Temporal Variation of Surface Water Quality in the Swan River Catchment in Himachal Pradesh India

Avinash Kumar Sharda, Harish Chander Sharma and Brij Bhushan

Abstract: As industrial growth in the lower Shiwalik hills has risen in past two decades, the last 10 years in the Una district has seen a rapid development in industrial and urban growth due to grant of industrial package by the central government of India. As a result, several production plants have sprung up within the Swan River catchment, threatening the water quality of this area. However, the actual effects on water quality are heretofore unknown. In this paper, we assess the water quality of the Swan River catchment by calculating the National Sanitation Foundation Water Quality Indicators (NSFWQI) and Overall Index of Population (OIP) between 2003-2012. Data on monitored cross sections were collected from State Pollution Control Board of Himachal Pradesh, India. The results indicate that there has been recent (within five years) considerable improvement in the water quality due to enforcement of proper pollution control technologies. The relationship between economic growth (GDP) and water quality was also studied.

We carried out regression analysis of the water quality data to determine significant parameters as independent variables and WQI and OIP as dependent variables. The regression analysis further identified that the contribution of each variable with significant values r = 0.733, R2 = 0.695. The study further suggests that sustainable development is possible through adoption of proper treatment technologies, enforcement of formal legislation, and preparation of remedial action plans to reduce the environmental stresses.

Keywords: Pollution, Swan River, Overall Index of Population, India.

Introduction

Development through industrialization brings increased rates of pollution. Often times environmental regulations will be relaxed so as to induce better economic growth, but at cost to the purity of natural resources and standard of living.

Li Yong et al. (2005) reported that surface waters in Suzhou region were found unsuitable for drinking purposes after a long period of industrial growth in the region. Wang et al. (2007) found temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, an economic and financial centre of China.

Teng et al. (2011) studied the impact of urbanization and industrialization on surface water quality in Panzhihua (Sichuan Province) and reported an increase in effluent bearing heavy metals causing degradation of water quality. They suggested policy measures such as adjusting industry structures, optimizing the clean technology, and controlling pollution sources. Brilley et al. (2006) reported that industrialization can impact the entire hydrological process due to its potential to change land use patterns, population density, and watershed coverage.

But industrialization and development alone are not sufficient explanations for water quality changes. Seasonal variations of temperature and rainfall also play a role.

In the Dehradun district of Uttarakhand, India, Bartarya et al. (2012) reported that ion concentration in surface water is higher in the summer as compared to the monsoon period, indicating the effect of elevated temperature, increased evaporation and absence of recharge during the low water level period of pre monsoon season. Cronin et al. (2003) studied the temporal variations in depth-specific hydro-chemistry and sewage-related microbiology in an urban sandstone aquifer in Nottingham, England. The authors reported low levels of microbial contamination should be expected at depths in fissured sand stone due to aquifer heterogeneities such as fissuring and the occurrence of sand stone bands.

It is equally important to have the proper toolkit to study changing water quality over time. Shrestha et al. (2007) assessed surface water quality using multivariate statistical techniques, including Cluster Analysis (CA), Principal Component Analysis (PCA), Factor Analysis (FA) and Discriminal Analysis (DA). Working in the Fuji River basin, they worked out large water quality data sets for 12 parameters for the years 1995-2002. Mustapha et al. (2012) used robust statistical tools to water quality datasets to determine the most significant parameters regarding temporal water quality variations. These two studies informed our methods for the present study.

The Swan River is an appropriate site for our study because the river runs through an area of Himachal Pradesh in India that has experienced rapid industrial growth in the past 50 years, including steel, pharmaceuticals, and fermentation products. All of these initiatives were supported by the Indian government.

As a result of industrialization and urbanization, the environmental pollutants found in most of the surface waters in the Swan River catchment have been deemed not suitable for drinking in both the rural and urban areas, and force them to exploit ground water resources. In order to study the relationship between economic development and environmental pollution on the Swan River, we collected water quality data for 2003 to 2012 and evaluated the Water Quality Indices, which were used to characterize temporal variation of Swan

River surface water quality during a period of industrial and urban growth in the catchment.

