Chapter 17
Sustainable Water Management in the Kelani River Basin

T. R. S. B. Bokalamulla, G. G. T. Chaminda, Y. Otaki, M. Otaki, and Manish Kumar

17.1 Introduction

Kelani River is the most sensitive river in Sri Lanka, and the Kelani River serves as primary source of water covering 80% of the portable water supply. The coverage includes millions of people, more than ten thousands of industrial and business establishments located around Colombo and suburb areas. The river upstream has minimum exposure to the domestic and industrial waste discharges; however, agriculture pollutions are present. The Kelani River is 144 km long and drains an area of 2292 km^2 (Herath and Amarasekara 2004). The most active part of the river lies between Avissawella (59 km chainage) to downstream Ambathale (14 km chainage). The poor local authority service delivery, weak environment management and governance (Arewgoda 1986; Ileperuma 2000; CEA 2014; Patel et al. 2019; Das et al. 2017) coupled with inadequate awareness and education have lead pollution in Kelani River (Mallawatantri et al. 2016). The sources of pollutant entered into the Kelani River include agricultural discharges, forest disturbances, grazing land fecal bacteria, industrial discharges, discharges from septic systems, sewage treatment plant effluent and urban runoff (CEA 2016; Kumar et al. 2019a; Das et al. 2017).

T. R. S. B. Bokalamulla (✉) · G. G. T. Chaminda
Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Galle, Sri Lanka
e-mail: bokalamulla@gmail.com

Y. Otaki
Faculty of Sociology, Hitotsubashi University Graduate School of Sociology, Tokyo, Japan

M. Otaki
Department of Human Environmental Sciences, Ochanomizu University, Tokyo, Japan

M. Kumar
Discipline of Earth Sciences, Indian Institute of Technology Gandhinagar, Gandhinagar, Gujarat 382355, India

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There are eight number of water purification plants extracting water from the Kelani River in the section between Avissawella to Kelaniya for producing drinking water to the community. At present, those plants extract around one million cubic meters of raw water per day. It has been forecasted that the future demand can increase up to 1.85 million cubic meters per day (Rajapaksha et al. 2016) with ongoing development activities, population growth and amplified urbanization in the Colombo and suburban areas. The flow of the river varies between 800 and 1500 m^3/s during the monsoon and 20–25 m^3/s in the dry season (Abeysinghe and Samarakoon 2017; Kumar et al. 2019b; Das et al. 2015). The shortages in river flow have already been experienced during the dry season, and conditions are heading toward the critical level with alteration in the global climate pattern and the increasing demand for freshwater. The study focused on two types of analysis to review the present condition in downstream of the Kelani River and future water quality characteristics. Also, water consumption details of the consumers and their perceptions over the future challenges in the water supply to the area were investigated. The results obtained from the analysis are used to predict the extreme conditions of the river, possibility of introducing alternative water source to reduce the raw water demand from the Kelani River. (Kim et al. 2011)

Water quality investigations: There are diffident types of water quality assessment tools used in water quality assesments in rivers, WASP3 (Himesh et al. 2000), QUAL2K (Hemant 2014) are two type of water quality simulation tools. Availability of sufficient data for the model development, calibration and validation process is the most important factor to ensure the accuracy (Himesh et al. 2000) for all these tools. The QUAL2K is an Excel-based software, and according to the literature, this has been used in number of water quality studies in rivers.

End User measurements: The studies on end user consumption are first-hand experience in Sri Lanka. The literature shows three major methods for predicting domestic water consumptions on end usage.

1. The direct measurements from outlet of the household,
2. Estimations through interviews and determination of each micro-component,
3. Collect time series data of total residential water consumption and calculate by the water flow pattern.

The first two options are identified as suitable for developing countries as time series measurement will not possible without highly built-up facilities. Adaptation of correct methods has been considered to be significant for the end user consumption (Otaki et al. 2008). Another study carried out in UK noted that “only way to record an individuals’ water use behavior is through qualitative means (i.e., diary-based questionnaires and interviews) combined with micro-component data. This method can be subjective when it comes to identify actual versus perceived (or intended) user behavior” (Zadeh et al. 2014). Being a developing nation and due to constrain in water supply infrastructures in Sri Lanka, adaptation of more complex method is not useful. The direct measuring of individual household is the most useful method for estimation of consumption.

17.2 Materials and Methods

The area selected for the analysis starts 59 km chainage at Avissawella and ends 14 km chainage at Ambathale. Based on the water quality data, industrial influences and the river utilization as drinking water source are the most significant part of the river in this section. Figure 17.1 shows Kelani River Basin and the research area. The quality behavior was investigated through water quality modeling software (QUAL2k) and the consumer consumption, and the perceptions were studied through the direct household measurements and the questionnaire surveys.

