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Research Paper

Assessment of Environmental Flow Requirement and Ecosystem Analysis of Bhadra River, Karnataka, India

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The assessment of Environmental Flow is river-specific, as each catchment has its own hydrological character, and each river may have a different blend of ecosystems that provide a wide range of valuable services to the society. Environmental flow assessments should be made for a river where development is planned or, equally, for an impacted one where an improvement in river 'health' (i.e. condition) is desired. Bhadra river, which flows through Shivamogga and Davanagere districts of Karnataka, is one of the tributary of river Krishna which faces acute problems of water pollution due to major industries like Visvesvaraya Iron and Steel Limited and Mysore Paper Mills located in the Bhadravathi taluk, downstream of Bhadra reservoir. According to the local public, both surface and ground water quality are affected due to the inadequate treatment of wastes generated from the above mentioned industries. It is also reported that the river does not carry enough flow during the lean season due to which the water quality issues have become severe. Thirty five years of inflow and outflow data (1972-2007) of Bhadra Reservoir Project were analyzed and compared with the French fisheries law method and Montana method of environmental flow assessment. The study revealed the fact that the flow is altered significantly over the years due to unscientific methods of agriculture and encroachment of riparian land which resulted in massive loss of aquatic habitat and ecological imbalance. Further, the surface and ground water quality studies carried out in the Bhadravathi area indicated that there is a considerable decline in water quality status of the river due to the discharge of both domestic and industrial wastes without adequate treatments. Water Quality Index (WQI) shows a wide variation among all the water samples (39 to 169) indicating that the quality of water is deteriorated in major part of the selected stretch and also in the surrounding ground water. This is substantiated with the observed DO-BOD relationship and also by using QUAL2K model. The average flow analysis of the Bhadra reservoir showed that the major part of the water is released to canals for irrigation and river receive only limited quantity of water during the lean period. Flow is completely negligible during the lean season. From the present study it is estimated that about 5m^3/s of water is required to maintain the self-purification capacity of the river in Bhadravathi area. The present investigations and observations indicated that there is a significant decline in the flow level during the lean season due to which number of species (fish genera and plant species) reduced significantly over the years.

Keywords: Environmental flow, Dissolved oxygen, WQI, Self purification

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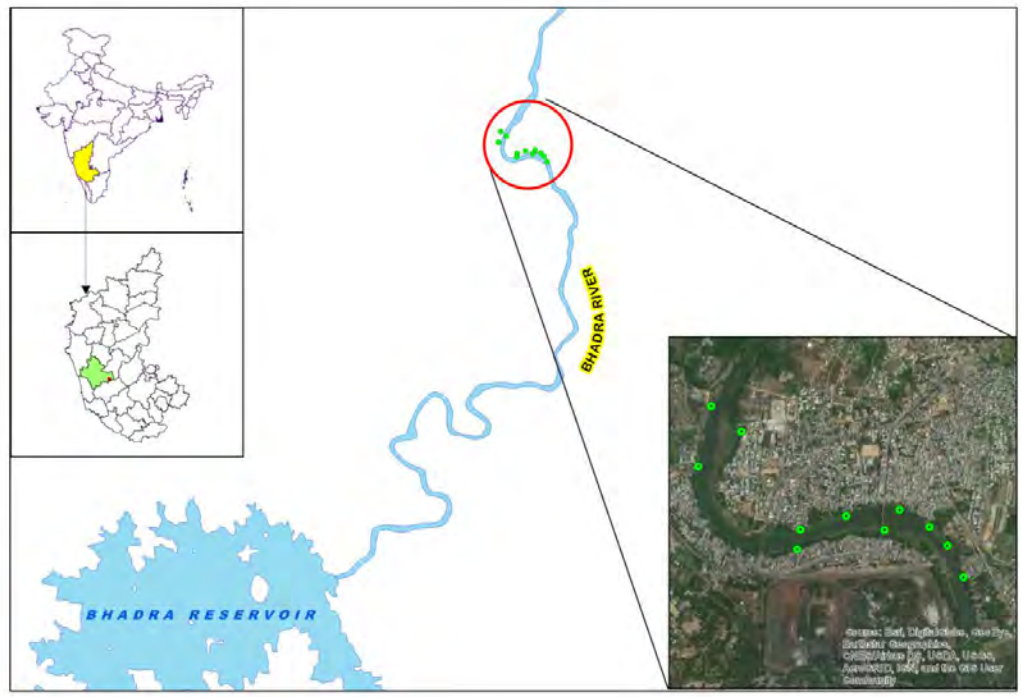
Introduction