Study Area

The Swan River, also known as the River of Sorrow and a tributary of the Sutlej River, flows from the north in a south westerly direction. Swan River Flood Management and Integrated Development (SRFMID) has implemented controls for the flood hazards, which has made the river more usable to the people of the Una district, Himachal Pradesh. Major towns located on the banks of river Swan include Gagret, Una, Mehatpur and Santokhgargh. Each of these locations feature heavy industrial areas.

The total length of the Swan is approximately 85 kilometers, of which 65 fall in Himachal Pradesh. The total catchment area of the river watershed is 1400 km^2 with 80 tributaries contributing to the flow during monsoon. The Swan is an intermittent river and maintains base flow in the lower reaches. Eighty percent of its catchment area falls in Una district and the river divides the district into two parts. The river is the main source of sub-soil water in the catchment for domestic, industrial and irrigation (Venu & Madhvri, 2011).

The Swan River passes through three industrially developed areas: 49 are medium-sized units and 575 small-scale. The SRFMID Project was formulated by Irrigation and Public Health (IPH) department in order to reclaim the land by providing embankments on both sides for fishery development, flood control and water utilization.

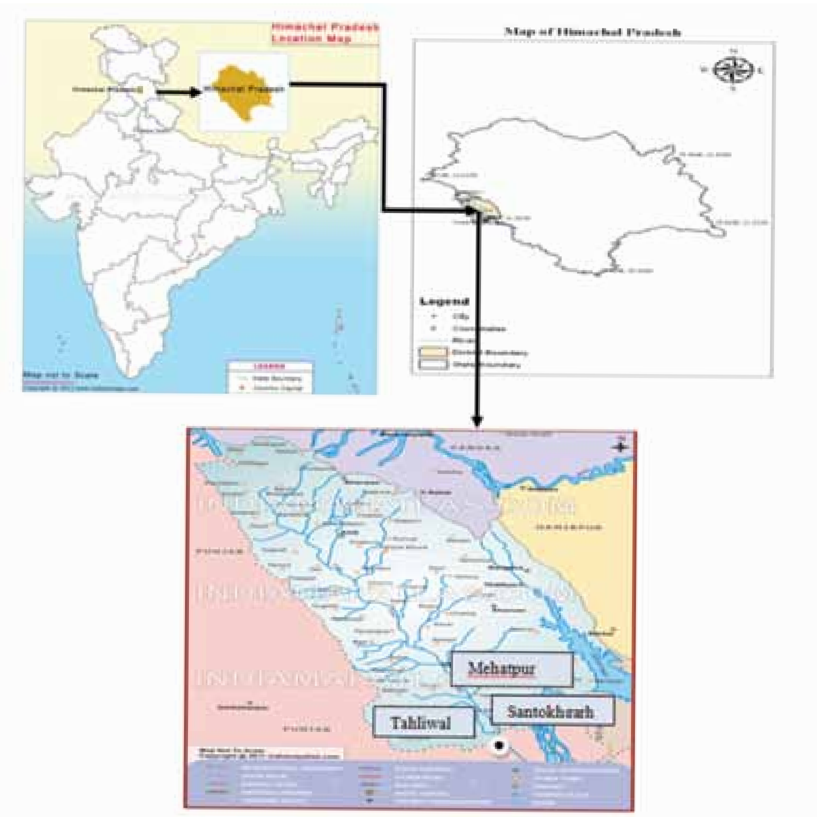

Figure1: Location Map of Swan River catchment and study sampling location

In the light these increased human activities on the Swan River, it becomes necessary to evaluate the river water quality. What follows is our study of the relationship between WQIs and population and industrial growth by assessing surface water quality using different methods calculation of different indices between period 2003 to 2012. From this analysis, we suggest implementation of formal regulations and enforcement of proper pollution control measures.

