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Assessment of the effect of COVID-19 Lockdown on Water Quality of Baldi River Sahastradhara Sulphur Spring, Dehradun, Uttarakhand, India

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ABSTRACT

Due to imposed restrictions during COVID-19 lockdown on air- rail - road traffic and industrial activities, early signs of improvement in water quality of several Indian rivers were noticed in terms of higher dissolved oxygen and lower biochemical oxygen demand and total Coliforms, on account of least discharge of industrial effluents and restricted human outdoor movement. In the backdrop of above, this study was aimed to assess the water quality index (WQI) of Baldi River -Sahastradhara Sulphur Spring, Dehradun, India, by following the U.S. National Sanitation Foundation, NSF-WQI model, during lockdown (April to June 2020) and after unlocking process (July – September, 2020). The spatial and seasonal variations in ten water quality parameters of Baldi River -Sahastradhara Sulphur Spring were investigated by monitoring the water quality at three locations; *Baldi river upstream*, *Sahastradhara proper* and *Baldi river* d*ownstream*. During the entire study period, improved water quality was observed, in terms of high DO ranging from 9.17±0.035 to 8.38±0.028 mg/L and comparatively low BOD ranging from 1.68±0.032 to 2.31± 0.031 and low total coliform counts ranging from 06±1.09 to 31±2.75 MPN/100 mL. The NSF-WQI water quality status of Baldi River -Sahastradhara Sulphur Spring was found to be ***Good*** all the time and the computed WQI at Baldi river upstream, Sahastradhara proper and downstream were 85.53, 83.48 and 82.30 during lockdown period (summer). However, during unlocking process (monsoon), due to continued weekend restrictions, on account of minimum tourists activities the water quality was still computed ***Good*** that NSF-WQI were found to be 83.20, 80.58 and 79.27, at the studied locations respectively.

Key words : *Baldi River, Sahastradhara Sulphur spring, Water quality, NSF-WQI Model*

Introduction

Rivers in Uttarakhand are mostly running, eroding, turbulent, depositing and riffling due to altitudinal gradient and substratum composition (Semwal and Akolkar, 2006). The quality of moving river water varies spatially and temporarily due to the variation in its composition and concentrations of the components (Chang *et al.*, 2008). Activities such as, dumping of waste, mining of sand- stone -gravel in river beds and adjoining areas, stone crushing, construction of road, hydro – irrigation projects, fishing- rafting etc. affect river water quality greatly (Semwal and Akolkar, 2006). Industrial activities, rapid urban growth, agricultural intensification and other domestic activities caused charging of deleterious materials to water bodies that the self purifying capability of ground water, rivers and lakes gradually diminished (Kulshrestha, 2020).

Doon valley is bounded on the north-eastward by the lesser Himalayan Ranges and on the eastern half of its south- west by the Shivalik Ranges. The lesser

Himalayan belt consists of high grade limestone and shale at the base, passing gradually to dolomite towards the top, which is covered with a shallow layer of soil. By 1982 there were more than 100 quarry lease holders with about 1250 hectares of leased area (Bandyopadhyay and Shiva, 1985). Mining and mineral processing adversely affected the ecology of the area by disturbing the land mass, the water systems and floral-faunal populations (Rajdeep *et al*., 2011). After intervention of Supreme Court, the limestone quarrying in Doon valley was stopped and the ecological restoration of the Sahastradhara limestone mine sites with adjoining forests could initiated only in 1988-89, as an effective tool to regenerate the disturbed forests sites (Rajdeep *et al*., 2011).

Sahastradhara sulphur water fall in Dehradun is located at the left bank of river Baldi that comprises of caves and waterfalls along with fresh sulphur water springs. Sulphur water is used for treating skin infections due to presence of sulphur oxidizing bacteria (Koul *et al.,* 2018). The Baldi River is one of the tributary of the River Song flowing in Doon Valley of Garhwal Himalayas, India (Singh and Sharma, 2016). At Sahastradhara water drips from the limestone stalactites, making the water abundant in sulphur and thus the place is known for its sulphur springs. This place attracts thousands of tourists coming across the country round the year (Badhula *et al.,* 2014). Heavy influx of tourists' activities is considered one of the reasons of deterioration in river water quality (Bhutiani *et al.,* 2016). During COVID-19 epidemic, the strategy was to break the cycle of transmission through social distancing; nationwide lockdown was enforced strictly from 25 March, 2020 with several restrictions including stepping out of homes. All transport Services, road transport, railways and airways were suspended, except transportation of essential goods, police and emergency services. Educational institutions, industrial establishments were closed, while services such as pharmacy, hospitals, banks, ATMs, LPG, petrol pumps, vegetables- fruits, milk, kirana shops, other essentials and their manufacturing were exempted. The benefits of these restrictions on mass movement, industrial activities and transport services in particular were visible in terms of the improvement in river water quality that showed enhanced DO, reduced BOD and coliforms and river bed under water was visible clearly. All this was possible because of restricted industrial activities and closing of hotels, restaurants and restricted human movements that caused generation of ever lowest industrial effluents and no bathing activities at River Ghats (Kulshrestha, 2020a).