Figure 17.2 shows overview of the methodology adopted for the data collections, model development, calibration, validation, simulations and analysis of the results. The river bathymetric and discharge data were collected from Department of Irrigation. The water quality data was used as secondary data and was collected from the Pavithra Ganga program conducted by National Water Supply and Drainage Board (NWSDB) and the Central Environmental Authority (CEA). Qual2K software was used for the development of river model. The intake volumes and outfall volumes from Avissawella to Ambathale are shown in Table 17.1.

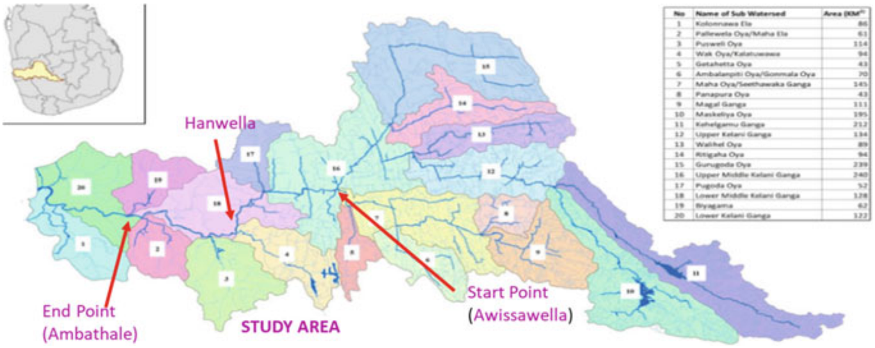
The calibration and validation of the model were carried out referring to the water quality parameters obtained from the NWSDB for wet and dry season, respectively. The validated model was used for the analysis of three different flow conditions forecasted on the water usage point of view.

20-year dry weather flow with the present water demand (2020 year) and pollution loading

20-year dry weather flow with projected water demand as at year 2030 with same pollution loading

20-year dry weather flow with the present water demand (2020 year) and increased pollution loading of 50% from the existing.

The same scenarios were simulated under the wet flow conditions and compared variations between wet and dry flow conditions.



No	Name of Sub Watersed	Area (KM^2)
1	Kolonnawa Ela	86
2	Pallewela Oya/Maha Ela	61
3	Pusweli Oya	114
4	Wak Oya/Kalatuwawa	94
5	Getahetta Oya	43
6	Ambalanpiti Oya/Gonmala Oya	70
7	Maha Oya/Seethawaka Ganga	145
8	Panapura Oya	43
9	Magal Ganga	111
10	Maskeliya Oya	195
11	Kehelgamu Ganga	212
12	Upper Kelani Ganga	134
13	Walihel Oya	89
14	Ritigaha Oya	94
15	Gurugoda Oya	239
16	Upper Middle Kelani Ganga	240
17	Pugoda Oya	52
18	Lower Middle Kelani Ganga	128
19	Biyagama	62
20	Lower Kelani Ganga	122

Fig. 17.1 Study areas in downstream of Kelani River

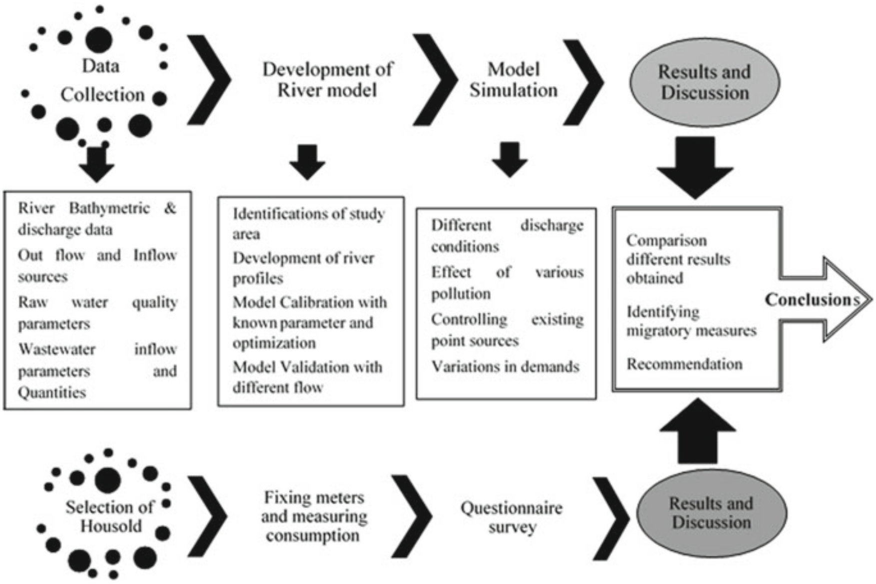


Fig. 17.2 Flow diagram of the methodology adopted

The end user household measurements were carried out through direct measurement of each consumer outlet of 25 houses located in the area. A questionnaire survey was carried out for 50 number of houses including end user consumption measured households.