"Environmental flows (EF)", refers to the minimum water required for protecting the structure and function of an ecosystem and its dependent species. This flow requirement is defined by both long term availability of water and its variability and is established through environmental, social and economic assessment. One of the major ecosystem that takes care of all the said characteristics are the river basins. Healthy rivers protect the environment and serve both human and animal kingdom. However, in recent years due to the increased population and industrial civilization resulted in degradation of ecosystem services thereby enhancing the social and economic costs. In this context, it is important to assess the long term variability of flow and its impact on the existing ecosystem. In Karnataka, majority of the rivers face acute shortage of water during the dry seasons due to wide variations in climatic conditions and environmental degradation arising out of industrial and agriculture growth. One of the well studied river basins of Karnataka is Bhadra river with a reservoir located at Lakkavalli, a small village in Chikmagalur district of Karnataka. The designed capacity for the storage of water allocated is 67 thousand million cubic feet. The upstream of Bhadra river, is known for its iron ore mining which disturbed the environmental significance of the river water and as it reaches Shivamogga district, number of industries like Iron and Steel and paper manufacturing have severely affected the ecosystem. It is reported that the Bhadra dam has altered the natural flow, resulting in massive loss of riparian, aquatic habitat and water quality. A long term flow analysis carried out for the river indicated that there is a significant variation in the flow, in the downstream reaches of the river due to excessive activities such as agriculture, fishing and discharge of wastes resulted in wide spread deterioration of water quality in certain stretches of the river. Communities have been impacted by irregular dry season water level fluctuations, which are characterized by extreme highs and lows, and rapid changes in water levels. Based on the observations, more than 60% of the downstream dwellers have changed their livelihood occupations, and also migration level has increased in the fishermen communities.

All over the world environmental degradation and ecological imbalance in an aquatic ecosystem is a serious matter of concern in the last two decades. Number of investigators and organizations have stressed the maintenance of flow as a key factor for rescuing the ecological sensitivity of a river basin and adjoining riparian belts (Millennium Ecosystem Assessment, 2005; Dyson et al., 2003; Postel and Richter, 2003; Revenga et al., 2005; Poff et al., 1997). Jain et al (2014) summarised the issues related to Environmental flows requirements in India. Since long, it has been reported that the river Bhadra, one of the major tributary of river Krishna in southern part of India has been facing an acute problem of water pollution due to industries such as Visveswaraya Iron and Steel and Mysore Paper Mills. Pollution is mainly observed in downstream of BRP, from Bhadravathi to Kudli. It is estimated that around 15 villages in the area have been affected by industrial pollution (Manjappa, 2002). Studies also have been conducted by Purandara et al (2011) by carrying out water quality studies in Bhadravathi taluk of Shimoga district. The study also estimated the minimum flow requirement for the environmental sustenance of the river stretch. Harish kumar et

Figure 1: Study Area Map with Sampling Locations



al carried out flow analysis of Bhadra river and assessed the minimum flow requirement for the ecological balance.

Methodology

Water quality data of surface and ground water samples were collected from various Research and Academic organizations. With the available data, Water Quality Indices were developed and the DO-BOD data was used for QUAL2K modeling. The detailed methodology of calculation of water quality index and DO modeling is discussed below.