Materials and Methods

The water quality data (Table 1) for the last 10 years was used along with water quality indices estimated by National Sanitation Foundation Method Water Quality Index (NSFWQI) and Overall Index of Pollution (OIP). These figures were calculated by taking into consideration various parameters: Temp (o C), pH, DO (mg/l), BOD5 (mg/l), Turbidity (NTU), MPN, TDS (mg/l), NO3-N (mg/l), Total Phosphate (mg/l), Hardness (mg/l) and Fluoride (mg/l).

Following methods have been used for evaluating water quality indices.

National Sanitation Foundation Water Quality Index (NSFWQI) for estimating water quality of any water body and is mathematically expressed as;

$$WQI = \sum W_i Q_i$$

Where Qi= Sub Index of ith water quality parameter

Wi= Weight (in terms of importance) associated with water quality parameter

N= Number of water quality parameters

We calculated 42 NSFWQI using software downloaded from the website http://www.swrp.esr.pdu.edu. NSF WQI Water Quality ratings based on the Water Quality Index per sub index function for parameters on 100 point scale are presented in Table- 1.

Overall Index of Pollution (OIP)

Different water quality parameters were measured in different units of measurement. Hence, it is necessary to translate them into commensurate units so that integrated indices can be obtained and used in decision-making. An integer value in geometric progression (e.g., 1, 2, 4, 8, 16) to each of class (C1, C2, C3, C4 and C5) is assigned. Where the number termed as class index indicating level of pollution . This forms the basis for comparison of water quality from “excellent” to “heavily polluted.” The limits and ranges for different parameters have been shown in Table 1. OIP is estimated as the average of all the pollution indices (Pi) for individual water quality parameters considered and is given by the mathematical expression.

OIP= ∑iPi /n

Where Pi= pollution index for ith parameter. i=1,2,------,n and n= number of parameters.

The pollution index (Pi) is obtained for each parameter by using mathematical expressions developed by Saragaonkar and Deshpande (2003) and further using value function curves.

Water Quality Index					
Range	90-100	70-90	50-70	25-50	0-25
Quality	Excellent	Good	Medium	Bad	Very bad

Table1: NSFWQI Limits

The interpretation of OIP values to determine the pollution status is calculated the same was as we calculate individual parameters (discussed above). The OIP is simple to estimate and flexible to the addition or deletion of parameters. However, comparative assessment of water quality at different places or at different times can be made only when parameters included in the OIP are the same. Accordingly, recommendations may be made regarding the specific use of water. The numerical estimates of OIP correspond to classes shown in Table 2.

S.No	Range	Category	Class
1	0-1	Excellent	C_1
2	1-2	Acceptable	C_2
3	2-4	Slightly Polluted	C_3
4	4-8	Polluted Class	C_4
5	8-16	Heavily Polluted	C_5

Source – A. Saragaonkar, Deshpande., 2003: Development of Overall Index of Pollution

Table 2: Estimation of OIP on basis of different classes

The water quality parameters (turbidity, pH, color, DO, BOD, TDS, hardness, Cl, SO4, total Coliform) are considered as significant indicator parameters of surface water quality for evaluating OIP. The concentrations (levels/ranges) of these parameters in the above classes are defined with due consideration of CPCB standards/ criteria and IS10500. For parameters and classes not included in the CPCB standards, reference was made to the standards defined by other agencies.

Year	WQI	Rating	OIP	Classes
2003	54.82	Medium	2.62	Slightly Polluted
2004	72.4	Good	1.78	Acceptable
2005	62.33	Medium	2.48	Slightly Polluted
2006	67.58	Medium	2.22	Slightly Polluted
2007	65.7	Medium	2.22	Slightly Polluted
2008	69.53	Medium	2.06	Slightly Polluted
2009	70.11	Good	1.91	Acceptable
2010	67.62	Medium	2.09	Slightly Polluted
2011	72.69	Good	1.93	Acceptable
2012	64.36	Medium	2.39	Slightly Polluted

Table 4: Summarized results of WQI and OIP for 2003-2012

The values of WQI and OIP based on average values of parameters for the period 2003-2012 AD has been summarised in Table 4.

Results and Discussion

Impact of Urbanization and Industrialization on Water Quality. The variation between WQI, urbanization level and industrial growth for the period between 2003 to 2012 is shown in Figure 2.

