Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 21 | No. 1 | pp. 21-32 | 2022
Original Research Paper
https://doi.org/10.46488/NEPT.2022.v21i01.003
Open Access Journal

A GIS-Based Study of Air and Water Quality Trends in Madurai City, India

L. Balaji*, M. Muthukannan† and R. Kanniga Devi*****
*Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India
**Department of Civil Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India
***Department of Computer Science and Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India
†Corresponding author: M. Muthukannan; m.muthukannan@klu.ac.in, civilkannan@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 28-05-2021
Revised: 26-06-2021
Accepted: 04-07-2021

Key Words:
Air pollution
Water pollution
TNPCB standards
GIS
Interpolation
Mitigation

ABSTRACT

The objective of this study is to assess the air quality and water quality at Madurai city using the spatial interpolation technique of the Geographic Information System (GIS). Inverse Distance Weighting (IDW), Kriging, Gaussian- Kriging methods of interpolation are used in the study. The study area is divided into 8 zones and primary data is collected through direct sampling for water. The air pollution concentration data on Suspended Particulate Matter (SPM), Respirable Particulate Matter (RPM), and Lead are collected from an air quality monitoring network system of Tamilnadu Pollution Control Board (TNPCB). The results indicate that the Kriging interpolation method performs well with an error value of 0.02. The data collected from the years 2006 and 2020 are compared using GIS and observed data. The comparison of results indicates that there is a good accord with the predicted value using Inverse Distance Weighting (IDW) and Kriging interpolation with the observed data. The analysis report indicates that the pollution level at all 8 blocks was severely affected in 2020 and it is above the prescribed standard of TNPCB. Particularly, Kalavasal, Arapalyam, and Periyar blocks are severely affected. This work also presents suitable mitigation measures to reduce pollution.

INTRODUCTION

Rapid industrial development, employment opportunities, and urbanization have led to the large-scale migration of people into developed cities (Patel & Burkle 2012, Muthukannan et al. 2019). Migration and industrial development create a negative impact on the environment especially on water, air, and soil (Huff & Angeles 2011, Cassidy et al. 2014). Air and water are the most important for all forms of life on Earth, and polluting either one or both will be a serious problem. The Government is taking all initiatives to monitor and control air and water pollution. Air and water quality monitoring networks have been established to assess the daily pollution level and improve policymaking to monitor pollution. Madurai city is now facing all kinds of water pollution and air pollution and as a consequence, environmental degradation is taking place. Madurai is one of the districts in Tamilnadu, which is known for its cultural heritage and historical importance. Today, the city is facing a lot of problems due to the increase in population, vehicle, and development in all four directions. As a result of urbanization, extensive quarrying, a rise in automobile population, and mining activities, the historical city's air and groundwater have been polluted. (Prince et al. 2020). Hence, there is a pressing need to study the present and past status of pollution in the city and as well as to develop a database tool for prediction.

Air and water quality monitoring and evaluation have become a critical issue in the past years and every year the severity is increasing steadily (Varol et al. 2012). The recent study shows that for assessing air quality and water quality various techniques have been used by the researchers, Water Quality Identification (WQI) (Xu 2005, Shankar & Sanjeev 2008), Single Factor Pollution Index (SFPI) (Guo 1999), Complex Pollution Indices (CPI) (Meng et al. 2009), fuzzy and Artificial Neural Network (ANN) (Jiang et al. 2006, Liu et al. 2010), Analytic Hierarchy Process (AHP) (Pang et al. 2008). However, all the practicing methods are focused on a single location, are parameter centric and data are spatially discontinuous. As a result of the data discontinuity, it is impossible to identify hazardous and vulnerable locations and implement mitigation measures. (Gerdol et al. 2014). The air quality and water quality involve a large number of variables and the associated factors need to be evaluated individually (Yan et al. 2015). Hence, GIS is the most powerful tool for spatial interpolation of data, which creates surface grid maps and facilitates spatial analysis (Vairavamoorthy et al. 2007).

A Geographical Information System (GIS) is a tool, which is used to store, manage, retrieve and analyze all types of spatial data, and provides excellent analysis and solutions to spatial problems (Kumar et al. 2015, Facchinelli et al. 2001). GIS and modeling have been used by various researchers for air pollution monitoring (Maantay 2007, Sohrabinia & Khorshiddoust 2007, Dikshit 2020), air pollution and health impact assessment (Lai et al. 2012), water quality and environmental impact (Donohue et al. 2006, Chang 2008, Jiang et al. 2014, Jasmin & Mallikarjuna 2014). Many studies have been conducted using GIS and spatial interpolation. Kim et al. (2014) studied air quality data monitoring using spatial interpolation methods, Ryan & Lemasters (2008) conducted epidemic logical studies. The study conducted by various researchers has used air and water quality models for mapping of air quality (Kumar et al. 2015), however, it is observed that the air and water quality models underestimate the pollution level (Kumar et al. 2015, Rood 2014). In addition, some unidentified ground-level data are also found missing and have uncertainty in prediction due to multiple assumptions. As a result, the observed air and water quality data are used in this study to make accurate inferences about the impact and policymaking. The study also uses the interpolation technique for air and water quality levels in the study area. Finally, the study compares the interpolation values to the observed data to ensure that the results are reliable.

STUDY AREA

Madurai is the third-largest city in Tamilnadu and twenty fourth in India consisting of 100 wards. The city is located at 9.93ºN latitude and 78.12ºE longitude. The altitude of the city is 101m above sea level. The temperature during summer is 40ºC max and 26.3ºC min and during winter 29.6ºc max and 18ºc min and the average rainfall is 85.76 cm. The city extends to an area of 147.97 km^2 and the population is 14.62 lakhs as per the 2011 census. The river Vaigai flows across the city from North West to South East. The National Highways NH 7, NH 45B, NH 208, and NH 49 pass through Madurai. The State Highways, SH 32, SH 33, and SH 42 connect various parts of Madurai city. Fig. 1 shows the location map of Madurai city and the roads in the city.

DATA COLLECTION

The water samples were collected from all the eight blocks of Madurai namely, Matuthavani, Arapalayam, Thepakulam, Goripalayam, Kalavasal, Periyar, Palanganatham and

