Water Quality Index (WQI) for Evaluation of the Surface Water Quality of Bangladesh and Prediction of WQI from Limited Parameters

Zayed Mallick[a], Md Rakib Bin Hossain[a], Fariha Tasannum Ayshi[a], Addrita Tahsin[b], Synthia Parveen Mallick[c*]

[a]Department of Environmental Science & Management, North South University, Bashundhara, Dhaka-1229, Bangladesh

[b]Institute of Water and Flood Management, Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh

[c]Department of Civil, Construction and Environmental Engineering, Marquette University, 1637 West Wisconsin Avenue, Milwaukee, WI 53233

Emails:

Zayed Mallick: zayed.mallick@northsouth.edu

Md Rakib Bin Hossain: rakib.hossain01@northsouth.edu

Fariha Tasannum Ayshi: fariha.ayshi@northsouth.edu

Addrita Tahsin: addrita.tahsin16@gmail.com

[*]Corresponding author: synthiaparveen.mallick@marquette.edu, +1 (409)-225-0454

Final published version can be downloaded freely from the journal website:

http://www.aiscience.org/journal/paperInfo/jepsd?paperId=5338

Abstract

Healthy aquatic environment is crucial for preserving aquatic lives in surface waters. Increasing discharge or run-off from industrial or agricultural sources can pollute water leading to an unhealthy aquatic environment that can cause distress in fishes and other aquatic lives. In places with lack of infrastructure and regulatory enforcement, pollution can be particularly challenging to handle. Assignment of an indexing system can be helpful for analyzing pollution pattern in the polluted rivers which can be helpful for remediation purposes and prevention of future pollution. Bangladesh currently does not have any indexing system in place. Assignment of indices in the rivers of Bangladesh can be helpful for remediation of the rivers on a preferential basis as remediation of all the rivers at once will pose challenges with funding and infrastructural allocation. Parameters monitored in the water monitoring stations of ten rivers were extracted from the reports published by the Department of Environment (DOE) of Bangladesh. A water quality index (WQI) was assigned on the rivers across seven years of time period to identify the most polluted rivers. The degree of pollution in the river was in the order of Mayuri > Buriganga > Korotoa > Turag > Shitalakhya > Surma > Halda > Dhaleshwari > Mathavanga > Brahmaputra based on the WQI analysis. The most polluted rivers were located in areas with manufacturing, textile etc. industries. Hence, monitoring of industrial discharge intro the rivers and regulatory enforcement is crucial for the prevention of pollution in rivers. Installment of more monitoring stations and more frequent samplings can be helpful for better assessment of WQI of the rivers. However, deployment of these strategies can be challenging for Bangladesh due to funding and infrastructural constraints. Hence, a formula has been derived in this study to calculate WQI in a resource limited situation (WQI = 4.42 – 0.42 Dissolved oxygen + 0.11 Biochemical oxygen demand).

Keywords: Water quality, water quality index, dissolved oxygen (DO), biochemical oxygen demand (BOD), industrial discharge, pollution

Highlights

- Rivers located in industrialized areas were highly polluted
- The five most polluted rivers were Mayuri, Buriganga, Korotoa, Turag, and Shitalakhya
- Brahmaputra and Mathavanga were in good condition
- Water quality index (WQI) can be predicted using the relationship derived in this study.

1. Introduction

All living being need water for sustaining life. Quality of life is directly correlated to accessibility of clean water [1]. However, to meet the increasing demand for food and various products, demand for agricultural and industrial production is increasing with time which consequently causes water pollution with high strength agricultural run-off and industrial discharge into receiving water bodies [2]. With a lack of well-developed infrastructure and regulatory enforcement, water pollution is particularly more prevalent in the developing countries [3]. Moreover, remediation of polluted waterbodies also poses challenge for implementation due to lack of financial resources [4]. However, use of polluted water for everyday needs including for drinking, cooking, bathing, and irrigation is a common trend in the developing countries [5]. This poses a public health risk along with a high risk associated with sustaining healthy aquatic lives in the waterbodies. Hence, remediation of polluted waterbodies is crucial for sustainable water resources management.

Bangladesh is relatively a small country consisting of about 700 rivers, including tributaries flowing through it that are a key source of domestic, industrial, and agricultural water use [6]. These rivers are major role players in the advancement of economic growth of Bangladesh as they provide multiple uses including transportation of goods and production materials [7]. However, rapid and unplanned urbanization and industrialization to meet the demands exerted by an overly populous country resulted in an overabundant and unchecked pollution of the river waters in Bangladesh with untreated discharge or run-off of chemical, industrial and agricultural wastes, micro-organisms, or fecal matters [8,9]. In addition to the anthropogenic activities, river water is also polluted for a combination of other factors such as geochemical factors, chemical composition, and lithogenic structure [7,10]. About 80% of diseases in the world are caused due to poor hygiene and contaminated water [6]. Water pollution negatively affects the quality of life for both terrestrial and aquatic beings, directly or indirectly. Therefore, water quality needs to be closely monitored and maintained for achieving sustainable economic and social development, and preservation of terrestrial and aquatic beings.

Generally, river water quality can be evaluated based on several physical, biological, and chemical parameters [7]. For instance, the National Science Foundation (NSF) recommends evaluation of water quality by monitoring dissolved oxygen (DO), biochemical oxygen demand (BOD), fecal coliform, pH, temperature, total phosphate, nitrate, turbidity, total solids etc. and assigns weights to each parameters to determine the overall quality of a water body [11]. The combination of the monitored parameters in different intensities helps define the status of pollution and determine the degree of it for a certain surface water body [12]. Hence, a single parameter assignment considering the monitored parameters and associated values can help quantify the degree of pollution and water quality of a water body. Generally, the cumulative assessment of the monitored parameters is quantified as an index termed as water quality index (WQI) which is a useful tool for overall water quality evaluation [12]. The assignment of weights on different parameters and which parameters are considered for WQI calculation can vary across different kind of water quality monitoring agencies. WQI has been used as a strong tool for water quality assessment in different countries for the purposes of aquatic ecosystems preservation and monitoring of water usage for different purposes [1,13]. As discussed above, assessment of water quality is often poorly structured in the developing countries. Consequently, a universal WQI assignment and evaluation is seldom prevalent among the developing countries. Similarly, Bangladesh currently monitors a few parameters only and there has been no attempt at employment of WQI to assess water quality quantitatively and qualitatively in the country. A

WQI particularly adopted for the monitored parameters in Bangladesh will be useful for determining water quality and the degree of pollution in the rivers of Bangladesh. Evaluation of the pollution level in different waterbodies will be helpful in remediation planning and management by focusing on the most polluted waterbodies on priority basis.

