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Surface water quality and health risk assessment of Kameng river (Assam, India)

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Abstract

Present study evaluated the surface water quality of Kameng River (Assam, India). Kameng River is the tributary of the river Brahmaputra, having its confluence at its north bank. Water samples were collected from 9 different locations along the stretch and 24 parameters were analysed. Water quality at all sampling sites was expressed in terms of overall index of pollution (OIP). The OIP of all sampling sites varied between 1.30 and 1.74. Principal component analysis (PCA) was used to identify the latent factors influencing the water quality of the river. PCA revealed that domestic wastewater and agricultural runoff were the leading sources causing adulteration of the river's water quality. The degree of contamination of each sampling site due to heavy metals was calculated by the contamination index and an associated human health risk assessment was done by computing average daily intake and Hazard quotient (HQ). The HQ of all sampling sites varied from 0.14 to 1.21. This work presents the reliability and practicability of the integrated use of these approaches in river water quality monitoring and assessment. These methods will be very useful for policy makers for assessing the cause and effect of pollution of water bodies and implementing policies to keep pollution under check.

Key words: average daily intake, contamination index, hazard quotient, overall index of pollution, principal component analysis, water quality

Highlights

- Water quality of Kameng River has been assessed.
- Water quality was expressed in terms of OIP.
- PCA was used to identify the latent factors influencing water quality.
- The degree of contamination due to heavy metals was calculated by the CI and HQ.
- The study demonstrated the reliability and practicability of the combined use of PCA and indexing approaches for getting useful information from a large water quality data set.

INTRODUCTION

The socio-economic and ecological importance of freshwater resources form the very foundation for growth and progress of a nation. Rivers are the foremost source of freshwater and have been used for municipal water supply, irrigation, transportation, energy production and for carrying wastewater since ancient time (Iscen *et al.* 2008). Various natural and anthropogenic activities are adversely affecting the water quality of rivers and impeding their use for various purposes (Carpenter *et al.* 1998). Now water quality has become a serious issue and has garnered worldwide consideration for its preservation and protection (Simeonov *et al.* 2003). Therefore, monitoring of rivers is essential for authentic information on their water quality and to prevent and control their pollution (Singh *et al.* 2004).

A major problem in river water quality monitoring is handling of the complex data sets generated due to the large number of water quality variables at different monitoring stations (Dixon & Chiswell 1996). Elucidation of monitored data is a challenging task for scientists and policy makers involved in the field of river monitoring. Multivariate statistical methods (MSMs) are an important tool to extract the significant information from enormous and complex data matrices. Over the last three decades, MSMs have been extensively used in surface water quality assessment.

A water quality index (WQI) is another important process to encapsulate the large data sets to a numerical score for easy understanding by users and policy makers. It expresses the water quality in the form of an index number. This index is a great help to the various agencies that take care of the water supply and water pollution control, since these form a significant tool for easy understanding and thereby make their applicability uncomplicated. Indeed, these methodologies make the use of water quality datasets enormously easy and lucid and help policy makers to make decisions in allocating funds and determining priorities. Depiction of water quality in terms of WQI allows for a better evaluation of water quality conditions in different places and therefore better prioritization of resources to the areas in most need.

The first modern WQI was proposed by Horton (1965). Since then several researchers have proposed and applied different indices to categorize the water quality in their region (Abbasi & Abbasi 2012). Sargaonkar & Deshpande (2003) developed the Overall Index of Pollution (OIP) for surface water, considering Indian standards and Central Pollution Control Board criteria. It is based on a general classification scheme in the Indian context and is very useful to identify changes in the quality of water along the stretch of river. Similar types of indices have also been developed for metals. Mohan *et al.* (1996) developed a heavy metal pollution index (HPI) to provide information about metal contamination in a single value. Backman *et al.* (1998) applied a contamination index (CI) to measure the degree of contamination of groundwater in Finland and Slovakia due to the presence of numerous heavy metals.