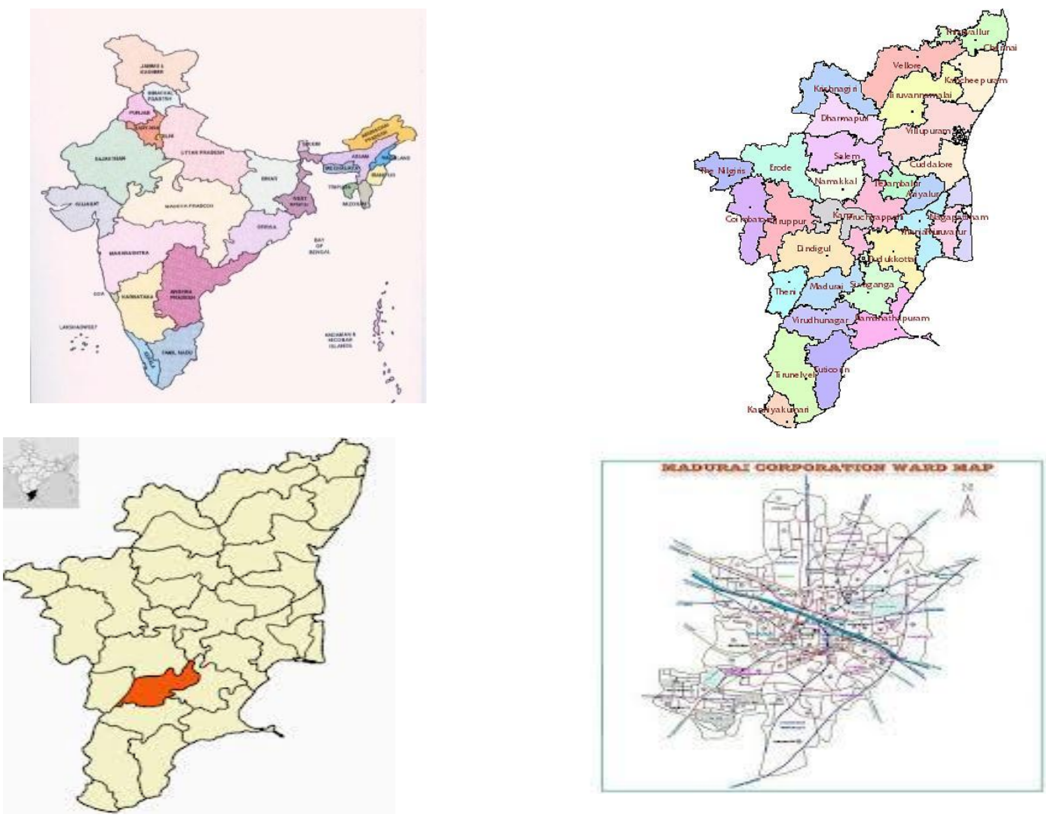

Fig. 1: Location map and road map of Madurai city.

Avaniyapuram. The houses were identified using a random numbering system that took into account the distance between them. The bore water samples were collected, labeled according to the blocks, and stored for analysis. To study the air pollution in all these eight blocks, air samplers were used. Air pollution concentration data on SPM, RPM, and Lead were collected from an air quality monitoring network system. These monitoring stations are operated continuously by Tamilnadu Pollution Control Board (TNPCB). TNPCB monitors air quality data at eight locations. The suspended particulate matter, irrespirable particulate matter, lead and carbon monoxide content was examined in the study area and recorded. Tamilnadu Water Supply and Drainage (TWAD) board kit was used for testing the water samples in the field and laboratory. Fig. 2 shows the TWAD board kit.

MATERIALS AND METHODS

To study the pollution level, it is required to formulate the following objectives (i) To study the past and present status of water and air pollution at Madurai city (ii) To develop GIS structure based on different attributes using Arc View 3.2 software (iii) To compare the air and water quality standards with WHO requirements and study the impact of air and water pollution in the study area (iv) To compare the interpolation values with the observed data to ensure the reliability of the results (v)To suggest possible solution for mitigating air and water pollution.

A shapefile for Madurai city was collected with geo-referencing associated with physical earth space using ArcGIS. Madurai city was divided into eight blocks and a point shapefile for water quality and air quality monitoring stations was created. The water quality and air quality concentrations of alkalinity, hardness, chloride, total dissolved solids, ammonia, fluoride, phosphate, residual chlorine, SPM, RPM and lead were attributed to the concerned point shapefile. The average annual concentrations were obtained from TNPCB and compared with the observed data. Inverse Distance Weighting (IDW), Kriging, and spline are the interpolation technique used in GIS (Colin 2004, Jha et al. 2011). In particular, IDW is used when the points are closely packed. This technique uses the grid values using a linear weighted combination of a dataset and its functions (Gunnink & Burrough 1996). The points with more weights are assigned to the point where SPM is to be interpolated. As per Equation (1) the weightage is an inverse function of distance.

Fig. 2: TWAD Board kit for testing water samples.

$$\boldsymbol{Zj = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i} \ and \ W_i \frac{1}{d_{ji}{}^{P}}} \quad \ldots(1)$$

Where,

Zj = j^{th} Perception Point

Wi = Weight of recorded i^{th} point

${d_{ji}}^{P}$ = i^{th} to j^{th} point distance, P= Power

n = Total number of point in the neighborhood

Kriging's method of interpolation using the Gaussian process is a powerful interpolation technique (Bailey & Gatrell 1995) used for various applications like health science, geochemistry, and modeling (Griffith 1988). This interpolation technique produces better estimates assuming that the distance and direction reflect in spatial correlations. The mathematical interpolation and correlation model Kriging Gaussian is as given in Equation (2)

$$Z^{*}(u) - m(u) = \sum_{i=1}^{n(u)} \gamma_i \,(Z\,(u_i) - m\,(u_i) \quad \ldots(2)$$

Where,

u and u_i = Location Vectors indexed by i

n (u) = Number of points

m (u), m (u_i)= Mean value expected of Z_u and Z (u_i)

γ_i = Kriging Weight assigned fo datum Z (u_i) for specific locations u

To evaluate the water quality using the spatial analysis with GIS as a tool, a potentially polluted area was identified using the observed data in the study area. The water quality assessment was made with a single factor pollution index method to identify alkalinity, hardness, chloride, ammonia, fluoride, and phosphate. SPSS was used to perform mathematical and statistical analyses. Ordinary Kriging method of geospatial interpolation was done (Deutsch 1996) and compared with the observed data. The single factor pollution index was formulated as given in Equation (3)

$$Pi = \frac{\boldsymbol{C_i}}{\boldsymbol{S_i}} \quad \ldots(3)$$

Where,

P_i = Pollution index of i units

C_i = Concentrations of i units pollutants ($mg.L^{-1}$)

S_i = Standard Water quality level

$P_i = \leq 1$= Better quality of water

The water quality depends on many factors and involves many components and chemicals. Hence, a comprehensive pollution index is essential to reflect all the pollutants. The comprehensive pollutants were assessed using Equation (4). The P-value indicates pollution level: Clean (0.2-0.4), Slight to medium pollutants (0.4-0.7), Medium (0.7-1.0) and Heavy pollution (1-2).

$$P = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i} \quad \ldots(4)$$

Where,

P = Comprehensive pollution index

C_i = Pollution concentrations i units

S_i = Water Quality standard

N = Number of selected pollutants

RESULTS AND DISCUSSIONS

Water was collected from various places like Palanganatham, Avaniyapuram, Kalavasal, Arapalayam, Thepakulam, Matuthavani, Goripalayam and Periyar. The water quality was measured using TWAD BOARD kit to test Alkalinity, Hardness, Chloride, TDS, Ammonia, Fluoride, Phosphate, and Residual chlorine. The air quality parameters SPM, RPM, and Lead were studied and inferred. The collected water quality and air quality parameter dataset were given as input to point shapefiles. The observed value and model value were compared with TNPCB, and CPCB (2009) standards. The standard given by CPCB (2009) for air quality is 500, 150, and 0.5 $\mu g.m^{-3}$ for SPM, RPM, and Lead respectively. The standard for water quality for Alkalinity, Hardness, Chloride, TDS, Ammonia, Fluoride, Phosphate, Residual chlorine is given as 500, 500, 500, 1000, 1, 1.5, 1 $mg.L^{-1}$ respectively. To analyze the changes in the air and water quality the data were collected from TNPCB for the year 2006 and compared with the current observed air and water quality levels. In addition, the efficiency of the developed model Inverse Distance Weighting (IDW), Kriging, and ordinary Kriging were compared with the observed data in the selected locations. Table 1 shows the observed level of concentration of Water and Air pollution and level of concentration in the year 2006.