The Department of Environment (DOE) of Bangladesh monitors some parameters at different monitoring stations, but DOE does not assign WQI to the different waterbodies. There are several published works on assigning WQI to different water sources in Bangladesh. Two of the identified studies were focused on WQI for groundwater while other studies focused on WQI for surface water. Iqbal et al. (2020) studied and assigned WQI for groundwater quality evaluation in Bangladesh [14]. Assignment of WQI for groundwater quality evaluation in Tala Upazila in the Sathkhira district covering a smaller geographical area has also been reported [15]. However, surface water is the main resource for water usage in different sectors and it is directly correlated to a well-preserved aquatic ecosystem. Hence, WQI assignment to surface water bodies will be helpful for preservation of aquatic systems and remediation of the polluted waterbodies to achieve sustainable water resources management [10]. Currently, there are limited studies investigating different surface water quality parameters to employ WQI to surface waterbodies in Bangladesh. Hossain et al. (2019) studied water quality of the Karnaphuli river by assigning WQI at five different sampling locations of the river [16]. Similar studies were published on WQI assignment based on selected parameters at different sampling locations of Buriganga, Turag and Dhaleshwari rivers [17,18,19,20]. However, a more holistic approach for WQI assignment on the main rivers and more widespread area of Bangladesh is yet to be employed. Assignment of WQI to several major rivers, especially those located in industrialized areas, will be helpful for identifying the rivers requiring the most focus for remediation. Moreover, trend analysis of water quality by studying WQI of a number of rivers across a several years of time period will help understand the overall timeline, degree of improvement or deterioration in the rivers. Additionally, a simplified formula for WQI prediction with one or two parameters will be helpful for countries like Bangladesh where monitoring of more parameters might be challenging due to lack of funds and access to other resources. Therefore, the objective of this study is to (i) analyze DO and BOD trend in the selected rivers, and (ii) assign and analyze WQI trend in ten selected rivers and investigate the correlation of WQI with the observed parameters. A correlation between WQI with one or two most frequently observed parameters (DO and BOD in Bangladesh) will help evaluate water quality in a resource limited situation, especially in developing countries, where monitoring of more parameters might be limited by availability of funds and infrastructures.

2. Methods

Ten rivers were selected based on the availability of most data points both in terms of number of parameters and timeline of data collection for trend analysis of parameters (DO and BOD) and WQI calculation [Figure 1]. Moreover, the selected ten rivers were located in industrialized, urban residential or agricultural areas. The ten selected rivers were Buriganga, Shitalakhya, Turag, Dhaleshwari, Brahmaputra, Halda, Moyuri, Surma, Korotoa, Mathavanga. Among these rivers, Buriganga, Shitalakhya, Turag, Dhaleshwari, Moyuri, Surma, Korotoa rivers have different types of industries located on their banks or in surrounding areas. Halda flows though areas where tea gardening is prevalent while Mathavanga flows through Chuadanga district that is mostly agricultural economy dependent. Brahmaputra flows through an urban unindustrialized residential area, Mymensingh district.

