



Identification of potential strategic sites for city planning based on water quality through GIS-AHP-integrated model

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Abstract

Freshwater is one of the most important resources for the ecosystem's sustenance and any nation's development. However, clean water bodies are exploited to cater to urban societies' growing demands and economic expansion. This has led to the scarcity of clean water on the planet since the last decade, which is a crucial environmental concern in the present time. Therefore, proper water quality assessment and better management plan integrated with city planning have become an essential need of the hour to combat the clean water stress problem. This study aims to frame a model to identify the potential sites suitable for water use and document an effective development plan for a highly industrialized, populated, planned, and critically polluted city. The potential strategic sites were identified based on the impact of water quality on factors such as human health and economy, which are directly linked to drinking, irrigation, fisheries, as well as industrial production. The relative importance of each criterion (weightage) was estimated using the analytical hierarchy process (AHP). The physico-chemical parameters of groundwater and surface water of the strategic locations were analyzed to calculate multi-purpose water quality index (WQI) and Ryznar suitability index (RSI). These indices were interpolated through a geospatial tool and reclassified using a scoring system to a uniform scale. These thematic maps were weighted overlaid through the GIS model builder tool in GIS interface to develop suitability maps through developed potential site index (PSI) of the ground as well as surface water. The final suitability maps were used to identify the potential strategic sites for various uses such as drinking, fishery, irrigation, and industries, which can be considered by the planners for improvising the city planning. Various management practices were also drawn through these maps, which will safeguard human health as well as the environment.

Keywords Groundwater · Surface water · Water quality index (WQI) · Analytical hierarchy process (AHP) · Potential site index (PSI) · Water quality management plan

Introduction

Freshwater is the most vital natural resource that directly links to human health and a country's socio-economic status. Apart from the basic needs of human, good quality water is also needed for industries, irrigation, as well as fisheries. Unfortunately, the water quality across the world has deteriorated because of this resource's extensive use and mismanagement to fulfill the growing population's needs.

Among all other countries, India records 70% of water bodies as polluted (Murty and Kumar 2011). Unaware of the contamination of these water bodies, 30% of the urban population and 90% of the rural population of the country still depend on these untreated surface and groundwater for their daily use (Kumar et al. 2005). It results in health risk as well as a decrease in the productivity of agriculture, fishery, and various industries. Therefore, the government has taken remedial measures to clean the polluted water bodies to safeguard human health and increase economic turnover. However, the treatment technologies crave a high cost and slow process (Kumar Reddy and Lee 2012). Alternatively, an effective management plan can protect the water quality and define the suitability of water bodies for various uses. This will save the country's economy, which is invested in advanced and long-term treatment process.

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The documentation of an effective management plan involves assessment of water quality and identification of potential strategic sites. The plan will demarcate the areas for proper water use and implementation of pollution prevention and low-cost pollution control measures. The statistical and GIS integrated techniques will help to prepare an efficient and effective management plan. Statistical techniques transform the analytical data set into a useful format and aid in the decision-making process. The GIS framework, in addition to the interpretation of the data by the geo-statistical model, will also assist in the identification of potential sites. These techniques provide a better understanding and visualization of the area for the public and authorities responsible for documenting water management or city development plan.

Several studies have been conducted to analyze and improve the water environment across the world. Previous work used either statistical tools or GIS techniques to analyze the water quality (Bodrud-Doza et al. 2016; Fu and Wang 2012; Misaghi et al. 2017; Wu et al. 2018). Further research was directed to integrate GIS with the water quality index and irrigational water quality to represent the overall water quality. However, these studies were limited to either drinking water quality or health risk or irrigational water quality (Abbasnia et al. 2019; A Elubid et al. 2019; Arulbalaji and Gurugnanam 2017; Ghandali et al. 2019; Saha and Paul 2018). These conventional approaches have not clearly documented a water quality management plan—defining potential sites having safe water usage for drinking, irrigation, fisheries, or industrial application. Therefore, there is a need to frame a model for identifying suitable areas, integrating all the useful parameters using GIS and statistical techniques to document effective water management as well development plan for a polluted city.

The industrial cities of the states of Uttar Pradesh, Rajasthan, Andhra Pradesh, Punjab, Orissa, Jharkhand, and West Bengal in India have contaminated water bodies (Tiwari et al. 2015). One such city Durgapur, in West Bengal, is identified as one of the critically polluted areas by environmental regulatory authorities of the country (CPCB 2009). This developed city consists of numerous large- and small-scale industries, earning its name as the industrial belt. Rapid industrialization has raised concern for water pollution in the area. Unaware of the water quality status, nearly about 17% of the total population and a counting percentage still depend on untreated water bodies for daily use, agriculture, and fisheries (City Development Plan 2006). This affects the health of the population as well as reduces the productivity of irrigation and fisheries (Austin 1999; Bodaghpour et al. 2012; Simsek and Gunduz 2007; WHO 2016). The industries using this contaminated water also face corrosion in metal pipes and machineries (Hoseinzadeh et al. 2013). This eventually affects the socio-economic status of the city.

This condition is also faced by other regions throughout the world such as Lagos City in Southwest Nigeria, Sialkot City in Pakistan, Chittagong City in Bangladesh, Maanshan in Eastern China, Urmia City in Iran, Sylhet City in Bangladesh, and Western Jiangnan Plain in China (Chen et al. 2019; Chitsazan et al. 2017; Niu et al. 2017; Ullah et al. 2009; Yusuf 2007; Zakir 2019). These cities also recorded deterioration in the quality of water, which is used for various purposes without being aware of water quality status. Therefore, the present study aims to frame a model to delineate the potential sites suitable for various water usages. This could be applied to other regions across the world for the betterment of city planning.

This study concerning limitation of research techniques for identification of potential strategic sites for water uses was carried out with the following objectives: (i) assessment of water quality status for drinking, irrigation, fishery, and industry using a common assessment indexing tool; (ii) model development using GIS and statistical approach to delineate the potential sites; and (iii) documentation of water quality management plan and city planning.

Material and methods

Study area

The Durgapur industrial city, located in West Bengal, India, is selected as the study area because of its rapid industrialization, urbanization, surface water bodies utilized for fisheries, and land for irrigation. It is geographically bounded by 23° 35' 33.18" N, 87° 11' 48.77" E and 23° 35' 33.18" N, 87° 22' 48.77" E in the north and 23° 28' 41.92" N, 87° 18' 22.15" E and 23° 28' 41.92" N, 87° 22' 48.77" E in the south with a lithology of red shale, coarser size sandstone, and laterite. Panchet formation, Durgapur Bed, and Laterite Panskura formation from Triassic to Upper Holocene age represent the area's geological succession. It receives an annual rainfall of 1200 to 1500 mm and has a humid tropical climate. The city has been planned in a mode where the residential block and industrial block are specified in different locations (Fig. 1). The industrial block consists of integrated iron and steel, chemical, thermal power, alloy, fertilizers, cement, mining, and approximately 200 small-scale allied industries such as base metals, urea, ceramic, batteries, and heavy machineries. Despite the city's planning, the migrated citizens settled haphazardly and has been using untreated surface and groundwater. Nearly about 566,937 people rely on these untreated water bodies for their daily use. Moreover, irrigation and fisheries also solely depend on these water bodies (City Development Plan 2006). Therefore, it is required to delineate the water suitability status of the city for the betterment of planning to safeguard human health and economic loss.

