prepared for the range of values of each parameter. The rating varies from 0 to 100 into five intervals. $q_n = 0$ implies that the parameter exceeds the standard maximum permissible limits and water is severely polluted. q_n value = 100 implies that the parameter present in water has the most desirable value. This scale is the modified version of the rating scale given by Tiwari and Mishra (1985) and is calculated as follows:

$$q_n = 100 (V_n - V_{io}) / (S_n - V_{io})$$

Where:

q_n = Quality rating or sub-index

V_n = Laboratory test result for each parameter tested

S_n = Standard value of each parameter tested (WHO standard for drinking water)

V_{io} = ideal value of selected parameters tested (in pure water, $V_{io} = 0$ for all parameters, pH and dissolved oxygen which is 7.0 and 14.6 respectively).

2.6. WQI Calculation

The following steps were employed in computing the overall water quality.

i. Weightage unit (W_n) for all parameters tested and was determined individually and summed up to obtain $\sum W_n$

ii. The index $W_n \times q_n$ was calculated for each parameter tested and summed up to obtain $\sum W_n . q_n$

iii. Water Quality Index (WQI) was computed using the mass balance equation:

$$(\sum W_n . q_n) / (\sum W_n)$$

2.7. Statistical Analysis

The quality of river water is affected by a lot of variables. The most common statistical application that is widely used to identify the components, their sources, and impacts on the water environment is principal component analysis (PCA). The principal component analysis is used to explain the variance of a large set of inter-correlated variables and transform them into a smaller set of (uncorrelated) variables (Bu et al. 2009; Howladar et al. 2017). Another commonly used statistic includes a correlation matrix which shows the relation between any two parameters, their strength, and the direction of a relationship between the variables. Statistics were done by using SPSS software version 20.00.

3. RESULT

The values of WQI in different seasons at six different sites of river is presented in Table 4.

Table 4. WQI values at six different sites of rivers in different seasons

Season	Water From	Value	Comment
Summer	Control Pond	30.11	Excellent
	Upstream	57.20	Good
	Effluent	169.92	Poor
	Downstream	111.97	Poor
	Pond1	161.32	Poor
	Pond2	177.11	Poor
Rainy	Control Pond	24.30	Excellent
	Upstream	91.50	Good
	Effluent	95.76	Good
	Downstream	314.03	Unsuitable
	Pond1	392.61	Unsuitable
	Pond2	268.50	Very Poor
Winter	Control Pond	25.38	Excellent
	Upstream	59.87	Good
	Effluent	261.74	Very Poor
	Downstream	240.65	Very Poor
	Pond1	251.56	Very Poor
	Pond2	254.44	Very Poor

The average pH WQI values were 7.09/7.01/7.11; 6.91/7.01/7.14; 5.89/6.67/7.27; 6.16/6.44/7.06; 5.72/6.85/7.01; and 5.73/6.53/6.82 respectively for Control Pond (CP), River Upstream (RU), Effluent Discharge Site (EDS), River Downstream (RD), Sewage Fed Pond 1(SP1) and Sewage Fed Pond 2 (SP2) during summer/rainy/winter. The pH of the water was relatively high in the winter season and low in rainy than the summer season.

The average DO WQI values were 6.35/6.22/6.73; 5.20/5.94/6.98; 1.18/2.20/2.80; 2.72/3.53/3.67; 1.19/2.46/2.84 and 1.55/2.05/3.0 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The DO of the water was relatively high in the winter season and low in rainy than the summer season.

The average TDS WQI values were 253.14/256.66/499.29; 231.57/293.75/528.91; 304.12/424.64/692.5; 279.85/356.45/652.14; 304.13/425.74/704.16 and 328.05/337.97/644.08

respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The TDS of the water was relatively high in the winter season and low in rainy than the summer season.

The average TSS WQI values were 16.16/19.01/24.05; 16.87/20.42/26.52; 18.97/30.01/50.15; 18.03/27.80/48.34; 19.60/29.64/50.20 and 19.55/43.51/44.92 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The TSS of the water was relatively high in the winter season and low in rainy than the summer season.

The average BOD WQI values were 8.11/7.96/9.42; 7.75/8.21/9.61; 5.71/7.46/10.62; 7.19/7.93/8.98; 5.94/7.39/10.28 and 7.67/6.79/9.64 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The BOD of the water was relatively high in the winter season and low in summer than the rainy season.

