Groundwater quality assessment with respect to Heavy metal content by using Heavy metal pollution index (HPI)of Moradabad district, Uttar Pradesh, India

ABSTRACT

Heavy metal pollution index (HPI), is a rating method to assess the water quality and to categorize the groundwater pollution with respect to heavy metals content.The aims of the present study are to look over the current status of heavy metals pollution in and around Moradabad city.Heavy metal pollution in water has gain universal consciousness due to its tenacity, accumulation in the food chain and negative effects on ecological as well as human health. Its variation in concentration can causes deterioration of water. The study focuses on examining the content of heavy metal (Zn, Fe, Cd, Mn, Pb, Ni, Cu, and Cr) in the 30 water samples from the surrounding areas of Moradabad city. The concentrations of Cd, Mn, Fe, Cu, Pb, Zn, Ni, and Cr in water samples have recorded in the pre- and post-monsoon season of 2017. The examined samples reveal that the contamination level of heavy metal is in the following sequence Ni>Fe>Pb>Cd>Cr>Cu>Zn>Mn in premonsoon 2017, whereas in postmonsoon season, heavy metals values are shown as Fe>Pb>Ni>Mn>Cr>Cu>Zn>Cd. The HPI average value in pre-monsoon 2017 is 13.07, which recommended that the groundwater quality is good. While in post-monsoon season HPI average values has been found 159.26 suggesting that the water quality is poor to inferior. The correlation matrix has been evaluated and shows a positive correlation with the elements.The immense production of industrial solid waste in Moradabad city and its improper disposal in the form of heap piled outside the city area generates leachate. Heavy metal leaching from these disposal points may contaminate the groundwater as well as surface water resources. The study shows that heavy metal concentration has a noticeable rise in water due to different anthropogenic and various natural sources of contamination.

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Keywords: Heavy metal pollution, HPI, Spearman's correlation coefficient, Groundwater quality

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1. INTRODUCTION

Water is an essential component for all living being, and it is indispensable. It forms a vital naturalwater resource recognized for its supreme importance[**1**].Groundwater is essential as it forms the primary drinking water source in several parts in India. Surface water contamination frames an approach to get contaminated groundwater resource**[2]**The quick development of urban focuses on the deterioration of groundwater quality rapidly because of the despicable transfer of industrial and sewage outflow without earlier treatment and excessive usage of groundwater assets[**3**]. Groundwater quality evaluation is essential as due to increasing urbanization, industrialization and population cause an impact on water resources and level of contamination**[4**]. The groundwater request has been increased suddenly in recent decades due to developing utilization for the drinking water system, and industrialization alongside the weakening of surface water resources[**5**].The consumption rate of groundwater and decay in quality is of prompt worry in significant urban areas and cities of the nation[**6**]. Moreover, urbanization has seriously influenced the water resources by expanding the weight on urban hydrology [**7**].The release of wastewater from metropolitan, industrial and rural regions is an issue of genuine worry as it influences waterway's environment[**8**].The fundamental elements that restraint groundwater chemistry are soils and minerals of the territory, atmosphere, and vegetation cover. These components are likewise in charge of the spatial and transient changes in groundwater chemistry**[9].** It has been noticed that water quality gets influenced by standard components, i.e., geologically and geochemically.Geogenic sources are one of the most important reasons for the alteration in chemical composition of water which changes with space and time [**10**].Anthropogenic disruption through industrial and horticultural pollution leads to an increase in consumption and urbanization degrade the water quality and its suitability for domestic uses **[11].** As per Central Pollution Control Board (CPCB) report, around more than 85% water that are distributed in India to the town and urban communities are contaminated, out of which just 1.6% gets treated. In this manner, water quality analysis is crucial for human welfare**[12].** River basins are endangered to pollution due to absorption and transportation of sewage waste, industrial effluents, and agricultural wastewater. Therefore,it is necessary to monitor the quality for controlling purpose **[13].** The foundation brief given above made the need to complete the present investigation in Moradabad district.It is a standout amongst the biggest creating and sending out the focal point of metal products in India.The main industrial release is from brassware, steel ware, paper mills, sugar mills, crushers, dye factories, and several associates' ancillaries.**[14]** classify trace element whose concentration in water is less than 1ppm. Some of the metals in limited concentration is necessary for the metabolism and growth of living beings. But if these elements' concentrations increase beyond permissible limits they may have toxic effects on human beings [**15**]. Heavy metals make a pathway through weathering process and anthropogenic sources and enter into the dynamic environment.Primary sources of Heavy metals are industrial outflow, mining activities, disposal of pollutants, and pesticides as well as fertilizers release toxic metals and metal chelates.Heavy metals may pollute surface and groundwater and also cause deterioration of drinking water quality. Heavy metals, known as micronutrient include Fe, Mn, Cu, Zn, Co, and Ni and are essential for all living beings **[16].** The quick advancement in the late decades adversely affects the nature of groundwater. The continuous deterioration in water quality, the investigation of Heavy metals has been evaluated to explore the physicochemical variance in groundwater by various factors to determine the effective groundwater management strategies and suitability of groundwater for the domestic purposes.