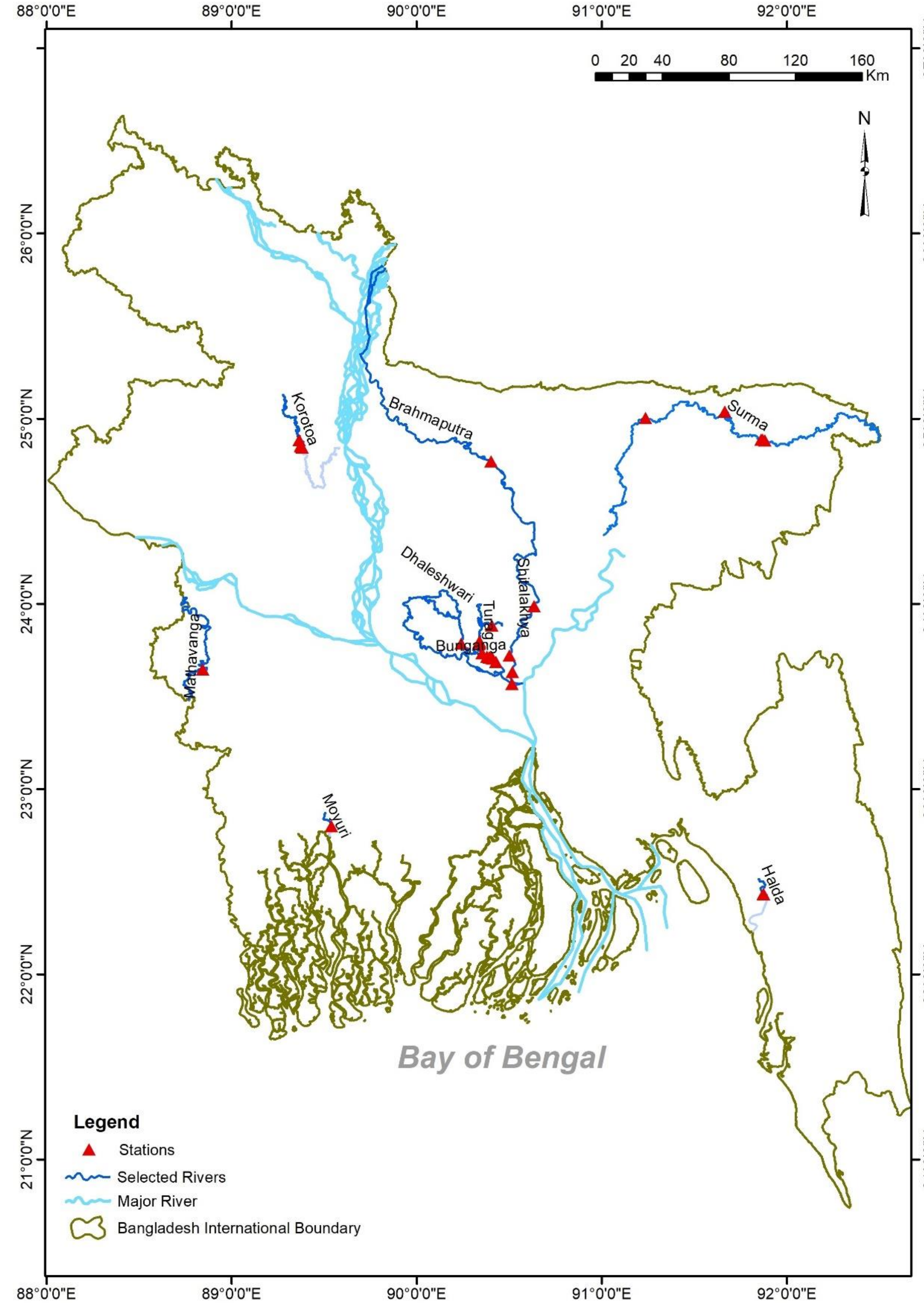


Figure 1: Map of Bangladesh showing the ten selected rivers and corresponding monitoring stations

Water quality reports published by the DOE from 2010 till 2016 (the latest published report) were extracted for analysis of DO and BOD trend for seven years (2010 – 2016) and WQI calculation using DO, BOD, pH, and SS [21,22,23,24,25]. Among the four parameters used for WQI calculation, DO and BOD trend over the years was analyzed for the ten selected rivers as pH was found to be near the neutral range and SS data was not available for all rivers across the observed time period. Moreover, DO and BOD can be a good indicator of pollution in the rivers. The amount of oxygen available in water for aquatic uptake is DO and if it drops between 2 – 4 mg/L, fishes get distressed in a hypoxic condition [26]. BOD is an indirect measurement of the organic matters present in water which is quantified by tracking DO depletion needed for degradation of the organic matters [27]. Therefore, there is a DO depletion in a water sample with high BOD concentration; typically, BOD greater than 15 mg/L indicates a very polluted water unsustainable for healthy aquatic environment. In a limited data acquisition situation, DO and BOD can be very helpful for determining water quality of a waterbody. Therefore, DO and BOD was calculated for all ten rivers from 2010 – 2016 using the data extracted for DOE reports.

In addition to DO and BOD, two other parameters, i.e. pH and SS were considered for WQI calculation. For aquatic sustainability, pH ranging from 6 – 9 is sufficient and a sudden change in pH of a water indicates introduction of foreign matters into the waterbody [28]. The amount of insoluble matters is quantified as SS which might be an indicator of a number of aquatic events, i.e. runoff of particulate organics, algal bloom etc. WQI was calculated using a weighted average of four parameters, i.e. DO, BOD, suspended solids (SS), and pH. Weights were employed on DO, BOD, SS, and pH according to their values and an average of the assigned weighted values were calculated for quantifying the water quality of the rivers as WQI [Equation 1].

$$WQI = \frac{1}{n}\sum_{i=1}^{n} I_i \qquad \text{[Equation 1]}$$

where, n = the number of parameters monitored, and I is the weight normalized value assigned to the monitored parameters.

The weights assigned to the parameters for WQI calculation was conducted following weight assignment proposed by Liou et al. (2004) [28]. Table 1 lists the weight assignment to the parameters used in this study for WQI calculation.

Table 1: Weight assignment on the parameters (pH, dissolved oxygen, biochemical oxygen demand, suspended solids) used for water quality index (WQI) calculation

Parameter weight		**Parameters for WQI calculation**			
Qualitative interpretation	**Quantitative weight**	**pH**	**DO (mg/L)**	**BOD (mg/L)**	**SS (mg/L)**
Good	1	6.5 – 8.5	> 6.5	< 3	< 20
Slightly polluted	3	4.6 – 6.4, 8.6 – 10.4	4.6 – 6.4	3 – 4.9	20 – 49
Moderately polluted	6	2 – 4.5, 10.5 – 12	2 – 4.5	5 – 15	50 – 100
Very polluted	10	< 2, > 12	< 2	> 15	> 100

A qualitative interpretation of the WQI was made according to Table 2.

Table 2: Qualitative interpretation of water quality index (WQI) assigned to the rivers

Water quality index (WQI)	Quantitative interpretation
< 2	Good
2 – 2.9	Slightly polluted
3 – 4.9	Moderately polluted
≥ 5	Very polluted

In addition to the assigned weights and WQI calculation, regression analysis of the data points across seven years were performed to analyze correlation of WQI with DO or BOD or both to help predict water quality of rivers in resource-limited situations where only DO or BOD parameters are available for monitoring. The regression analysis was performed using the Analysis ToolPak add-on provided with Microsoft Excel.

3. Results & Discussion

3.1. Dissolved oxygen (DO) level in ten selected rivers

The amount of gaseous form of oxygen (O_2) dissolved in the water is measured as DO which indicates the availability of oxygen for aquatic uptake. DO is therefore crucial for all forms of aquatic lives [29]. By the direct absorption of O_2 from the atmosphere, rapid movement of water and byproduct of photosynthetic activities atmospheric oxygen enters water. A number of factors including temperature, salinity, presence of organic matter can affect DO level in water. The DO levels in the ten selected rivers were extracted from the DOE reports and then annual average was calculated to analyze trends of DO change 2010-2016 for all ten rivers as presented in Figure 2.