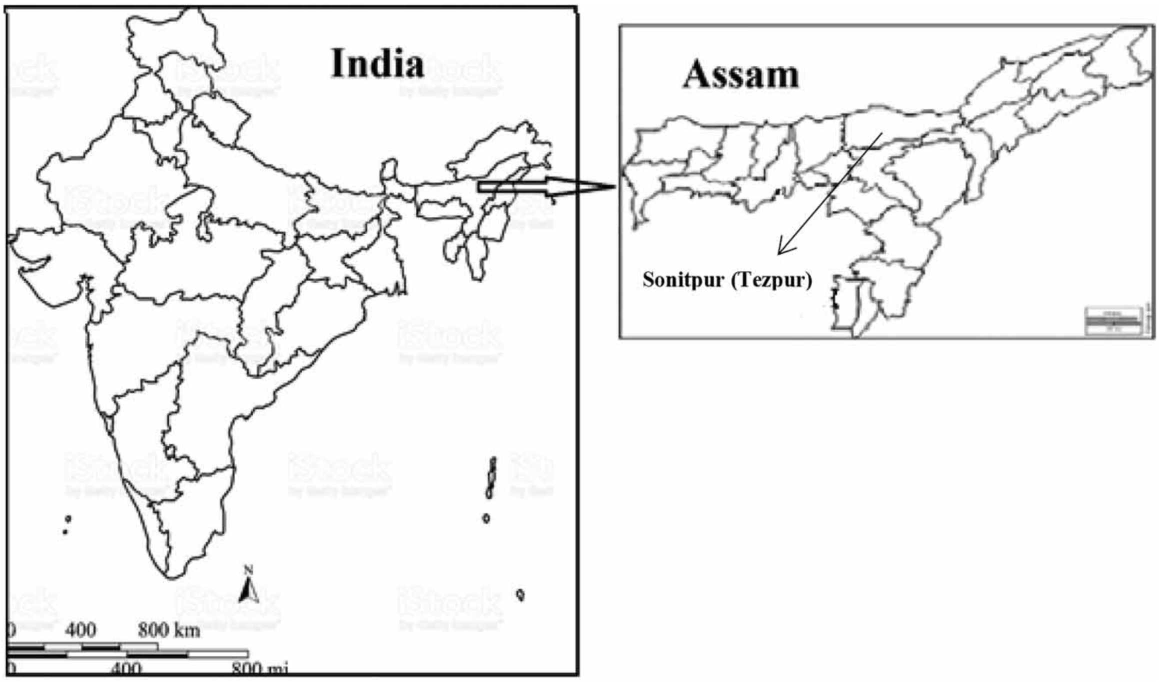

Figure 1 | (a) Map of Assam, (b) Location of sampling sites. *(continued)*.