Assessment of the surface water quality to judge the suitability for human consumption is a complex process involving multiple parameters capable of causing stresses on overall water quality (Bhutiani *et a*l., 2016). WQI is an efficient method for assessing the suitability of water quality. The concept of WQI was first proposed by Horton on observing several important water quality parameters, such as, temperature, turbidity, pH, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), total Coliforms, total dissolved solids (TDS), total hardness (TH) and chlorides (Horton, 1965). Another notable WQI model was developed by Brown and supported by the US, National Sanitation Foundation, referred as NSF-WQI (Brown *et al.,* 1970). Several other WQI models are also in use with their own merits and short comings (Dunnette, 1979, BCWQI, 1996, CCMEWQI, 2001). The WQI summarizes the combined effect of a number of water quality parameters analyzed in a single unit less value. WQI compares the water quality parameters to regulatory standards.

This study was undertaken to assess the effect of COVID-19 nationwide lockdown, on the water quality of the Baldi River-Sahastradhara Sulphur Spring, Dehradun, when restrictions were imposed strictly on human movement, opening of educational institutions, industrial activities, and all type of transports, except essential services during March, 25, 2020. The effect of these restrictions, especially human movement on the water quality of the Baldi River -Sahastradhara Sulphur Spring was assessed by evaluating important physical, chemical and biological parameters of the river water, namely water temperature, pH, TDS, TH, EC, DO, BOD, total Coliforms, nitrate and total phosphate. River water samples were collected from three identified locations of Baldi river- Sahastradhara Sulpur spring, during lockdown period, April to June, 2020 (summer) and during unlocking process, July to September (monsoon). For assessment of water quality status NSF-WQI model was used (Brown *et al.,* 1970).

Materials and Method

Description of Study area

Baldi River -Sahastradhara sulphur spring is a natural perennial hill stream which originates from the upper mountainous terrains of Mussoorie in Garhwal region. It is located at an altitude of about 830 m above the sea level and situated between 30° 23′N and 78° 8′ E in Raipur Block of Dehradun district of Uttarakhand state (Singh and Sharma, 2016). The forest of Sahastradhara has tropical mixed deciduous scrubby vegetation (Rajdeep *et al*., 2011). Baldi River, after emerging from Loharigarh, flows to south-east and then to southward where a small river Kaligad meets it near Sera then flows further south to Silkati towards Sahastradhara. Baldi River after covering a distance of 14 km from Sahastradhara meets the Song River near village Maldevta (Sharma *et al.,* 2016). Song River is perennial tributary of Ganga, arising from Surkanda peak (9000 msl) in Tehri Garhwal district, which then flows in the South direction meets with Suswa river near Kans Rao forest and finally confluences with Ganga at Raiwala (Bisht *et al.,*2017). Doon valley is a tectonically formed longitudinal, synclinal basin with fluvial sediments deposited in front of the abruptly rising Lesser Himalaya in the north having an average elevation of 1,800–2,400 m. The Blaini Formation composed of slate, boulder bed with well-rounded quartzite pebbles and limestone, the Krol Formation comprised of massive grayish blue crystalline limestone and dolomitic limestone with subordinate slate and siltstones (Dudeja *et al*., 2011). The lime stone deposits in Doon Valley are a gift of Nature that underneath the soil cover there is an unseen store house almost everywhere (Rajdeep *et al.,* 2011). In Mussoorie Hills the limestone rocks are sedimentary in origin and lies in a tectonically active zone (Dudeja et al., 2011). After 1965 the lime stone mining operations in the area became wide-spread, trees were felled at random and lush green forests disappeared, rains became less, the aquifers ceased to exist (Rajdeep *et al.,* 2011). Explosives used to remove the rocks further weaken the rock structure. The steep gradient of the hills and high rainfall during monsoon further increases the land's instability initiated by mining, causing slope failure and landslides. Landslides lead to the raising of the river beds, by the piling up of the debris in drainage channels (Bandyopadhyay and Shiva, 1985). The over extraction of limestone, converted the mine areas and its surroundings into a barren land with boulders and debris (Rajdeep *et al.,* 2011). The heavy limestone quarrying in Mussoorie hills continued till 1988 with 105 working mines. The ecological restoration of these sites was initiated during 1988-1989, when the quarrying activities were stopped by the Supreme Court in 1988 (Rajdeep *et al.,* 2011). The limestone quarrying and its processing for three decades adversely affected the ecology of the region that the natural flow of river water was reduced substantially (Bandyopadhyay and Shiva, 1985).