The WQI was 54.82% in 2003, which was slightly above the class of water, which falls under in the bad category, indicating that steps should be taken for treating domestic sewage. The results show an increase of pollution and effluents bearing Coliforms, COD, BOD5, nitrogen and phosphorous.

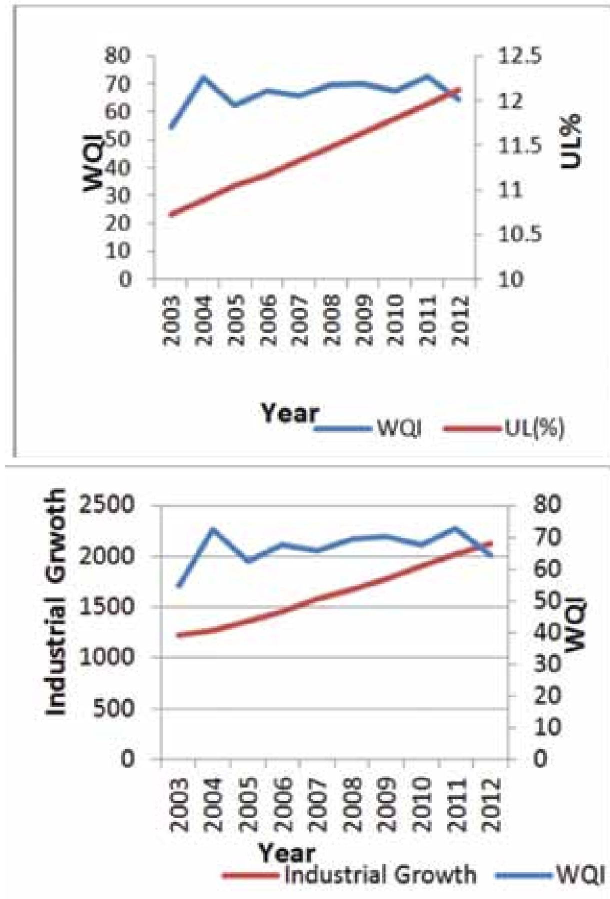

Figure 2: Relationship of WQI with UL (%) and Industrial Growth for the period (2003-12)

The WQI improved in the consequent years up to 2011-12, showing that waste water treatment and disposal had been put into operation and the WQI improved with the increase in population. Prior industrial package grants in 2003, the value of WQI was found to fall under medium category and slightly above the bad category. In preceding years, the value of WQI varies between 62.33% and 72.69% and falls under the medium category. Maximum industrial growth took place between 2003 to 2011, and the WQI declined initially, but improved after that showing that water quality also improved due to enforcement of formal regulations and implementation of best available technologies that effectively improved waste water treatment in the area.

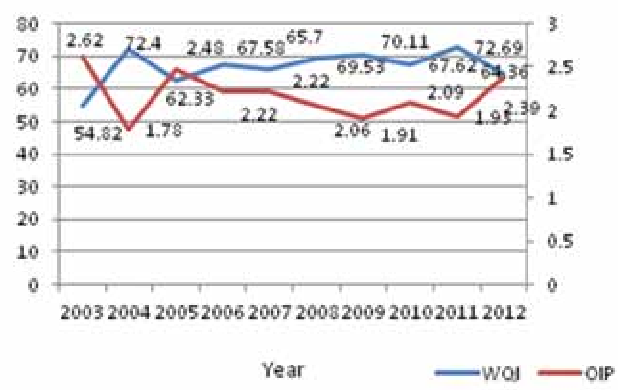

Figure 3: Spatial pattern of WQI and OIP due to IL Industrialisation Level and UL Urbanization Level

Evaluation of Water Quality

Figure 3 shows the relationship between WQI and OIP in our study.

Water quality was found medium and slightly polluted in 2012 showing that untreated domestic sewage from urban centres and effluent from industrial areas were being discharged into the Swan River, and suggests that some remedial action plan is required in order to reduce environmental stresses.