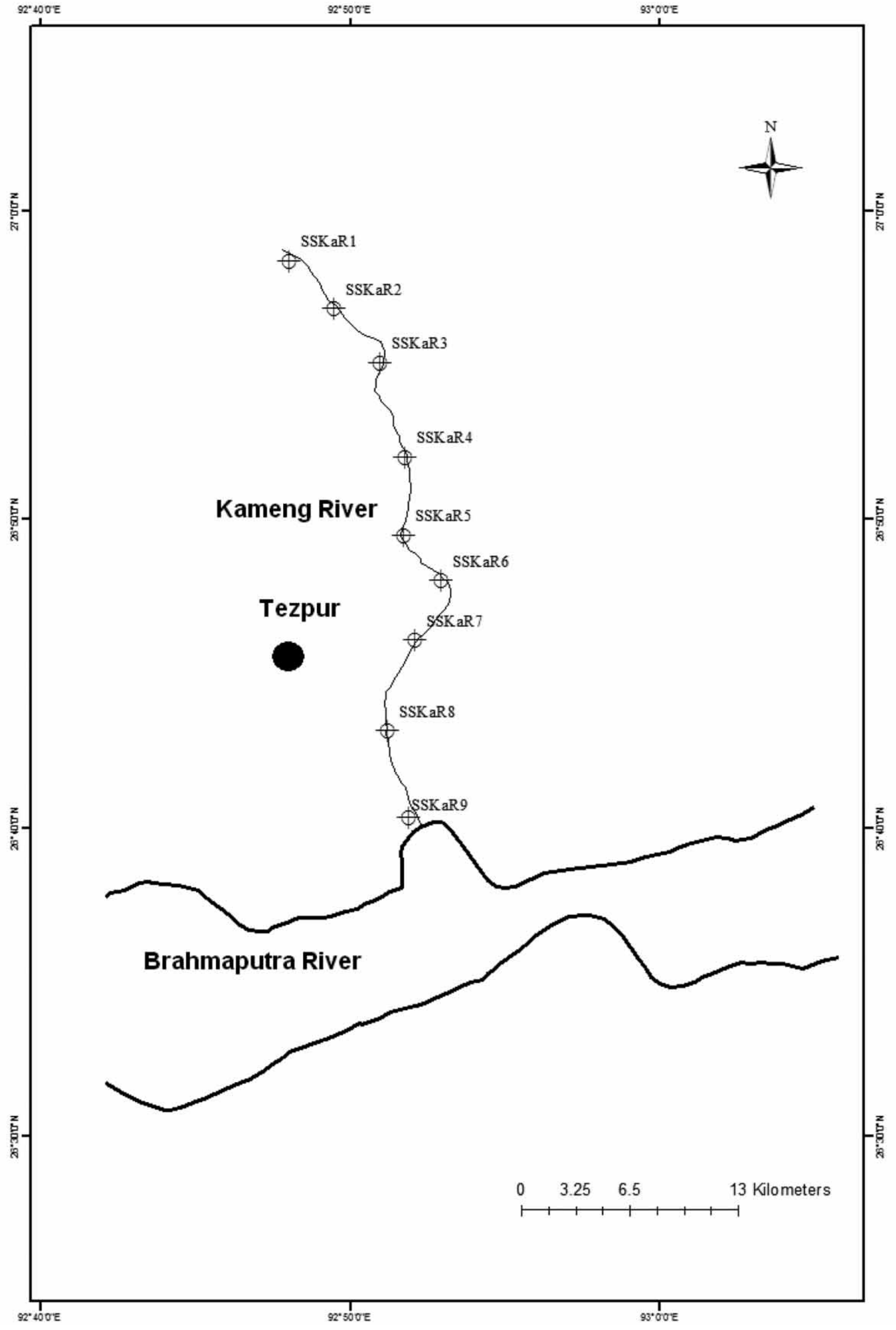

Figure 1 | Continued.

Various studies have been performed on the utilization of these techniques individually. Very limited literatures are available on the feasibility of the combined use of these tools. The present study demonstrates the water quality assessment of the Kameng River (Assam, India) by applying principal component analysis (PCA) and an indexing approach together with a health assessment due to heavy metals.

MATERIALS AND METHODS

The Kameng river (Jia Bhoreli in Assam) is a northern bank tributary of the mighty river Brahmaputra. It has its origin in a glacial lake (Tawang, Arunachal Pradesh) and joins the Brahmaputra at Tezpur, the centre of administration for the Sonitpur district (Assam) (Figure 1(a) and (b)). The total length of the river is approximately 264 kilometres and its drainage basin is about 11,843 square kilometres. Dirang Chhu, Bichom, the Tenga river and Tippi are its few major tributaries (Khound & Bhattacharyya 2017). Industrial activities are very few along the stretch, but the river receives untreated or partially treated sewage and surface runoff. Major agricultural activities in the catchment area are tea plantations and rice cultivation (Khound & Bhattacharyya 2017).