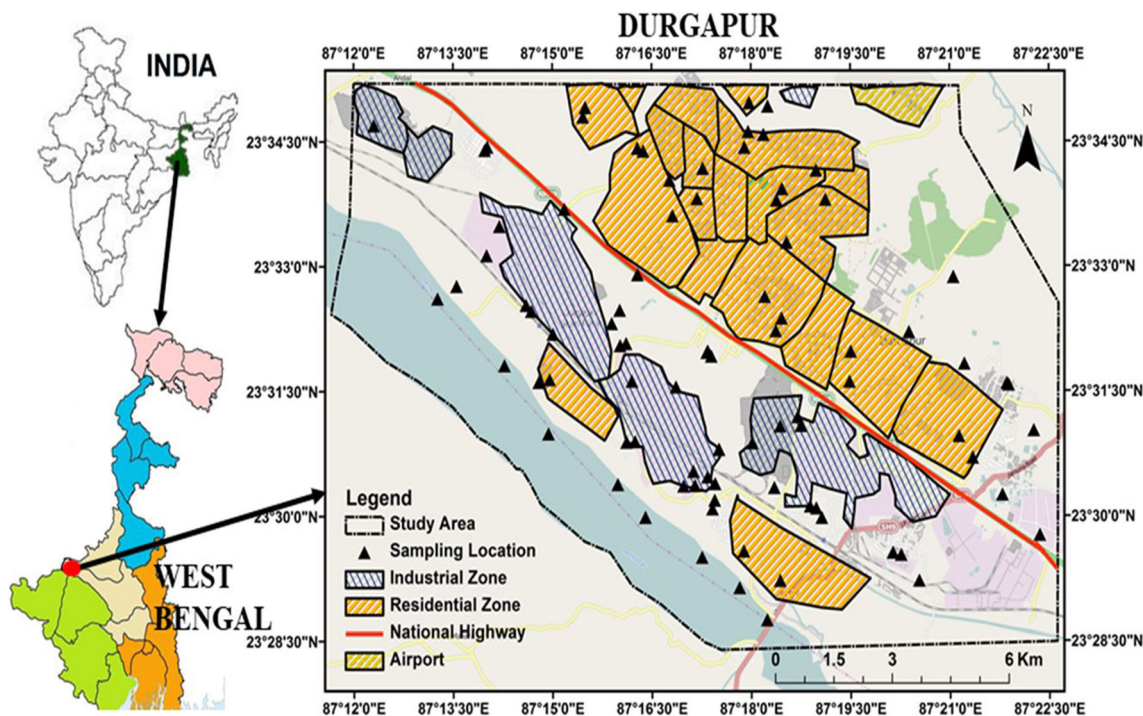


Fig. 1 Study area map representing planning of the city and sampling sites

Methodology framework

In the present study, a model was developed to identify potential water use sites while considering numerous constraints and criteria. Four crucial factors were identified for the planning of the city. The selection of the criteria depends on the water quality influencing human health, irrigation, fishery, and industries. The relative importance of each criterion was estimated using the analytical hierarchy process (AHP), followed by the preparation of the suitability map through the spatial analyst tool and model development in the GIS interface. The brief methodology adopted in the present study is shown in Fig. 2.

Assessment of factors influencing potential site identification

The study presents the planning of the city depending on water quality influencing the vicinity. Human health, irrigation, fishery, and industrial activities are the major parameters that rely on water quality. The drinking water quality directly impacts human health. The high concentrations of ions and heavy metals in water may cause acute or chronic diseases such as muscle weakness, skin lesions, diarrhea, gastric problems, Alzheimer’s, Parkinson’s, multiple sclerosis, methaemoglobinemia, and cancer (Mebrahtu and Zerabruk 2011; Mishra et al. 2010). Therefore, simple random sampling was done from the residential and industrial zones where the habitats are dependent on shallow tube wells or open dug wells

(groundwater) as well as ponds or river water (surface water) for drinking as well as their daily use, agricultural activities, and fishery. Even the water samples were

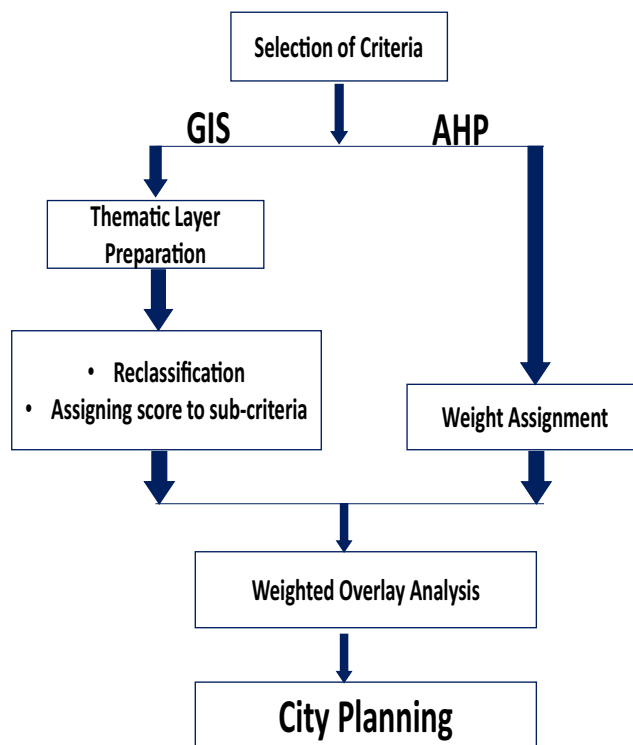


Fig. 2 An integrated GIS-AHP framework for city planning based on the water quality

collected from the industrial zone, where the industries fetch water for their production.

Surface water samples were collected from 48 sampling sites and groundwater from 40 different strategic locations within the city in a post-monsoon season of 2016 (Fig. 1). The shallow groundwater samples of open dug wells were collected from 30 cm below the water surface level, and tube wells samples were collected after discarding the water for 5 min. However, the surface water samples of the ponds were collected from approximately 20 to 30 cm below the water surface level by facing the mouth of the sampling bottle downward flowed by upright to fill the mouth. Moreover, the samples from the rivers were filled in the sampling bottle by pointing the mouth upstream. The sampling bottle lid was tightened while dipped in the water. Acid washed high-density polypropylene bottles (1 L) were used for collecting the samples. The pH, temperature, electrical conductivity (EC), salinity, and total dissolved solids (TDS) were measured on site instantaneously.