Table 1: Observed level of concentration of Water and Air pollution in 2020 (level of concentration in the year 2006 is given inside bracket).

	Name of the Salt/ Pollutants	Standards in mg/ liter (Water), µg/ m^{-3} for Air	Name of the Block							
			Palaganatham	Avaniyapuram	Kalavasal	Arapalayam	Thepakulam	Matuthavani	Goripalayam	Periyar
WATER POLLUTION	Alkalinity	500	620 (495)	645 (410)	725 (575)	695 (510)	550 (390)	625 (475)	630 (440)	685 (485)
	Hardness	500	700 (520)	655 (425)	745 (565)	685 (535)	630 (430)	560 (395)	680 (475)	545 (360)
	Chloride	500	595 (420)	680 (375)	715 (580)	715 (510)	580 (420)	590 (465)	535 (390)	690 (450)
	TDS	1000	2298 (1722)	2376 (1452)	2622 (2064)	2514 (1866)	2112 (1488)	2130 (1602)	2214 (1566)	2304 (1554)
	Ammonia	1	1.20 (0.77)	0.35 (0.12)	1.20 (1.10)	0.80 (0.65)	0.62 (0.23)	0.20 (0)	0.90 (0.40)	1 (0.68)
	Fluoride	1.5	1.5 (1)	1.6 (1.2)	1.7 (1.6)	1.7 (1.1)	1.6 (1.2)	1 (0.7)	1.8 (1.5)	1.8 (0.9)
	Phosphate	1	0.9 (0.86)	0.70 (0.34)	1.05 (1.01)	1 (0.88)	0.90 (0.56)	0.59 (0.23)	0.60 (0.42)	0.90 (0.84)
	Residual Chlorine	1	1 (0.82)	0 (0)	1.25 (1.13)	0.95 (0.62)	0.95 (0.65)	0.14 (0)	0.74 (0.49)	0.84 (0.76)
AIR POLLUTION	SPM	500 $\mu g.m^{-3}$	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)	985.4 (469.2)
	RPM	150 $\mu g.m^{-3}$	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)	258.4 (129.6)
	Lead	0.5 $\mu g.m^{-3}$	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)	0.48 (0.42)

Table 1 shows that the salt content and air pollution level in the study area. It is observed that the alkalinity in all the blocks has been increased considerably up to 40 per cent in the study area. This indirectly makes the water very hard. The permissible standard for hardness is 500 mg.L^{-1}. it is observed that the hardness level is increased up to 50 per cent in the Kalavasal region compared to the year 2006. The standard permissible limit for chloride is 500 mg.L^{-1}. It is observed that Avaniyapuram, Kalavasal, Arapalayam, and Periyar blocks are affected by the increase in chloride content.

WHO prescribed the maximum permissible limit for TDS as 1000 mg.L^{-1} and it is very clear that all the blocks, the TDS level are increased by 100 per cent. The standard for Ammonia is 1 mg.L^{-1}. It is observed that the ammonia level has been increased up to 40 per cent in the study area. The standard permissible limit of fluoride is 1.5 mg.L^{-1}. The fluoride content has been increased by 50 per cent and above. The permissible limit of phosphate is 1 mg.L^{-1} and it is evident that the level has faced 10 per cent increases in the study area. The standard level of residual chlorine is 1 mg.L^{-1} and it is evident that the level has been increased to 40 per cent in the study area. The standard permissible limit is about 500 μg.m^{-3}. The suspended particulate matter is increased to 90 per cent in the study area.

The standard limit for residual particulate matter is 150 μg.m^{-3} and it is clear that the RPM level got increased to 80 per cent in the study area. The standard level for lead is 0.5μg.m^{-3} and it is clear that the lead level got maintained below the standard limit. Fig. 3 (a-k) shows the effect of water pollution and air pollution in the study area. Fig. 4 (a-c) shows the effect of water and air pollution at the station Kalavasal with the performance of the IDW and Kriging

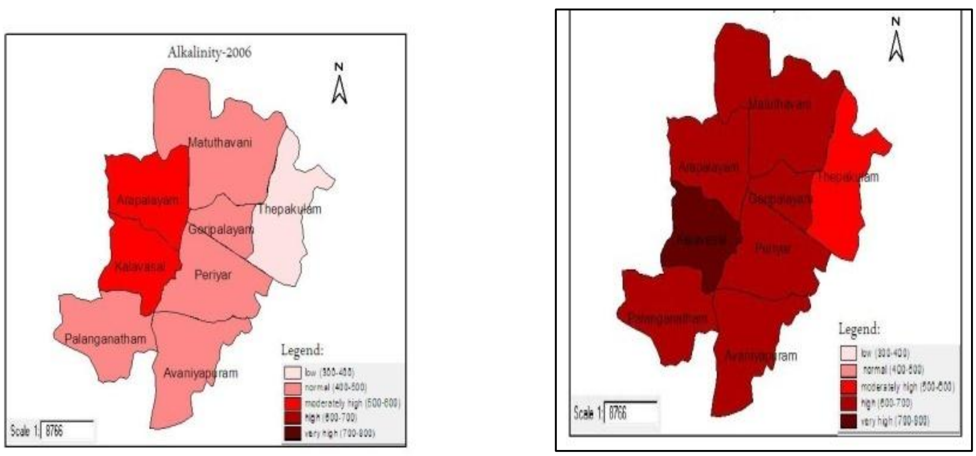

Fig. 3a: The changes in alkalinity level at Madurai City.

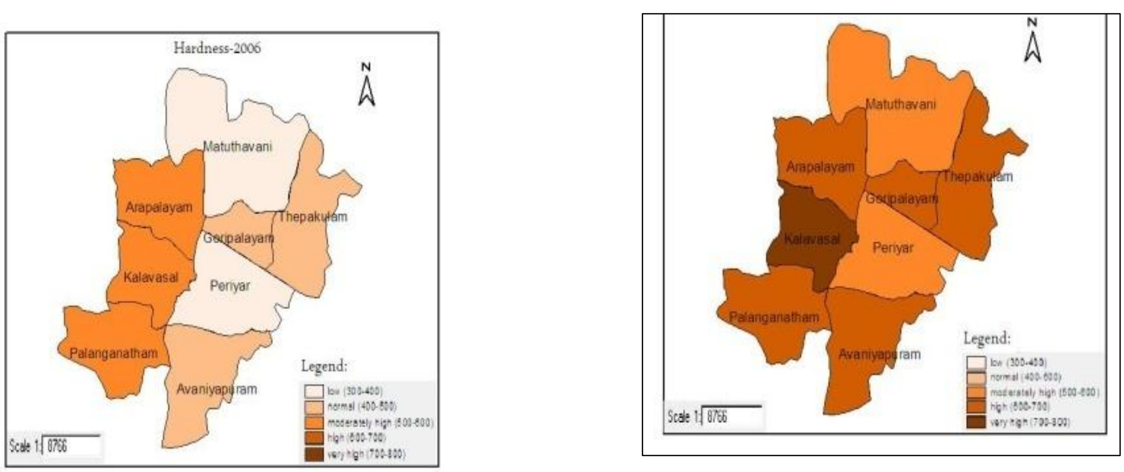

Fig. 3b: The changes in hardness level at Madurai City.