Water samples were collected from nine sampling sites along the stretch from a well-mixed section (Figure 1(b)). Water samples were collected twice in the pre-monsoon and twice in the post-monsoon period. All samples were collected in triplicate. A total of 108 samples were collected and analysed. A number of factors are used in selecting parameters for determining the status of a particular water body with respect to its quality. The selection of parameters should depend on various factors such as the geographical condition of the study area, a literature review and expert opinions, and the intended use of the water. In the present study, 22 water quality parameters were selected based on drinking water supply (Table 1). Temperature (T), pH, and dissolved oxygen (DO) were measured at the site itself. Standard Methods (APHA 2012) were followed for the analysis of water samples.

Table 1 | Water quality parameters associated with their units, abbreviations and analytical methods used in this study

PARAMETERS	UNIT	Abbreviation	Analytical methods	Detection limit
Temperature	°C	T	Thermometer	−50 to 250 °C
pH	–	pH	pH-meter	–
Dissolved oxygen	mg/L	DO	DO meter	0.1 mg/L
Alkalinity	mg/L	TA	Titrimetric	–
Hardness	mg/L	TH	Titrimetric	–
Total Dissolved Solids	mg/L	TDS	Gravimetric	–
Total Suspended Solids	mg/L	TSS	Gravimetric	–
Electrical conductivity	µS/cm	EC	Electrometric	0.1 ms/cm
Sodium	mg/L	Na^+	Flame photometer	0.1 mg/L
Potassium	Mg/L	K^+	Flame photometer	0.1 mg/L
Calcium	mg/L	Ca^{2+}	Flame photometer	5 mg/L
Magnesium	mg/L	Mg^{2+}	Atomic absorption spectroscopy	0.003 µg/mL
Fluoride	mg/L	F^-	Ion chromatography	0.01 mg/L
Chloride	mg/L	Cl^-	Ion chromatography	0.01 mg/L
Sulfate	mg/L	SO_4^{2-}	Ion chromatography	0.01 mg/L
Nitrate	mg/L	NO_3^-	Ion chromatography	0.01 mg/L
Iron	mg/L	Fe	Atomic absorption spectroscopy	0.06 µg/mL
Manganese	mg/L	Mn	Atomic absorption spectroscopy	0.02 µg/mL
Lead	mg/L	Pb	Atomic absorption spectroscopy	0.1 µg/mL
Copper	mg/L	Cu	Atomic absorption spectroscopy	0.03 µg/mL
Chromium	mg/L	Cr	Atomic absorption spectroscopy	0.06 µg/mL
Zinc	mg/L	Zn	Atomic absorption spectroscopy	0.01 µg/mL

Based on work done by Khound & Bhattacharyya (2017), Sharma and Sharma (2018) and Khound *et al.* (2017) on the Kameng River Basin, six heavy metals (Fe, Mn, Pb, Cu, Cr, and Zn) were selected for analysis. The selected heavy metals were analysed by using AAS (AAS, iCE 3000 AA spectrometer developed by Thermo Scientific). All water samples were analysed in triplicates. Calibration of AAS was done separately for all the metals. A summary of analytical procedures is given in Table 1.

Overall index of pollution (OIP)

Water quality of each sampling site on the Kameng river was represented in terms of OIP. OIP was estimated using the following mathematical expression (Sargaonkar and Deshpande 2003):

$$\mathrm{OIP} = \frac{\sum \mathrm{Pi}}{n} \tag{1}$$

where Pi is the pollution index of the i^{th} parameter and n is the total number of parameters. Pi of all water quality parameters was calculated using the mathematical equations given by Sargaonkar and Deshpande (2003). Table 2 shows the mathematical equation used for calculation of Pi. Water quality classification based on OIP score is given in Table 3.