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1.1 Study Area

Moradabad is well known as Brass city of western Uttar Pradesh, India. Moradabad is famous all over the world for the manufacturing of Brass Handicrafts.The study area lies in between two streams Ramganga at its northeastern edge and Gagan at the southeasternside. It lies between the scope 28^{0}47´ to 28^{0}53´ N and 78^{0}44´ to 78^{0}49´E. The urbanization and industrialization have prompted

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decay of groundwater quality to a large extent. The region of Moradabad lies east of the Ganges and west of the local territory of Rampur. It exists in the enormous Gangetic plain and is divided into three subdivisions by the streams Ramganga and Sot. Moradabad City depleted by Ramganga and its tributaries Gagan, Dhela, and Koshi.

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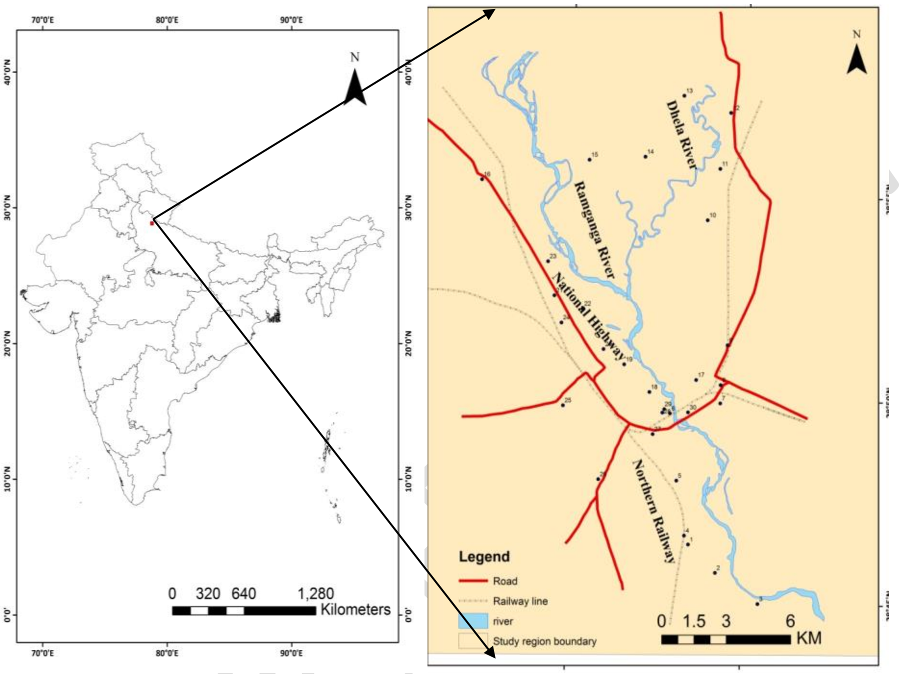

Fig.1. Sample locations map of Moradabad district.

1.2 Climate, Topography, and Drainage

The area is sub-humid described by the rare event of sweltering summers, direct rains,and cool winters. The study area faces general dryness, but in southwest monsoon time, a wetcondition exists which causes high humidity. The rainy season prevails end of June to September, and about 86% rainfall takes place for the same period. During the monsoon period, intense leaching and circulation of material take place by the water. The mean annual rainfall is 967 mm in the study region**.[16]**

1.3 Soil, Geology, and Hydrogeology

Geologically, the study area has been classified into two topographical units, i.e., Younger Alluvium (Khadar) and Older Alluvium (Banger). The investigation zone secured by more youthful alluvium can be depicted along Ramganga and Dhela streams depleting the area. Khadar is limited predominantly inside the flood plain of these two streams.The soil of the investigation region is fundamentally silty, clayey and sandy in fluctuating amount **[17].**The hard Paleogene rocks are overlain by loose alluvial deposits, and these rocks are overlain by Precambrian basement **[18].**The area is secured by alluvial sediments of Quaternary age with a thickness of around 1,000 m composed clay, silt and various

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grades of sand. The alluvial deposits have been drained by the river Ganga and particularly the river Ramganga. Drilling conducted by CGWB (2008) down to a depth of 450 m below ground level (blog) disclose the presence of aquifer with a marked change in sedimentation below 390 m below ground level.