17.3 Results and Discussion

17.3.1 Present Status Downstream of Kelani River

Figure 17.3 shows the average river discharge over one year and the tributary flow data during the wet and dry periods. As shown in the figure, the dry period of the year falls in December, January and February months of the year (Fig. 17.4).

Ruwanwella is the next intake located around 65 km chainage in upstream of Avissawella. The secondary data collected with referring to the Ruwanwella intake shows PH, Coliform values of 7.7, 6000/(100/ml) and 7.3, 1100 (100/ml) for dry and wet seasons, respectively. In addition, turbidity is around 2 (NTU) and Nitrate is less than 1 for both seasons.

Table 17.1 Intakes and outfall source to the Kelani river downstream (million meter cube per day)

Chainage (distance from the sea)/km	Name of the facility/location	Outfall/(MCM)	Intake/(MCM)
51.25	Seethawaka Industrial Zone WTP		0.1200
50.50	Seethawaka Industrial ZoneWWTP	0.1160	
41.34	Pugoda Oya (H5)	3.6900	
33.44	Kosgama Water Intake		0.0600
30.04	Wak Oya	1.5900	
29.90	Samanbedda (Water Intake)-Future		
29.71	Hanwella Water Intake-Future		
29.80	Varun Beverages	0.1200	
27.20	Amunugam Ela	1.7000	
25.89	Nawagamuwa Water Treatment Plant		0.0200
22.21	Chico Water Intake		
21.07	Fonterra Brand Lanka	0.1200	
20.01	Pahuru Oya	1.0400	
19.72	Maha Ela	1.9200	
19.34	Coca Cola Beverages	0.1000	
19.13	New Biyagama Village	0.2000	
18.92	Lion Brevery (Ceylon) PLC	0.1200	
17.6	Raggahawatta Ela	1.9400	
16.27	Biyagama Water Treatment Plant (KRBI)		2.3100
14.9	Ambathale Water Treatment Plant		6.3600

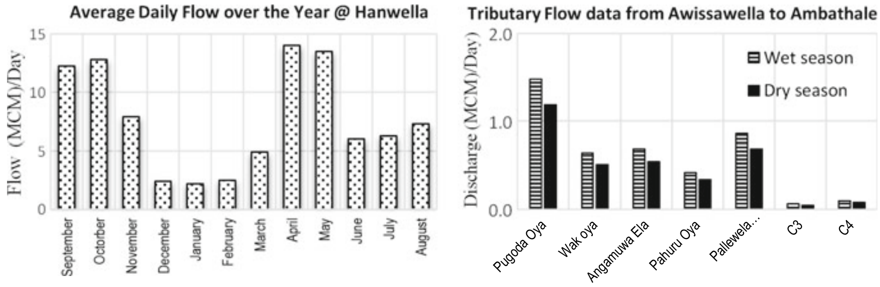


Fig. 17.3 Daily discharge variation and the tributary flow data over the year

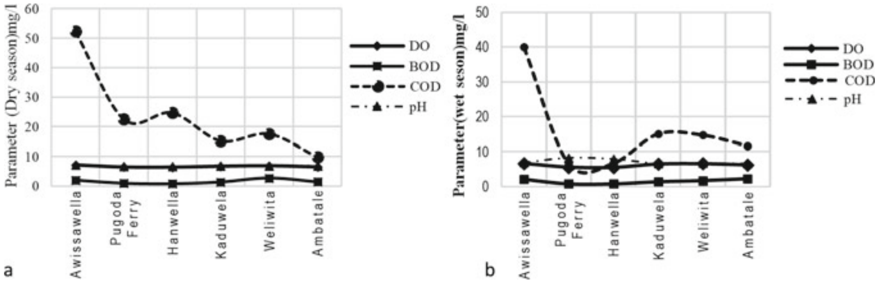


Fig. 17.4 Average water quality data obtained from the NWSDB and its variation across the river during the dry season (**a**) and wet season (**b**)

17.3.2 Calibration and Validation

The calibration was carried out for the month of February which is the driest month of the year, and validation was carried out for the month of July. The calibration and validation results are shown in Fig. 17.5.

Five parameters were considered for the model calibration and validation. Initially, the rate coefficients were defined based on the similar previous studies. Then, the coefficient was optimized to achieve the minimum difference between the model representation and the field measured figures. Table 17.2 shows the route mean squared errors of different parameters for calibration and validation.