The average COD WQI values were 39.44/42.76/44.42; 34.77/43.83/47.20; 54.79/96.80/56.91; 46.90/95.49/75.32; 54.35/98.73/57.19 and 36.59/32.98/48.20 respectively CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The COD of the water was relatively high in the winter season and low in summer than the rainy season.

The average hardness WQI values were 43.25/38.85/39.15; 47.91/40.24/41.31; 122.73/101.30/99.04; 113.88/94.89/90.06; 122.61/100.33/98.57 and 121.22/100.45/86.55 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The hardness of the water was relatively high in the summer season and low in winter than the rainy season.

The average alkalinity WQI values were 43.29/42.82/41.52; 65.59/64.0/45.32; 210.79/209.86/131.56; 187.84/194.50/125.16; 210.53/210.73/130.45 and 150.58/163.03/125.15 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The alkalinity of the water was relatively high in the summer season and low in rainy than the winter season.

The average chloride WQI values were 16.57/12.11/18.36; 16.63/15.40/20.65; 88.84/72.75/96.06; 78.12/67.53/82.80; 89.22/71.10/94.93 and 87.20/81.14/91.40 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The chloride of the water was relatively high in the winter season and low in summer than the rainy season.

The average nitrite WQI values were 0.16/0.04/0.10; 0.42/0.35/0.05; 1.09/0.88/0.72; 0.68/1.00/0.80; 1.08/0.83/0.72 and 1.19/0.72/0.72 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The nitrite of the water was relatively high in the summer season and low in rainy than the winter season.

The average nitrate WQI values were 0.70/0.96/0.63; 0.93/1.01/0.39; 2.96/4.41/0.73; 1.37/1.36/0.68; 2.80/4.46/0.71 and 1.28/4.39/2.05 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The nitrate of the water was relatively high in the rainy season and low in summer than the winter season.

The average iron WQI values were 0.06/0.06/0.02; 0.02/0.08/0.04; 0.50/0.58/0.38; 0.23/0.21/0.20; 0.51/0.55/0.38 and 0.85/1.28/0.63 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The iron of the water was relatively high in the rainy season and low in winter than the summer season.

The average copper WQI values were 0.14/0.08/0.05; 0.13/0.09/0.18; 3.80/2.41/8.52; 0.78/0.61/1.38; 3.83/2.59/5.69 and 4.11/4.97/4.78 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The copper of the water was relatively high in the winter season and low in summer than the rainy season.

The average coliform WQI values were 0.38/0.17/0.23; 1.30/2.48/1.41; 3.44/1.17/5.96; 2.78/9.70/7.14; 3.45/11.76/6.24 and 3.20/6.12/6.30 respectively for CP, RU, EDS, RD, SP1 and SP2 during summer/rainy/winter. The coliform of the water was relatively high in the rainy season and low in winter than the summer season.

In this study KMO value found to be 0.847 (Table 5) which indicates good sampling adequacy and Bartlett's Test of Sphericity produced a high significant value of 0.001 (chi square=10270.892) (Table 5) proving that correlation matrix was not an identity matrix and there exists significant relationships between the variables.

Table 5. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.847
Bartlett's Test of Sphericity	Approx. Chi-Square	10270.892
	df	15
	Sig.	0.001

In Table 6 results of correlation matrix with their significant levels are presented.

Table 6. Correlation Matrix with significant levels

		CONTROL	UPSTREAM	EFFLUENT	DOWNSTREAM	POND1	POND2
Correlation	CONTROL	1.000	0.989	0.945	0.947	0.946	0.957
	UPSTREAM	0.989	1.000	0.954	0.955	0.956	0.952
	EFFLUENT	0.945	0.954	1.000	0.990	0.999	0.979
	DOWNSTREAM	0.947	0.955	0.990	1.000	0.991	0.982
	POND1	0.946	0.956	0.999	0.991	1.000	0.978
	POND2	0.957	0.952	0.979	0.982	0.978	1.000
Sig. (1-tailed)	CONTROL		0.001	0.001	0.001	0.001	0.001
	UPSTREAM	0.001		0.001	0.001	0.001	0.001
	EFFLUENT	0.001	0.001		0.001	0.001	0.001
	DOWNSTREAM	0.001	0.001	0.001		0.001	0.001
	POND1	0.001	0.001	0.001	0.001		0.001
	POND2	0.001	0.001	0.001	0.001	0.001	

The anti image correlation matrix presnted in Table 7.