2. MATERIALS AND METHODS

2.1 Sampling and Preparation

30 groundwater samples in the months of May and November 2017 were collected from the study area for the analyses of trace elements. Samples collection can be done from the site of industrial discharge, along with the side of the river, from open streams and groundwater samples from bore wells, dug well as well as surface and river water.So as to pronounce the nature of groundwater, 30 water samples in the post monsoon and 30 in the premonsoon seasons, were gathered from various handpumps and surface river water. Almost all the samples were collected from hand pump and only sample number 6 was collected from surface river water.1-liter polyethylene bottle is pre-washed with double distilled water for sample collection to assess theunpredictable changes in the chemical composition of groundwater. All samples were acidified by the use of ultrapure 65% Nitric acid (.5ml/100ml of water) so that trace element concentration would not change. All the samples were analyzed for pH,EC, and Trace element **[19]**. The trace element analysis(Pb, Zn, Cd, Ni, Fe, Co, Cr, and Cu)was accomplished by Atomic Absorption Spectrophotometer (Perkin Elmer 800, Waltham Massachusetts, USA) in the Geochemical Lab, Department of Geology, Aligarh Muslim University, Aligarh.Trace element analysis the analytical detection limits for elements such as Pb, Cd, Ni, Cr, and Cu were 2.1, 0.07, 3.6, 019, and .75 pg respectively**.** All the trace element concentration were compared with standards.The analytical data quality was assured through the execution of research facility quality confirmation and quality control techniques, including the utilization of standard working strategies, alignment with norms, examination of reagent blanks, recuperation of known increments, and investigation of repeats.All examinations were completed in triplicate, and the results were communicated as the mean. Concentrations of different Heavy metals in the ground of the study region are shown in table 4. **[19]**

2.2 Heavy Metal Pollution Index (HPI):

Heavy metals are group of metals that have relatively high density and are very toxic even at ppb levels.These metals are released into the groundwater by both anthropogenic and natural sources such as, automobiles exhaust, industrial waste discharge and mining waste. In contrast to natural toxins, heavy metals are nonbiodegradable and have propensity to amass in living creatures.Various harmful health hazards are known by heavy metals due to its long term and continuous exposure. HPI is a strategy for the evaluation of the nature of water concerning the concentration of heavy metal**[20].** To calculate HPI, unit weight *(Wi)* value is inversely proportional to the recommended standard (Si). The model of HPI was proposed by [**20].**

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$$\textbf{HPI=}\ \frac{\sum_{i=1}^{i=n} Q_i * W_i}{\sum_{i=1}^{i=n} W_i} \qquad \textbf{(1)}$$

where,***Qi****:* - sub-index of the i^{th} parameter and ***Wi:***-the unit weight of the i^{th} parameter
n: - number of parameters considered.

The unit weight (Wi) of the parameter is determined by: -

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***Wi* =K/Si (2)**

where, *Si:* - standard for ith parameter and K: - proportionality constant

The sub-index (Qi) of the parameter is calculated by: -

$$Q_i = \sum_{i=n}^{n} \frac{[M_i - I_i]}{[S_i - I_i]} \times 100 \quad (3)$$

Where **M$_i$**- monitored value of heavy metals of ith parameter
I$_i$ - ideal value of the ith parameter

The factor [M$_i$−I$_i$] is the difference between the two values. HPIvalues used for water quality suitability for drinking purposes and the water having HPI values 100 beyond is not potable for drinking **[21].**

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Table.1. Range of HPI values for categorizing the quality of water concerning heavy metal content.

HPI	Water quality
0-25	**Very Good**
26-50	**Good**
51-75	**Poor**
>75	**Very Poor**

2.3 Spearman’s correlation coefficient:

Spearman’s correlation coefficient(r_s) is generally used to measure the strength of a monotonic relationship among paired data. A monotonic relationship is a relationship that does one of the accompanying: (1) as the estimation of one variable increment, so does the estimation of the other variable. (2) as the value of one variable increases, the other variable value decreases. It is a statistical tool to determine the degree of dependency of one variable to the other**[22].** The values correlation coefficient always varies in between -1 and +1.

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$$r_s = \frac{\Sigma(\mathbf{x} - \mathbf{X}|\mathbf{y} - \mathbf{Y})}{\sqrt{\left(\sum\left[(\mathbf{y} - \mathbf{Y})^2\right]\middle|\sum(\mathbf{x} - \mathbf{X})^2\right)}} \quad (4)$$

In the above equation x and y value for which rs is calculated. X and Y indicate mean values of x and y r_s represents a linear association between two variables.Positive connection demonstrates an expansion in one variable related to an expansion in the other, while the negative relationship implies an expansion in one variable identified with the abatement in the other.