Major cations (Na^+ , K^+ , Ca^+ , Mg^+), anions ($\text{CO}_3^-/\text{HCO}_3^-$, SO_4^{2-} , NO_3^- , F^-), TA (total alkalinity), TH (total hardness), and heavy metals (Cu, Co, Cd, Cr, Fe, Mn, Pb, Ni, Zn, As) were analyzed in ISO 9001: 2008 and 18,001: 2007 certified lab of ESE, IIT (ISM) Dhanbad with appropriate precautions and quality assurance procedures (APHA 2012). All analytical analysis were carried out using double deionized water (Milli-Q, Millipore; < 18 M Ω cm) for the reliability of results. Even the glassware were cleaned with 2% HNO_3 followed by rinsing with Milli-Q water to prevent any interference in the result. Analytical grade reagents (Merck, Germany) were used for the preparation of the standards and reagents. The biasness in the results was omitted by taking the triplicate reading of each sample. The blank reagent, standard sample, and QC sample were analyzed after every 10–15 sample analyses to eradicate experimental error.

The Na^+ and K^+ were measured through ESiCO model-1385 microprocessor flame photometer with a lower detection limit of 0.2 mg/L. Moreover, anions were estimated through Shimadzu UV-1800 spectrophotometer using a spectral wavelength of SO_4^{2-} : 420 nm, NO_3^- : 220 nm and 275 nm, F^- : 570 nm. The method detection limits of SO_4^{2-} , NO_3^- , and F^- were 1.29 mg/L, 0.12 mg/L, and 0.19 mg/L respectively. The correlation coefficient (r^2) of the linear regression calibration curve of SO_4^{2-} , NO_3^- and F^- was > 0.995. Apart from this, the other parameters were analyzed using the titrimetric method while following proper QA/QC protocol. The laboratory-fortified blank and matrix were evaluated to confirm the recovery of the samples. The recovery percentages for cations and anions were approximately 95% to 112%.

The accuracy for the concentration of ions were verified using electrical neutrality (EN%) as given in Eq. 1

$$\text{Error of ion balance (EN\%)} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100 \quad (1)$$

The analytical result's accuracy is doubtful beyond an error of $\pm 5\%$ (Patel et al. 2016).

The sample-set preserved by adjusting $\text{pH} < 2$ was used to analyze the heavy metal concentration in GBC Scientific Avanta PM double-beam atomic absorption spectrophotometer (AAS). The wavelength for the measurement of the heavy metals were as follow: Cu: 324.8 nm, Co: 240.7 nm, Cd: 228.8 nm, Cr: 357.9 nm, Fe: 248.3 nm, Mn: 280.1 nm, Pb: 217 nm, Ni: 232 nm, Zn: 213.9 nm, and As: 193.7 nm. The instrument was calibrated using Accu (New Haven, USA) standards for all the elements. The National Institute of Standards and Technology (NIST) reference standard material for water (SRM 1640a) were used to determine the accuracy, where the recoveries of the metals were recorded from 95 to 106%. The detection limits (in mg/L) of Cu, Co, Cd, Cr, Fe, Mn, Pb, Ni, Zn, and As were 0.001, 0.004, 0.0004, 0.003, 0.005, 0.0015, 0.01, 0.009, 0.0005, and 0.0005, respectively.

Further, water quality suitability for drinking, irrigation, and fishery were assessed using a common assessment-indexing tool. The water quality index (WQI) developed by Horton in 1965 is used in the present study to evaluate water quality for drinking, irrigation, and fishery. The WQI is defined by W_i (relative weightage of the i th parameter) and Q_i (sub-index of the i th parameter) as:

$$\text{WQI}_{(\text{drinking/irrigation/fishery})} = \sum W_i Q_i \quad (2)$$

$$Q_i = 100 \left[\frac{V_i}{S_i} \right] \quad (3)$$

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (4)$$

V_i is the monitored value of the i th parameter; S_i represents the recommended standard (BIS, IS 10500: 2012 for drinking, IS 11624: 2009 for irrigation, and IS 13891: 2003 for fishery) value of the i th parameter, and w_i is unit weightage of the i th parameter. The critical value was assigned as 100, beyond which the water quality is categorized as polluted. Further, it was divided into four different classes, as 0–25: excellent; 25–50: slightly polluted; 50–75: moderately polluted; 75–100: polluted; > 100: excessively polluted (Saha and Paul 2018; Saha and Paul 2019).

Water quality for industrial activity was assessed by the level of corrosion and calcium carbonate scale formation in pipes and machineries. It is mathematically computed through the Ryznar suitability index (RSI) (Patel et al. 2016). It

depends on the relation of pH, TDS, and total alkalinity, which is expressed as:

$$RSI = 2(pH_s) - pH_w \tag{5}$$

$$pH_s = (9.3 + A + B) - (C + D) \tag{6}$$

$$A = (\log_{10}TDS - 1) / 10 \tag{7}$$

$$B = -13.12 \times \log_{10}(\text{°C} + 273) + 34.55 \tag{8}$$

$$C = \log_{10}(\text{Ca}^{2+} \text{ as CaCO}_3) - 0.4 \tag{9}$$

$$D = \log_{10}(\text{Alkalinity as CaCO}_3) \tag{10}$$

$$pH_w = \text{measured pH} \tag{11}$$

RSI is categorized as heavy scale: < 5.5; moderate scale: 5.5–6.2; aggressive water and corrosion is likely: 6.8–8.5; and very aggressive water and corrosion is possible: > 8.5. The value between 6.2 and 6.8 denotes its suitability for use in industrial application (Patel et al. 2016).

Model design

The weighted overlay method was used to determine the potential area considering all parameters according to their importance. The model was developed in the ARC-GIS platform (Fig. 3).

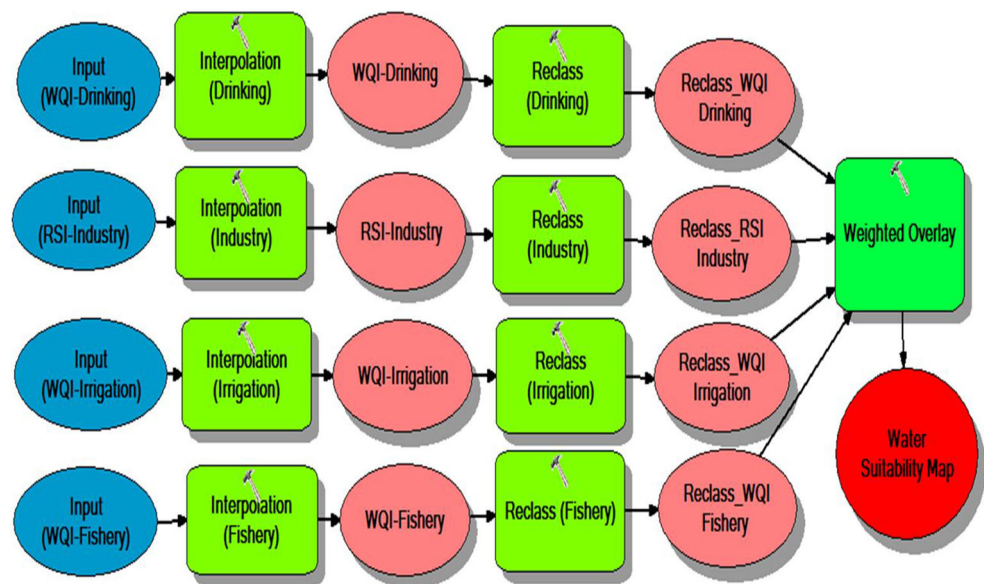
The thematic map of all the parameters were generated using the inverse distance weightage (IDW) geo-statistical interpolation method. Since all the selected criteria were in different units, therefore, reclassifications of the raster layers were done. This will help in the standardization of all the selected criteria values into the same scale to analyze comparative significance. City planning was done so that the area has