Statistical Analysis

The water quality data shown as per Table 1 for the last 10 years were considered and Water Quality Indices estimated by National Sanitation Foundation Method NSF (WQI) and Overall Index of Pollution (OIP) were taken as dependent variables and the extent of dependency on different water quality parameters was studied using multiple regression analysis.

Independent variables	Coefficient	t-ratio	p-value
pH	-4.993	-2.318	0.02
Temperature	-0.203	-1.256	0.22
DO	-2.137	-4.241	0.00
BOD	-0.622	-2.361	0.02
Nitrate	-2.225	-2.370	0.02
Total Coliform	-0.004	-1.549	0.13
Constant	101.601	4.805	0.00

Table 5: Variables affecting river water quality (NSFWQI)

Table 5 presents the results of analysis when NSFWQI was taken as dependent variable. Maximum variation in NSFWQI has been explained by mentioned variables in the same table. Temperature and Total Coliform were found as insignificant variables affecting water quality and a close look at the Student's t-statistics or t-ratio indicated that Dissolved Oxygen (DO) was the most important parameter affecting water quality with value of R2=0.457 in the river followed by Nitrate (R2=0.379) and Biochemical Oxygen Demand (BOD) with value of R2=0.192 as shown in Figure 4, which further shows that DO is directly in proportion with WQI, whereas NO3 and BOD varies inversely proportion to the WQI.

Independent variables	Coefficient	t-ratio	p-value
pH	-3.162	-3.200	0.00
Temperature	-0.068	-1.150	0.26
DO	0.683	2.742	0.01
BOD	-0.710	-3.879	0.00
Nitrate	-0.440	-1.565	0.13
Total Coliform	-0.002	-2.003	0.05
Constant	31.120	3.647	0.00

Table 6: Variables effecting River Water Quality (OIP)

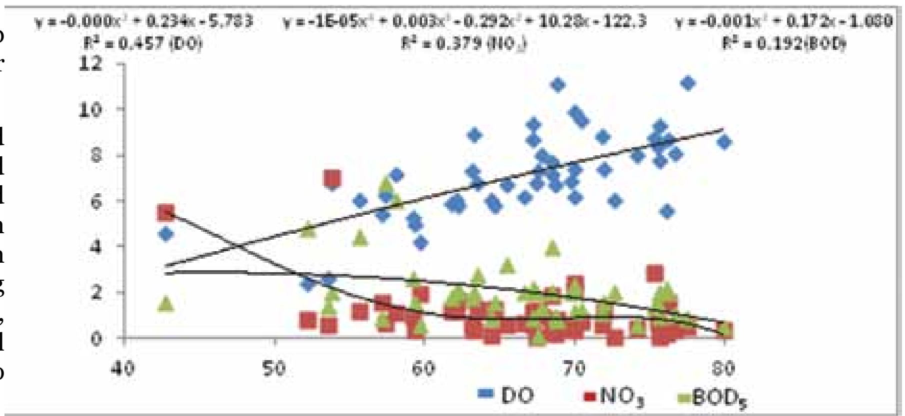

Figure 4: Polynomial fit of WQI (NSF) for the WQ data from 2003-2012

Table 6 presents the results of analysis when OIP was taken as dependent variable. The R2 values are more than estimated by NSFWQI method results. Here temperature and nitrate were found as insignificant variables affecting river water quality and among other variables again DO was found as most important variable followed by BOD and total Coliform and a close look at the Student's t-statistics or t-ratio indicated that Dissolved Oxygen (DO) was the most important parameter affecting water quality with value of R2=0.538, n=35 in the river followed Biochemical Oxygen Demand (BOD) with value of R2=0.484,n=35 as shown in Figure 5.