Sahastradhara, the 'thousand fold springs' or thousand streamlets (Koul *et al.,* 2018) is used for the water that virtually drips down from limestone stalactites in a sort of a grotto or cave system that are formed from the carbonates of the Krol belt, along with freshwater sulphur springs (Jaiswal and Tiwari, 2012). Sahastradhara caves are small in sizes and some have falls of 10 m and width of 2 m (Jaiswal and Tiwari, 2012). The scene of the spring site is further magnified due to dozens of 3-4 feet deep clean fresh water swimming pool like structures made by raising temporary walls along the width of Baldi river bed (40-45 feet wide) for blocking river water on both upstream and downstream. During summer months these structures attract tourists to have a bath under the Sahastradhara sulphur springs and dives in swimming pools. These structures are made by the local restaurant - shop owners in front of their area so that friends and families of costumers and tourists may enjoy the destination. Such swimming pools are repaired or built fresh every year when damaged by turbulent storm water during monsoon. Thousands of tourists come across the country visit this place on weekends, festival holidays and during summer. Public

Fig. 1. Sahastradhara Sulphur water springs and swimming pools like manmade structures on Baldi River.

transport is available at *Parade ground bus stand,* Dehradun from 6AM to 8PM at very economical prices (Badhula *et al.,* 2014). Sulphur springs and caves are on the left bank of the Baldi River. While, along the right bank of the river there are many hotels, restaurants, parking areas, shops and one exciting *rope way* to reach the top of the mountain. On weekends due to increase in tourists size at Sahastradhara proper, pollution level of river water is usually high because of tremendous bathing activities and dumping of wastes and usable (Bhat and Mir, 2015).

Sampling Sites and Collection of water Samples

Prior to lockdown, the *upstream* (location-1) was supposed to be least affected, the *Baldi river Sahastradhara proper* (location-2) is most affected due to the main centre of tourist activities and the *downstream* (location-3) was comparatively lesser affected due to lesser number of tourist activities (Sharma *et al.,*2016). To evaluate the effect of COVID-19 lockdown on the water quality of the Baldi River - Sahastradhara Sulphur Spring, the river water samples during lockdown period i.e. from April to June, 2020 were collected biweekly (between 7.30 AM to 8.30 AM) from selected locations. For comparison purpose, river water samples were also collected during July – September, 2020, when the restrictions were lifted in phased manner, except weekend restrictions. The brand new transparent Polythene cans, cleaned by washing in detergent, rinsed with tap water and finally rinsed with deionised water, were used for collection of wastewater samples. Prior to use, cans were once again cleaned thoroughly with distilled water and rinsed with water sample to be collected. For the estimation of dissolved oxygen, biochemical oxygen demand, well-sterilized BOD bottles were used. They were dried, cooled, and labeled. The samples were collected by following the standard methods of sampling techniques (Trivedy and Goel, 1986; APHA, 2005). All necessary precautions were taken during transportations of samples to the laboratory.

Analysis of Water Quality Parameters

The parameters such as water temperature, dissolved oxygen (DO) and pH of samples were analyzed at the spot immediately after the collection by using thermometer, WTW OXI 3205 Portable DO Meter and EUTECH pH Meter. While, TDS, EC, TH, BOD, total coliforms, nitrate and total phosphate were evaluated in the laboratory by following the standard procedures and guidelines (Goel, 2006, Maiti, 2004; BIS, 2012). The BOD was estimated by the modified Winkler method, using WTW OXI Top IS 16 BOD Meter, from the difference in DO values after 5 days of incubation at 20^0C (Ademoroti, 1996). Total hardness was estimated by EDTA titration method. TDS was determined by the evaporation method. Conductivity was measured on Cyber Scan CON 700 Conductivity Meter. Nitrate was measured using Carry 60 UV-Vis spectrometer (Agilent). Phosphate was estimated by digesting with molybdophosphoric reagent, the molybdenum blue complex was measured spectrophotometrically. The total Coliforms were determined by using the Most Probable Number (MPN) method by following the standard methods (Trivedy and Goel, 1986; Aneja, 2007). The reagents, chemicals, and solvents used were of analytical grade. Doubly- distilled water was used for all purposes.

Results and Discussion

The representative water samples of Baldi River – Sahastradhara Sulphur Spring, Dehradun, India were analysed for 10 water quality parameters namely water temperature, pH, TDS, TH, EC, DO, BOD, total Coliform, nitrate and total phosphate. The seasonal and spatial variations in the studied parameters are presented in Table 1.

