Sustainable Development Research; Vol. 2, No. 2; 2020
ISSN 2690-9898 E-ISSN 2690-9901
https://doi.org/10.30560/sdr.v2n2p10

Comparative Study of Conventional Groundwater Quality Results with WQI Technique: A Case Study of Surjani Town, Karachi, Pakistan

Adnan Khan[1], Aasma Khan[2], Bisma Naz[1] & Rukhsar[1]

[1] Department of Geology, University of Karachi, Pakistan

[2] Department of Chemistry, University of Karachi, Pakistan

Correspondence: Adnan Khan, Department of Geology, University of Karachi, Pakistan. Tel: 923-0036-35848. E-mail: adkhan@uok.edu.pk

Received: November 1, 2020 Accepted: November 12, 2020 Online Published: November 19, 2020

Abstract

Present study is aimed to calculate the water quality index (WQI) of Surjani Town by using weighted arithmetic index method to assess its suitability for drinking purpose. For calculating WQI, 12 parameters (pH, TDS, EC, Hardness, Na, Ca, K, Mg, HCO_3, SO_4, NO_3 and Cl) have been taken into account. Except pH, all physicochemical parameters are exhibiting the maximum prominence in WQI quality rating scale (Qn) which suggests that groundwater is highly polluted. The computed value of water quality index (WQI= 331.62) is also found to be high which is comparable with enormously high concentrations of physicochemical parameters that are violating the WHO admissible limit for drinking purpose. Results revealed that the groundwater is under the influence of anthropogenic activity from nearby Jam Chakro solid waste dumping site. It is concluded that groundwater is highly deteriorated which is immensely inappropriate for drinking purpose according to WQI rating score.

Keywords: Groundwater Quality, Quality Rating Score (Qn), Unit weight (Wn), Weighed Arithmetic Index, WQI, Anthropogenic Activity, Surjani Town

1. Introduction

Water quality assessment is one of the most important aspects which determine the chemical, physical and biological characteristics of water with respect to its suitability for a particular purpose i.e. drinking, irrigation, fishing and swimming. (Diersing N. 2009; Sargaonkar, et al., 2003; Khan, et al., 2003). Generally, traditional groundwater quality assessment consists of comparing the results of individual water quality parameters with guideline or standard values based on allocated water use. This type of assessment is simple and detailed but insufficient to provide a whole and interpreted picture of water quality (Abtahi, et al., 2013). For this purpose, a number of water quality indices have been developed to summarize groundwater quality data into an integrated indicator value. Hence, WQI method has been discovered which is a useful and an efficient technique to assess the groundwater quality (Khwakaram, et al., 2012). Horton (1965) proposed the first WQI by weighting some water quality variables, and then it was further modified by Brown, et al. (1970). Besides, WQI is a dimensionless number which transforms complex water quality data into a single numerical score using mathematical tools (Srebotnjak, et al., 2012; Lumb, et al., 2011) which provides an extensive interpretation of the water quality and its suitability for various purposes (Abbasi 2002). Although, it is commonly used for detection and evaluation of water pollution (Priya and Vidya 2019). For establishment of WQI, the standard guideline values are used for each physicochemical parameter. The calculated WQI value is then classified into five categories which are ranging from 0 to 100 and classifies water bodies as excellent (0-25), good (25-50), fair (51-75), poor (76-100), very poor (101-150) and unfit for drinking (>150) (Brown, et al., 1972).

In order to testify this method and to classify the water quality, present study is aimed at assessment of groundwater data of Surjani Town which has already been declared unfit for drinking purpose due to extremely high concentration of measured parameters which is consistent with the transportation of leachate from nearby landfill site (Khan, et al., 2020).

2. Materials and Methods

2.1 Study Area

Study area is located in the northwest of Karachi city which lies between 25.00942^0 N to 67.417^0E (Fig. 1). Geologically, Surjani Town is resting on Gaj Formation of Miocene age which mainly comprises clastic sediments (sandstone and shale) with subordinate limestone. Study area sets on the common flank of Lalji syncline (western flank) and Manghopir anticline (eastern flank). It is the largest subdivision of Gadap Town which spreads over a land of 1200 sq. km. A landfill site is also located in the vicinity of study area at a distance of approximately 7 km. Surjani town is an affordable and low-income locality where lower to middle class is being accommodated. Due to shortage of municipally supplied water, residents of study area are highly depending on the groundwater for domestic purpose and extract through electrically pumped bore wells.