a less health impact, good surface water quality required for the fishery, suitable groundwater, and surface water for irrigation and industrial use. The health impact due to drinking of water and the impact of polluted water on irrigation, fishery, and industries were categorized in five different categories for delineation of critically polluted areas. Sub-criteria were scored on a scale of 1 to 5, where 1 signifies least significant, and 5 has the highest significance in pollution or impact.

The final stage comprises of assigning relative weightage to the input parameters. The decision of assigning weight to multiple criteria is very difficult and complex. Analytical hierarchy process (AHP) developed by Thomas L. Saaty (1977 and 1994) acts as a judgment support tool that solves the multi-criteria decision problem (Saaty 1994; Siddayao et al. 2014). The AHP helps the experts decide the weightage of the parameters in a simple way by breaking the problem into a hierarchical pattern and focusing on only a pair of parameters. Experts (hydrologist and planner) after discussion assign a score to the parameters in the scale of 1 to 9 according to Saaty rating scale as two factors contribute equally to the objective (equal importance): 1; experience and judgment slightly favor one over the other (somewhat more important): 3; experience and judgment strongly favor one over the other (much more important): 5; experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice (very much important): 7; the evidence favoring one over the other is of the highest possible validity (absolutely more important): 9; when compromise is needed (intermediate values): 2, 4, 6, 8 (Saaty 1980).

These scores were used to create pairwise comparison matrix $A [a_{ij}]$ for n parameters $\{A_1, A_2, A_3, \dots, A_n\}$.

Fig. 3 Model for preparation of water suitability map through weighted overlay technique in GIS framework



$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2j} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{1j} & 1/a_{2j} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1/a_{in} & \dots & 1 \end{bmatrix}$$

where the element a_{ij} shows the preference weight of A_i obtained by comparison with A_j . Further, the pairwise matrix was normalized, and the final weightage of the parameters were taken as the eigenvalue corresponding to the highest eigenvector of the matrix.

Saaty also proposes the cross check for measuring the logical consistency or inconsistency of judgment by decision makers through consistency index (CI) and consistency ratio (CR) (Wedley 1993):

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (12)$$

$$CR = CI / RI \quad (13)$$

where λ_{\max} is the highest eigenvalue of the matrix A , n is the number of parameters used, and RI denotes random index, such as for RI: 0 ($n = 1, 2$); RI: 0.58 ($n = 3$); RI: 0.9 ($n = 4$); RI: 1.12 ($n = 5$); RI: 1.24 ($n = 6$); RI: 1.32 ($n = 7$); RI: 1.41 ($n = 8$); RI: 1.46 ($n = 9$); RI: 1.49 ($n = 10$). The $CR < 0.1$ signifies that the decision of ranking the parameters is acceptable; otherwise, $CR > 0.1$ gives a meaningless result.

Finally, weighted overlay analysis was used to select a suitable area for the planning of the city. All the thematic layers were combined together with the appropriate weight of each layer through GIS. The model builder tool in ArcGIS multiplies the cell value of each layer with the corresponding weight value as

$$PSI = \sum_{i=1}^n W_i X_i \quad (14)$$

where PSI represents potential site index, W_i represents weight determined by AHP of the i th criteria or parameter, and X_i denotes the assigned sub-criteria score of i criteria determining the water suitability of the area.

Results and discussion

Water chemistry

The descriptive statistics of all the parameters for both surface water and groundwater are detailed in Table 1.

The data set checked for an error of ion balance (the total sum of all cations should be $\pm 5\%$, of the total sum of all anions) satisfies the criteria, which signifies the analytical analysis' appropriateness (Patel et al. 2016). The ground and

surface water samples were odorless and colorless. This signifies that the physical property of the water is suitable for various uses. The mean pH (7.09: groundwater; 8.13: surface water), TDS (527.75 mg/L: groundwater; 416.05 mg/L: surface water), EC (787.68 $\mu\text{S}/\text{cm}$: groundwater; 622.32 mg/L: surface water), TA (145.33 mg/L: groundwater; 115.45 mg/L: surface water), and salinity (213.85 mg/L: groundwater; 146.93 mg/L: surface water) of the water samples were more or less lies within the stipulated standard of the drinking, irrigation, and fishery recommended by BIS. The TDS < 1000 and salinity < 500 mg/L in water were considered fresh or non-saline, which is recommended for use in irrigation, fishery, and drinking (Patel et al. 2016; Subramani et al. 2005). The total hardness of the majority of locations (52.5%) has moderately hard groundwater (150–300 mg/L), and 66.6% of the surface water locations has slightly hard water (75–150 mg/L), whereas only 2.5% the groundwater, 29.2% of surface water as soft (< 75 mg/L); 12.5% of groundwater as slightly hard, 4.2% of surface water as moderately hard; and 32.5% of groundwater as very hard (> 300 mg/L) water (Patel et al. 2016).

The Na^+ in shallow zone groundwater predominates by constituting 39.52%, followed by Ca^{2+} as 35.31%, Mg^{2+} as 19.11%, and K^+ as 6.06%. A similar trend was observed in surface water where Na^+ constitutes the major portion of total cation as 42.34%, followed by Ca^{2+} as 32.36%, Mg^{2+} as 14.55%, and K^+ as 10.65%. Moreover, the shallow groundwater constituted 43.76%, 24.83%, 29.26%, 1.99%, and 0.16%, while surface water consists of 43.52%, 28.41%, 25.17%, 2.62%, and 0.28% of HCO_3^- , SO_4^{2-} , Cl^- , NO_3^{2-} , and F^- , respectively, among total anion percentages. This result is similar to those obtained by Rama et al. (2013) in the same study area. Therefore, the hydrochemistry revealed that the order of abundance of cation for both ground and surface water was $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and anions as $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^{2-} > \text{F}^-$ in groundwater and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^{2-} > \text{F}^-$ in surface water. The higher concentrations of SO_4 in the ponds and Damodar river of the study area with respect to the groundwater were attributed to aerosol deposition generated from the steel-iron, thermal power as well as surface runoff from the waste dump of these industries in the vicinity of the surface water bodies and agricultural runoff. Apart from these, concentrations of few heavy metals were below detection limit (BDL) of AAS such as $\text{Cd} < 0.0004$ mg/L, $\text{Cr} < 0.003$ mg/L, $\text{Ni} < 0.009$ mg/L, and $\text{As} < 0.5$ mg/L. Therefore, these metals do not contribute to water pollution. However, the average concentrations of other metals such as Cu, Fe, Mn, and Pb were far beyond the drinking, irrigation, and fishery standards recommended by BIS. This may contribute to chronic as well as acute diseases in human health and impact in irrigation, fishery, as well as industrial application. While the concentrations of Zn and Co were high but within the limit of these standards. Banerjee and Gupta