Development of Water Quality Index

Water Quality Index (WQI) is calculated using Weighted Arithmetic Index method

Unit Weight, $W_n = k / S_n$

where k = proportionality constant and S_n= standard desirable value of n[th] parameter.

$$WQI = \sum_{n=1}^{n} q_n W_n / \sum_{n=1}^{n} W_n$$

where, $q_n = \frac{100 \times (V_n - V_i)}{(S_n - V_i)}$,

V_i = except in certain parameters like pH and DO, and V_n = observed value.

Calculation of quality rating for pH and DO (Vi^1 0)

$$q_{pH} = \frac{100 \times (V_{pH} - 7.0)}{(8.5 - 7.0)} \text{ and}$$

$$q_{DO} = \frac{100 \times (V_{DO} - 14.6)}{(5.0 - 14.6)}$$

where n = number of parameters taken.

Quality rating scale (q_n) for each parameter is assigned by dividing its concentration in water sample by its respective BIS standard values and the result is multiplied by 100. The suitability of WQI values for human consumption are rated as given in Table 1.

Table 1: Water Quality Index

WQI	Rates
0-50	Very Good
50-100	Good
100 and above	Unfit

Dissolved Oxygen Model

Amongst the number of water quality parameters, dissolved oxygen (DO) concentration and oxygen saturation is known to be a critical factor for the survival of organisms in the ecosystem. At the same time, oxygen provides an indirect indicator for possible eutrophication. Dissolved oxygen concentration is directly affected by the atmosphere, temperature and pressure conditions. Although various models are developed, often-simpler approaches are used to estimate the DO concentration in streams affected by point sources of pollution. One of the most widely used model is QUAL2K

QUAL2K Model

QUAL2K is a mathematical model used worldwide for the evaluation of surface water quality(river/stream). The basic concept of the model are the following.

- One dimensional. The channel is well-mixed vertically and laterally.
- Steady state hydraulics. Non-uniform, steady flow is simulated.
- Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- Diurnal water-quality kinetics. All water quality variables are simulated on a diurnal time scale.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.

The basic equation that has been solved in formulation of QUAL2K is the one-dimensional advection-dispersion mass transport equation, which has numerically been integrated over time and space for each water quality constituent. This equation includes the effects of advection, dispersion, dilution, constituent reactions and interactions and sources and sinks. For any constituent *C*, the equation can be represented as:

$$\frac{\partial M}{\partial t} = \frac{\partial\left(A_x D_L \frac{\partial C}{\partial x}\right)}{\partial x} dx - \frac{\partial (A_x u C)}{\partial x} + (A_x dx)\frac{dc}{dt} + S$$

where, M = mass (M), X = distance (L), t = time (T), C = concentration (ML^{-3}), A_x= cross sectional area (L^2), D_L = dispersion co-efficient ($L^2 T^{-1}$), u = mean velocity (LT^{-1}), and S = external source or sinks (MT^{-1}).

Study Area

The Bhadra river originates in the Western ghat range of Karnataka and flows east across the Deccan Plateau, joined by its tributaries viz. Somavahini, Thadabehalla, and Odirayanahalla. The river flows through the Bhadra Wildlife Sanctuary. A dam was built across the river near Lakkavalli. The Bhadra meets the TungaRiver at Koodli, a small town near Shivamogga. The combined river continues east as the Tungabhadra, a major tributary of the Krishna, which empties into the Bay of Bengal. The total length of the river is 185.07 km, covering elevations

between 1688.59 m and 609.5 m above MSL and hence is sub montane in character. .At Bhadravathi, the river enters comparatively the dry part of Shivamogga district with an undulating countryside and is mainly rocky with occasional sandy and gravelly patches. The right bank (being lower than the left) is subjected to overflows whenever there is a moderate rise of water. Exposed sandy part of the bed is generally covered by scrubby and bushy vegetation. There are numerous broken up channels, quiet pools and riffles fit enough to shelter a good fish population in the stretch of the river near Bhadravathi.