2.2 Sample Collection and Analysis

Groundwater samples were carefully analyzed in the laboratory for its physico-chemical characteristics by standard analytical techniques (Table 1). Groundwater samples (n = 28) were collected from wells at variable depth range (35-220 ft.) through electrically pumped wells. Well water was pumped for 2 to 10 minutes subject to the depth of well. Plastic bottles of 1000 ml capacity were used for sample collection to determine physicochemical parameters. Bottles of 100 ml capacity were also used for nitrate determination in which about 1ml of boric acid solution (1%) was added to cease any further reaction. Sample bottles were thoroughly washed with distilled water and rinsed properly with well water. The field coordinates of sample locations were noted by using GPS (Global Positioning System) and plotted on the Google image (Fig. 1).

2.3 Determination of Water Quality Index (WQI)

Groundwater quality of Surjani Town was evaluated by using weighted arithmetic index method of WQI as proposed by Brown et al. (1970). Twelve physicochemical parameters (pH, TDS, EC, hardness, Na, K, Ca, Mg, HCO_3, Cl, SO_4, and NO_3) have been considered in WQI calculation.

2.3.1 Calculation of Unit Weight

First step in WQI calculation involves the estimation of unit weight (Wn) of all physicochemical parameters. The unit weight (Wn) is inversely proportional to the recommended standards for the corresponding parameters.

$$Wn = k / Sn$$

Where,

Wn = unit weight for the nth parameter

Sn= Standards permissible value for nth parameter

k= proportionality constant which is calculated by following formula

$$K = \frac{1}{\sum(\frac{1}{Vs})}$$

2.3.2 Calculation of Quality Rating

Second step involves in the estimation of quality rating scale (Qn) for each parameter by using the following equation.

$$Qn = [(Vn - Vi)/(Vs - Vi)] \text{x } 100$$

Where,

Qn = Quality rating of nth water quality parameters

Vn = Observed value of the water quality parameter obtained from laboratory analysis

Vi = Ideal value, in most cases Vi= 0 except in certain parameters like pH and dissolved oxygen which has Vi=7 and Vi= 14.6 respectively

Vs = Recommended WHO standard of the water quality parameter

Table 1. Analytical technique used for measuring physico-chemical parameters in collected samples

Physicochemical Parameters	Analytical Methods
pH	pH meter (JENCO 6230N)
TDS and EC	EC meter (Eutech Cyber Scan CON 11)
Na and K	Flame photometer (Model No. Jenway PFP7)
Ca and Mg	EDTA titration
SO_4	Gravimetric method
Cl	Standard titration method using silver nitrate
HCO_3	Standard titration method
NO_3	Cadmium Reduction method (HACH-8171) by Spectrophotometer.

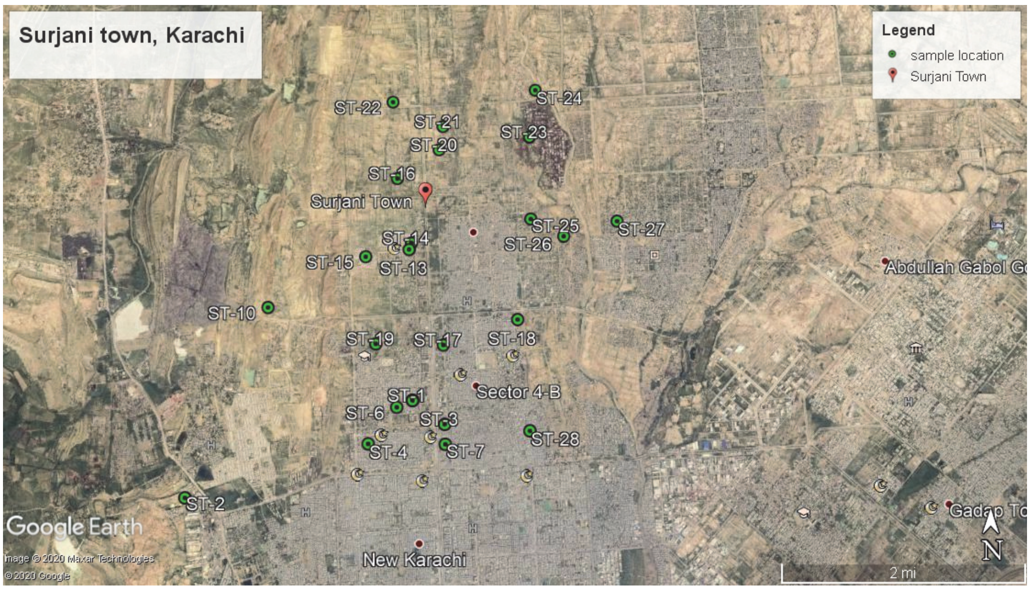

Figure 1. Map showing sample locations of Surjani Town, Karachi

2.3.3 Calculation of WQI

WQI is calculated by aggregating the quality rating with the unit weight linearly by using the following equation:

$$WQI = \Sigma Q_n W_n / \Sigma W_n$$

Where,

Q_n is the quality rating of *n*th water quality parameter

W_n is the unit weight of *n*th water quality parameter.

In last step, the calculated WQI value is classified into five categories in order to testify its suitability for human consumption. The maximum permissible WQI for drinking purpose was taken as 100 score.

3. Results and Discussion

3.1 Physicochemical Characteristics

Description of groundwater chemistry and its comparison with WHO standards have been summarized in Table 2. Data reveal that groundwater pH is highly fluctuating and varies between acidic to alkaline (ranges= 6.5 - 7.6; mean: 7.0) but within the permissible limit of WHO (6.5 - 8.5). Extremely wide range of total dissolved salts (TDS) and total hardness (TH) are observed (range: 609 - 28100 mg/l and 670 - 19750 mg/l) in collected samples. Extremely violating TDS concentration is reported (Mean: 11946 mg/l) which is twenty-three times higher than the permissible limit of WHO (500 mg/l). However, only three wells (ST-3, ST- 4 and ST- 14) have permissible TDS concentration (range= 609 - 847 mg/l).

Table 2. Physicochemical and Statistical descriptive of groundwater chemistry and its comparison with WHO standards

	Physical parameter				Chemical parameter							
					Major Cation				Major Anion			
Sample Code	**pH**	**TDS ppm**	**EC (ms/cm)**	**Hardness (mg/l)**	**Na (mg/l)**	**K (mg/l)**	**Ca (mg/l)**	**Mg (mg/l)**	**HCO3 (mg/l)**	**Cl (mg/l)**	**SO_4 (mg/l)**	**NO_3 (mg/l)**
ST-1	6.7	21800	43.7	6900	8500	49	1400	826.2	925	15035	2897.84	1.09
ST-2	6.5	16700	33.5	8500	7080	68	1740	1008.45	1050	9394	2653.64	0.16
ST-3	7.5	802	1600	760	240	28	68	143.37	1475	195	211.64	0.98
ST-4	7.14	609	1216	670	118	33	108	97.2	850	106	122.1	3.72
ST-5	7.49	6490	12.98	1220	4700	37	164	196.83	450	2399	18445.24	0.78
ST-6	7.41	1270	2.5	1180	420	27	112	218.7	1000	372	301.18	2.33
ST-7	6.9	24600	49.2	10000	9500	52	1400	1579.5	2725	7302	927.96	12.06
ST-8	7.18	7070	15.36	3500	5000	41	324	653.67	775	2630	3191	17.22
ST-9	7	20750	5.47	3000	3300	25	284	556.47	3050	744	830	27.66
ST-10	7.07	10800	21.5	6350	6000	61	792	1061.91	1025	3704	3053	28.89
ST-11	6.91	17500	35	8250	7800	53	1100	1336.5	625	4183	3077	46.75
ST-12	7.6	5100	10.2	3000	3500	46	276	561.33	1325	850	1498	6.65
ST-13	7.16	2640	5.28	4750	3300	50	494	854.145	925	762	521	55.93
ST-14	6.7	847	1697	2300	265	25	64	520.02	2125	159	8067	23.16
ST-15	6.84	1660	33.1	7500	12000	56	1200	1093.5	675	8543	2979	26.88
ST-16	7.34	25400	50.8	9500	11000	80	1100	1640.25	625	13577	2271	6.69
ST-17	7.07	22000	45.6	9450	9500	30	2000	1081.35	725	14304	4005	3.34
ST-18	7.04	1260	75	5350	8500	52	1080	643.95	875	4874	2922	44.4
ST-19	7.02	24500	80	10100	9300	49	2100	1178.55	275	13187	2824	26.22
ST-20	6.65	28100	118	12500	10000	56	2000	1822.5	1125	8330	3402	0.41
ST-21	6.87	3180	91	12500	14000	45	90	2982.825	1400	2658	3834	5.33
ST-22	6.51	3400	105	19750	22700	46	5600	1397.25	300	9926	2613	0.3
ST-23	6.8	6660	785	4900	4200	32	420	935.55	1875	2871	993	14.97
ST-24	7.09	6390	59	4400	5500	20	460	789.75	3375	1595	627	5.06
ST-25	6.9	19700	114	9500	8000	49	1760	1239.3	525	9571	1457	19.02
ST-26	7.3	8260	58	4700	6800	35	396	901.53	3450	921	1009	8.37
ST-27	6.7	26200	75	9500	13000	40	1400	1458	2900	10280	5275	23.04
ST-28	6.8	20800	95	8500	10000	47	1440	1190.7	3000	5884	2377	76.32
Max	7.6	28100	1697	19750	22700	80	5600	2982.825	3450	15035	18445	76.3
Min	6.5	609	2.5	670	118	20	64	97.2	275	106	122	0.16
Mean	**7.006**	**11946**	**233.292**	**6733.214**	**7293.678**	**44**	**1049**	**998.903**	**1409**	**5513**	**2942**	**17.4**
S.D	0.295	239.5	475.5	4337.8	4920.8	13.9	1119	601	988.8	4871	3491.8	19.2
WHO limit	**6.5-8.5**	**500 ppm**	--------	**500**	**200 mg/l**	**12 mg/l**	**200 mg/l**	**150 mg/l**	**300 mg/l**	**250 mg/l**	**500 mg/l**	**10 mg/l**