Table 1 Descriptive statistics of the analyzed physico-chemical parameters in shallow zone groundwater and surface water of the study area

Parameter	Groundwater					Surface water				
	Min	Max	Mean	SD	CV%	Min	Max	Mean	SD	CV%
pH	5.50	8.30	7.10	0.66	9.30	7.40	8.90	8.14	0.38	4.71
EC	334.00	1560.00	788.00	323.00	41.03	343.00	1180.00	622.00	171.00	27.50
Salinity	92.40	457.00	214.00	90.50	42.30	81.50	319.00	147.00	52.00	35.36
TDS	224.00	1050.00	528.00	217.00	41.03	230.00	788.00	417.00	115.00	27.50
Na	38.50	159.00	68.90	29.60	42.88	27.70	89.20	57.00	14.60	25.52
K	1.30	45.20	10.60	12.00	113.65	4.40	59.20	14.30	11.40	79.31
Ca	17.50	163.00	61.60	29.60	48.08	23.80	71.40	43.70	13.00	29.69
Mg	4.70	92.30	33.30	20.60	61.89	7.20	40.90	19.60	8.31	42.41
HCO ₃	54.10	414.00	177.00	82.50	46.50	32.00	261.00	141.00	51.40	36.49
SO ₄	45.20	222.00	101.00	45.80	45.52	47.80	169.00	91.90	30.00	32.61
Cl	51.20	253.00	119.00	50.20	42.30	45.20	177.00	81.50	28.80	35.36
NO ₃	2.70	16.80	8.05	4.10	50.96	3.90	16.40	8.46	2.54	30.05
F	0.35	1.40	0.63	0.19	29.85	0.45	1.93	0.92	0.39	41.98
TH	74.00	786.00	289.00	146.00	50.53	102.00	340.00	191.00	59.90	31.40
TA	44.30	339.00	145.00	67.60	46.50	26.20	214.00	115.00	42.10	36.49
Cu	0.00	0.06	0.02	0.01	62.04	0.02	0.07	0.04	0.01	39.52
Fe	0.41	4.21	1.14	0.92	80.84	0.51	5.41	1.43	0.84	58.69
Mn	0.22	2.72	0.92	0.62	67.95	0.32	2.67	0.96	0.46	47.55
Pb	0.00	0.04	0.02	0.01	97.47	0.00	0.05	0.02	0.02	104.96
Zn	0.04	1.29	0.44	0.35	79.35	0.06	1.08	0.46	0.30	65.73
Co	0.00	0.01	0.00	0.00	98.02	0.00	0.02	0.01	0.01	87.05

All ions, TDS, salinity, heavy metals are represented in mg/L; pH is unit less; EC in $\mu\text{S}/\text{cm}$; TH and TA in mg/L as CaCO_3

(2013) and Pobi et al. (2019) had similar inferences of the heavy metals in the streams of the study area.

Potential site identification

The individual interpretation of these parameters does not clearly define the potential sites for city planning. Therefore, the suitability map for city planning is developed through a weighted overlay of the thematic maps for four selected criteria such as drinking, irrigation, fishery, and industrial water quality. The thematic map for the three criteria, such as drinking, irrigation, and fishery water quality, was prepared through IDW interpolation of the WQI of the respective criteria. The WQI for drinking was assessed through integrating the parameters such as pH, TDS, Ca^{2+} , Mg^+ , SO_4^{2-} , Cl^- , NO_3^{2-} , F^- , TH, TA, Cu, Fe, Mn, Pb, and Zn. In contrast, total salt concentration, sodium absorption ratio (SAR), residual sodium carbonate (RSC), and heavy metals were considered for verifying irrigational water quality. Ph, salinity, nitrate, total alkalinity, and heavy metals were considered for checking fishery water quality. The standard recommended (S_i) and respective weightage of the parameters are detailed in Table 2.

The WQI for the drinking of groundwater ranged from 28.03 to 532.05 and surface water from 35.02 to 608.17. The geospatial assessment revealed that most locations have $\text{WQI} > 100$, representing its unsuitability for drinking (Fig. 4a, b). Similarly, the WQI for irrigation of shallow groundwater ranged from 18.91 to 219.37, while the WQI for surface water ranged from 32.66 to 228.18. The geospatial assessment of surface water illustrated that the residential zone has better quality than the industrial zone.

The water quality of the Damodar River was recorded as poor for irrigation. However, the shallow groundwater does not have much impact as surface water. The northwestern region of the area can be used for irrigation with proper treatment of the polluted water (Fig. 4c, d). The population of the area relies on ponds and river for the fishery. Therefore, the fishery was only taken into account for the surface water suitability map. The WQI for fishery ranged from 20.85 to 129.55, where stretches of Damodar river as well as the residential zone were found to be suitable for fishing (Fig. 4e). The fourth criteria as industrial water quality was computed through the Ryznar stability index (RSI). The RSI values in surface water ranged from 6.2 to 8.7 and from 5.52 to 11.53 in groundwater. The geospatial assessment also evidenced that

Table 2 Input parameters for multi-purpose water quality index to assess water quality for drinking, irrigation and fishery

Parameter	WQI _{drinking}		WQI _{fish culture}		WQI _{irrigation}	
	S_i	w_i	S_i	w_i	S_i	w_i
pH	7.5	9.89E-04	7.5	3.09E-03	-	-
EC	-	-	-	-	1500	2.04E-05
Salinity	-	-	1000	2.32E-05	-	-
TDS	500	1.48E-05	-	-	-	-
Na	-	-	-	-	-	-
K	-	-	-	-	-	-
Ca	75	9.89E-05	-	-	-	-
Mg	30	2.47E-04	-	-	-	-
HCO ₃	-	-	-	-	-	-
SO ₄	200	3.71E-05	-	-	-	-
Cl	250	2.97E-05	-	-	-	-
NO ₃	45	1.65E-04	2	1.16E-02	-	-
F	1	7.42E-03	-	-	1	3.06E-02
TH	200	3.71E-05	-	-	-	-
TA	200	3.71E-05	100	2.32E-04	-	-
Cu	0.05	1.48E-01	0.05	4.64E-01	0.2	1.53E-01
Fe	0.3	2.47E-02	2	1.16E-02	5	6.12E-03
Mn	0.1	7.42E-02	-	-	0.2	1.53E-01
Pb	0.01	7.42E-01	0.05	4.64E-01	5	6.12E-03
Zn	5	1.48E-03	0.5	4.64E-02	2	1.53E-02
Co	-	-	-	-	0.05	6.12E-01
SAR	-	-	-	-	10	3.06E-03
RSC	-	-	-	-	1.5	2.04E-02