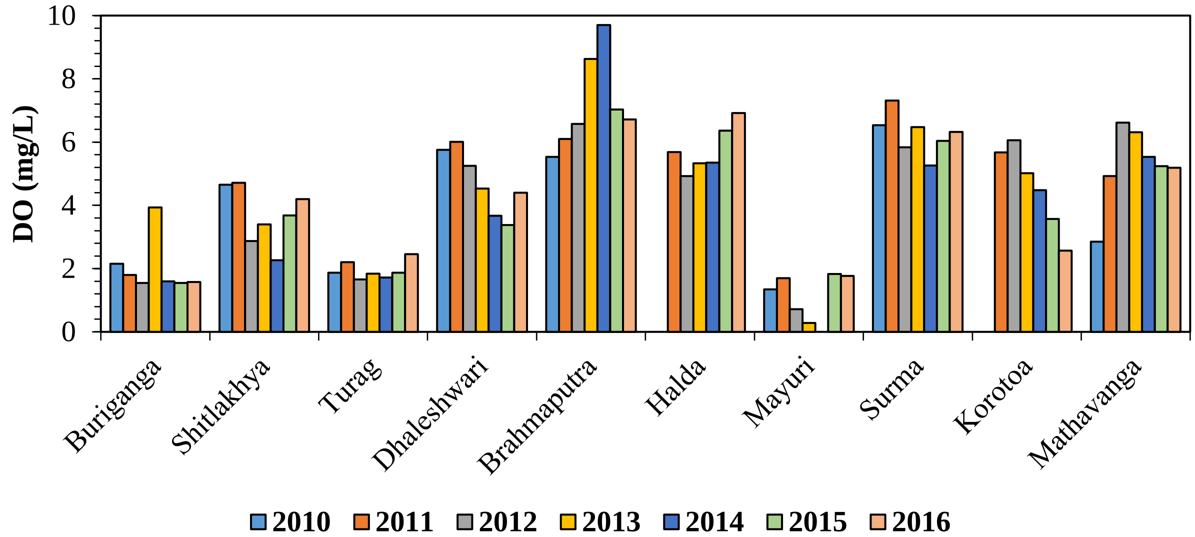


Figure 2: Level of dissolved oxygen (DO) in ten rivers of Bangladesh across a time period of seven years starting from 2010 till 2016.

Three rivers, Buriganga, Turag and Mayuri had overall the lowest DO for the seven years of period. Except for 2013, DO level was near or below 2 mg/L (1.575 – 2.150 mg/L) in Buriganga in all other years. Similarly, DO of Turag was in the range of 1.66 – 2.455 mg/L all through the seven years. The extremely hypoxic conditions in Buriganga and Turag might have been caused by industrial pollution as both these rivers are located in the heavily industrialized areas of Bangladesh [5,18]. The surrounding areas of Buriganga is a hotspot for the tannery industry while many textile industries are located on or near the banks of Turag. Mayuri had 0.280 – 1.675 mg/L DO in all through the seven years. Apart from industrial pollution, another reason for low level of DO in Mayuri can be relatively higher salinity in Mayuri as the river is very closely located near the Bay of Bengal.

Shitalakhya, Dhaleshwari, and Korotoa had DO level near 4 mg/L in the recent reported years, showing an overall downward trend. Shitalakhya river water sampling locations were near two of biggest factories in the country, Advanced Chemical Industries (ACI) Factory and Ghorashal

Fertilizer Factory. Dhaleshwari river water sampling stations were in Munshiganj and Hemayetpur surrounded by manufacturing and textile industries. Korotoa river sampling locations were in Bogura district where economy is heavily agriculture dependent with some minor industries in the area. While DO level of Shitalakhya and Dhaleshway rivers were above 4 mg/L in 2016, it showed an ever-decreasing trend for Korotoa river reaching 2.565 mg/L in 2016.

Brahmaputra, Halda, and Surma had near 6.5 mg/L DO in recent reported years while Mathavanga shows a downward trend for DO starting from 2012, the only year it had DO greater than 6.5 mg/L. Mathavanga river sampling locations were in Chuadanga, an agriculture dependent district. Brahmaputra and Halda sampling locations were in unindustrialized areas where sampling locations of Surma were near a few manufacturing industries including Chhatak Cement Factory. Level of DO in Brahmaputra was above 6.5 mg/L in 2012, 2013 and then decreased in the next few years. Surma's DO level stayed at the same level ranging from 6.04 – 7.315 mg/L across the seven reported years while Halda's DO level showed an upward trend, reaching 6.915 mg/L in 2016. Overall, location and surrounding industrialization level might be an important factor leading to low DO in industrialized and high DO in relatively less industrialized areas.

3.2. Biochemical oxygen demand (BOD) in ten selected rivers

Biochemical oxygen demand (BOD) is generally an indicator of presence of organic matter. With a high level of organic matter present in water, consumption of DO for breaking down organic matter causes DO depletion in water. Consequently, aquatic systems with high level of BOD generally has low level of DO in the system. Accordingly, it was observed that BOD was generally high in the rivers with low level of DO. Figure 2 shows the annual average BOD calculated from the data extracted from DOE reports published from 2010 till 2016. DO was very low in Buriganga, Turag, Moyuri and these three rivers had BOD always in the toxic regime across the observed time period [Figure 3]. Buriganga river's BOD level dropped from 17.6 mg/L in 2014 to 11.8 mg/L in 2016, but it was still toxic for aquatic healthy environment. Similarly, Turag and Mayuri rivers' BOD level was in the range of 18.9 – 21.6 mg/L and 12.6 – 17.3 mg/L, respectively. Notably, the BOD level in Mayuri river was not available from 2014 through 2016. However, low level of DO in Mayuri's water in 2015 (1.830 mg/L) and 2016 (1.765 mg/L) is likely an indicator of a toxic level of BOD in the river in 2015 and 2016.