Table.2. Spearman’s correlation coefficient range and data interpretation

r-valueInterpretation	
0.0 to 0.19	“very weak” (vw)
0.20 to 0.39	“weak”(w)

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0.40 to 0.59	“moderate”(m)
0.60 to 0.79	“strong”(s)
0.80 to 1.00	“very strong”(vs)

3. RESULT AND DISCUSSION

The statistical analysis of trace element for the 30 pre- and post-monsoon samples for eight heavy metals has been carried out, and their mean, maximum, minimum values and standard deviation were calculated as shown (Table.4).In pre-monsoon 2017, the average concentration of Zn, Fe, Cd, Mn, Pb, Ni, Cu, and Cr of all samples aren 0.12, 1.10, 0.44, 0.02, 0.92, 1.59, 0.23 and 0.27 mg/l respectively. During the period of Post-monsoon 2017, the average concentration of Zn, Fe, Cd, Mn, Pb, Ni, Cu, and Cr of all samples are 0.27, 2.32, 0.16, 0.40, 2.23, 0.97, 0.29 and 0.37 mg/l respectively.After comparing the trace element concentration values of pre- and post-monsoon seasons, the concentration of heavy metals are low in the premonsoon season as compared to the postmonsoon season.Based on average values, the order of heavy metals concentration in pre-monsoon season is Ni>Fe>Pb>Cd>Cr>Cu>Zn>Mn. While in the post-monsoon period Heavy metals are in increasing values i.e Fe>Pb>Ni>Mn>Cr>Cu>Zn.Cd.

Table.3. Spearman’s Correlation Coefficient of Heavy metals in the study area

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Heavy Metals	Premonsoon	r_s	Correlation	Postmonsoon		r_s	Correlation
Cd vs	Cr	0.38	w	Cd vs	Cr	-0.08	no
	Cu	0.40	m		Cu	0.33	w
	Fe	0.38	w		Fe	0.78	s
	Mn	0.34	w		Mn	-0.31	no
	Ni	0.08	vw		Ni	0.41	m
	Pb	-0.30	no		Pb	0.61	s
	Zn	0.10vw			Zn	0.01vw	
Cr vs	Cu	0.83	vs	Cr vs	Cu	-0.35	no
	Fe	0.78	s		Fe	-0.05	no
	Mn	0.63	s		Mn	0.11vw	
	Ni	0.23	w		Ni	0.01vw	
	Pb	-0.29	no		Pb	0.03vw	
	Zn	-0.35	no		Zn	0.39	w
Cu vs	Fe	0.82	vs	Cu vs	Fe	0.41	m
	Mn	0.75	s		Mn	-0.09	no
	Ni	0.36	w		Ni	0.08vw	

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	Pb	-0.25	no		Pb	0.23	w
	Zn	-0.04	no		Zn	-0.32	no
Fe vs	Mn	0.78	s	Fe vs	Mn	-0.25	no
	Ni	0.40	m		Ni	0.46	m
	Pb	-0.13	no		Pb	0.73	s
	Zn	-0.04	no		Zn	-0.03	no
Mn vs	Ni	0.58	m	Mn vs	Ni	-0.09	no
	Pb	-0.01	no		Pb	-0.43	no
	Zn	0.01	vw		Zn	-0.07	no
Ni vs	Pb	0.05	vw	Ni vs	Pb	0.31	w
	Zn	0.22	w		Zn	0.03	vw
Pb vs	Zn	0.06	vw	Pb vs	Zn	0.05	vw

The Spearman’s correlation coefficient is used for the measurements of strength and statistical denotation of the relation between two or more water quality parameters. Correlation of heavy metals of pre-monsoon and post monsoon 2017 are shown in (Table 3). For the pre-monsoon season 2017, it can be concluded that there is a positive correlation between heavy metals Cd with Mn, Fe, Cr, Cu, Zn and negative correlation for Pb. It can also be referring that Cd shows moderate correlation with Cu and other metals shows weak or very weak correlation with Cd. As far as Cr is concerned, it shows positive relation between Cu, Fe, Mn, Ni and very strong correlation with Cu also shows strong correlation with Fe, Mn. For about Cu, which shows very strong correlation with Fe and strong correlation with Mn, weak and no relation with Ni and other metals. As about Fe, which shows strong correlation with Mn and moderate or no correlation with Ni and other metals. Manganese only shows moderate correlation with Ni. All other heavy metals show weak or moderate correlation to remaining metals.