All ions, TDS, salinity, heavy metals are represented in mg/L; pH is unit less; and EC in $\mu\text{S}/\text{cm}$; TH and TA in mg/L as CaCO₃; SAR in $(\text{mmol}/\text{L})^{1/2}$; RSC in millieq/L; weightage (w_i) is unit less; standard value (S_i) IS 10500: 2012 for drinking (BIS 2012); IS 13891: 2003 for fish culture (BIS 2003); IS 11624: 2009 (BIS 2009) and Simsek and Gunduz (2007) for irrigation

the water is unsuitable for industrial use as the water varied from aggressive to very aggressive, which causes corrosion (Fig. 4f, g). However, the corrosivity is less in surface water than in groundwater, which may be due to water saturation with respect to CaCO₃. It is attributed to runoff from the industrial wastes such as slag (generated from the iron and steel industries) or limestone dumps stacked to be used as raw materials in the industries.

The geospatial interpolated map of the area was cross-validated for its accuracy. Random locations were selected, where data were unavailable for field validation of the interpolated map. The values of the unknown points obtained through analysis of the field-validated points were close to the interpolation map's predicted value. Apart from this, cross-validation was performed to check the accuracy of the interpolated map. The root mean square prediction error for all

the interpolated maps were close to the average estimated prediction standard error. Moreover, the standardized mean errors were also close to zero, and root-mean-square standardized errors were close to one in this study (Nas and Berktaş 2010). The field validation and cross-verification confirm the accuracy of the interpolation technique.

Further, the thematic layers of drinking, irrigation, industry, fishery water quality were reclassified into five sub-criteria. The respective parameters' scores were assigned according to their significance on a scale of 1–5. Simultaneously, a pairwise matrix for groundwater and surface water was calculated as the first step of AHP, as illustrated in Table 3.

The final weightage of the criteria was obtained through the normalization of the pairwise comparison matrix. The consistency ratios (CR) in this study were calculated as 0.08 and 0.09 for groundwater and surface water, respectively, which indicated that the weightage was logically consistent and valid (< 0.1). The weightage of the criteria and the scores of the sub-criteria are briefed in Table 4. Finally, the suitability map was obtained by potential site index (PSI). These were reclassified into five water quality classes as excellent, good, moderately polluted, polluted, and extremely polluted or unsuitable for use.

The final water suitability map illustrated that the shallow groundwater is more polluted respective to the surface water. The surface water map records that only 0.17% of the area has good water quality, which is suitable for use, whereas 1.79%, 86.76%, and 11.28% of the area have moderately polluted, polluted, and extremely polluted water quality, respectively, which are unsuitable to use without proper treatment (Fig. 5a). However, more than half of the area, i.e., 52.19%, has extremely polluted shallow groundwater. Also, 42.86% and 4.72% of the area have polluted and moderately polluted groundwater, which requires proper treatment for its use. Only 0.21% recorded good shallow zone groundwater quality (Fig. 5b). These maps will give the planner an idea to implement appropriate water treatment techniques in the extremely polluted to moderately polluted areas. The segregation of techniques, according to the areas, will reduce the cost of treatment. It also provides an overview of the area, where water can be used for supply to the households or provides the water for irrigation, fisheries, and industries.

Proposed city planning based on a water quality management plan

The city planning is recommended according to shallow groundwater and surface water suitability map along with the comparison of the thematic maps. Table 5 briefs the preventive measures of the existing planned blocks to lessen health risk and improve the city's economic turnover. Apart from these, residential areas R18, R19, and R20 in the vicinity

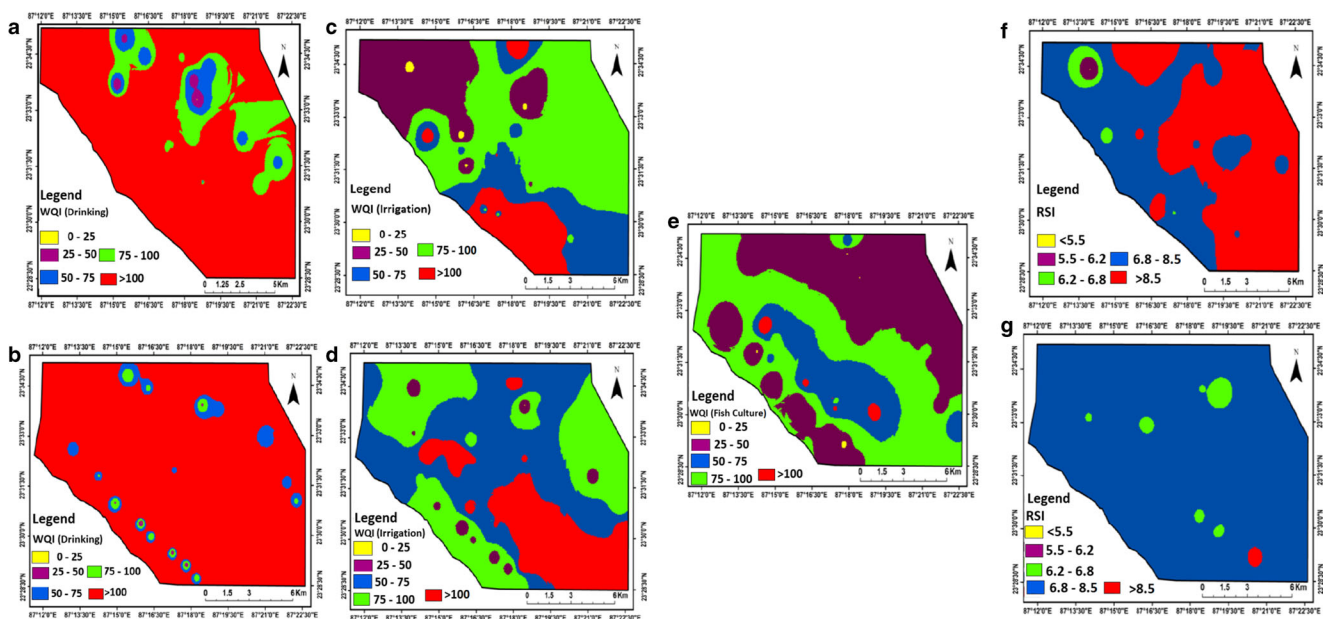


Fig. 4 Geospatial assessment for suitability assessment for **a** drinking in groundwater, **b** drinking in surface water, **c** irrigation in groundwater, **d** irrigation in surface water, **e** fishery in surface water, **f** industrial application in groundwater, and **g** industrial application in surface water. *(Index: for a–e, WQI 0–25, excellent water quality; 25–50,

good water quality; 50–75, poor water quality; 75–100, very poor water quality; > 100, unsuitable; and f–g, RI < 5.5, heavy scale; 5.5–6.2, moderate scale; 6.2–6.8, neutral water; 6.8–8.5, aggressive water and corrosion is likely; > 8.5, very aggressive water and corrosion is possible)

of the industries should be planned in the northeastern region of the study area to safeguard human health. The water distributed to the households should be extensively treated by the government or industries. The water treatment plant in the city should have activated carbon filtration units or microfilters apart from the existing rapid gravity filtration unit. The poly-electrolyte dosing, along with alum dosing, should be followed for effective removal of the pollutants. Tube settlers can be used instead of circular clarifiers or conventional rectangular sedimentation basins because it increases the settling capacity.