Table 2 | Mathematical equations for Pi (Sargaonkar and Deshpande 2003)

Parameters	Range	Equation
pH	7	$P = 1$
	>7	$P = \exp((y - 7.0)/1.082$
	<7	$P = \exp((7.0\text{-}y)/1.082$
% DO	<50	$P = \exp(-(y - 98.33)/36.067)$
	50–100	$P = (y - 107.58)/14.667$
	150–200	$P = (y - 79.543)/19.054$
BOD	<2	$P = 1$
	2–30	$P = y/1.5$
TDS	≤500	$P = 1$
	500–1,500	$P = \exp((y - 500)/721.5)$
	1,500–3,000	$P = (y - 1{,}000)/125$
	3,000–6,000	$P = y/375$
TH	≤75	$P = 1$
	75–500	$P = \exp(y + 42.5)/205.58$
	>500	$P = (y + 500)/125$
Cl	≤150	$P = 1$
	150–250	$P = \exp((y/50) - 3)/1.4427$
	>250	$P = \exp((y/50) + 10.167)/10.82$
NO_3^-	≤20	$P = 1$
	20–50	$P = \exp((y - 145.16)/76.28)$
	50–200	$P = y/65$
SO_4^{2-}	≤150	$P = 1$
	150–2000	$P = ((y/50) + 0.375)/2.5121$
F^-	0–1.2	$P = 1$
	1.2–10	$P = ((y/1.2) - 0.3819)/0.5083$

Table 3 | Water quality scale (Sargaonkar and Deshpande 2002)

OIP	Class	Water quality
0–1	C_1	Excellent
1–2	C_2	Acceptable
2–4	C_3	Slightly polluted
4–8	C_4	Polluted
8–16	C_5	Heavily polluted

Principal component analysis (PCA)

PCA is an MSM that allows the size of the data set to be reduced without much loss of information. PCA involves following major steps (Ouyang *et al.* 2006):

(a) Standardization of all water quality parameters (zero means and unit variance)
(b) Calculation of covariance matrix
(c) Estimation of eigenvalues and eigenvectors
(d) Development of factor loading matrix
(e) Perform varimax rotation

PCA was performed using the 'IBM SPSS Statistics 20' Software.

Contamination index (CI)

The degree of contamination of each sampling site due to heavy metals was estimated by the contamination index (CI). It involves the summation of the contamination factors (C_{fi}) of the individual metals, exceeding their upper permissible limits. The composite influence of the heavy metals was thus aggregated to a single number. CI was calculated using the following mathematical expression (Backman *et al.* 1998):

$$CI = \sum_{i=1}^{n} C_{fi} \tag{2}$$

and

$$C_{fi} = \frac{C_{ai}}{C_{ni}} - 1 \tag{3}$$

where C_{ai} is the observed value of the i^{th} parameter and C_{ni} is the maximum permissible limit of the i^{th} parameter. The grade scale of contamination index is such that samples with $CI < 1$ denote low contamination, CI values lying between 1 and 3 denote medium contamination and CI values greater than 3 denote high contamination (Backman *et al.* 1998).

Average daily intake (ADI)

ADI of each metal was measured by using the given formula:

$$ADI = Ci \times IR \times EF \times ED/(AT \times BW) \tag{4}$$

where Ci is the concentration of the i^{th} parameter (μg/l), IR is the ingestion rate (2.2 l/day), EF is the exposure frequency (365 day/year), ED is the exposure duration (65 years), AT is the average time (365 days/year), and BW is the average body weight (60 kg).

Hazard quotient (HQ)

HQ was evaluated by using the given expression:

$$HQ = ADI/RfD \tag{5}$$

where RfD denotes the reference dose.