According to the values shown in Table 17.2, the error percentages of all parameters are less than 25% both in the calibration and validation processes except BOD. The BOD has been further deviated from the observation where validation values having best approximation of 32% deviation. The finalized model was used to investigate various river flow conditions and the pollution loadings. The finalized rate parameter used in the validated model is shown in Table 17.3

17.3.3 Model Analysis for Different Flow Conditions

17.3.3.1 The BOD Variation Over Three Different Flow Conditions

Similar to field observation, the BOD levels are high at the beginning of the section predominantly due to the waste discharges from industrial zone located just upstream of the sampling location. Subsequently, the conditions got diluted and stable up to 21 km chainage point downstream of Hanwella. Again, the BOD levels increased with the increase of absorptions and addition of pollutant toward the downstream. There is risk of exceeding the pollutant level beyond the tolerance limits of drinking raw water quality just before Ambathale. Further, it is noted that worst condition will occur once the absorption is increased to cater the future demand (Fig. 17.6).

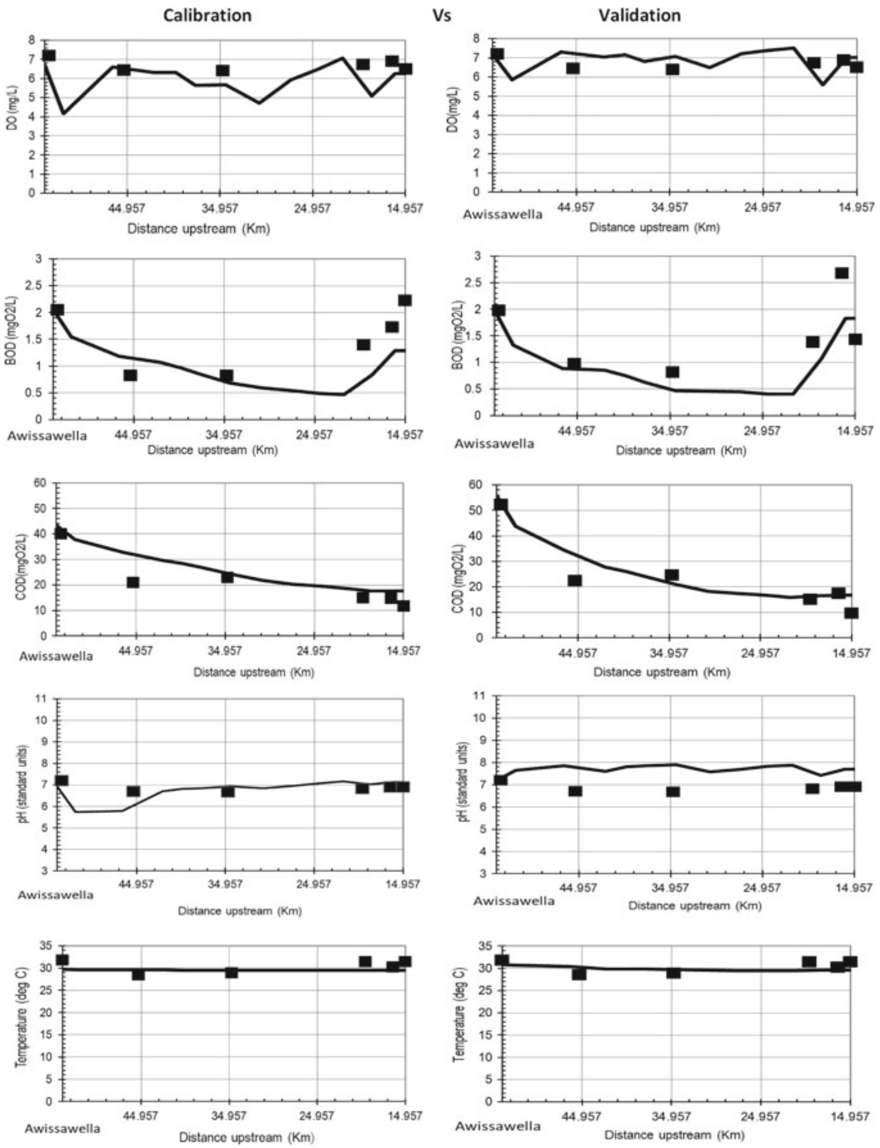


Fig. 17.5 Model calibration (dry season) versus validation wet season

17.3.3.2 The COD Variation Over Three Different Flow Conditions

Similar to characteristics shown in for BOD, the higher COD levels prevail at the beginning of the section. The conditions beyond the tolerance limits for drinking raw water are present at the upstream. Subsequently, the conditions get diluted into

Table 17.2 Route mean squared errors of different parameters for calibration and validation