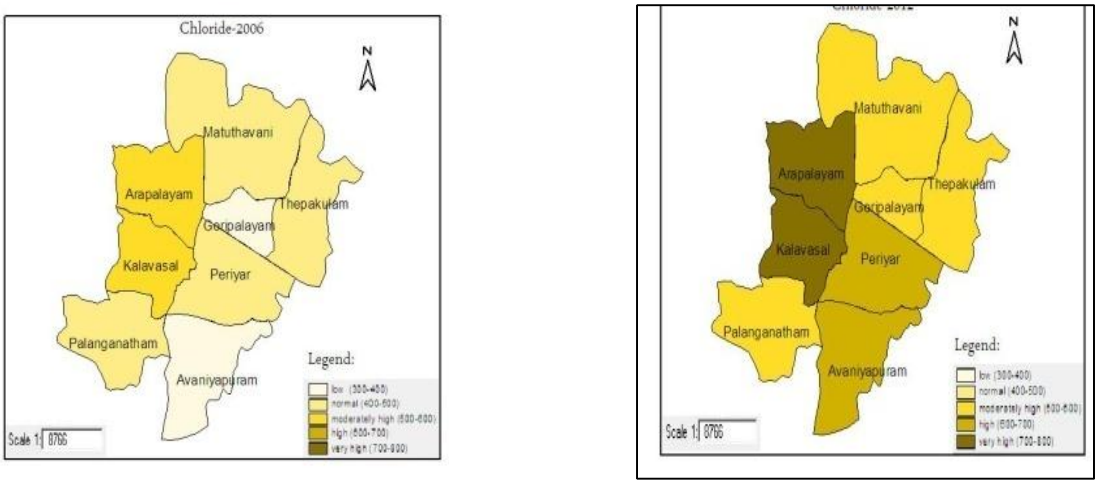

Fig. 3c: The changes in chloride level at Madurai City.

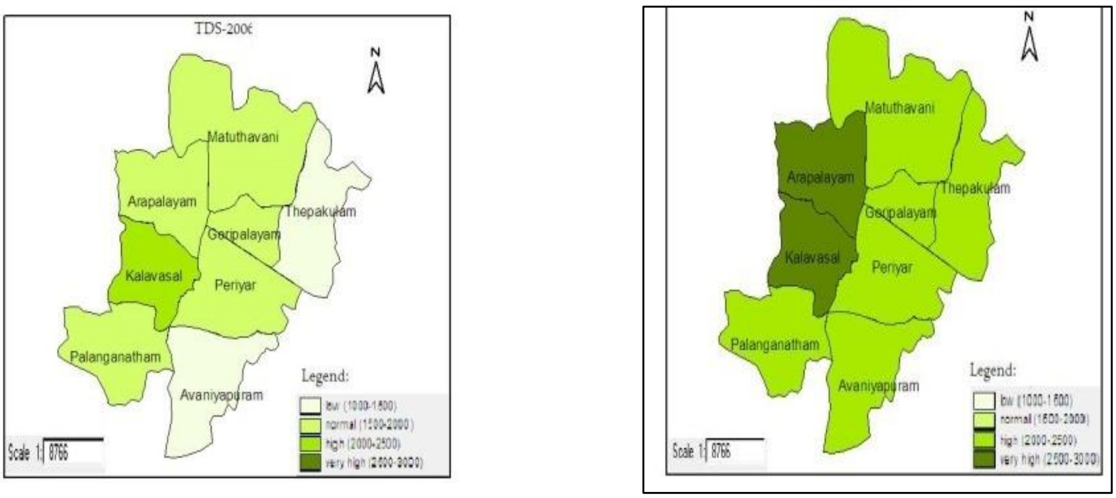

Fig. 3d: The changes in TDS level at Madurai City.

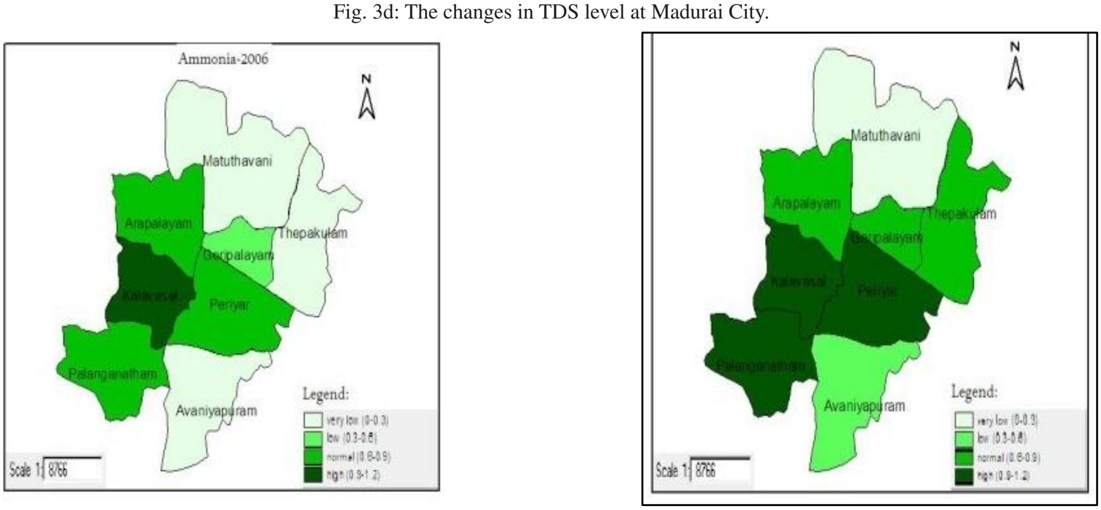

Fig. 3e: The changes in ammonia level at Madurai City.