Water Temperature

Water temperature generally varies with sites and seasons and regulates the maximum dissolved oxygen concentration of water and the rate of chemical and biological reactions (Rai *et al*., 2011). The seasonal variation in water temperature at *locations 1, 2* and *3* varied during summer as 17.78±0.086, 18.62±0.040 and 19.74±0.068, respectively. However, during monsoon season water temperature varied as 19.68±0.050, 18.80±0.052 and 19.06±0.058. The temperature change (ΔT) refers to the change in temperature between *upstream* and *downstream* control points. It is function of season, humidity, air temperature, solar angle and sampling time. (Rai *et al*., 2011). To determine (ΔT), water temperature was also recorded from *Shera chowki*, nearly 1.6 Km *upstream* to *location 1*, during summer and monsoon, mean values were found 17. 94^0 ±0.049 and 17. 90±0.046, respectively.

Table 1. Mean values of water quality parameters of Baldi River – Sahastradhara Sulphur Spring, Dehradun, during April to June, 2020 and July – September, 2020.

Para-meters	Period	Location—1 (Upstream)	Location-2 (Sahastradhara proper)	Location-3 (Downstream)	Standard
Water Temp. ^{0}C	April-June	19.06±0.058	19.43. ±0.050.	19.74±0.068	—
	July-Sept.	18.91±0.052	19.18±0.086	19.42±0.040	
pH	April-June	7.65±0.029	7.60±0.033	7.62±0.027	7.0-8.5(WHO)
	July- Sept.	7.68±0.034	7.64±0.027	7.66±0.026	
TDS, mg/l	April-June	799±32.62	851±24.91	919±50.79	500(WHO)
	July- Sept.	977±63.14	1018±58.95	1040±49.52	
TH,mg/l	April-June	654±15.11	635±17.57	622±17.87	5.0(WHO)
	July- Sept.	617±32.81	589±34.63	583±30.38	
EC, µS/cm	April-June	1191±31.0	1219±31.47	1257±33.10	300(ICMR)
	July- Sept.	1276±48.33	1316±39.59	1350± 38.06	
DO,mg/l	April-June	9.17±0.035	8.69±0.034	8.46±0.028	5.0(WHO)
	July- Sept.	8.86±0.029	8.41±0.027	8.38±0.029	
BOD, mg/l	April-June	1.68±0.032	1.89±0.031	1.97± 0.031	28-30(BIS)
	July- Sept.	1.80±0.032	2.20±0.041	2.31±0.046	
Coli form*	April-June	06±1.09	11±1.89	17±1.67	Nil/100 ml, (WHO)
	July- Sept.	10±1.41	22±2.14	31±2.75	
NO_3^-, mg/l	April-June	0.065±0.004	0.071±0.003	0.075±0.003	10 (WHO)
	July- Sept.	0.072±0.003	0.076±0.005	0.079±0.004	
PO_4^{-3}, mg/l	April-June	0.037±0.0029	0.043±0.0036	0.045±0.0029	0.10 (WHO)
	July- Sept.	0.041±0.003	0.044±0.0035	0.048±0.0034	

*MPN/ 100 ml

pH

The pH of water is governed by carbon dioxide-carbonate system (Rao and Rao, 2010). The recorded pH of river water was slightly alkaline at all the locations during summer as well as monsoon seasons. All values were within WHO limit (6.5-8.5). The pH mean values varied from 7.60±0.033 to 7.65±0.029 in summer and from 7.64±0.027 to 7.68±0.034 during monsoon.

Total dissolved solids (TDS)

TDS contains mainly carbonates, bicarbonates, sulphates, chloride, nitrates and phosphates of calcium, magnesium, sodium, potassium etc. (ICMR, 1975). All the TDS values are much higher than the WHO prescribed values (500 mg/l) in drinking water and varied from 799±32.62 to 919±50.79 mg/l in summer and from 977±63.14 to 1040±49.52 mg/l in monsoon. TDS values were higher during high flow monsoon period than low flow summer months. The recorded TDS values are comparable with earlier findings (Dudeja *et al*., 2011; Badhula *et al.,* 2014; Bharti, 2014). On the other hand, Sahastradhara sulphur spring water samples recorded much lower TDS (555±16.46 mg/l) than observed in Baldi river water samples (Table 1).

Total Hardness (TH)

Hardness is predominantly due to dissolved carbonates, bicarbonate, chloride and sulphates of calcium, magnesium, strontium and iron salts in river water samples (ICMR, 1975, Madan *et al.*, 2013). The river water flowing through various geological land masses containing deposits of the limestone and other rocks may assimilate these salts in varying concentration. Total hardness varied from 622±17.87 to 654±15.11 mg/l. in summer and from 583±30.38 to 617±32.81 mg/l in during monsoon. The observed values of TH in monsoon at all the sites were lower than found in summer months. The TH values are lower than earlier finding (Dudeja *et al*., 2011). Hardness of the Sahastradhara-Baldi river water is much above permissible limit possibly due to dominant limestone rocks. However, much lower hardness were recorded in Sahastradhara sulphur springs water collected from caves (298 ± 11.13mg/l) than found in Baldi river water (Table 1).