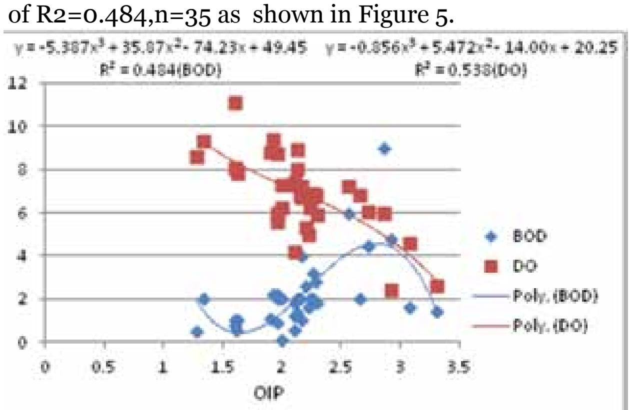

Figure 5: Polynomial fit of OIP for the WQ data from 2003-2012

The variation between OIP and BOD shows an inverted U-shaped curve, which reflects a phase of development “pollution first treatment after”.

The maximum values of BOD initially increase with OIP and lesser values decrease as OIP increases during the period 2003-2012.

Variable	Max	Min	Mean	Std Deviation
pH	8.63	7.60	8.14	0.312
Temperature	36.00	10.00	23.45	5.993
DO	11.10	2.40	6.85	1.818
BOD	14.00	0.10	2.52	2.642
Nitrate	7.02	0.00	1.042	1.436
Total Coliform	1800	32	296	484.525

Table 7: Statistics of water quality parameters

Table 7 provides the descriptive statics of water quality parameters giving maximum, minimum, mean and standard deviation of the parameters mentioned.

The relative variation of pH and Nitrate has been observed on lower side compare to the Temperature, DO, BOD and Total Coliform, which has been found as significant parameters and should be monitored on regular basis.

Although the pH and temperature are important, they have been found to be insignificant and need only be observed as routine parameters.

Month/ year	pH	Temp °C	D.O (mg/l)	BOD mg/l	Turbidity	PO_4	NO_3-N	F.C MPN/ 100ml	T.C MPN/ 100ml	E.Coli MPN/ 100ml	WQI	Ratings	OIP	Ratings
Mar-03	8.54	20	6.8	2	14	NA	7.02	780	1800	1170	53.83	Medium	2.66	Slightly Polluted
Jun-03	7.78	30	4.6	1.6	104	NA	5.545	780	1790	1170	42.74	Bad	3.08	Slightly Polluted
Dec-03	8.2	15	8.9	2	9.5	NA	0.325	600	1760	900	63.28	Medium	2.13	Slightly Polluted
Mar-04	8.27	24	7.8	1	3	NA	0.086	40	110	60	75.56	Good	1.63	Acceptable
Jun-04	7.71	28	4.2	0.6	22	NA	1.922	40	110	60	59.71	Medium	2.11	Slightly Polluted
Oct-04	8.42	23	8	0.6	20	NA	0.415	22	80	33	74.1	Good	1.61	Acceptable
Apr-05	7.76	23	2.6	14	9	NA	0.6	70	200	102	53.61	Medium	3.3	Slightly Polluted
Jul-05	8.39	26.5	6.8	2	6	NA	0.07	140	240	196	67.36	Medium	2.15	Slightly Polluted
Oct-05	8.1	24	7.3	0.1	NA	NA	1.2	160	280	223	67.52	Medium	2	Slightly Polluted
Jan-06	7.95	18	8.7	0.9	18	NA	1.188	120	400	176	67.22	Medium	1.96	Acceptable
Apr-06	8.58	32.5	7.3	1.8	8	NA	0.54	60	240	87	63.16	Medium	2.1	Slightly Polluted
Jul-06	8.34	34	7.2	6	NA	NA	1.1	56	160	81	58.04	Medium	2.56	Slightly Polluted
Oct-06	7.96	24	6.7	3.2	NA	NA	0.589	100	300	147	65.5	Medium	2.26	Slightly Polluted
Jan-07	8.43	14	11.1	0.8	NA	NA	0.8	52	130	76	68.8	Medium	1.6	Acceptable
Apr-07	7.82	32	6.8	2.8	1.4	0.23	1.28	46	180	71	63.48	Medium	2.28	Slightly Polluted
Jul-07	8.37	36	5	1.6	NA	NA	0.36	56	220	83	59.38	Medium	2.22	Slightly Polluted
Oct-07	8.63	26.5	2.4	4.8	NA	NA	0.824	50	180	70	52.2	Medium	2.92	Slightly Polluted
Jan-08	8.01	10	9.4	2.2	NA	NA	0.55	64	160	86	67.2	Medium	1.92	Acceptable
Jul-08	8.36	22	6.9	2	NA	NA	0.42	50	220	79	69.71	Medium	2.26	Slightly Polluted
Oct-08	8.07	24	6.2	2	NA	NA	0.69	38	150	65	66.66	Medium	2	Slightly Polluted
Jan-09	7.6	20	9.3	2	NA	NA	0.48	42	140	69	75.57	Good	1.34	Acceptable