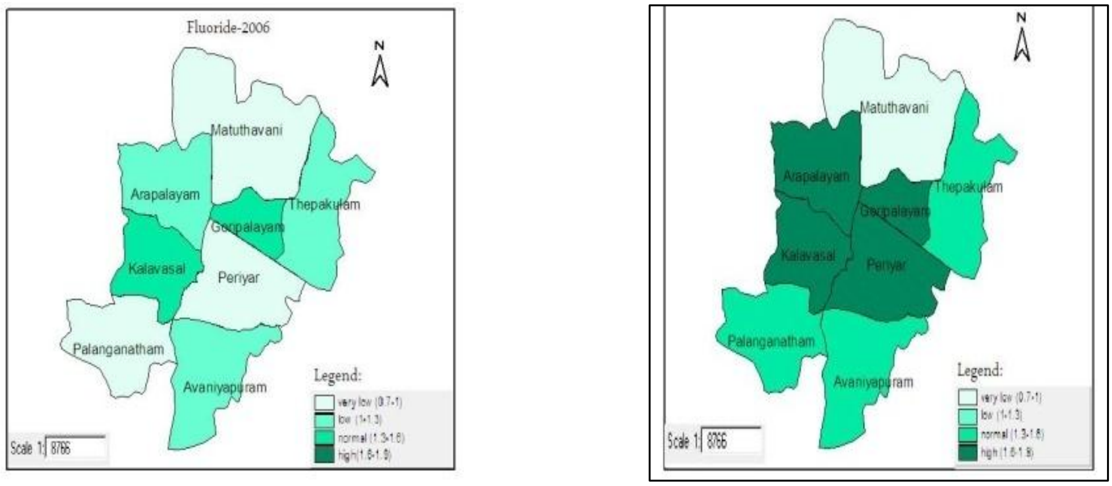

Fig. 3f: The changes in fluoride level at Madurai City.

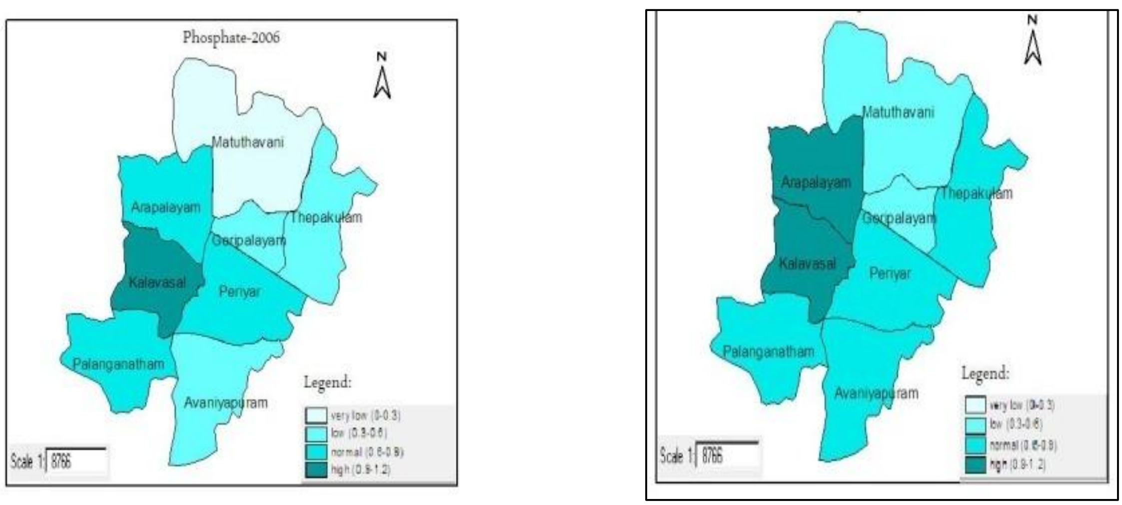

Fig. 3g: The changes in phosphate level at Madurai City.

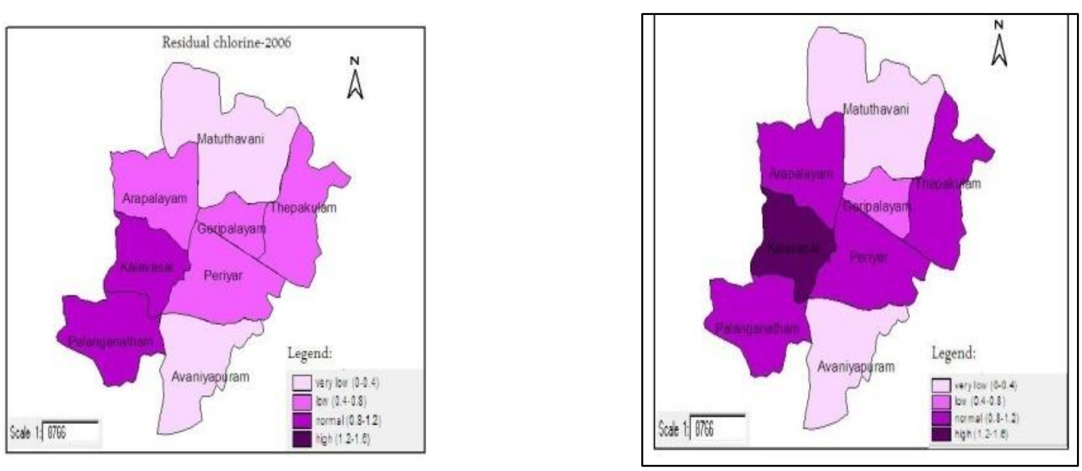

Fig. 3h: The changes in residual chlorine level at Madurai City.

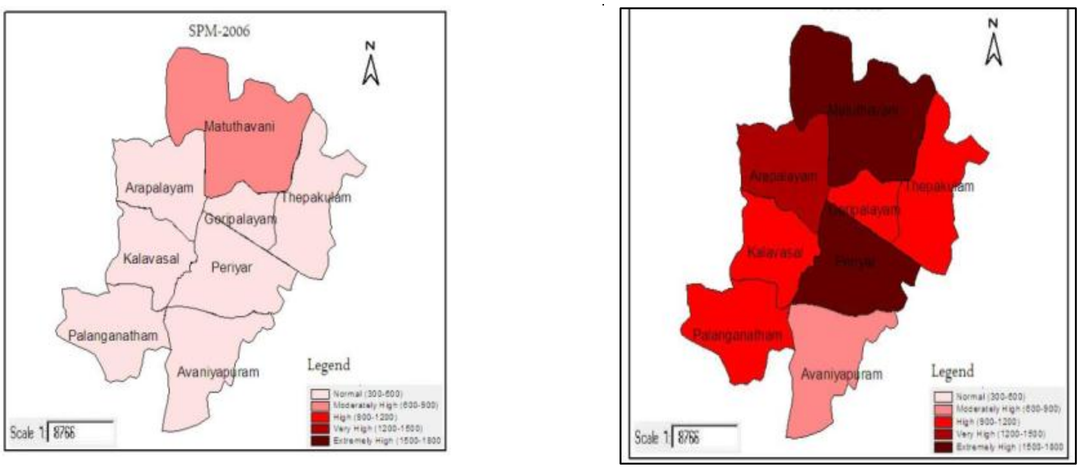

Fig. 3i: The changes in SPM level at Madurai City.