Electrical conductivity (EC)

Water is universal solvents and dissolves almost all the inorganic salts present in ionic form, in varying concentration. Thus electrical conductivity is due to the dissolved ions in water sample. All the observed values of conductivity, (Table 1) were above ICMR standard. EC showed seasonal changes at all the sites, the recorded values of EC in summer months varied from 1191±31.0 to 1257±33.10 µS/cm and in monsoon months it varied from 1276±48.33 to 1350± 38.06 µS/cm. The recorded EC values are comparable with earlier findings (Dudeja *et al.*, 2011). However, much lower conductivity was recorded in water samples collected from sulphur springs water samples from caves (626± 18.26 mg/l), than found in Baldi river water Table 1).

Dissolved Oxygen (DO)

Dissolved Oxygen in water is an important parameter to monitor the biological quality of water (Haritesh *et al.*, 2016) and reflects its self-purification capacity of water body and organic matter in it (Rao and Rao, 2010). DO is inversely related with water temperature as cold water has high oxygen holding capacity than warm water (APHA, 2005). Oxygen enters in water bodies by diffusion of air, photosynthesis in aquatic plants and wind action (Rani *et al.*, 2011). Most part of DO of a water body is consumed to decompose organic matter present in it that leads to the depletion of DO causing the loss of aquatic organisms (Rao and Rao, 2010). During lockdown period (summer), mean DO values varied from 9.17±0.035 at location 1 (upstream), 8.69±0.034 at location 2 (Sahastradhara proper) and 8.46±0.028 mg/l at downstream (location 3). DO values were generally higher at upstream and the lowest at the downstream. (Rani *et al.*, 2011). During monsoon mean values of DO were 8.86±0.029, 8.41±0.027 and 8.38±0.029 at locations 1, 2 and 3, respectively. Thus, observed DO values were higher during lockdown period at all the locations (9.17±0.035, 8.69±0.034 and 8.46±0.028 mg/l) than during monsoon (8.86±0.029, 8.41±0.027 and 8.38±0.029 mg/l). This suggested that Baldi river water quality was improved during COVID lockdown period in terms of the higher DO values than monsoon period when the lockdown was lifted in phased manner. The results of this finding are superior to earlier findings (Bhadula *et al.*, 2014; Bharti, 2014; Sharma *et al.*, 2016).

Biochemical Oxygen Demand (BOD_5)

The BOD quantifies the degree of organic matters and nutrients present in a river water sample. BOD is a measure of the oxygen required by aerobic organisms to decompose organic matter present in water samples. BOD estimates the consumption of dissolved oxygen from a water body during microbial bio-degradation of the organic matter present. The greater the decomposable matter present, the greater the oxygen demand and the greater the BOD values (Madan *et al.*, 2013). Higher is the BOD, the more rapid is the depletion of the dissolved oxygen in the river water (Ram and Joshi, 2012). The BOD during summer (lockdown period) were recorded as 1.68±0.032, 1.89±0.031 and 1.97± 0.031 mg/l, at upstream, Sahastradhara proper and downstream, respectively. Such low values of BOD found in summer months, indicated much better water quality of Baldi river water during lockdown period. However, during monsoon period (after lifting of lockdown) BOD values showed regular increasing trend and values were 1.80±0.032, 2.20±0.041 and 2.31±0.046 mg/l, respectively. Low BOD values may be attributed to the restrictions imposed on outdoor movement and other activities during lockdown and weekend restrictions thereafter.

Total Coliforms

Coliforms in a water sample are undesirable and its presence in water indicates the inputs of human and live stock's faecal waste and household waste water that causes water-borne diseases such as diarrhea, typhoid and hepatitis (Seth *et al.*, 2016). Like other fast flowing hill streams (Bisht *et al.*, 2018) in Baldi river water coliforms counts at upstream location were nil or very low, therefore separate samplings were done from comparatively low lying or somewhat depressed area of each location containing some stagnant water. During lockdown period, mean values of total Coliforms were found as 6±1.09, 11±1.89 and 17±1.67 MPN/ 100 ml, respectively at locations 1, 2 and 3. However, during monsoon the recorded values were 10±1.41, 22±2.14 and 31±2.75MPN/100 ml (Table 1). Although all the ob-