Climate

The average temperature in the summer is between 25°C and 37°C. The average winter temperature is between 20°C and 30°C. The annual precipitation in the city is around 950 mm. Taluk wise rainfall data for the last 10 years suggest that average annual rainfall is around 769.4 mm at Bhadravati.

Results and Discussion

Water Quality Index

Based on the concentration of the various chemical parameters Water Quality Indices (WQI) were computed. Water quality index (WQI) is defined as a rating reflecting the composite influence of a number of water quality parameters. It provides a convenient means of summarizing complete water quality data. Water quality index developed for the surface water and groundwater samples indicate that there is a wide variation from station to station. The WQI of all the locations is as shown in the Table 2.

Table 2: WQI of Pre- and Post-monsoon Samples

Locations	Pre-monsoon	Post-monsoon
Surface water samples		
BRP D/S	86.07	45.87
GondhiVillage	114.32	54.69
Dam water Timlapur	72.64	33.29
Sunnadahalli	52.03	33.62
D.G.Halli 1	49.93	36.18
D.G.Halli 2	74.64	36.55
Ujjainipura	66.94	48.08
OldBridge	70.59	45.98
New bridge	169.53	118.47
Groundwater samples		
Ujjainipura OW	52.63	40.46
Ujjainipura Main Road BW	54.25	41.91
By pass RoadGanapathiTempleOW	48.01	43.24
HaladammaTempleOW	146.47	89.81
HaladammaTempleBW	121.62	65.88
LaxmiNarasimhaTempleOW	63.19	58.67
Veerashaiva Sabha Bhavan BW	45.14	39.47
HindhuMahasabaTempleBW	61.55	46.67
HindhuMahasabhaTempleOW	69.90	53.16
MGM complex BW Santhe Maidana	89.48	63.46

The WQI of surface water samples showed variation between 49.93 and 114.32 during pre-monsoon season while during post-monsoon it ranges from 33.29 to 118.47. In order to understand the status of water quality, observed parameters were compared with the standard index values. Accordingly three groups were identified. First category having index value between 0 and 50 is considered as very good, with all parameters within the permissible ranges. Surprisingly, only 11% of the samples fall under this category during pre-monsoon and 78% of the samples during post-monsoon. This clearly indicated that the water quality variation is temporary and primarily it depends on rainfall pattern and dilution factors. A second category, which has the index value between 50 and 100, is significant in number of locations during the pre-monsoon and only one sample (about 11%) out of nine show this characteristic during post-monsoon. WQI is very high at New Bridge site (169.32) during pre-monsoon and it reduced to 118.00 during post-monsoon, which shows the signs of pollution throughout the year. The temporary variation in index values could be attributed to the excessive agriculture inputs flowing to the stream either as overland or as irrigation return flows. The index values higher than 100 is considered as unfit for use. Therefore, it is necessary to take appropriate measure to improve the water quality status at New bridge site. It is also suggested to control agriculture activities and use of fertilizers particularly at Gondhi Village, otherwise, during the course of time the water will become unfit for usage.

Application of QUAL2K Model to Bhadra River

Bhadra river is a fresh water stream, which supplies drinking water to various towns in Shivamogga District. Water quality parameters (major cations and anions) indicated that the water quality of the river is good for drinking, irrigation and all other domestic purposes. Though there are concerns over the water quality issue of Bhadra river, which is due to the presence of number of industries such as Mysore Paper Mills, Visvesvaraya Iron and Steel Limited etc. located on the bank of Bhadra river. However, the results of the analysis indicated that, the river water quality is all within the acceptable limits. As there were no reason to think of pollution in the river based on major cations and anions, it was planned to monitor the DO and BOD, which are the most significant parameters in surface water quality analysis. In-situ DO measurements were taken at selected sites and five days BODs were also determined for all samples. The experiments were repeated for different months and the data were used for QUAL2K model calibration and validation. Apart from the field measurement of DO, discretization of river stretch, hydraulic characteristics etc. were carried out as the input parameters for the simulation of DO and BOD under different environmental conditions by using QUAL2K.