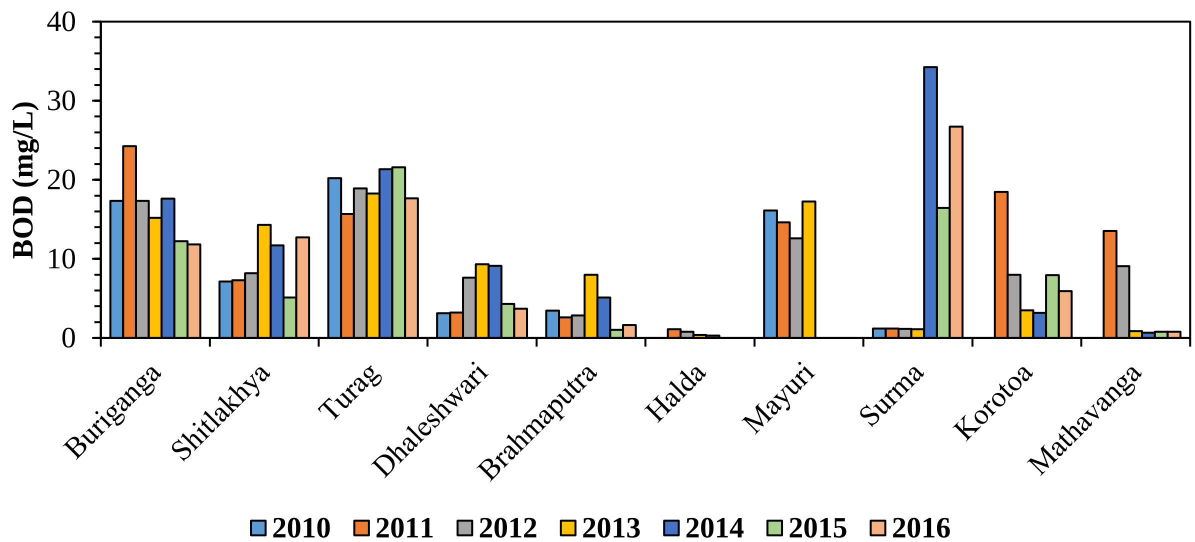


Figure 3: Level of biochemical oxygen demand (BOD) in ten rivers of Bangladesh across a time period of seven years starting from 2010 till 2016.

Brahmaputra, Halda, Mathavanga rivers showed a downward trend for BOD likely because of the less of an industrialization in the locations the rivers are located; especially, Mathavanga rivers' BOD level were in the healthy range of BOD (< 3 mg/L) in recent years. Notably, Halda's BOD levels in the most recent years were not available, but referring to the relatively high level of DO in Halda and the overall trend of DO And BOD in the river, it can be presumed that Halda's BOD was still within the healthy range in 2014, 2015, and 2016. Korotoa's BOD indicates moderate pollution (< 8 mg/L) but its BOD level stayed almost at the same level after 2010 indicating the pollution level in the river likely did not deteriorate further till 2016.

Dhaleshwari, Shitalakhya, and Surma rivers' BOD level was above the range for healthy level (> 3 mg/L). The level of BOD in Surma was in the range of 16.4 – 34.2 mg/L in recent years while Dhaleshwari's BOD was below 8 mg/L indicating a moderate pollution level in Dhaleshwari based on the recent BOD level in the river. The BOD level was above the healthy range in recent years in Shitalakhya with the exception in 2015 (5.1 mg/L).

3.3. Water Quality index (WQI) in ten selected rivers

Water quality index (WQI) can indicate the overall quality of water. In absence of a universal indexing of water quality different water quality agencies adopt different methods for WQI assignment. In this study, DO, BOD, pH, and SS- these four parameters were considered for WQI calculation. However, SS data was not available for all rivers. But weights were assigned to each parameter according to the associated intensity and then an average of the total weight was used for WQI employment to minimize the effect of lack of one or two parameters (if any). The level of DO and BOD in all ten rivers across a seven-year period was discussed in the previous sections. A separate section on pH level in the rivers was not provided as pH was within the range of 6.5 – 8.5 in all the rivers which is a normal pH level for surface water [30]. Moreover, no drastic fluctuation of pH was observed in the rivers. Additionally, SS values were also considered for WQI calculation, when available. Figure 4 shows the calculated WQI for all ten rivers in a seven-year period (2010 – 2016).

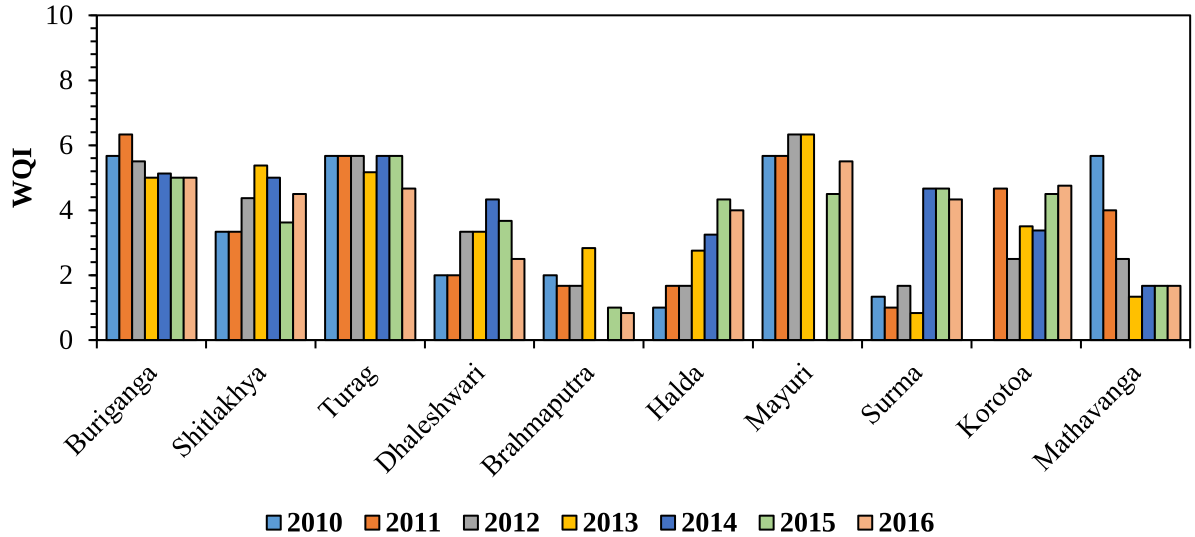


Figure 4: Calculated water quality index (WQI) for ten rivers from 2010 till 2016.