3.2 Water Solute Chemistry

Concentration of sodium and potassium ions is highly variable in the groundwater of study area (118-22700 mg/l and 20-80 mg/l respectively) where the mean values of both cations (mean: 7293.678 mg/l and 44 mg/l) showed the occurrence of very high concentration against corresponding WHO recommended limits. Only three wells have shown sodium concentration < 300 mg/l which are within the limit or marginally high values (Table 2). Likewise, distribution pattern of calcium and magnesium are also found to be very heterogeneous (range: 64 - 5600 mg/l and

97 - 2982 mg/l). On the other hand, the mean concentration of Ca and Mg ions (± 1000 mg/l) are five and six times higher than the WHO admissible limit (200 mg/l) and (150 mg/l) respectively (Table 2).

Chloride (Cl) and sulphate (SO_4) are the dominant anions followed by bicarbonate (HCO_3) and nitrate (NO_3). The mean concentration of chloride, sulfate and bicarbonate (Mean: 5513 mg/l, 2942 mg/l and 1409 mg/l) ions are extremely variable which are fluctuating between 106 - 15035, 122 - 18445 and 275-3450 mg/l respectively. Data revealed that about one third of total samples show remarkably high chloride content (range: 5885 - 15035 mg/l). Surprisingly high sulfate content (18445 mg/l) is reported in ST-5 well (Table 2). Similarly, high bicarbonate content (range: 1000 - 3450 mg/l) is reported in 50% of the total samples which is seven times higher than the permissible limit of 300 mg/l for drinking water (WHO, 2004). Likewise, nitrate content varied between 0.16 - 76.3 mg/l with a mean of 17.4 mg/l, where about half of the collected samples (n=14) showed nitrate content >10 mg/l which have objectionable concentration up to 76.3 mg/l (Table 2).

Table 3. WHO standard values (Vs) and unit weights (Wn) of their corresponding parameters

Parameters	**WHO Standard Vs**	**1/Vs**	**K (constant)** $K = \frac{1}{\sum(\frac{1}{Vs})}$	**Unit weight Wn=k/Vs**
pH	8.5	0.12	2.9	0.34
TDS (mg/L)	500	0.002	2.9	0.006
Hardness (mg/L)	500	0.002	2.9	0.006
Na (mg/L)	200	0.005	2.9	0.0145
K (mg/L)	12	0.083	2.9	0.24
Ca (Mg/L)	75	0.013	2.9	0.04
Mg (mg/L)	150	0.007	2.9	0.02
HCO3 (mg/L)	300	0.003	2.9	0.01
Cl (mg/L)	250	0.004	2.9	0.012
SO4 (mg/L)	250	0.004	2.9	0.012
NO3 (mg/L)	10	0.1	2.9	0.29
				∑Wn=0.99

3.3 Water Quality Index (WQI)

Groundwater chemistry was determined to evaluate the water quality index (WQI) of Surjani Town for drinking purpose as proposed by Brown et al (1970). Generally, water quality index is the reflection of composite influence of individual water quality parameter on the overall quality of water (Mitra and ASABE member, 1998). For computing WQI, the WHO standards for drinking water parameters have been taken into account. Twelve physicochemical parameters (pH, TDS, EC, Hardness, Na, K, Ca, Mg, HCO3, Cl, SO4 and NO3) have been selected which are mainly based on their direct influence for deteriorating groundwater quality for human consumption (Priya and Vidya, 2019). Further, the values of these parameters will proportionally increase WQI value (Priya and Vidya, 2019).