Apr-09	8.27	23	8.6	0.5	0.6	0.23	0	9	32	15	80.08	Good	1.28	Acceptable
Jul-09	7.84	17	6	9	NA	NA	0.114	22	80	31	64.44	Medium	2.86	Slightly Polluted
Oct-09	8.63	18.5	6.7	1	NA	NA	0.212	44	100	57	68.72	Medium	2.16	Slightly Polluted
Jan-10	8.5	18.5	6.2	2	NA	NA	0.341	18	60	26	69.95	Medium	2.24	Slightly Polluted
Apr-10	7.67	27	5.6	2.2	NA	NA	0.19	4	36	9	76.02	Good	1.96	Acceptable
Jul-10	7.74	31	5.3	2.6	NA	0.46	1	26	72	45	59.25	Medium	2.2	Slightly Polluted
Oct-10	8.03	28	6	2	NA	NA	0.018	10	32	16	72.67	Good	1.96	Acceptable
Jan-11	7.77	21	8.05	1.05	NA	0.22	0.359	13	126	19	76.69	Good	1.6	Acceptable
Apr-11	7.98	22.66	7.43	1.2	8.97	0.73	2.415	12	151.33	17	69.99	Medium	2.1	Slightly Polluted
Jul-11	8.39	29	8.03	1.36	7.5	0.58	0.933	16.33	99	27	67.71	Medium	2.13	Slightly Polluted
Oct-11	8.29	17.66	8.83	1.1	12.03	0.85	0.62	NA	NA	NA	71.78	Good	1.9	Acceptable
Jan-12	7.85	20.66	7.2	4	8.73	0.93	1.887	NA	NA	NA	68.48	Medium	2.16	Slightly Polluted
Apr-12	8.09	24.5	5.9	1.8	29.75	0.47	1.2	40	72	63	61.79	Medium	2.3	Slightly Polluted
Jul-12	8.57	16	6.05	4.45	34.2	0.55	1.18	45	78.5	71	55.69	Medium	2.73	Slightly Polluted

Table 3: WQI and OIP-based on Water Quality Data for the period (2003-2012)

Conclusion

In the paper, we analysed the NSFWQI and OIP in surface water quality across temporal variations for the Swan River between 2003-2012. The results indicate that the surface water quality falls into the medium and slightly polluted category in 2002, 2004 and 2012. This indicates that some sources of pollution were not controlled effectively. In the other years we studied, the water quality falls under "good" and "acceptable" categories indicating that enforcement of formal regulations had helped to improve water quality.

Multiple linear regression identifies DO and Nitrate as independent variables with significant value of r=0.676, 0.615 and R2=0.457, 0.379 ($p<0.05$), respectively, for WQI as a dependent variable. In case of OIP, the role of each variable with DO and BOD as independent parameters is significant with values r=0.733, 0.695 and R2=0.538, 0.484 ($p<0.05$), respectively. The tools used for statistical analysis provide the objective of stressor parameters and from where it is clear that DO, BOD and NO3 were found to be the most significant parameters responsible for water quality variation in Swan River.

As our study is confined to limited stretch of the river, we suggest that segment-wise analysis along different stretches could be done for control of stressor parameters. We suggest further that for sustainable development, measures such as environmental planning, total discharge control volume, and polluter-pays principle should be implemented to improve surface water quality.

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