Table 7. Anti image correlation matrix

		CONTROL	UPSTREAM	EFFLUENT	DOWNSTREAM	POND1	POND2
Anti-image Correlation	CONTROL	0.806 ^a	-0.888	0.114	0.191	-0.077	-0.504
	UPSTREAM	-0.888	0.829 ^a	-0.024	-0.212	-0.030	0.348
	EFFLUENT	0.114	-0.024	0.826 ^a	0.021	-0.957	-0.259
	DOWNSTREAM	0.191	-0.212	0.021	0.935 ^a	-0.222	-0.447
	POND1	-0.077	-0.030	-0.957	-0.222	0.824 ^a	0.198
	POND2	-0.504	0.348	-0.259	-0.447	0.198	0.873 ^a

a. Measures of Sampling Adequacy(MSA)

It was employed to test the capacity of the PCA in explaining the correlations between selected water parameters. Off diagonal matrix in the Table are less than unity and nearer to 1 which explains the applicability of PCA. A communality 1 (Table 8) represents that all variations is well explained by PCA.

Table 8. Computed communalities of surface water quality parameters

	Initial	Extraction
CONTROL	1.000	0.954
UPSTREAM	1.000	0.962
EFFLUENT	1.000	0.983
DOWNSTREAM	1.000	0.982
POND1	1.000	0.983
POND2	1.000	0.976

High extraction communalities indicates that extracted components represent the variables very well. Result of component factor is presented in Table 9. Factors with eigen values greater than one represent the factors needed to describe the underlying variation of the surface water quality. Factors having eigen value less than unity means that such factor do not have any influence on the surface water quality. From the results of Table 9, it was observed that one component factors had eigen value greater than one.

Table 9. Extraction of component factor using PCA method

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.840	97.332	97.332	5.840	97.332	97.332
2	0.110	1.836	99.168			
3	0.030	0.502	99.670			
4	0.012	0.195	99.865			
5	0.007	0.123	99.988			
6	0.001	0.012	100.000			

These component factor contributed to change in the quality of the surface water around the study area which is also supported by the scree plot presented in Figure 1.