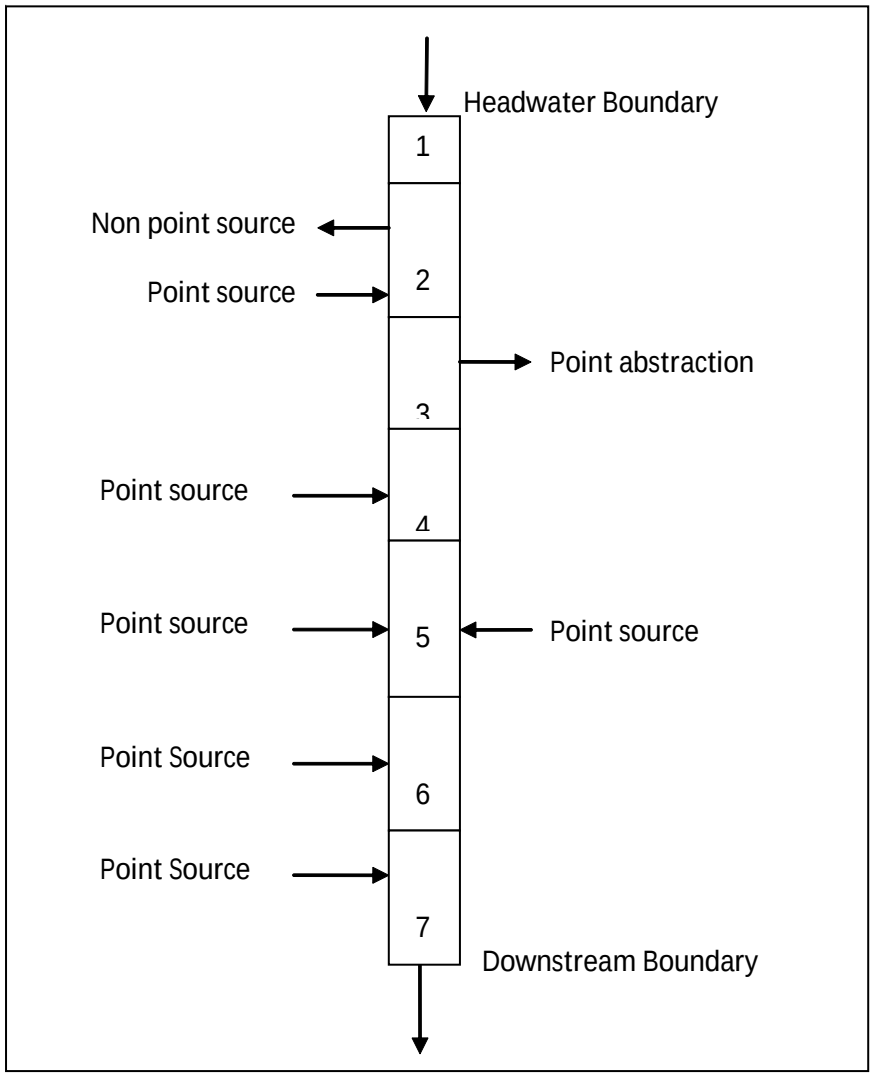
Discretization of River Reach

The total length of the river considered for the study is about 25 km which extend from Lakkavalli to Bhadravathi Town. The entire stretch of the river was discretized into reaches with computational elements of equal length. A schematic representation of the discretization is shown in the Figure 2.