Table 4. Calculation of water quality index of Surjani Town

Parameters	**Observed Value (Vn)**	**WHO standard (Vs)**	**Ideal Value (Vi)**	**Vn-Vi**	**Vs-Vi**		**Unit weight Wn=k/Vs**	**Qn*Wn**
pH	7.006	8.5	7	0.006	1.5	0.04	0.34	0.0136
TDS (mg/L)	11946	500	0	11946	500	2389.2	0.006	14.335

Hardness (mg/L)	6733.21	500	0	6733.214	500	1346.64	0.006	8.08
Na (mg/L)	7293.68	200	0	7293.678	200	3646.84	0.0145	**52.88**
K (mg/L)	44	12	0	44	12	366.67	0.24	**88**
Ca (Mg/L)	1049	75	0	1049	75	1398.67	0.04	**55.9**
Mg (mg/L)	998.90	150	0	998.90	150	665.94	0.02	13.32
HCO3 (mg/L)	1408.93	300	0	1408.93	300	469.64	0.01	4.7
Cl (mg/L)	5513.13	250	0	5513.13	250	2205.25	0.012	26.46
SO4 (mg/L)	2942.32	250	0	2942.32	250	1176.93	0.012	14.123
NO3 (mg/L)	17.418	10	0	17.42	10	174.18	0.29	**50.5**
							∑Wn=0.99	**∑QnWn=328.3**
				WQI=331.62				

First step in WQI calculation involves the estimation of unit weight (Wn) assigned to all selected physicochemical parameters. By assigning unit weights, all the concerned parameters of different units and dimensions are transformed into common scale (Priya and Vidya, 2019). The recommended standard values (Vs) and unit weights (Wn) of their corresponding parameters in WQI assessment are represented in Table 3. It is showing that the parameters such as pH, K and NO_3 which is usually required in least amount has more unit weight because the recommended water quality standard (Vs) is inversely proportional to unit weight Wn (Kumar and Dua, 2008).

Second step involves the determination of quality rating of all selected parameters by using the formula: $Qn = 100*[(Vn - Vi)/(Vs - Vi)]$. If quality rating $Qn = 0$ means complete absence of pollutants, while $0 < Qn < 100$ implies that the pollutants are within the prescribed standard and when $Qn > 100$ indicates that the pollutants are above the standards (Gungoa, 2016). Except pH, *Qn* values of all physicochemical parameters are above 100 which suggest that the groundwater is highly polluted (Table 4). Likewise, the parameters such as K > Ca > Na > NO_3 is showing highest influencing values in WQI computation as shown in Table 4. These parameters are exhibiting maximum prominence in WQI calculation.

In last step, computed WQI values are classified into five categories to evaluate the corresponding water quality status, the best value of water quality was given a low range and the bad level is designated to higher values as shown in Table 5 (Yogendra and Puttaiah, 2008).

Table 5. WQI range and corresponding water quality status (after Brown et al., 1972).

WQI	Status	Possible usages
0-25	Excellent	Drinking, irrigation and industrial
25-50	Good	Domestic, irrigation and industrial
51-75	Fair	Irrigation and industrial
76-100	Poor	Unsuitable for drinking
101-150	Very poor	Restricted use of irrigation
> 150	Unfit for drinking	Proper treatment required for use

The result of water quality index shows that the groundwater of Surjani town is inadmissible for drinking purpose in WQI rating scale (WQI= 331.62) which is consistent with the extremely high concentration of measured physicochemical parameters (Table 2). The non-suitability of groundwater is mainly attributed to the anthropogenic activities such as waste disposal, agricultural activities and pollution from nearby open dumpsite (Ameen, 2019). Moreover, the computed results are comparable with the recent study carried out in Surjani Town (Khan, et al., 2020) which reveals that the groundwater is being contaminated by leachate migration from nearby Jam Chakro landfill site.