S. No.	Parameter	RMSE			
		Calibration	%	Validation	%
1	Temperature	1.4	4.6	1.1	3.7
2	DO	1.3	25.3	0.8	11.5
3	BOD	0.5	41.6	0.4	32.0
4	pH	1.0	13.9	0.9	11.2
5	COD	3.9	15.1	6.0	22.4

Table 17.3 Major model parameters finalized at end of calibration and validation

Parameter	Used value/day
Reaeration rate, k_a	0–75
Hydrolysis rate, k_{hc}	1.8
BOD oxidation rate, k_{dc}	3.5
Pathogens, decay rate, k_{dx}	0.05
Decay rate	0.75

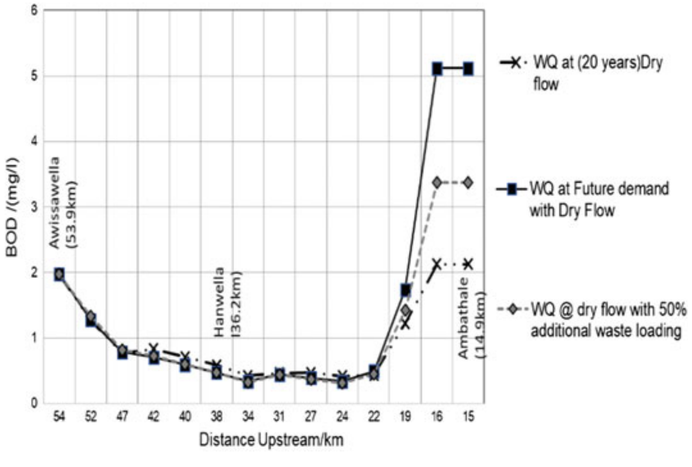


Fig. 17.6 Variation of BOD of three different flow conditions

stable level. However, marginal increase can be observed from 21 km chainage point at downstream of Hanwella. The influence of COD levels is not seemed to be severe compared to BOD, but possibility is there to increase with absorptions and mixing of additional pollutants (Fig. 17.7).

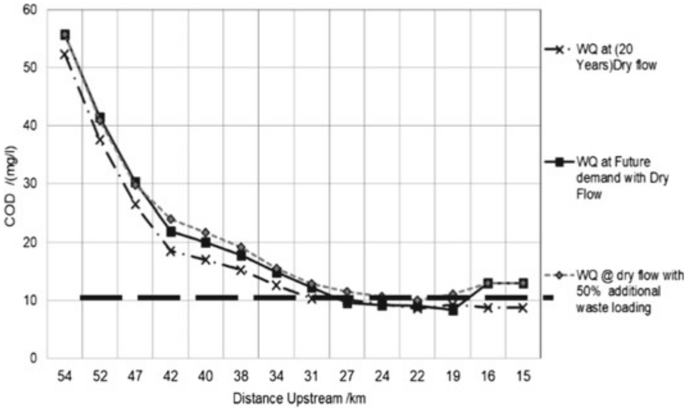


Fig. 17.7 Variation of COD of three different flow conditions

17.3.3.3 The BOD/COD Variation Over Three Different Flow Conditions

As shown in the figure, the BOD/COD ratio is increasing with growth of demand and pollution loading. The highest change was occurred at highest demand. As per the Figs. 17.6 and 17.8 biological pollutions creased toward the downstream and the pollution level was increased with increased demand. The overall results shows that increase in demand and the biological pollution are the key aspects to be addressed to mitigate the future risk of water supply.