Hydraulic Data

Hydraulic Data is the most important data required for the simulation of DO and BOD. Flow characteristics and river geometry were

Figure 2: Schematic Representation of Bhadra River from Lakkavalli to Bhadravathi Town



measured during post-monsoon and pre-monsoon season during the year 2010-2011. The energy gradient for the free surface of the river flow was computed using the Manning's equation (assuming n = 0.025) using the hydraulic data obtained from the field measurements. River hydraulic parameters for velocity and depth were measured at three different locations. The depth of flow varied from 0.5 m to 1.2 m across the river. The discharges from the point sources were also calculated using the velocity and cross-sectional area. In addition to this, data was collected from State organizations.

De-oxygenation Coefficient

The de-oxygenation rate coefficient has been obtained by standard procedure of incubation of the sample over a period of time and the samples have been analyzed for different days at 20ºC. Plots between the DO consumption and

incubation time give the laboratory rate constant at incubated temperature. The values were computed by using various methods and the average values were obtained as shown below.

$k_{1(20)}$ = 0.24/day

$k_{1(24)}$ = 0.288/day

L_o = 2.904 mg/l

Re-aeration Rate Coefficient

The oxygen transfer coefficient in natural water depends upon the various factors such as internal mixing and turbulence, temperature, wind mixing, sewage out falls and surface films. A fast moving shallow stream will have a much higher re-aeration coefficient than a sluggish stream. In the present study, the re-aeration coefficient was estimated by the method suggested O' Connor.