RESULTS AND DISCUSSION

Table 4 gives the statistical summary of all measured water quality parameters. OIP of all sampling sites is given in Table 5. OIP varied from 1.30 to 1.74. Slight variation in OIP along the river was due to low population density, absence of large industries and limited urbanization in the catchment area. A major part of the catchment area is rural in character with agriculture and allied activities being the main occupation of the population along the river. Assam is one of the least urbanized states of the country. Highest OIP was observed at sampling site 'SSKaR6', which is near Tejpur town, Assam. This may be because of discharge of untreated or partially treated sewage. Water quality at all locations falls under C_2 class, which is 'Acceptable'. PCA was performed on normalized datasets of water quality parameters. For extracting important factors, the eigenvalue-one criterion was used (Kaiser 1960; Kim & Mueller 1987). Varimax rotation has been used to maximize the variance of each factor and for better interpretation of results. Analysis showed that only four components had eigenvalues greater than 1 (Table 6). These four factors explained 91.88% of the total variance. The first factor (F1), attributed 45.786% of the total variance. F1 had strong positive loading on T (0.87), EC (0.98), TA (0.95), Mg^{2+} (0.96) and SO_4^{2-} (0.77) and moderately positive loading on TS (0.64), TDS (0.66) and TH (0.58). T is a significant physical parameter for study of water quality and ecosystems (Larnier *et al.* 2010; Varol *et al.* 2012). It not only affects the chemical and biological characteristics of water but also the aquatic organisms (Larnier *et al.* 2010). The solubility and toxicity of certain metals such as cadmium, zinc and lead also depends on temperature. EC represents the ability of water to conduct electricity and it depends on ion concentration in the water. There is an almost linear relationship between EC and T. EC is also an indicator of TDS. The more salts are dissolved in the water, the higher the value of the EC. CO_3^{2-} and HCO_3^{2-} are major sources of TA in water. Mg^{2+} is one of the major dissolved polyvalent metallic ions that contribute to TH in water. This factor had strong negative loading on pH (0.97) and DO (0.91). DO is an essential parameter for assessment of surface water quality because it influences the organisms living within the water body. It is mostly used as an indicator of a river's health. T & DO have an inverse relationship because the solubility of oxygen depends on temperature and it decreases as the water temperature increases. This factor is associated with inorganic constituents owing to the geological features in the aquatic environment (Bu *et al.* 2010). The second factor (F2) contributed 18.17% of the total variance. This factor had strong positive loading on F^- (0.91) and moderate positive loading on TSS (0.57), TH (0.56), and SO_4^{2-} (0.58). This factor is associated with natural rock weathering and runoff. The third factor (F3) explained 17.37% of the total variance and had strong positive loading on BOD (0.81) and moderate positive loading on TDS (0.54) and TH (0.55). This factor is associated with domestic wastewater. F4 had strong positive loading on TSS (0.76) and NO_3^- (0.88). Inorganic fertilizers contribute NO_3^- and runoff carries it to surface water bodies. So this factor represents agricultural runoff from catchment area (Varol *et al.* 2012).

Table 4 | Statistics of measured physico-chemical parameters

	T	pH	DO	BOD$_5$	TS	TDS	TSS	EC	TH	TA	Na$^+$	K$^+$	Ca^{+2}	Mg^{+2}	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$
MAX	26.7	7.98	9.3	11.1	680	605	260	101.2	97.38	32	3.36	3.57	18.85	14.83	0.29	29.14	6.49	8.45
MIN	24.1	6.78	8.14	2.85	210	70	50	73.1	57.74	19	2.35	1.47	2.3	7.75	0.07	13.92	0.74	5.25
MEAN	25.56	7.38	8.58	5.92	403.89	265	138.89	86.79	74.48	25.89	2.8	2.71	10.23	10.66	0.11	23.49	2.35	6.82
[a]SD	0.88	0.39	0.52	2.55	146.54	160.66	72.19	10.08	18.12	4.57	0.36	0.66	5.24	2.74	0.07	4.77	1.76	1.26
KURTOSIS	−1.04	−0.75	−1.66	0.99	0.18	1.67	−0.97	−1.29	−2.3	−1.2	−1.39	−0.05	−0.55	−1.5	6.05	0.65	4.07	−1.58
SKEWNESS	−0.27	0.17	0.68	0.89	0.65	0.93	0.43	−0.14	0.29	−0.35	0.37	−0.41	−0.02	0.32	2	−0.87	1.58	−0.13
#CoV	0.03	0.05	0.06	0.43	0.36	0.61	0.52	0.12	0.24	0.18	0.13	0.24	0.51	0.26	0.61	0.20	0.75	0.18

[a] SD, Standard deviation, #CoV, Coefficient of variation.