Among the ten rivers, Brahmaputra had the lowest WQI in recent years with a downward trend over the years while Halda showed an upward trend in WQI. As discussed earlier, Brahmaputra flows through a residential urban area that is not industrialized. Halda flows through hilly areas with tea gardens. One possible reason for Halda's increasing WQI over the years could be due to run-off from tea gardens that would carry sediments, nutrients with it. Buriganga, Turag, and Mayuri are the three most polluted rivers in terms of WQI across the observed time period, showing no major fluctuations over the years. Buriganga, Turag, and Moyuri are in the most industrialized areas of Bangladesh where some of the industries include tanneries, textiles, and manufacturing industries. Lack of regulatory enforcement and infrastructure for industrial discharge control very likely contributed to the high level of WQI in those three rivers. Contribution of industrial discharge can be more clearly observed by comparing WQI of these three rivers to that of Brahmaputra and Mathavanga. Being in relatively under-industrialized areas, Brahmaputra and Mathavanga had lower WQI compared to Buriganga, Turag, and Moyuri.

Shitalakhya (4.5 – 5.0), Surma (4.3 – 4.7), and Korotoa (4.5 – 4.8) rivers had WQI almost at the same level in recent years (2014 – 2016) indicating moderate pollution in the rivers. Pollution in Shitalakhya and Surma rivers might be because these rivers are adjacent to some of the largest factories in the country, i.e. ACI, Chhatak cement factory. Korotoa's moderate pollution might have been caused by the small industries located in the adjacent area. Dhaleshwari river showed a downward trend of WQI from 4.3 in 2014 to 2.1 in 2016. However, Dhaleshwari river is located in an area with manufacturing and textile industries. There is no evidence or documentation of any drastic regulatory enforcement in the area for controlling industrial discharge. The downward trend of WQI in the river might be due to lack of sampling in the monitoring stations which is a very common phenomena in many of the monitoring stations across the country. Overall, Brahmaputra and Mathavanga were the only two rivers with a WQI for healthy aquatic environment identified in this study. All the other rivers were either slightly or moderately polluted and not healthy for aquatic lives. The degree of pollution in the ten rivers in 2016 based on WQI was in the order of Mayuri > Buriganga > Korotoa > Turag > Shitalakhya > Surma > Halda > Dhaleshwari > Mathavanga > Brahmaputra. A qualitative interpretation was made based on the WQI calculated in this study for a convenient identification of the polluted rivers [Table 3].

Table 3: Degree of pollution in the ten selected rivers presented with different color codes

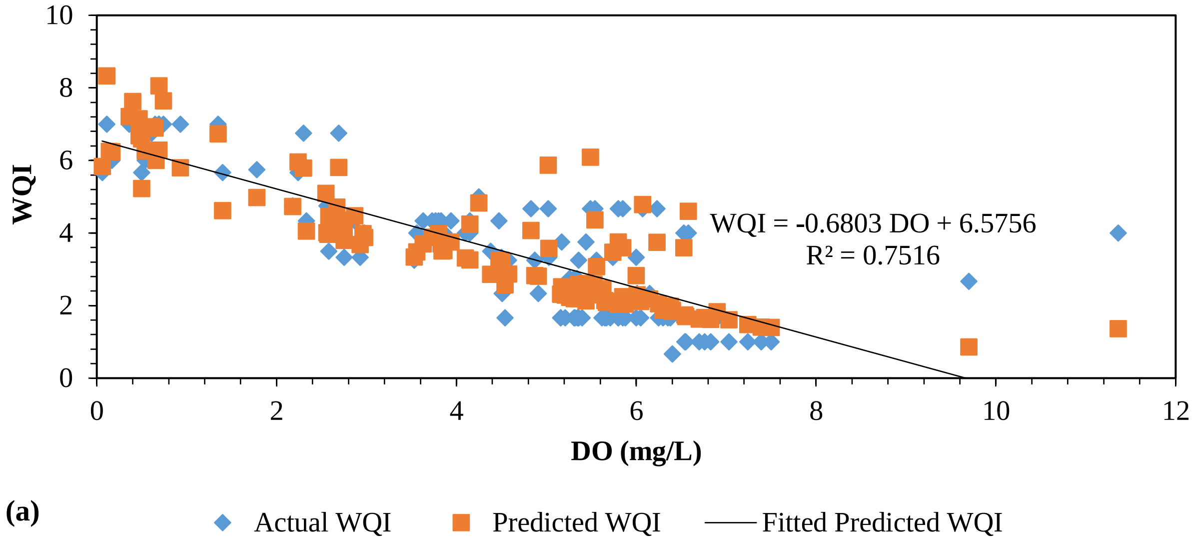
Color code:

	Good
	Slightly polluted
	Moderately polluted
	Very polluted

River	2010	2011	2012	2013	2014	2015	2016
Buriganga							
Shitlakhya							
Turag							
Dhaleshwari							
Brahmaputra							
Halda							
Mayuri							
Surma							
Korotoa							
Mathavanga							

As presented in Table 3, Buriganga, Shitalakhya, Turag, Halda, Mayuri, Surma, Korotoa rivers were moderately polluted in 2016, and Dhaleshwari was slightly polluted while Brahmaputra and Mathavanga were in good conditions. This shows a trend of rivers being more polluted when there are industries in surrounding areas which coincides observations made by other reports [5,16,17,18,19,20].

Monitoring of more parameters and incorporation of them into WQI will be helpful for calculation of more accurate WQI representative of the actual water quality. However, monitoring of more parameters might be challenging due to lack of resources and infrastructure in developing countries like Bangladesh. Therefore, WQI prediction with a few parameters will be helpful in resource limited situations. Hence, a correlation between DO, BOD and WQI was analyzed in this study [Figure 5].