4. Conclusion

Weighted arithmetic index method of WQI has been applied to evaluate the groundwater quality of Surjani Town for drinking purpose. The computed WQI results (331.62) clearly shows that the groundwater is highly deteriorated and unfit for drinking purpose in terms of WQI rating scale. The high WQI values are consistent with the extremely high concentration of measured physicochemical parameters in study area. It is concluded that the groundwater is mainly influenced by anthropogenic activities from adjacent landfill site which seems to be the main factor for groundwater contamination.

Acknowledgement

Authors are indebted to Department of Geology, University of Karachi for providing the analytical facilities.

References

Abbasi, S. A. (2002). Water quality indices. *Elsevier*. Amsterdam.

Abtahi, M., Mohebbi, M. R., Saeedi, R., Montazeri, A., Vaghefi, K. A., Labbafi, S., Oktaie, S., & Mohagheghian, A. (2013). Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). *Ecological Indicators, 30,* 28-34. http://dx.doi.org/10.1016/j.ecolind.2013.02.008

Ameen, A. H. (2019). Spring water quality assessment using water quality index in villages of Barwari Bala, Duhok, Kurdistan Region, Iraq. *Applied Water Science, 9,* 176. https://doi.org/10.1007/s13201-019-1080-z

Brown, R. M., McClelland, N. I., Deininger, R. A., Tozer, R. G. (1970). A water quality index: Do we dare? *Water & Sewage Works*, *117*, 339-343.

Brown, R. M., McClelland, N. I., Deininger, R. A., & O'Connor, M. F. (1972). A water quality indexcrashing the physiological barrier. *Indic. Environ. Qual*, *1,* 173-182.

Diersing, N. (2009). Water Quality: Frequently Asked Questions. Florida Keys National Marine Sanctuary, Key West, FL. Retrieved from http://floridakeys.noaa.gov/scisummaries/wqfaq.pdf.

Gungoa, V. (2016). Use of Water Quality Indices for Water Quality Assessment in Small Island State: A Case Study in the Northern Aquifer of Mauritius. *International Journal of Sciences: Basic and Applied Research*, *30,* 142-150.

Horton, R. K. (1965). An index number system for rating water quality. *Journal-Water Pollution Control Federation*, *37*, 300-305. http://dx.doi.org/10.26479/2019.0502.08

Khan, A., Khan, S. A., Saeed, Z., & Naz, B. (2020). Impact of Leachate Percolation on Groundwater Quality near the Municipal Open Dumpsite (Jam Chakro): A Case Study of Surjani Town, Karachi, Pakistan. *International Journal of Ground Sediment & Water, 10,* 541-556.

Khan, F., Husain, T., & Lumb, A. (2003). Water quality evaluation and trend analysis in selected watersheds of the Atlantic Region of Canada. *Environmental Monitoring and Assessment*, *88,* 221-242. http://dx.doi.org/ 10.1023/a:1025573108513.

Khwakaram, A. I., Majid, S, N., & Hama, N, Y. (2012). Determination of water quality index (WQI) for qalyasan stream in sulaimani city/ kurdistan region of iraq. *Ijapes, 2*(4), 148-157.

Kumar, A., & Dua, A. (2008). Water quality index for assessment of water quality of river ravi at madhopur (india). *Global journal of environmental sciences, 8*(1), 49-57. http://dx.doi.org/ 10.4314/gjes. v8i1.50824

Lumb, A., Sharma, T., & Bibeault, J. F. (2011). A review of genesis and evolution of waterquality index (WQI) and some future directions. *Water Qual. Expo. Health, 3,* 11-24.

Mitra, B. K., & ASABE Member. (1998). Spatial and temporal variation of ground water quality in sand dune area of aomori prefecture in Japan.

Priya, T. D., & Vidya, A. K. (2019). Evaluation of water quality index using physicochemical parameters of treated domestic sewage water. *Life Science Informatics Publications, 5*(2), 98.

Sargaonkar, A., & Deshpande, V. (2003). Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environmental Monitoring and Assessment*, *89*, 43-67. http://dx.doi.org/ 10.1023/A:1025886025137

Srebotnjak, T., Carr, G., Sherbinin, A., & Rickwood, C. (2012). A global water qualityindex and hot-deck imputation of missing data. *Ecol. Indic, 17,* 108-119. http://dx.doi.org/10.1016/J.ECOLIND.2011.04.023

Yogendra, K., & Puttaiah, E. (2008) Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka. Paper presented at the Proceedings of Taal 2007: The 12th World Lake Conference.

Copyrights