$k_{2(20)}$ = 2.25×10^6/day

$k_{2(24)}$ = 2.47×10^6/day

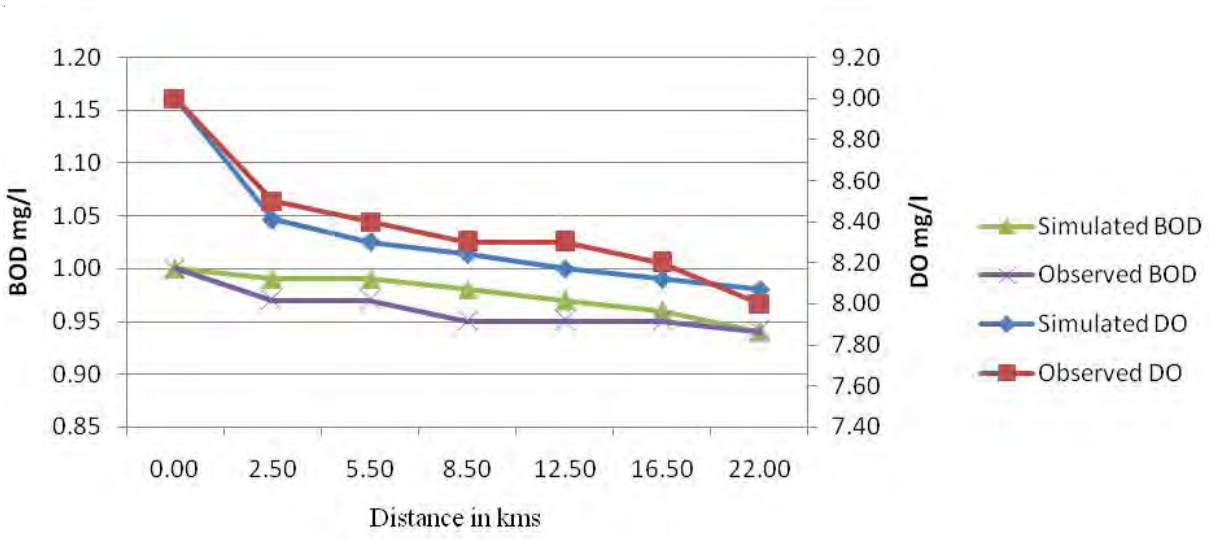
Calibration and Validation of the Model

QUAL2K being a steady state one-dimensional model, it has got its limitation of data acceptability. Considering the data requirement and availability, attempts were made to obtain as much data as possible from the field. Accordingly, data collected from field observations and those obtained from laboratory analysis have been prepared in the representative form as acceptable to the model. The model was calibrated to match the observed values. Once the input file is prepared, the foremost task in the model application is that of calibration and validation of the model. In this present case, i.e. for DO – BOD modeling, the first task would be to match the observed and computed values of BOD rather than DO. This is because the concentration of DO is mainly governed by many factors such conversion of NH_3–N to NO_3–N, re-aeration coefficient, river hydraulic parameters, algal concentration, conservation and respiration etc. Once BOD is matched, the second task would be to match the DO concentration in each reach. Since the re-aeration coefficient varies with river hydraulic and climatological data, efforts were made to calibrate those data rather than adjusting the measured values. Option of sensitivity analysis of each / multiple parameters given in the model provides an appropriate tool to determine the response of the parameters at any desired location. The trail run, which represents the best matching between observed and computed values, is considered as the calibrated values of the model. During the calibration utmost care was taken to match the calibrated and observed values of river data. The calibrated curve with observed curve for DO and BOD is shown in the Figure 3.

It is observed that there is a gradual decrease in DO level from the downstream of BRP to Bhadravathi New Bridge site. It is also interesting to observe the declining trend in both DO and BOD from the upstream to downstream. The DO is reduced from 9 mg/l to 8.07 mg/l while BOD is decreased from 1 mg/l to 0.94 mg/l. The similar trend is also observed in the field measured DO and BOD concentrations. The average flow estimated in the river was 5 m^3/s. Further, the model was calibrated without considering any outfalls. The results obtained after calibration clearly show a close match between the observed and simulated curves. This is an indication that the model can be used for simulation.

In the present study, in order to assess the impact of various outfalls coming from sources