Table 5 | Overall index of pollution (OIP)

Sampling sites	OIP
SSKaR1	1.56
SSKaR2	1.32
SSKaR3	1.49
SSKaR4	1.31
SSKaR5	1.48
SSKaR6	1.74
SSKaR7	1.53
SSKaR8	1.30
SSKaR9	1.52

Table 6 | Variance explained and rotated component matrix

	F1	F2	F3	F4
Eigen Value	8.241	3.271	3.127	1.900
% Total variance	45.786	18.172	17.373	10.556
Cumulative	45.786	63.958	81.331	91.887
Variables				
T	0.868	−0.112	0.429	0.121
pH	−0.968	0.089	0.006	−0.013
DO	−0.911	−0.306	−0.072	−0.221
BOD	0.328	−0.122	0.814	−0.014
TS	0.636	−0.210	0.477	0.489
TDS	0.655	−0.446	0.544	0.105
TSS	−0.166	0.566	−0.242	0.760
EC	0.978	0.030	−0.010	−0.006
TH	0.577	0.560	−0.553	−0.193
TA	0.954	0.246	0.000	−0.061
Na^+	0.935	−0.171	0.099	−0.196
K^+	−0.385	0.418	0.616	−0.072
Ca^{2+}	−0.015	−0.217	−0.968	−0.021
Mg^{2+}	0.956	−0.148	0.000	−0.151
F^-	0.137	0.911	0.091	−0.316
Cl^-	0.086	−0.835	−0.119	−0.097
NO_3^-	0.026	−0.263	0.114	0.879
SO_4^{2-}	0.765	0.577	−0.158	0.140

Heavy metals and associated health risk assessment

Statistical summary of all measured heavy metals is given in Table 7. Metal contamination is a major concern due to its toxicity and persistence in the environment (Morillo *et al.* 2002; Milivojević *et al.* 2016). Because of its various adverse impacts on the environment and public health, heavy metals have become a major focus area for researchers and policy makers (Nasrabadi 2015). Heavy metals present in surface water find their way into the human body directly by ingestion or indirectly via food consumption and pose a health risk (Khan *et al.* 2013). Some metals are necessary for all

Table 7 | Statistics of heavy metals

	Fe	Mn	Cr	Pb	Cu	Zn
MAX	1.34	0.05	0.02	0.04	0.01	0.01
MIN	0.14	0	0	0	0	0
MEAN	0.54	0.01	0.01	0.02	0	0
SD	0.42	0.02	0.01	0.01	0	0
KURTOSIS	0.29	− 0.81	− 1.12	− 0.35	− 1.12	− 1.12
SKEWNESS	0.98	0.87	0.49	− 0.71	0.49	0.49
CoV	0.78	1.54	1.05	0.49	1.05	1.05

living beings in a definite concentration but may cause harmful effects at high concentrations (Ouyang *et al.* 2006; Shah *et al.* 2012).