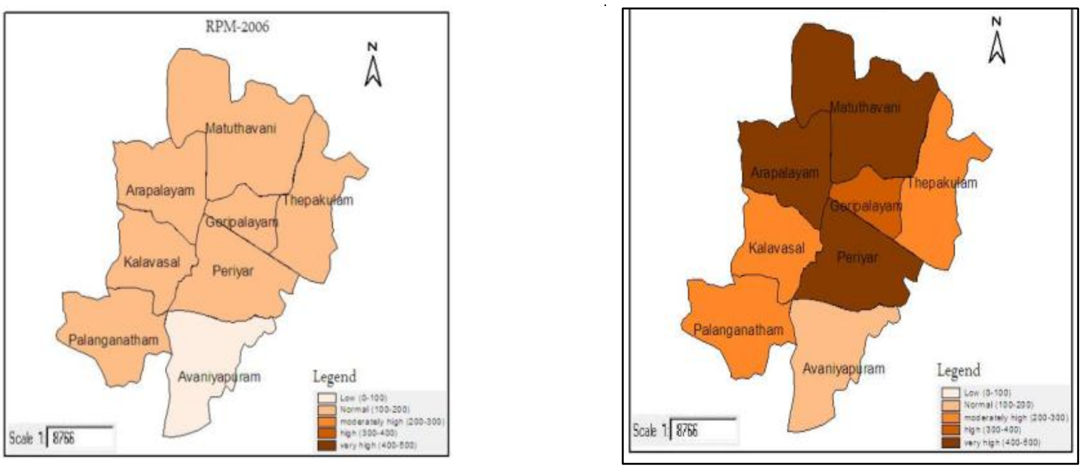

Fig. 3j: The changes in RPM level at Madurai City.

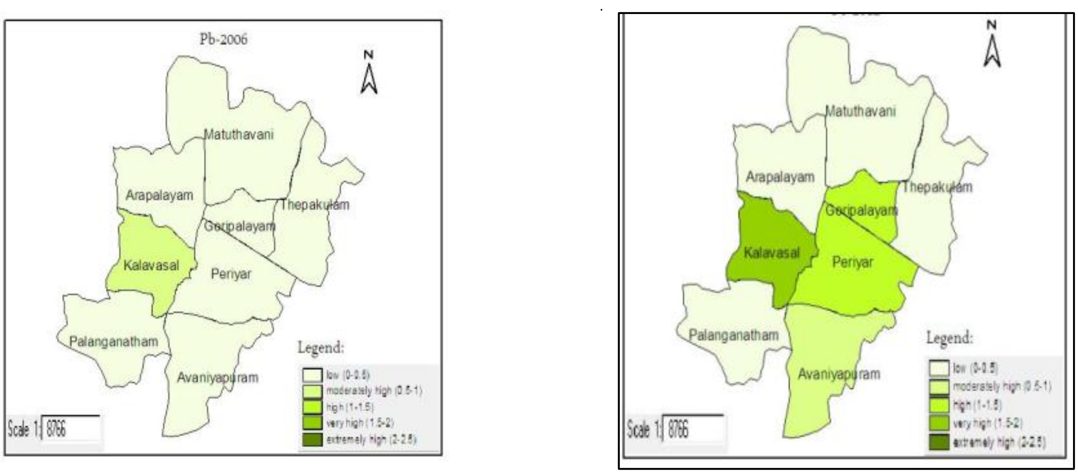

Fig. 3k: The changes in lead level at Madurai City.

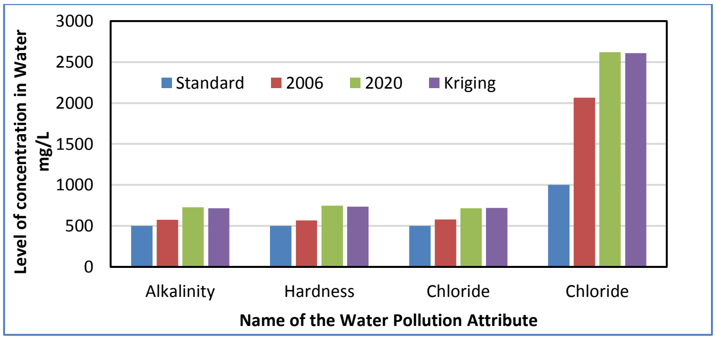

Fig. 4a: Water pollution and level of concentration at Kalavasal.

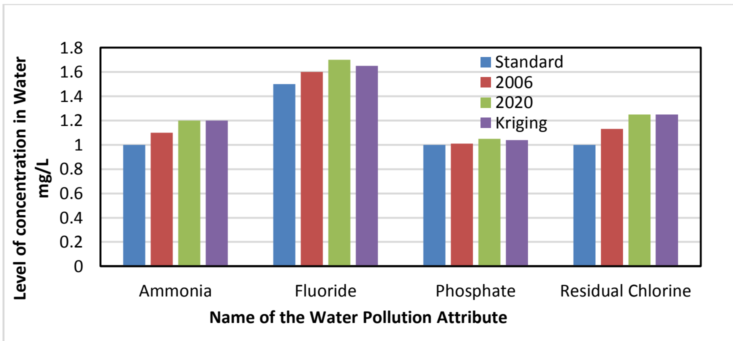

Fig. 4b: Water pollution and level of concentration at Kalavasal.

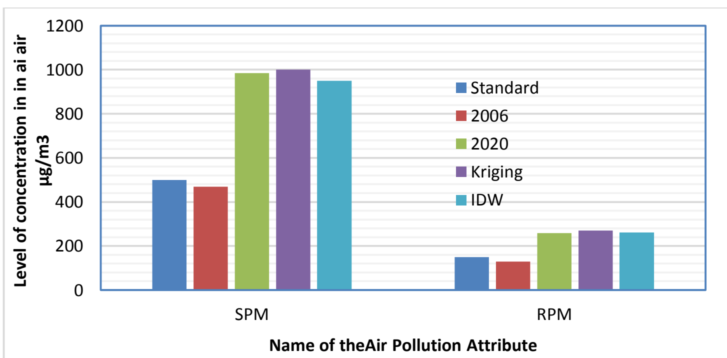

Fig. 4c: Air pollution and level of concentration at Kalavasal.

model. From Fig. 4 (a-c), it is observed that the model and observed value are similar and of error less than 2 percentage. The results of the interpolation models and observed data are shown in Table 2.

DISCUSSION

To study the impact of air and water pollution, data were collected for the years 2006 and 2020. A shapefile for Madurai city was collected with geo-referencing associated with physical earth space using ArcGIS. Madurai city was divided into eight blocks and a point shapefile for water quality and air quality monitoring stations was created. The water quality and air quality concentrations pertaining to alkalinity, hardness, chloride, tds, ammonia, fluoride, phosphate, residual chlorine, SPM, RPM, and lead were attributed to the concerned point shapefile. The average annual concentrations were obtained from TNPCB and compared with the observed data. The Inverse Distance

Table 2: Performance of Spatial Interpolation Models and observed data for Kalavasal Block.