The planning authorities can mark the northeastern part of the study area for irrigation activities for better yield. Here, groundwater can be used without any treatment; however, the surface water will require a low-cost treatment such as flocculation and sedimentation. Moreover, the Damodar River

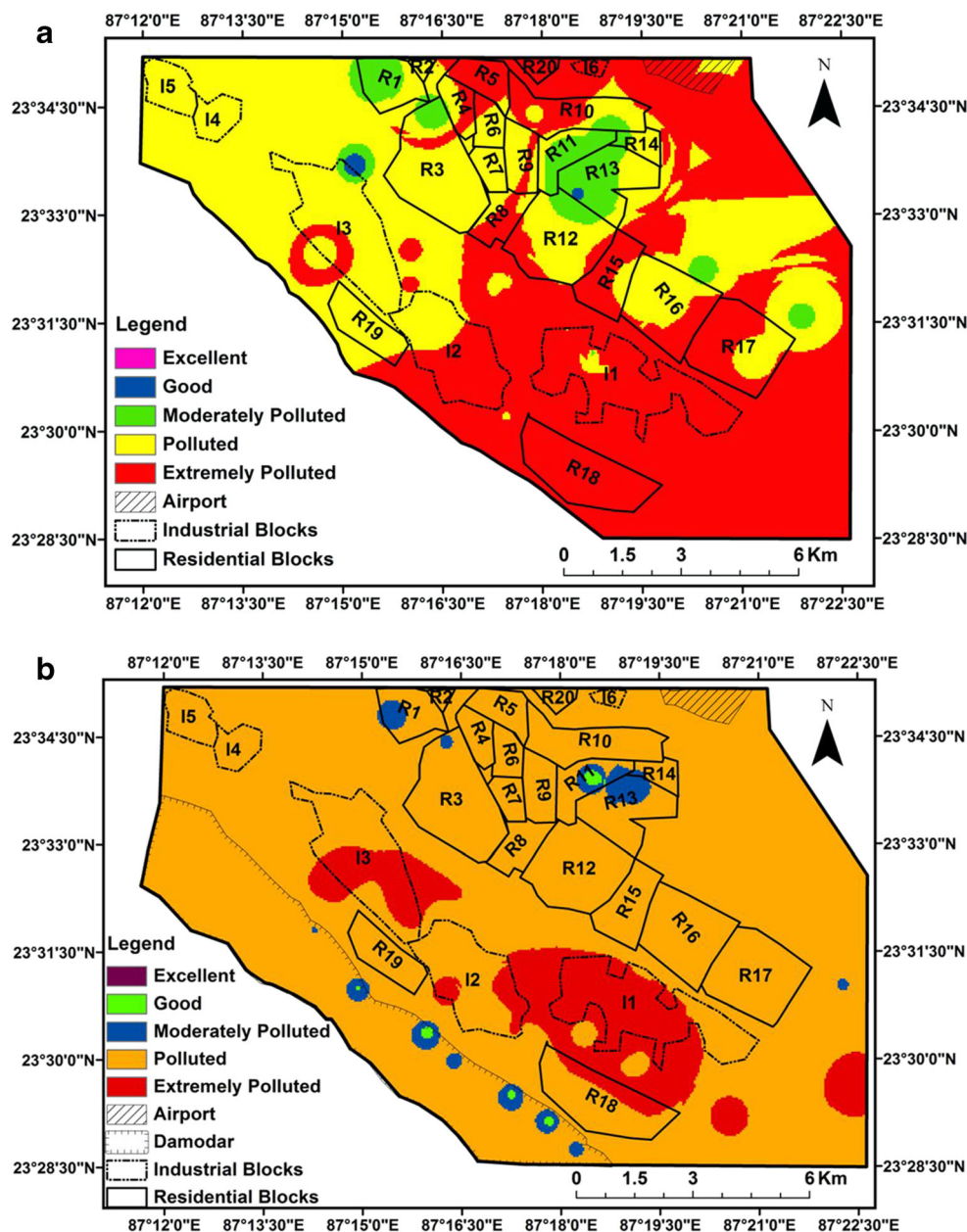
Table 3 Scores for assignment of weightage to the parameters through pairwise comparison matrix

		Drinking	Irrigation	Fishery	Industry
Drinking	Groundwater	1	5	-	5
	Surface water	1	5	5	5
Irrigation	Groundwater	1/5	1	-	1/2
	Surface water	1/5	1	1/2	2
Fishery	Groundwater	-	-	-	-
	Surface water	1/5	2	1	3
Industry	Groundwater	1/5	2	-	1
	Surface water	1/5	1/2	1/3	1

Table 4 Weightage of the criteria and score of the sub-criteria

Main criteria	Weightage (%)	Sub-criteria		Score
		Shallow groundwater	Surface water	
Drinking	70.3		0–25	1
			25–50	2
			50–75	3
			75–100	4
			>100	5
Irrigation	11.5		0–25	1
			25–50	2
			50–75	3
			75–100	4
			>100	5
Industry	18.2		<5.5	5
			5.5–6.2	3
			6.2–6.8	1
			6.8–8.5	3
			>8.5	5
Fishery	-		0–25	1
			25–50	2
			50–75	3
			75–100	4
			>100	5

Fig. 5 Map representing potential sites required for city planning in **a** groundwater and **b** surface water



and the northern to the western side of study area can be restricted for the fishery.

The planning authorities can plan blocks on the western side of the area, where the fisherman community can carry their livelihood, which will increase the fisherman community's economy and distribute the population in an even fashion.

The groundwater in the western zone of the study area is highly corrosive. Therefore, water in the industries should be fetched from the eastern zone of the study area. However, surface water can be used for the industrial process with proper treatment. The industries in the northern side of the city should be shifted near the Damodar River, so that the water

of this river can be used, but with proper treatment to protect the metallic machineries and industrial processes.