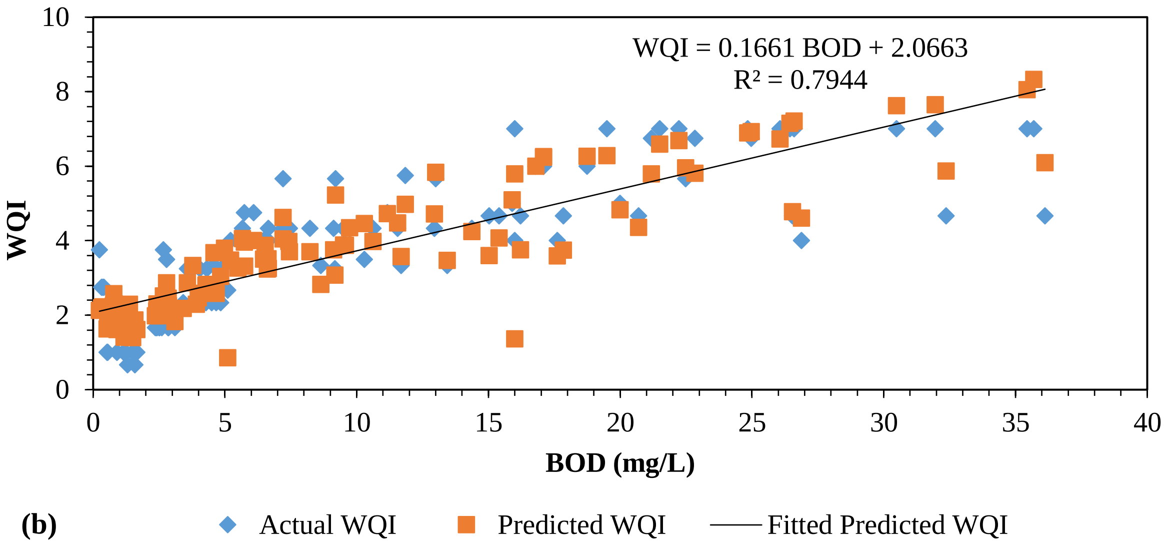


Figure 5: Regression analysis of (a) dissolved oxygen (DO) and water quality index (WQI), and (b) biochemical oxygen demand (BOD) and WQI to determine correlation between them. Predicted WQI using DO and BOD as variable resulted in R^2 of 75.16% and 79.44%, respectively.

With using DO and BOD both as variables, WQI can be predicted as follows (R^2 = 86.68% and standard error = 0.68)

$$WQI = 4.42 - 0.42\ DO + 0.11\ BOD \quad \text{[Equation 2]}$$

In challenging situations with difficulty in monitoring multiples parameters, the correlation of WQI with DO and BOD individually or both parameters can be helpful for prediction of water quality. Notably, BOD levels for some rivers in some years were not available (Halda and Moyuri: 2014 – 2016; Korotoa: 2013). In the correlation analysis, those data points were hence not considered.

4. Conclusion

Access to clean water is essential for all living beings. Similarly, clean and pollution free surface water is crucial for a healthy aquatic environment where all aquatic beings can sustainably thrive. However, with an increasing industrial and agricultural production to meet the demand of the ever-increasing population, water pollution is becoming challenging for sustainable development. This phenomenon is particularly more challenging in developing countries like Bangladesh where lack of infrastructure and regulatory enforcement pose higher risk for water pollution. Anthropogenic activities generated huge transformations in the river water quality and ecosystem in the country. Because of economic benefit many industries are established near the river side and the subsequent discharge of untreated and semi treated toxic waste into the river is likely to negatively affect the water quality in the receiving waterbodies.

The water quality index can be helpful for reducing the bulk of the monitored parameters into a single value to communicate in a rearranged and consistent manner. Hence, a well-adopted water quality indexing system can be helpful for remediation planning and implementation purposes. However, currently the country does not have a country wide indexing system in place. There are a few published works on assignment of WQI on some selected waterbodies. But an overall indexing to apply on a vast region of the country covering both industrialized and under-industrialized areas is yet to be explored. This study proposed an indexing system considering four parameters (DO, BOD, pH, and SS) generally monitored in the monitoring stations of DOE. An analysis of DO, BOD, and WQI in the ten selected rivers showed that rivers located in the heavily industrialized areas were highly polluted and the degree of pollution were generally lower in the areas with fewer industries. Rivers in the industrialized areas showed a general trend of having low DO and high BOD. The rivers can be in the order of Mayuri > Buriganga > Korotoa > Turag > Shitalakhya > Surma > Halda > Dhaleshwari > Mathavanga > Brahmaputra in terms of the degree of pollution based on the WQI assignment in this study. This order can be helpful for identifying which rivers need remediation on a preferential basis.

Similarly, WQI can be calculated for other rivers in the country to gather a better understanding of the degree of pollution in the rivers and make a holistic plan for remediation of the rivers. However, setting up more monitoring stations in the rivers and frequent sampling is crucial for assignment of WQI for development and implementation of remediation plans. In a resource limited situation where only one or two parameters are available for monitoring, a simplified WQI formula can be helpful. The relationship derived in this study can be useful for prediction of WQI using DO, BOD or both parameters.

Author Contributions

Mallick, Z.: Conceptualization, Methodology, Investigation, Data Curation, Writing – Original draft, Writing – Review & Editing. **Hossain, M.R.B.:** Investigation, Data Curation, Writing – Original draft, Writing – Review & Editing. **Ayshi, F.T.:** Investigation, Data Curation, Writing – Original draft, Writing – Review & Editing. **Tahsin, A.:** Data Curation, Writing – Review &

Editing. **Mallick, S.P.:** Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original draft, Writing – Review & Editing, Supervision.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Oni, O., & Fasakin, O. (2016). The Use of Water Quality Index Method to Determine the Potability of Surface Water and Groundwater in the Vicinity of a Municipal Solid Waste Dumpsite in Nigeria. American Journal of Engineering Research (AJER), 5(10), 96 – 101.

[2] UN Water. (2018). The United Nations World Water Development Report 2018: Nature-Based Solutions for Water, UNESCO, Paris, France.

[3] da Silveira Barcellos, D., Schimaleski, A. P. C., & de Souza, F. T. (2021) Downsizing water quality monitoring programs in river basins in Brazil, Urban Water Journal, 18:4, 223-236. https://doi.org/10.1080/1573062X.2021.1877740

[4] Joseph, L., Jun, B., Flora, J. R. V., Park, C. M., & Yoon, Y. 2019. Removal of heavy metals from water sources in the developing world using low-cost materials: A review. Chemosphere, 229, 142-159, https://doi.org/10.1016/j.chemosphere.2019.04.198.