Attribute	Standard	2006	2020	Kriging (Gaussian)	Kriging	IDW	SD	Trend	Error	RMSE
Alkalinity	500	575	725	715	--	--	3.3	Increase	1.0140	1.0282
Hardness	500	565	745	735	--	--	2.1	Increase	1.0136	1.0274
Chloride	500	580	715	720	--	--	4.4	Increase	0.9931	0.9862
Chloride	1000	2064	2622	2610	--	--	3.3	Increase	1.0046	1.0092
Ammonia	1	1.1	1.2	1.2	--	--	2.8	Increase	1.0000	1.0000
Fluoride	1.5	1.6	1.7	1.65	--	--	2.9	Increase	1.0303	1.0615
Phosphate	1	1.01	1.05	1.04	--	--	2.6	Increase	1.0096	1.0193
Residual Chlorine	1	1.13	1.25	1.25	--	--	1.6	Increase	1.0000	1.0000
SPM	500	469.2	985.4	--	1000	950		Increase	0.9854	0.9710
RPM	150	129.6	258.4	--	270	262		Increase	0.9570	0.9159
Lead	0.5	0.42	0.48	--	0.46	0.42	0.45	Normal	1.0435	1.0888

Weighting (IDW) and Kriging interpolation techniques are used with GIS and compared to the observed data to avoid any missing data and underestimating of pollution levels. The results of the observed and arrived value using interpolation spatial model are given in Fig. 3 (a-k) and Fig. 4 (a-c). Inverse Distance Weighting (IDW), Kriging and Kriging Gaussian interpolation technique predicted the pollution level accurately with an error of less than 2 percentage. Hence, the model provides efficient predictions. Overall, the population and pollution level from 2006 to 2020 has drastically increased due to large-scale urbanization, industrial development, and migration of the people into the city (Balaji & Muthukannan 2020, 2021). In most of the parameters, alkalinity, hardness, chloride, TDS, ammonia, fluoride, phosphate and residual chlorine are found to be above the standard prescribed by the TNPCB and CPCB.

The alkalinity of Madurai city has increased up to 725 $mg.L^{-1}$, which is above the standard value of 500 $mg.L^{-1}$. The effect of alkalinity will seriously affect the kidney and other functions of humans. Particularly, Fluoride which is above the limit of 1 $mg.L^{-1}$ will seriously affect the tooth and make dental-related problems. The increase in water pollution was observed due to continuous pumping of groundwater through bore wells and recharge well that have also not been constructed properly in which, the stations like Periyar, Mattuthavanui, and Kalavasal are found to be the highly polluted area. In 2006, only some places out of 8 zones were affected, but in 2020, all the 8 zones are above the specified limit. Hence, to improve the water quality, (i) Artificial recharge bore wells and percolation pond to be created, (ii) Check dams can be provided in the water flowing streams to retain water to recharge the bore wells, (iii) De-silting the existing water sources dams and ponds will also improve water recharge (iv) To construct in rainwater recharge wells at each house and make it mandatory (v) Good soil management measures and practice can be adopted improve surface percolation. (vi) Good sanitation facilities to be provided to avoid mixing of sewerage in the surface water bodies.

Air quality is a serious problem in all the cities in the world. The air pollution is not only due to urbanization, industrial development but also due to the increase in the traffic into the city. As Madurai is the center place for all eight districts, all the wholesale and retail markets are available in the city Central Business District (CBD). Hence, naturally, the traffic will be heavy in the CBD of the city. From the analysis, it could be observed that the stations Matthuthavani, and Periyar are the most affected by air quality attributes like SPM and RPM, whereas stations Kalavasal and Periyar are affected by lead. The concentration of lead in these stations is due to more industries. Hence, to avoid and improve the air qualities (i) Divert the traffic through the ring road and thereby avoid air pollution into the city, (ii)To restrict the industrial development inside the city, (iii)Industry that emits pollutants like NOx and SOx should be restricted, (iv)To create awareness about air pollution among the community.

CONCLUSIONS

The study was conducted at Madurai City to assess the air and water quality changes from 2006 to 2020. The study area was divided into 8 blocks and the primary data were collected from bore wells to assess the groundwater quality and the air quality data were obtained from network stations of TNPCB. To assess the impact on air and water quality, a GIS tool was used. The study used Inverse Distance Weighting (IDW), Kriging and Kriging Gaussian interpolation technique to predict the pollution level accurately and the results were compared with the observed data and it was found that the error was less than 2 percentage. Hence, the model provides efficient predictions. Kriging Gaussian interpolation technique performed best among all the interpolation techniques. The results of the air and water pollution assessment indicate that in 2006 only 2 blocks had pollution levels beyond the threshold level of CPCB but, in 2020 all the 8 blocks were found to be polluted and the pollution level was much higher than the standards given by CPCB. The most affected blocks were found to be Kalavasal, Arapalayam, and Periyar. The maximum water pollution and air pollution recorded in Madurai was Alkalinity 725 $mg.L^{-1}$ (Std. 500), Hardness 745 $mg.L^{-1}$ (Std. 500), Chloride 715 $mg.L^{-1}$ (Std. 500), TDS 2622 $mg.L^{-1}$ (Std. 1000), Ammonia 1.1 $mg.L^{-1}$ (std. 1), Fluoride 1.7 $mg.L^{-1}$ (Std. 1), Phosphate 1 $mg.L^{-1}$ (1), Residual chlorine 1.25 $mg.L^{-1}$(1), SPM 985 $\mu g.m^{-3}$ (Std. 500), RPM 258.4 $\mu g.m^{-3}$ (std. 150), and Lead 0.48 $\mu g.m^{-3}$(0.5). Hence, immediate mitigation methods should be carried out to stop further development of air and water pollution in Madurai city. The conclusion may be very useful for efficient air and water quality management at Madurai City.

REFERENCES

Bailey, T.C. and Gatrell, A.C. 1995. Interactive Spatial Data Analysis. Longman, London, UK.

Balaji, L. and Muthukannan, M. 2020. Investigation into the valuation of land using remote sensing and GIS in Madurai, Tamilnadu, India. Europ. J. Remote Sensing, 6: 1-9, -https://doi.org/10.1080/22797254.2020.1772118

Balaji, L. and Muthukannan, M. 2021. Land use Land cover studies and its effects on Valuation using GIS Techniques in Madurai Town Planning Area, Tamilnadu, India. IOP Conf. Series: Mater. Sci. Eng., 983(1), 012012. doi:10.1088/1757-899X/983/1/012012

Cassidy, T., Inglis, G., Wiysonge, C. and Matzopoulos, R. 2014. A systematic review of the effects of poverty deconcentration and urban upgrading on youth violence. Health Place 26: 78–87. doi:10.1016/j.healthplace.2013.12.009

Chang, H. 2008. Spatial analysis of water quality trends in the Han River basin, South Korea. Water Res., 42: 3285-3304. doi: 10.1016/j.watres.2008.04.006

Colin, C. 2004. Interpolating Surfaces in Arcgis Spatial Analyst. Arcuser, ESRI Education Services. www.esri.com

CPCB 2009. Status of Water Supply, Wastewater Generation and Treatment in Class I Cities & Class II Towns of India 2009.CPCB, Central Pollution Control Board, Delhi.

Deutsch, C.V. 1996. Correcting for negative weights in ordinary kriging. Comp. Geosci., 22(7): 765-773.