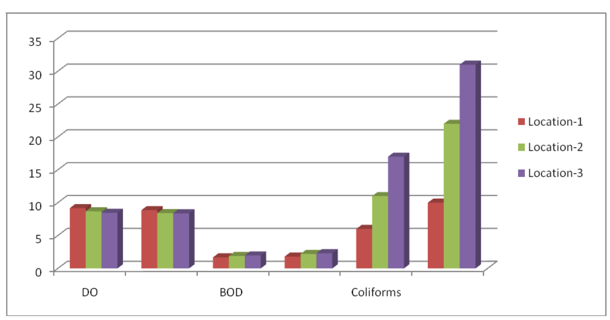

Fig. 2. The levels of DO, BOD and Coliforms at locations 1, 2 and 3 during summer and monsoon

served values are above the WHO prescribed limit of Nil/ 100ml, these low coliform counts suggested the lowest contamination of human and live stock's faecal waste in river water. However, river water at downstream (location 3) exhibited comparatively higher coliform counts (31.0±2.75) during monsoon, than during summer (17±1.67 MPN/100 ml).

Nitrate

Nitrate enters in river water due to inputs of drainage from fertilizers, livestock feeding areas and farm manures, septic systems, decayed vegetables (Madan *et al*., 2013). The presence of nitrates in the water samples is suggestive of some bacterial action and bacterial growth (Majumder *et al*., 2006). During lockdown period (summer months) concentration of nitrate (Table 1) varied from 0.065±0.004, 0.071±0.003 and 0.075±0.003 and during monsoon the values were 0.72±0.003, 0.076±0.005 and 0.79±0.004 mg/l at locations 1, 2 and 3, respectively. All the recorded nitrate values at all the locations were comparatively lower than earlier finding (Sharma *et al*., 2016), suggested that the river water quality was improved during lockdown period.

Phosphate

Phosphate is one of the essential nutrients for all biotic organisms present in a water body. High concentration of phosphate and organic matter favor the algal growth causing condition of eutrophication (Trivedy and Goel, 1986; Majumder *et al*., 2006). The source of phosphates in water bodies are dung water from dairies, laundry effluents, agriculture and urban runoff. The levels of phosphate in all samples were below the WHO limit of 0.10 mg/l. High concentration of phosphate was recorded in monsoon than summer months, as during high flow months rain water carry with it waste water, street and agricultural runoff. The concentration of phosphate in river water samples recorded was 0.037±0.0029, 0.043±0.0036 and 0.045±0.0029 in lockdown period, and 0.041±0.003, 0.044±0.0035 and 0.048±0.0034 mg/l (Table 1) after lifting of lockdown (during monsoon months), respectively at locations1, 2 and 3.

Water quality index (WQI)

The assessment of water quality is needed to find the suitability of water for drinking, cleaning, sanitation, irrigation, construction and industrial purposes (Haritesh *et al*., 2016). The WQI is a 100 point scale that is evaluated on the basis of various physical, chemical and bacteriological parameters to judge the overall water quality of a stream. To determine the WQI, weight age is assigned to each parameter according to their importance and potential impacts on the water quality. The water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of a stream with a single number. This number is placed on a relative scale that rates the water quality in categories ranging from very bad to excellent (Brown *et al*., 1970). Each parameter has its own NSF-WQI *Rating curve* on a scale of increasing water quality from 0 to 100 depending on what values for that parameter are considered *good* or *bad*. *Rating Curves* are plotted from the raw data, showing the level of that water quality for each parameter. *Q-value* for a parameter is obtained by comparing observed results (*raw data*) with the NSF-WQI *Rating curve* of that parameter. Thus obtained Q-value is then multiplied by the *weighting factor*, based on the importance of that parameter. The resulting values are then added to get an overall water quality index (NSF-WQI), which is expressed by following mathematical relation.

Table 2. NSF WQI Analytes, WQI Weights, Descriptor Words and WQI Value Ranges

	NSF WQI Analytes and Weights		Descriptor and WQI Value Ranges	
S. N.	Analytes	WQI Weight	Descriptor	Numerical Range
1	Dissolved Oxygen	0.17	Very Bad	0-25
2	Total Coli forms	0.16		
3	pH	0.11	Bad	26-50
4	BOD	0.11		
5	Nitrates	0.10	Medium	51-70
6	Total Phosphates	0.10		
7	Temperature change	0.10	Good	71-90
8	Turbidity	0.08		
9	Total Dissolved Solids	0.07	Excellent	91-100

$$NSFWQI = \sum_{i=1}^{p} W_i I_i \quad .. (1)$$

Where, **Ii** is the *sub-index* for **i th** water quality parameters, **Wi** is the weight (in terms of importance) associated with **i th** water quality parameter (Brown *et al*., 1970) and **n** is the number of water quality parameters. The higher is the WQI score the better the Quality of water. The scores are then ranked into one of the five categories described in

Table 3. WQI Status of Baldi River- Sahastradhara Sulphur Spring during Lock down