However, the industries are the primary source of water pollution in the study area; therefore, the environmental regulatory authority should ensure that the industries to follow zero effluent discharge to limit water pollution. Compliance with appropriate national discharge standards should also be ensured. The integrated iron-steel plant, thermal power plant, cement, fertilizers, chemical, and other small-scale industries should be equipped with advanced treatment process such as ion exchange; membrane filtration; and electrochemical, biological, and adsorption through industrial, domestic, and agricultural waste apart from installed conventional treatment

Table 5 Management strategies for safeguard of human and environment health based on water quality suitability map

SL. no.	Impacted area/blocks	Water quality status	Management plan
1	Industrial zone (I1, I2, I3)	Extremely polluted (GW, SW)	<ul style="list-style-type: none"> • Supply of treated water through pipelines for domestic purpose • Drinking water should be extensively treated. • Irrigation or fisheries should be prohibited in this area. • Treated water should be used for economical industrial activities.
2	Industrial zone (I4, I5)	Polluted (GW,SW)	<ul style="list-style-type: none"> • Agricultural activities can be carried out by groundwater, rather than surface water. • Surface water should be treated with low-cost and available treatment adsorbents to carry fishery. • Treated water should be used for Industrial activities to avoid corrosion.
3	Industrial zone (I6)	Extremely polluted (GW), polluted (SW)	<ul style="list-style-type: none"> • Treated surface water can be used for industrial activities. • Groundwater usage should be avoided for any industrial process that may lead to excessive corrosion • Extensively treated groundwater for drinking • Water suitable for fishery • Irrigation will be uneconomical in this area.
4	Residence (R18, R19)	Extremely polluted (GW), polluted (SW)	<ul style="list-style-type: none"> • Residences may be shifted to the northeastern portion of the study area to avoid health impact. • Supply of treated water through pipelines for domestic activities • Irrigation should be avoided using groundwater; however, with extensive treatment of surface water, the activity can be carried out. • Surface water should be treated properly for fisheries. • Only surface water is suitable for industrial purpose, with proper treatment.
5	Residential zone (R8, R9, R10, R5, R4, R16, R17, R15, R20)	Extremely polluted (GW), polluted (SW)	<ul style="list-style-type: none"> • Drinking water should be extensively treated. • Supply of treated water through pipelines for domestic activities • Fishery can be practiced. • Irrigation after proper water treatment
6	Residential zone (R3, R7, R6, R2)	Polluted (GW, SW)	<ul style="list-style-type: none"> • Drinking water requires extensive treatment. • Supply of treated water through distribution system will lessen the risk to human health. • Fishery in this water will be a good option for livelihood. • Water requires proper treatment for irrigation.
7	Residential zone (R1, R11, R14, R13, R12)	Good to moderately polluted (GW, SW)	<ul style="list-style-type: none"> • Properly treated water should be supplied by government for drinking purpose. • Water with lost cost treatment can yield good fish production. • Irrigation with groundwater will have more yield rather than the surface water.
8	Damodar River	Polluted	<ul style="list-style-type: none"> • Extensive water treatment for drinking • Proper treatment for use in industries • Low-cost treatment for fishery and irrigation will increase the yield.

units (Beh et al. 2012; Bhatnagar and Sillanpää 2010; Bhatnagar et al. 2010; Malik et al. 2017; Pahade and Sharma 2015; Parab et al. 2006; Sud et al. 2008; Tadepalli et al. 2016; Fu and Wang 2011; Saha and Paul 2018). The reliability of these treatment technologies should be assessed regularly for proper treatment of industrial effluent.

Optimum use of fertilizers, sweep cultivation, construction of artificial wetland system reduces the pollution load in the water bodies. Even proper post-harvesting management practices such as plantation of cover crops, use of straws in agricultural field and delay in plowing minimize mineralization phase in soil, which eventually prevent the release of harmful ions as well as metals in water from agricultural land (Di and

Cameron 2002). Even the constructions of proper swear systems and retention ponds also reduce domestic and municipal water load in the natural water bodies (Gregoire et al. 2009). Apart from these, the municipal wastewater should also be adequately treated with conventional and improved treatment technologies before its discharge.

Monitoring and maintenance of the conservation (i.e., rain-water/storm-water management/recharge) facilities or water treatment units installed by municipalities or industries should be regularly investigated, so that the pollutants are not discharged into the aquatic environment. Many researchers in Australia have recognized this approach as the best management practice and even

integrated storm-water management with urban planning (Rietveld et al. 2016).

The management plan should be reviewed periodically based on water body monitoring to conserve the environment and human health. Public awareness about water quality status and its preservation should be raised.

The study area Durgapur imitates many cities worldwide, which are struggling pressure on the key natural resources such as water (Riffat et al. 2016; Luo et al. 2019). Therefore, the city plan should aim for healthy development, composed of adequate water provision (Rietveld et al. 2016). Moreover, UN environmental planning has also specified that proper city planning in view of protecting natural resources is one of the significant key for sustainable development. Many countries in Australia, Asia, USA, and Europe have already integrated water quality with socio-economic, urban design, and development plans (Carmon and Shamir 2010; Costa et al. 2015; Chang et al. 2017). However, there is a need for holistic approaches that will integrate water into the urban planning process to build sustainable cities (Bergkamp et al. 2015; Rietveld et al. 2016). Therefore, this study will open a window for the world to integrate water quality with the cities' urban development plan.

Conclusions

The developed GIS-AHP integrated model in this study helps to identify the potential strategic sites for various uses, such as drinking, irrigation, fisheries, and industrial production. The suitability maps generated through this model also assist in the documentation of an effective water quality management plan. The residential areas in the vicinity of the industries should be planned away from the industries of the study area to safeguard human health. The drinking water should be supplied to the households by the government with extensive treatment as the water may pose a health risk on oral ingestion. Moreover, the northeastern part of the study area is suitable for irrigation, the Damodar River, as well as the northern to the western side for fishery and the water from the Damodar River with proper treatment for industrial use. The proposed management plans incorporated with city planning will improve the city's health and economy. The maps generated through the model will give the planners an idea to adopt suitable techniques to treat the polluted water. It also provides an overview of the area, where water can be used for supply to the households or provides the water for irrigation, fisheries, and industries. This map will not only contribute to a better understanding of the water quality to the scientists and researchers but also increase the awareness of the water pollution problem to the general public. Since the situation of the Durgapur Industrial city in India is very much similar to various industrial cities across the other countries in the world, such as Nigeria, Pakistan,

Iran, Bangladesh, and China, therefore, this study provides a scope to analyze and improve the water quality in such areas. Moreover, this study will be a practical guideline to minimize the problem of deteriorating water quality as well as water scarcity in the near future.

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Authors' contributions BP has guided the research and has provided the idea to carry out the research. PS was a major contributor in sampling, analyzing water quality parameters, data interpretation, and writing the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets analyzed during the current study are given in the manuscript, which is easily understandable by the public. However, the huge raw data in its primitive form is not understandable by the public, but the raw data can be available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate Not Applicable.

Consent for publication Not Applicable.

Competing interests The authors declare that they have no competing interests.

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