Dikshit, V.M. 2020. Groundwater Recharge Potential Sites in Semi-Arid Region of Man River Basin, Maharashtra State, India: A Geoinformatic Approach. Nat. Environment and Pollution Technology, 19(4), pp.1367-1378.

Donohue, I., McGarrigle, M.L. and Mills, P. 2006. Linking catchment characteristics and her chemistry with the ecological status of Irish rivers. Water Res., 40(1): 91-98.

Facchinelli, A., Sacchi, E. and Mallen, L. 2001. Multivariate statistic a land GIS-based approach to identify heavy metal sources in soils. Environ. Pollut., 114: 313-324.

Gerdol, R., Marchesini, R., Iacumin, P. and Brancaleoni, L. 2014. Chemosphere monitoring temporal trends of air pollution in an urban area using mosses and lichens as biomonitors. Chemosphere, 108: 388-395. doi:10.1016/j. chemosphere.2014.02.035

Griffith, D.A. 1988. Advanced Spatial Statistics. Kluwer Academic, Dordrecht, The Netherlands.

Gunnink, J.L. and Burrough, P.A. 1996. Interactive spatial analysis of soil attribute patterns using exploratory data analysis (EDA) and GIS. In Masse, I. and Salge, F. (eds), Spatial Analytical Perspectives on GIS, Taylor & Francis, New York, pp. 87-99.

Guo, J.S., Wang, H. and Long, T.R. 1999. Analysis and development of water quality evaluation method. Chongqing Environ. Sci., 21(6): 1-9.

Huff, G. and Angeles, L. 2011. Globalization, industrialization, and urbanization in pre-World War II Southeast Asia. Explor. Econ. Hist., 48(1): 20-36. doi:10.1016/j.eeh.2010.08.001

Jasmin, I. and Mallikarjuna, P. 2014. Physicochemical quality evaluation of groundwater and development of drinking water quality index for Araniar River Basin, Tamil Nadu, India. Environ. Monit. Assess., 186(2): 935-948. doi: 10.1007/s10661-013-3425-7 PMID: 24052238

Jha, D.K., Sabesan, M., Das, A., Vinithkumar, N.V. and Kirubagaran, R. 2011. Evaluation of interpolation technique for air quality parameters in Port Blair, India. Univ. J. Environ. Res. Technol., 1: 301-310.

Jiang, W.J., Cai, Q., Xu, W., Yang, M., Cai, Y. and Dionysiou, D.D. 2014. Cr(VI) adsorption and reduction by humic acid-coated on magnetite. Environ. Sci. Technol., 48(14): 8078-8085. doi: 10.1021/es405804m PMID: 24901955 24.

Jiang, Y.P., Xu, Z.X. and Yin, H.L. 2006 Study on improved BP artificial neural networks in eutrophication assessment of China eastern lakes. Journal of Hydrodynamics.; 18(3): 528-532

Kim, S., Yi, S., Eum, Y.S., Choi, Shin, H., Ryou, H.G. and Kim, H. 2014. Ordinary Kriging approach to predicting long-term particulate matter concentrations in seven major Korean cities. Environ. Health Toxicol., 29: 1-8. doi:10.5620/ eht.e2014012

Kumar, A., Dikshit, A.K., Fatima, S. and Patil, R.S. 2015. Application of WRF model for vehicular pollution modelling using AERMOD. Atmos. Clim. Sci., 5: 57-62.

Lai, A.C.K., Thatcher, T.L. and Nazaroff, W.W. 2012. Inhalation transfer factors for air pollution health risk assessment. J. Air Waste Manage. Assoc., 50: 1688-1699. doi:10.1080/10473289.2000.10464196.

Liu, J.T., Gao, J.F. and Jiang, J.H. 2010. Application of different fuzzy assessment methods of water quality assessment in Dianchi Lake. Environ. Pollut. Control, 32(1): 20-25.

Maantay, J. 2007. Asthma and air pollution in the Bronx: Methodological and data considerations in using GIS for environmental justice and health research. Health Place, 13(1): 32-56. doi:10.1016/j.healthplace.2005.09.009

Meng, W., Zhang, N., Zhang, Y. and Zhang, B.H. 2009. Integrated assessment of river health based on water quality, aquatic life, and physical habitat. J. Environ. Sci., 21: 1017-1027.

Muthukannan, M. and Aruna, S. and Chithambar, G. 2019. The environmental impact caused by the ceramic industries and assessment methodologies. Int. J. Quality Res., 13(2): 315-334. Doi: 10.24874/IJQR13.02-05

Pang, Z.L., Chang, H.J., Li, Y.Y., Zhang, N.Q., Du, R.Q. and Hu, L.Q. 2008. Analytical hierarchy process (AHP) evaluation of water quality in Danjiangkou reservoir-source of the middle line project to transfer water from south to north, China. Acta Ecol. Sin., 28(4): 1810-1819.

Patel, R.B. and Burkle, F.M. 2012. Rapid urbanization and the growing threat of violence and conflict: A 21st 21st-century crisis. Prehosp. Disaster Med., 27(2): 194-97. doi:10.1017/ S1049023X12000568

Prince, O.U., Ugochukwu, E. and Chibuzo, V.O. 2020. Environmental pollution: Causes, effects, and the remedies. Microorg. Sustain. Environ. Health, 87: 419-429. Doi: 10.1016/B978-0-12-819001-2.00021-8.

Rood, A.S. 2014. Performance evaluation of AERMOD, CALPUFF, and Legacy Air Dispersion Models using the winter validation tracer study dataset. Atmos. Environ., 89: 707-20. doi:10.1016/j.atmosenv.2014.02.054

Ryan, P.H. and Lemasters, G.K. 2008. A review of land-use regression models for characterizing intraurban air pollution exposure. Natl. Inst. Health Public Access, 19(2): 127-33.

Shankar, B.S. and Sanjeev, L. 2008. Assessment of water quality index for the groundwaters of an industrial area in Bangalore, India. Environ. Eng. Sci., 25(6): 911-915

Sohrabinia, M. and Khorshiddoust, A.M. 2007. Application of satellite data and GIS in studying air pollutants in Tehran. Habitat Int., 31(2): 268-75. doi:10.1016/j. habitatint.2007.02.003

Vairavamoorthy, K., Yan, J.M., Galgale, H.M. and Gorantiwar, S.D. 2007. IRA-WDS: A GIS-based risk analysis tool for water distribution systems. Environ. Model. Software, 22: 951-965.

Varol, M., Gökot, B., Bekleyen, A. and Sen B. 2012. Water quality assessment and apportionment of pollution sources of Tigris River (Tukey) using the multivariate statistical techniques-A case study. River Res. Appl., 28(9): 1428-1438.

Xu, Z.X. 2005. Comprehensive water quality identification index for environmental quality assessment of surface water. J. Tongji Univ. Nat. Sci., 33(4): 482-488.

Yan, C.A, Zhang, W., Zhang, Z., Liu, Y., Deng, C. and Nie, N. 2015. Assessment of water quality and identification of polluted risky regions based on field observations & GIS in the Honghe River watershed, China. PLoS ONE 10(3): e0119130. doi:10.1371/journal.pone. 0119130