Parameters	Observed Mean Value	Q-value from Rating Curve, Ii	W_i used	Sub Index (W_i x Ii)	WQI	WQ Status
WQI at Location 1 during Lockdown (April-June 2020)						
DO	9.17				WQI = Σ	
Temp. (U/S) ^{0}C	17.94				(W_i x Ii) /	
Temp. (Site) ^{0}C	19.06				Weight factor	
% DO Sat.	98.94	99	0.17	16.83	used	
Coli forms	06.00	78	0.16	12.48		Good
pH	7.65	92	0.11	10.12	78.69 /0.92	(71-90)
BOD	1.68	86	0.11	9.46	85.53	
ΔT ^{0}C	1.12	88	0.10	8.80		
Nitrate	0.065	97	0.10	9.70		
TP	0.037	99	0.10	9.90		
TDS	977	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	78.69		
WQI at Location 2 during Lockdown (April-June 2020)						
DO	8.69					
Temp. (U/S) ^{0}C	19.06				WQI =Σ	
Temp. (Site) ^{0}C	19.43				(W_i x Ii) /	
% DO Sat.	94.35	98	0.17	16.66	Weight factor	
Coli forms	11.00	70	0.16	11.20	used	
pH	7.60	92	0.11	10.12	76.80/0.92	Good
BOD	1.89	82	0.11	9.02	83.48	(71-90)
ΔT ^{0}C	0.37	89	0.10	8.90		
Nitrate	0.071	97	0.10	9.70		
TP	0.043	98	0.10	9.80		
TDS	851	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	76.80		
WQI at Location 3 during Lockdown (April-June 2020)						
DO	8.46					
Temp. (U/S) ^{0}C	19.43				WQI = Σ	
Temp. (Site) ^{0}C	19.74				(W_i x Ii) /	
% DO Sat.	92.53	97	0.17	16.49	Weight factor	
Coli forms	17.00	65	0.16	10.40	used	
pH	7.62	92	0.11	10.12		Good
BOD	1.97	81	0.11	8.91	75.72/0.92	(71-90)
ΔT ^{0}C	0.31	89	0.10	8.90	82.30	
Nitrate	0.075	97	0.10	9.70		
TP	0.045	98	0.10	9.80		
TDS	919	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	75.72		

U/S = upstream, unit of Coliforms = MPN/100 mL, TP = total phosphates, NM = Not measured

Table 2.

When test results fewer than above nine measurements are available, in such case, WQI is obtained by dividing *total of Sub-Index* with *total of weight factor used* (Des Moines River Water Quality Network, 2011, Rai *et al*., 2011). In present study eight water quality parameters, DO, total Coliforms, pH, BOD, nitrates, total phosphate, temperature change and

Table 4. WQI of Baldi River- Sahastradhara Sulphur Spring after lifting of Lockdown

Analytes	Observed value	Q-value from Rating Curve, Ii	Weight factor, W_i	Sub-Index (Li x W_i)	WQI	WQ status
WQI at Location 1 after lifting of Lockdown (During Monsoon)						
DO mg/l	8.86					
Temp. (U/S) ^{0}C	17.90				WQI = Σ	
Temp. (Site) ^{0}C	18.91				(W_i x Ii) /Σ	
% DO Sat.	96.3	97	0.17	16.49	W_i	Good
Coli forms	10.00	72	0.16	11.52	76.55/0.92	(71-90)
pH	7.68	90	0.11	9.90	83.20	
BOD mg/l	1.80	84	0.11	9.24		
ΔT ^{0}C	1.01	85	0.10	8.50		
Nitrate mg/l	0.072	97	0.10	9.70		
TP mg/l	0.041	98	0.10	9.80		
TDS mg/l	977	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	76.55		
WQI at Location 2 after lifting of Lockdown (During Monsoon)						
DO mg/l	8.41					
Temp. (U/S) ^{0}C	18.91					
Temp. (Site) ^{0}C	19.18				WQI = Σ	
% DO Sat.	90.96	95	0.17	16.15	W_i =	Good
Coli forms	22.00	62	0.16	9.92	(W_i x Ii) / Σ	(71-90)
pH	7.64	91	0.11	10.01	W_i	
BOD mg/l	2.20	76	0.11	8.36	74.14/0.92	
ΔT ^{0}C	0.27	88	0.10	8.80	80.58	
Nitrate mg/l	0.076	97	0.10	9.70		
TP mg/l	0.044	98	0.10	9.80		
TDS mg/l	1018	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	74.14		
WQI at Location 3 after lifting of Lockdown (During Monsoon)						
DO mg/l	8.38					
Temp. (U/S) ^{0}C	19.18				(W_i x Ii) / Σ	
Temp. (Site) ^{0}C	19.42				WQI = Σ	Good
% DO Sat.	87.85	93	0.17	15.81		(71-90)
Coli forms	31.00	58	0.16	9.28	W_i 72.93/0.92	
pH	7.66	90	0.11	9.90	79.27	
BOD mg/l	2.31	74	0.11	8.14		
ΔT ^{0}C	0.24	89	0.10	8.90		
Nitrate mg/l	0.079	97	0.10	9.70		
TP mg/l	0.048	98	0.10	9.80		
TDS mg/l	1040	20	00.07	1.40		
Turbidity	N M	0	0	0		
Total			0.92	72.93		