Iron (Fe) is an essential trace element required for good health. It helps in transportation of oxygen in the blood. High level of Fe can cause hemochromatosis, which can harm the liver, heart, and pancreas. It can cause fatigue, weight loss, joint pain, stomach problems, and vomiting (Anderson 1994). Loose intracellular iron can also promote DNA damage. The minimum daily requirement for iron varies from person to person and depends on age, sex, and physiological status. Average concentration of Fe in the river was 0.54 mg/L, which is higher than the acceptable limit (0.3 mg/L) of BIS (IS10500 2012). Manganese (Mn) is necessary for humans to survive, as it is required for the functioning of many cellular enzymes. Its chronic exposure can cause Manganism or manganese poisoning and Parkinson's disease (Goldhaber 2003). The average concentration of Mn in the river was 0.01 mg/L. The effect of chromium (Cr) on human health depends on its oxidation state. Cr (III) is an essential nutrient for the human body but too much uptake can cause liver and kidney problems (Goldhaber 2003). Cr (VI) is toxic to human health and may cause adverse health impacts. Intravascular haemolysis and renal failure have also been reported from high levels of Cr in the body (Plaza 2002). The average concentration of Cr in the river was 0.01 mg/L. Lead (Pb) is generally recognized as one of the most pervasive environmental health threats. It can damage mainly the hematopoietic system, nervous system and renal system (Papanikolaou *et al.* 2005; Khan *et al.* 2013). It is known to be a potent inhibitor of heme synthesis. Pb compounds can also damage RBCs. They cause abdominal pain, vomiting, diarrhoea, collapse, high blood pressure and heart attack (Khan *et al.* 2013). The average concentration of Pb in the river was 0.02 mg/L, which exceeds the safe limits set by the Bureau of Indian Standards (0.01 mg/L) for drinking purposes. Copper (Cu) is a necessary element for the function of various cellular enzymes (Tapiero *et al.* 2003). Long-term exposure to Cu can cause irritation of the nose, mouth and eyes and also causes vomiting, diarrhoea and can damage the liver (Goldhaber 2003; Harmanescu *et al.* 2011). The maximum concentration of Cu in the river was 0.01 mg/L. Zinc (Zn) is an essential nutrient for body growth and development because it is a component of a wide variety of enzymes (Goldhaber 2003). High levels of Zn can lead to stomach cramps, nausea, vomiting, skin irritations, gastrointestinal irritation and anaemia (Prasad 1976; Fosmire 1990). Concentration of Zn in the river was well below the acceptable limit (5 mg/L). CI at each sampling site is shown in Table 8. CI ranged between 0 and 4.5. Sampling site 'SSKaR5' and 'SSKaR8' was highly contaminated. Maximum CI was observed at sampling site 'SSKaR5' (4.5). HQ is given in Table 8. HQ $>$ 1 shows potential for adverse effect on human health (US EPA 2004; Wu *et al.* 2009). At three sampling sites HQ was greater than 1, which may bring serious health concerns for those who are using these sites as a source of drinking water and it necessitates further study (US EPA 2004; Li & Zhang 2010).

Table 8 | Contamination index (CI) and hazard quotient (HQ)

Sampling sites	CI	$\sum$HQ
SSKaR1	2.0	0.80
SSKaR2	0.0	0.30
SSKaR3	2.8	0.14
SSKaR4	1.8	0.84
SSKaR5	4.5	1.01
SSKaR6	2.5	1.03
SSKaR7	2.0	0.95
SSKaR8	3.9	1.21
SSKaR9	2.0	0.81

CONCLUSIONS

In this study, the effectiveness of combined use of PCA and an indexing approach with health risk assessment has been demonstrated with a case study. Following conclusions have been drawn from this study:

- PCA is an effective tool to find the factors accountable for alteration/pollution of water quality. Analysis revealed that domestic wastewater and agricultural runoff were the major factors influencing the water quality of Kameng River.
- Water quality of the river was evaluated using OIP which is based on Indian standard. At all sampling sites water was categorized as ‘Acceptable’ according to OIP scale.
- The degree of contamination due to heavy metals was calculated by the CI. Two sampling sites were found to be highly contaminated.
- Assessment of the risk of heavy metals to human health was made by using ADI and HQ. At three locations, the value of HQ was higher than one that shows a potential risk to human health.
- The water of Kameng River is not suitable for drinking purposes due to high concentration of heavy metals. It is a serious health concern for those who are using water near these contaminated sites as a source of drinking water without proper treatment.

The present study revealed the applicability and reliability of the integrated use MSMs such as PCA, the indexing approach and HQ in surface water quality monitoring and assessment. Utilizing these methods provide all useful and important information about water quality such as source of pollution, level of pollution and associated health risk.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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