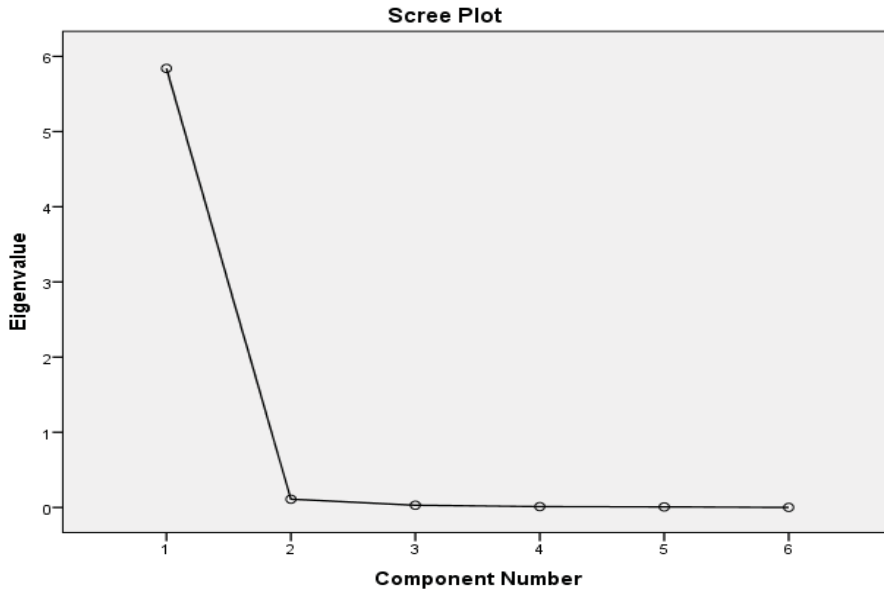


Figure 1. Scree plot showing factor with high significant influence

4. DISCUSSIONS

The maximum pH reported during summer was very low due to the water levels and concentration of nutrients in water (Narayana et al. 2008; Bhateria and Jain, 2016) and the minimum was during monsoon due to the dilution of water by the addition of rainwater (Reddy et al. 2009; Bhateria and Jain, 2016). Water having more than 500 mg/L of TDS is not suitable for drinking (Saksena and Kaushik, 1994; Meride and Ayenew, 2016). Water with high TDS is undesirable or harmful for human and aquatic life. High TDS water is also less thirst-quenching and interferes with the taste of foods. Irrigation with high TDS resulted in soil salinization and a decrease in macro-porosity but did not decrease crop yields, relative to irrigation with low TDS water. The lowest dissolved oxygen recorded during the summer season was due to the high temperature and addition of sewage and other waste which can be responsible for the low value of dissolved oxygen. The BOD may be defined as the oxygen required for the microorganism to the performed biological decomposition of dissolved solids under aerobic conditions (Solanki and Pandit, 2006; Velusamy and Kannan, 2016). The highest demand for oxygen in the water was recorded due to the possible addition of a high amount of waste along with rainwater from the surrounding and the addition of organic waste in the river by certain human activities which also be responsible for the increase in BOD (Solanki, 2001, 2007). The total hardness of water depends on a complex mixture of cations and anions. Water hardness depends upon calcium and magnesium in addition to sulfate and nitrate in the sewage waste (Pawar and Palle, 2005; Grochowska, 2020) and it also which prevents lather formation with soap (Trivedy and Goel, 1986; Nag and Das, 2017). Based on hardness, water classified into three different categories: soft water (0-75 mg/L), moderately hard water (76-150 mg/L), and hard water (151-300 mg/L) (Soni et al., 2013). Total alkalinity depends on presence of bicarbonate, carbonate, and hydroxide compound of calcium, sodium, and potassium

(Murhekar, 2011). The highest chloride reported is due to frequent run-off loaded with contaminated water from the surrounding slum area and evaporation of water (Verma et al. 2010, Qureshimatva et al. 2015). Nitrates contribute to freshwater through the discharge of sewage and industrial wastes and runoff from agricultural fields (Solanki, 2012). The highest amount of nitrate concentration helps in the formation of blooms. The high concentration of nitrates is useful in irrigation but their entry into water resources increases the growth of nuisance, eutrophication and pollution (Sinha and Biswas, 2011). High nitrate concentrations are results of ammonium nitrogen (Ali et al. 1996). Many workers have been reported to have potential health risks from nitrate in drinking water above the threshold of 45 mg/L, which may give rise to a condition known as methemoglobinemia in infants and pregnant women (Kross et al. 1993). People accustomed to higher chloride in water are subjected to laxative effects (Shrinivasa and Venkateswaralu, 2000). The WQI value ranges from 30.11 to 177.11 (summer season), 24.30 to 392.61 (rainy season) and 25.38 to 261.74 (during winter season) falls under the excellent, good, poor, very poor to unsuitable for use category. The present study revealed that the water of river Damodar at Dharampur, West Bengal, India is polluted (due to surface run-off, bathing activities, agriculture run-off, effluents from upstream from surrounding industrial and garden area, the immersion of idols of God and Goddess during festival season), and is unsuitable for human consumption, and also for the survival of life forms unless treated properly. This study showed that the water quality of the Damodar river is gradually destroying. The government body and other civic organizations should take the action against releasing the domestic waste directly into the river or installed a water purification system.

5. CONCLUSIONS

The study contributes a transparent view of the standard of surface water and therefore the variations in it. It could be noted that the water quality has deteriorated in this area due to mining activities. The surface water bodies have been contaminated to a significant extent compared to ground water. Though mining company at the site have adopted proper control measures such as construction of garland drains, mining walls, settling ponds, effluent treatment plants etc., still a lot more is required to be achieved. From the information, it's evident that the water sources may be used for drinking purposes only after prior treatment. This data can expect the adoption of suitable remedial measures by the government. Because of limited published studies within the area of interest discussed here, the information provided is one in all the pioneer reportings.

6. CONFLICT OF INTEREST

We declare that we have no conflict of interest

7. ETHICAL APPROVAL

This article is not under consideration or published elsewhere. Ethical clearance for the study was obtained from IAEC, Approval No. 17/IAEC (05)/RNLKWC/2019, Dated 27.07.2019.

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9. AUTHORS CONTRIBUTIONS

AD- Data Curation, Original Draft writing, Carry out Research work, IB, BM- Data curation, Writing Draft, TD- Reviewing, Editing PPC- Designing, Monitoring, Reviewing, Communication

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