(U/S) = upstream, unit of Coliforms = MPN/100 mL, TP= Total phosphates, NM = Not measured

TDS were used to evaluate the WQI of Baldi river- Sahastradhara Sulphur spring. The results are presented in Table 3, 4 and 5. Measured DO mg/l values were converted to % DO Saturation by using *DO⇆%Saturation Calculator*. To obtained temperature change (ΔT), water temperature was also recorded at *Shera chowki*, nearly 1.6 Km (one mile) upstream to *location 1*, during summer and monsoon.

Table 3 indicated that the water quality status throughout was **Good** and computed values of WQI of Baldi River- Sahastradhara Sulphur Spring during COVID-19 lockdown period were 85.53, 83.48 and 82.30 at upstream, Sahastradhara proper and at downstream, respectively. This was possible as the entire study area was subjected to imposition of restrictions on transport and tourism activities. After lifting up of lockdown in phased manner some outdoor activities were allowed. However, the weekend restrictions (Saturday evening to Monday morning) were continued that discouraged tourist turnout in study area which resulted in limited human activities in the area. All this reflected in terms of **Good** water quality status during lockdown as well as during unlocking process with continued weekend restrictions. The computed WQI values during unlocking process (July- September, 2020) at locations 1, 2 and 3 of the study area were 83.20, 80.58 and 79.27, respectively (Table 4). Thus such a high WQI values computed for lockdown period and after lifting up of lockdown confirmed the improved water quality that resulted due to imposition of various restrictions including human movement, on entire study area and there existed no much difference among the three locations. The WQI values and WQ Status are summarized in Table 5.

Conclusion

Water quality of a hill stream depends upon the geology of the region through which it flows, agricultural inputs, commercial activities and human influences. During summer and weekends, bathing activities by tourists and waste from restaurants etc. lead to increase dumping of solid waste that degrades river water quality. In comparison to earlier findings, this study reported considerable improvement in the Baldi river- Sahastradhara water quality during COVID-19 lockdown period, in terms of high DO (9.17 - 8.38 mg/l), low BOD (1.68 – 2.31 mg/l), coliforms (6 - 31 MPN/100ml), nitrate (0.065 – 0.079 mg/l) and phosphate (0.037 – 0.048 mg/l) that reflected in overall WQI at studied locations. The improvement was on account of effective implementation of imposed restrictions during the lockdown period on transport, tourism activities, closure of hotels – restaurants and commercial establishments. Continuation of weekend restrictions even after lifting up of lockdown during monsoon also made possible human activities at minimal, around the entire study area. Upstream (Location 1) of the study area (Baldi River) exhibited high NSF-WQI values (85.53 and 83.20) during lockdown period and after lifting up of lockdown, respectively. However, computed WQI values at *Sahastradhara proper* (Location 2) were, 83.48 and 80.58, respectively during the same period. On the other hand, at Baldi river *downstream* (location 3) WQI values during lockdown period and during unlocking process were 82.30 and 79.27, respectively. The WQ Status of Baldi River - Sahastradhara being *Good* at all the locations, throughout. However, when using for human consumption Baldi River water needs pre-treatment.

Table 5. Season WQI Model wise NSF-WQI and WQ Status of Baldi River- Sahastradhara Sulphur Spring using NSF-

Sampling Sites	Season/ Months	NSF-WQI	WQ status
Location 1 (Baldi River upstream)	During lockdown (April- June)	85.53	Good (71-90)
	After lifting of lockdown (July- September)	83.20	
Location 2 (Sahastradhara proper)	During lockdown (April- June)	83.48	Good (71-90)
	After lifting of lockdown (July- September)	80.58	
Location 3 (Baldi River downstream)	During lockdown (April- June)	82.30	Good (71-90)
	After lifting of lockdown (July- September)	79.27	

The imposed restrictions not only served the purpose to control effectively the spreading of COVID-19 pandemic, but has also resulted relatively clean environment especially significant reduction in air pollution. Similarly, the rivers have shown early signs of rejuvenation at least for lockdown period, that within few days of restrictions, river water were so clean that river beds were visible clearly. These restrictions has also created glimpses of hope in the minds of 1350 million Indian citizens that in coming days, effective and united efforts of all, may rejuvenate our water bodies and environment.

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