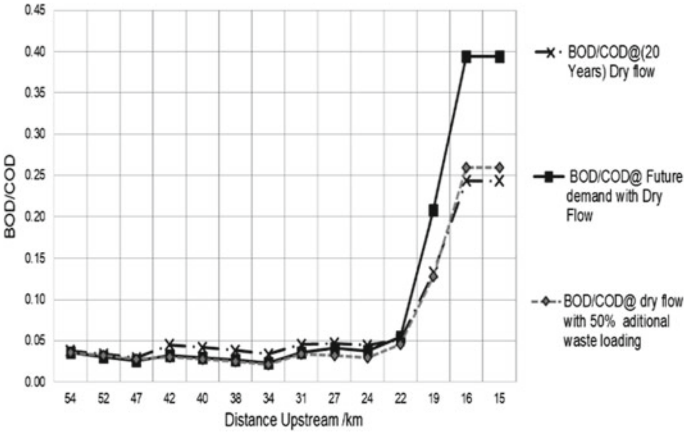


Fig. 17.8 Variation of BOD/COD of three different flow conditions

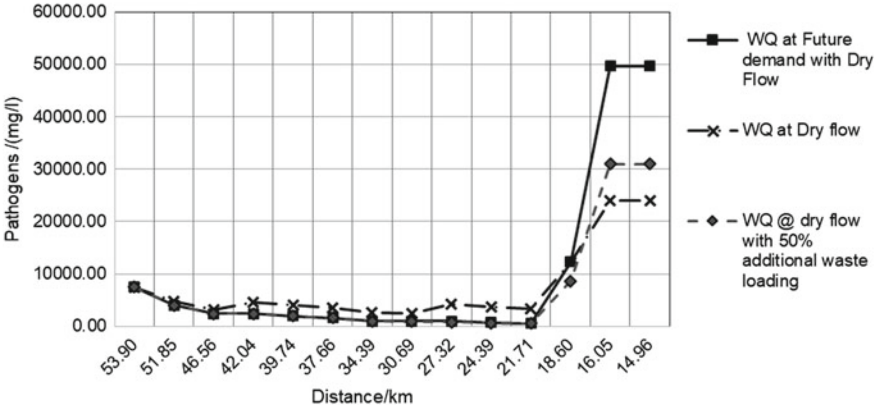


Fig. 17.9 Variation of pathogen for three different flow conditions

17.3.3.4 The Pathogen Variation Over Three Different Flow Conditions

Similar to characteristics shown in for BOD and COD, the pathogen concentration has significant influence toward the downstream. The worst conditions were predicted at the future demand with 50% additional pollutions. The results indicate that extraction of the river causes to increase the concentration of pathogen and conditions aggravated with the addition of more pollution (Fig. 17.9).

17.3.3.5 The River Characteristics at the Wet Season

During the wet season, the average river discharge volumes increase substantially than dry flow volumes. Therefore, river carries high volume of water, and potential of diluting pollutant loading is high. However during the wet flow conditions, the rate of pollution entering the river through the industries and the extraction from the river has no changes. Accordingly, the four scenarios considered for dry flow conditions were modeled at wet flow situation. Fig. 17.10 show the results of the modeling.

As per the results shown from Fig. 17.10a–d for wet season, the influence extraction of water from the river and addition of more pollutant to the river have no significant effect over the overall pollution in river. The BOD levels vary between 2.0 mg/l and 0.5 mg/l which is well above the raw water quality requirements. The COD variation was similar to the field observations and shows continuous reduction from the high levels of COD at the start point, but the value is above the 15 mg/l throughout the river indicating less oxidation characteristics. The BOD/COD ratios have only minor increments compared to dry conditions. The pathogen concentration has similar status both in wet and dry flows up to 22 km; thereafter only slight increase could be observed in wet flows compared to rapid increasing shown in the dry flow.

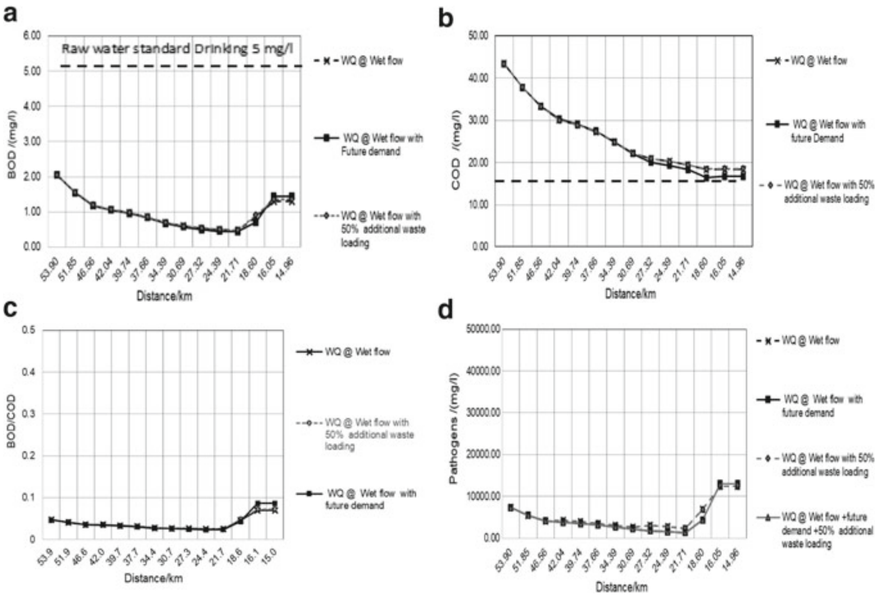


Fig. 17.10 **a** BOD variation at wet flow. **b** COD variation at wet flow. **c** BOD/COD variation at wet flow. **d** Pathegen variation at wet flow

The pathogen values of 50,000–20,000 in dry season have changed to 10,000–15,000 at wet season in the downstream areas.