[5] Ahmed, F., & Alam, A. K. M. R. 2019. Temporal Variation of Physical and Chemical Characteristics of Water in Buriganga River. International Journal of Science and Research (IJSR), 10(2), 1210 – 1219.

[6] Bhuyan, M. S., Bakar, M. A., Sharif, A. S. M., Hasan, M., & Islam, M. S. (2018). Water Quality Assessment Using Water Quality Indicators and Multivariate Analyses of the Old Brahmaputra River. Pollution, 4(3), 481-493. doi: 10.22059/poll.2018.246865.350

[7] Tajmunnaher, & Chowdhury, M. A. I. (2017). Correlation Study for Assessment of Water Quality and its Parameters of Kushiyara River, Sylhet, Bangladesh. International Journal of New Technology and Research (IJNTR), 3(12), 1-6.

[8] Islam, M. S., Sultana, A., Sultana, M. S., Shammi, M., & Uddin, K. M. (2016). Surface Water Pollution around Dhaka Export Processing Zone and Its Impacts on Surrounding Aquatic Environment. Journal of Scientific Research, 8(3), 413-414. Htps://doi.org/10.3329/jsr.v8i3.27819.

[9] Puri, P. J., Yenkie, M. K. N., Sangal, S.P., Gandhare, N.V., Sarote, G.B., & Dhanorkar, D.B. (2011). Surface water (Lakes) quality assessment in nagpur city (India) based on water quality index (WQI). Rasayan Journal of Chemistry, 4(1), 43-48.

[10] Shil, S., Singh, U.K. & Mehta, P. Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. Applied Water Science 9, 168 (2019). https://doi.org/10.1007/s13201-019-1045-2

[11] Kumar, A., & Dua, A. (2009). Water quality index for assessment of water quality of river ravi at Madhopur (India). Global Journal of Environmental Sciences, 8(1), 49 – 57. https://doi.org/10.4314/gjes.v8i1.50824

[12] Kotoky, P., & Sarma, B. (2017). Assessment of Water Quality Index of the Brahmaputra River of Guwahati City of Kamrup District of Assam, India. International Journal of Engineering Research & Technology (IJERT), 6(3), 536-540.

[13] Wu, H., Yang, W., Yao, R., Zhao, Y., Zhao, Y., Zhang, Y., Yuan, Q., & Lin A. (2020). Evaluating surface water quality using water quality index in Beiyun River, China. Environmental Science and Pollution Research. 27, 35449 – 35458. https://doi.org/10.1007/s11356-020-09682-4

[14] Iqbal, A. B., Rahman, M. M., Mondal, D. R., Khandaker, N. R., Khan, H. M., Ahsan, G. U., Jakariya, M., & Hossain, M. M. (2020). Assessment of Bangladesh groundwater for drinking and irrigation using weighted overlay analysis. Groundwater for Sustainable Development. 10, 100312. https://doi.org/10.1016/j.gsd.2019.100312.

[15] Saha, R., Dey, N. C., Rahman, S., Galagedara, L., & Bhattacharya, P. 2018. Exploring suitable sites for installing safe drinking water wells in coastal Bangladesh, Groundwater for Sustainable Development, 7, 91-100, https://doi.org/10.1016/j.gsd.2018.03.002.

[16] Hossen, M. A., Rafiq, F., Kabir M. A., & Morshed, M. G. (2019). Assessment of Water Quality Scenario of Karnaphuli. American Journal of Water Resources, 7(3), 106 – 110. https://doi.org/10.12691/AJWR-7-3-3

[17] Hasan, M. M., Ahmed, M. S., Adnan, R., & Shafiquzzaman, M. 2020. Water quality indices to assess the spatiotemporal variations of Dhaleshwari river in central Bangladesh. Environmental and Sustainability Indicators, 8, 100068, https://doi.org/10.1016/j.indic.2020.100068

[18] Khan, S. A., Ahammed, S. S., Rabbani, K. A., & Khaleque, M. A. 2020. Water Quality Assessment of Turag River Using Selected Parameters. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 14(1), 61 – 66.

[19] Fatema, K., Begum, M., Zahid, M. A., & Hossain, M. E. (2018). Water quality assessment of the river Buriganga, Bangladesh. Journal of Biodiversity Conservation and Bioresource Management. 4(1), 47 – 54. https://doi.org/10.3329/jbcbm.v4i1.37876

[20] Pramanik, B. K., & Sarker, D. C. (2013). Evaluation of surface water quality of the Buriganga river. Journal of Water Resources and Desalination, 3(2), 160 - 168, https://doi.org/10.2166/wrd.2013.059

[21] Department of Environment, Bangladesh. (2016). Surface and Ground Water Quality Report.

[22] Department of Environment, Bangladesh. (2015). River Water Quality Report.

[23] Department of Environment, Bangladesh. (2014). River Water Quality Report.

[24] Department of Environment, Bangladesh. (2013). River Water Quality Report.

[25] Department of Environment, Bangladesh. (2010). River Water Quality Report.

[26] Francis-Floyd, R. 2011. Dissolved Oxygen for Fish Production. FA27, One of a series of the Fisheries and Aquatic Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/fa002

[27] Lee, A. H., & Nikraz, H. (2015). BOD:COD Ratio as an Indicator for River Pollution. International Proceedings of Chemical, Biological and Environmental Engineering, 88, 89 – 94. https://doi.org/ 10.7763/IPCBEE

[28] Liou, SM., Lo, SL. & Wang, SH. 2004. A Generalized Water Quality Index for Taiwan. Environmental Monitoring and Assessment, 96, 35 – 52. https://doi.org/10.1023/B:EMAS.0000031715.83752.a1

[29] Ewaid, S. H., & Abed, S. A. (2017). Water quality index for Al-Gharraf River, southern Iraq. The Egyptian Journal of Aquatic Research, 43(2), 117-122, https://doi.org/10.1016/j.ejar.2017.03.001.

[30] Qiao, Y., Feng, J., Liu, X., Wang W., Zhang, P., & Zhu, L. 2016. Surface water pH variations and trends in China from 2004 to 2014. Environmental Monitoring and Assessment, 188, 443. https://doi.org/10.1007/s10661-016-5454-5