Figure 3: QUAL2K Model Calibration Using Bhadra River DO-BOD Data

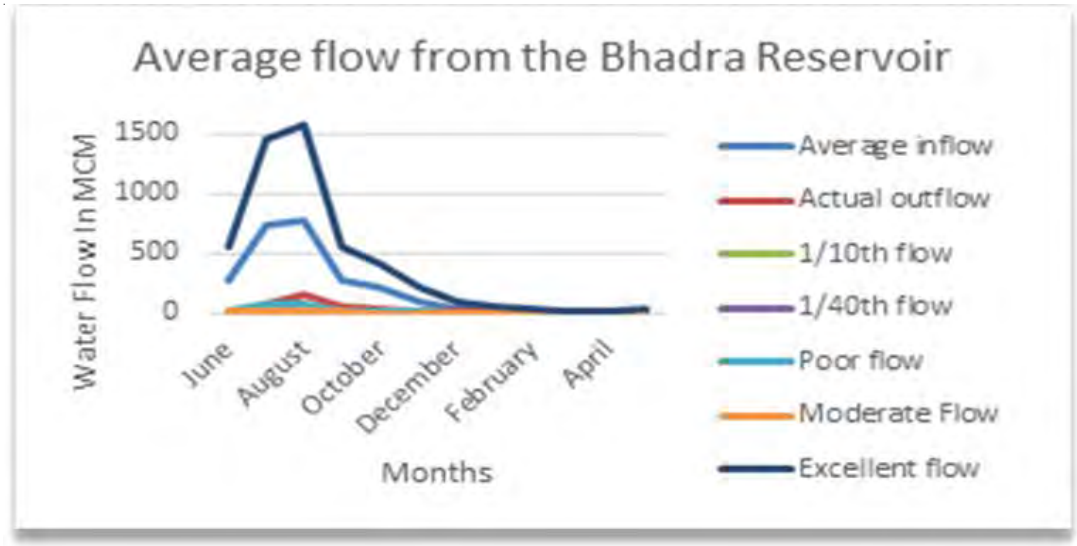


like Mysore Paper Mills, Visvesvaraya Iron and Steel Limited and others, 3 outfall discharges were collected and given as input to the model. In the present analysis, the average flow of the river was considered same as that of the calibration (5 m^3/s). The model was run with the said inputs and it is noted that there is a decline in DO concentration wherever the outfall meets the stream and then again it shows an improvement further downstream depending on the outfall concentration. Similarly, in contrast to the DO variation, the DO concentration gets shoot up, from 0.99 mg/l to 1.7 mg/l when the outfall enters the stream water. At all outfall points, an increase in BOD and a decline in BOD were observed. This clearly shows that sewage outfall from industries have a strong impact over the stream water quality. Therefore, it is essential to maintain the minimum flow conditions in order to have acceptable water quality conditions in the Bhadra river. From the study it is clear that if the minimum river flow of 5 m^3/s is not maintained and the wastages from factories are discharged in to the river directly without adequate treatments, definitely there are chances of water quality deterioration from time to time. Plot of observed and simulated BOD and DO is shown in Figure 3.

Apart from the water quality, the freshwater fish diversity is influenced by several factors including flow variation. In this connection, flow variability was assessed based on thirty five years of inflow and outflow data (1972-2007) of Bhadra Reservoir Project (Figure 4). It is noticed that the flow is perennial with a maximum discharge of 2500 cumecs during the height of the monsoon and a minimum flow of 2.12 cumecs during the month of May. The results were compared with the French fisheries law method and Montana method of environmental flow assessment.

The study revealed the fact that the flow is altered significantly over the years due to unscientific methods of agriculture and encroachment of riparian land which resulted in massive loss of aquatic habitat and ecological

Figure 4: . Flow variation Observed in Bhadra Reservoir during (1972-2007)



imbalance. Further, the surface and ground water quality studies carried out in the Bhadravathi area indicated that there is a considerable decline in water quality status of the river due to the discharge of both domestic and industrial wastes without adequate treatments. With regard to ecological status of river Bhadra, it is observed that there is a reduction of about 30-40% of fish species due to changes in flow pattern and water quality.

These environmental factors have a great impact on both species richness and the tropic structure of fish assemblages. In the present study it is observed that both Tunga and Bhadra rivers have shown similarity in species composition because of their close resemblances in origin and pattern of environmental set-up. However, the river stretch in Bhadravathi town showed significant decline in species richness due to the contamination of river water from industries located on the banks of river Bhadra. It is further noticed that species richness is high in lower elevation and low at higher altitude. This is because, the lower reaches of the rivers are generally characterized by the presence of increased water temperature, conductivity and decreased water velocity due to wider channel shape which could be considered as favorable factors for high algal production that leads to increase in herbivorous fish species.

Conclusion

1. Based on the flow assessment, it is observed that during the major part of the year the river maintains moderate flow. It is also noticed that the flow goes below the specified minimum flow conditions. This results in ecological and environmental imbalance leading to reduction in fish assemblages.
2. Water Quality observed along the two stretches of Bhadra river indicated that the surface water quality is acceptable for drinking, domestic and irrigation purposes. However, a deterioration of water quality (both surface and groundwater) was found due to the mixing of industrial and domestic wastes. It is also

important to note that the quality improves towards Kudali where the Bhadra meets Tunga. This clearly indicates the major cause for water quality reduction is industrial existence. In Bhadra River water samples sodium concentration is found to be very high in both the seasons, which is due to the presence of Mysore Paper Mills factory.

3. Water Quality Index (WQI) shows a wide variation among all the water samples. For example: the water sample at New Bridge site has very high WQI during both the seasons making it unfit for usage. This necessitates the undertaking of certain measures in this area to improve the water quality. WQI is also very high at Haladamma Temple and Gondhi Village, which is above 100 indicating its non-potability. Therefore, proper waste disposal technique and fertilizer usage is required to be diagnosed.

- QUAL2K model was applied to estimate the minimum flow required to maintain the DO-BOD levels within the prescribed limits. Various flow conditions were considered for the modeling. Based on the results it is concluded that 5m3/s is the minimum flow required to keep the DO (7-8 mg/l) and BOD (less than 2 mg/l).

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