According to overall observation made for the wet flow molding, it is emphasized that most critical condition of the river occurred only in the dry flow condition.

17.3.4 End User Measurements

As per the results shown in Figs. 17.11 and 17.12, the average per capita water consumption is 161 l/p/day. The water requirement for drinking and cooking is 28 l/d/(17%) which is the highest water quality requirement (WQR). Water requirement for washing clothes, washbasin, bathing, bidet and outdoor is 110 l/p/d and accounts for consumption 68% which needs average WQR. Toilet flushing and others are 23 l/p/d and account for 14% of total consumption and could be utilized with lowest WQR.

Accordingly, the healthy purified water requirement is 17% of total consumption, and water needs to match with all drinking water requirements. Out of the total consumption, 14% is for toilet flushing, and alternative method could be easily adopted by means of rainwater harvesting and partially treated recycled water replacing 30–70% of the consumption. The other catenary has the highest consumption but needs to be utilized with average quality water. This too could be

Fig. 17.11 End user consumption versus different applications

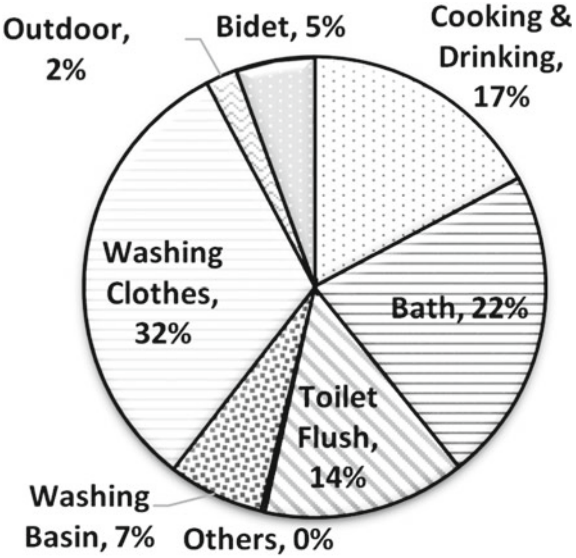
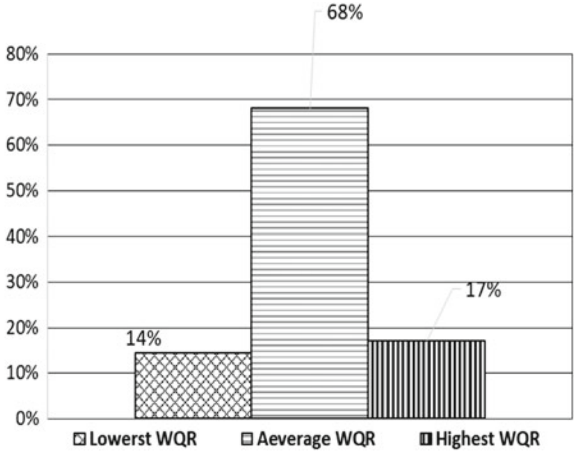


Fig. 17.12 Water quality requirements versus utilization



utilized with alternative sources such as groundwater or treated rainwater. However, finding average quality water is not possible as low quality water. Therefore, replacement of major percentage of average quality water has constrains, and around 20–30% of the consumption will be within manageable level.

17.4 Conclusion and Future Directions

17.4.1 Water Quality Variations in Kelani River Downstream

BOD levels have significant increase in river with high industrial and urbanization effects. Increased BOD to COD ratios show comparatively higher biological degradations than the industrial pollution. Mitigatory measure are needs to control biological pollution stimulated from uncontrolled wastewater discharges, solid waste discharges and other human activities. Future demand at dry flow increases BOD level above tolerance limits (5 mg/l) for raw water. Risk in drinking water supply systems at future occurs if pollution and extraction are not managed.

17.4.2 End User Measurement

As per the outcome of the end user measurement, the alternative water sources could be adopted to reduce the water demand. As shown in Table 17.4, 30% alternative consumption for toilet flushing could save 600–1300 million rupees per year, and water demand can be reduced by 0.043 MCM/Day as minimum. In addition, alternative use of groundwater and water with limited treatment to cover 30% of washing, bathing and bidet will reduce water demand by 0.377 MCM/Day in year 2030 and millions of investment required for the development of maintenance of

Table 17.4 Alternative water usage and respective projected saving

Type of usage	Per capita consumption (L/P/day)	Proposed percentage to use alternatives (%)	Saving volume/(MCM)		Project cost saving			
			Present demand (0.85)	Future demand (1.85)	Present demand (million rupees/year)		Future demand (million rupees/year)	
					O&M	O&M + Capital	O&M	O&M + Capital
Toilet flushing and out door	28	75	0.09	0.19	1499	5180	3261	11,273
		50	0.06	0.13	999	3453	2174	7516
		30	0.04	0.08	599	2072	1305	4509
Washing bathing and bidet	110	30	0.17	0.38	2911	10,063	6337	21,902
		20	0.12	0.25	1941	5709	4224	14,602
		10	0.06	0.13	970	3351	2112	7301
Total project saving	84	34	0.26	0.57	4410	15,243	9598	33,176
	102	22	0.18	0.38	2940	10,162	6399	22,117
	118.6	12	0.09	0.20	1570	5426	3417	11,810

water infrastructure facilities. It will also reduce water absorption from the river and risk of adverse pollution in Kelani River downstream in future.

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References

Abeysinghe NMDeA, Samarakoon MB (2017) Analysis of variation of water quality in Kelani River, Sri Lanka. Int J Environ Agric Biotechnol (IJEAB) 2(6):2772. http://dx.doi.org/10.22161/ijeab/2.6.1

Alcamo J, Flörke M, Märker M (2007) Future long-term changes in global water resources driven by socio-economic and climatic changes. Center for Environmental Systems Research (USF), University of Kassel, p 247

Das N, Sarma KP, Patel AK, Deka JP, Das A, Kumar A, Shea PJ, Kumar M (2017) Seasonal disparity in the co-occurrence of arsenic and fluoride in the aquifers of the Brahmaputra flood plains, Northeast India. Environ Earth Sci 76(4):183

Herath G, Amarasekara T (2004) Assessment of urban and Industrial pollution on water quality Kelani River. In: The second international symposium on Southeast Asian water environment, Hanoi, Vietnam, pp 92

Himesh S, Rao CVC, Mahajan AU (2000) Application of steady state stream water quality model. J Indian Assoc Environ Manag 27:33–37

Kim J, Kuwahara Y, Kumar M (2011) A DEM-based evaluation of potential flood risk to enhance decision support system for safe evacuation. Natural Haz 59:1561–1572

Kumar M., AL Ramanathan, S. Chidambram, R. Goswami (2015) Criterion, indices, and classification of water quality and water reuse options. In: Eslamian S (ed) Urban water reuse handbook (UWRH), 1st ed, chap 6. CRC Press, pp 163–176. ISBN: 13-978-1-4822-2915-8

Kumar M, Ram B, Honda R, Poopipattana C, Canh VD, Chaminda T, Furumai H (2019a) Concurrence of antibiotic resistant bacteria (ARB), viruses, pharmaceuticals and personal care products (PPCPs) in ambient waters of Guwahati, India: urban vulnerability and resilience perspective. Sci Total Environ 693:133640. https://doi.org/10.1016/j.scitotenv.2019.133640

Kumar M, Chaminda T, Honda R, Furumai H (2019b). Vulnerability of urban waters to emerging contaminants in India and Sri Lanka: resilience framework and strategy. APN Sci Bull 9(1). https://doi.org/10.30852/sb.2019.799

Mallawatantri A, Rodrigo A, De Silva K (2016) Medium to long-term multi-stakeholder strategy and action plan for management and conservation of the Kelani River Basin 2016–2020. Natural Resource Management and Monitoring Unit, Central Environment Authority, pp 2–3

Otaki Y, Otaki M, Pengchai P, Ohta Y, Aramaki T (2008) Micro-components survey of residential indoor water consumption in Chiang Mai. Drinking Water Eng Sci 1:17–22

Patel AK, Das N, Goswami R, Kumar M (2019) Arsenic mobility and potential co-leaching of fluoride from the sediments of three tributaries of the Upper Brahmaputra floodplain, Lakhimpur, Assam, India. J Geochem Explor 203:45–58

Rajapaksha RWCN, Subasinghe SMCK, Halgahawatte HRLW, Weerasinghe WLK, Manoranjan M, Nandalal KDW, Raveenthiran K, Cassim M (2016) Water resources modelling study to update Water supply master plan for western Province metropolitan area. In: 20th congress of the Asia Pacific Division of the International Association for Hydro Environment Engineering & Research, Colombo, Sri Lanka, pp 5, 6

Water Quality in Kelani River Introduction Last Updated on Wednesday, 26 March 2014, Children's Fund UNICEF, and Cited on 19 Nov 2017 from. http://www.cea.lk/web/en/water?id=160 https://www.ck12.org/book/CK-12-Earth-Science-Concepts-For-Middle-School/section/6.1/

Zadeh SM, DVL Hunt, CDF Rogers (2014) School of Civil Engineering, College of Engineering and Physical Sciences, University of Birmingham, Birmingham B152TT, UK, pp 1961–1965