In post-monsoon season, a positive correlation has been noticed between heavy metals as Cd with Pb, Ni, Cu, Zn and strong correlation with Fe, Pb and weak or no correlation with other metals. For about Cr, which shows moderate correlation with Zn and very weak or no correlation with other metals. Cu is also showing same correlation trend as Cr. As far as Fe is concerned, it shows strong correlation only with Pb. All other remaining heavy metals shows weak or no correlation with the metals

It can be concluded that if the concentration of one metal increases which also causes the concentration of other metals to increase. This is because of huge industrial wastes seepage into the groundwater through various media. The positive correlation between these heavy metals shows their common source of industrial contamination. However, in a few heavy metals, there are no significant correlations between them, indicating that there is no association between heavy metals. Furthermore, these heavy metals might have originated from different sources.

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Table.4. Statistical analysis of Heavy metals in all groundwater samples

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Parameters		**Cd**	**Pb**	**Ni**	**Cu**	**Zn**	**Mn**	**Fe**	**Cr**
Pre-monsoon 2017	**Min**	0.35	0.19	1.45	0.12	0.04	0.0	0.70	0.0
	Max	0.60	2.50	1.80	0.31	0.30	0.08	2.21	0.41
	Mean	0.44	0.92	1.59	0.23	0.12	0.02	1.18	0.27
	SD	0.05	0.63	0.08	0.05	0.07	0.02	0.32	0.12
Post-monsoon 2017	**Min**	0.08	0.33	0.15	0.13	0.07	0.13	0.94	0.06
	Max	0.23	3.64	1.37	0.54	0.88	1.74	2.92	0.61
	Mean	0.16	2.23	0.97	0.30	0.27	0.40	2.32	0.37
	SD	0.04	0.79	0.32	0.13	0.19	0.37	0.53	0.16
WHO	**2012**	**0.003**	**0.01**	**0.07**	**2.0**	**3.00**	**0.01**	**0.30**	**0.05**
BIS	**2012**	**0.003**	**0.01**	**0.02**	**2.0**	**5.00**	**0.01**	**0.30**	**0.05**

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Table.5. PremonsoonAnovaresult

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Cd	30	13.24	0.44	0.00
Cr	30	8.10	0.27	0.01
Cu	30	6.94	0.23	0.00
Fe	30	33.25	1.11	0.11
Mn	30	0.67	0.02	0.00
Ni	30	47.76	1.59	0.01
Pb	30	27.88	0.93	0.40
Zn	30	3.74	0.12	0.01

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	65.41	7	9.34	137.5	7E-79	2.049
Within Groups	15.77	232	0.07			
Total	81.18	239				

Table.6. Post monsoon anova

result

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Cd	30	5.044	0.17	0.00
Cr	30	11.17	0.37	0.03
Cu	30	8.898	0.30	0.02
Fe	30	69.64	2.32	0.28
Mn	30	12.19	0.41	0.14
Ni	30	29.19	0.97	0.10
Pb	30	67.06	2.24	0.64
Zn	30	8.327	0.28	0.04

ANOVA

Source of Variation	SS	df	MS	F	P-value	F -crit
Between Groups	168.45	7	24.06	153.64	2.2E-83	2.05
Within Groups	36.338	232	0.16			
Total	204.78	239				

Anova response clearly showing high variance of heavy metals in post-monsoon season. It is also clear from table 5 and table 6 that Pb, Fe and Ni show high variance in the concentration in both seasons.

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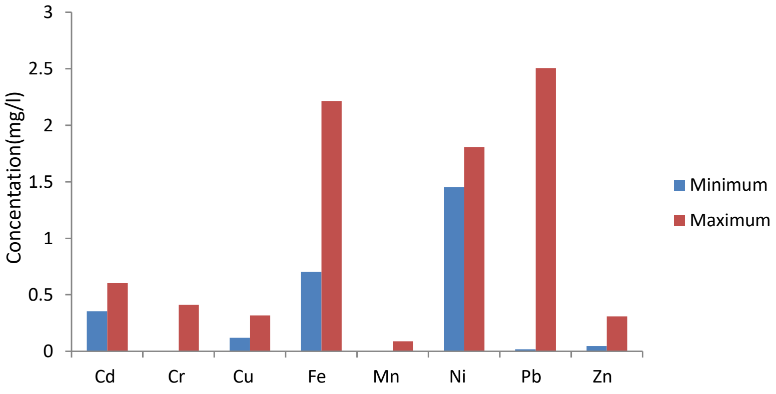

Fig. 2 Comparison of Heavy metals concentration in Premonsoon 2017.

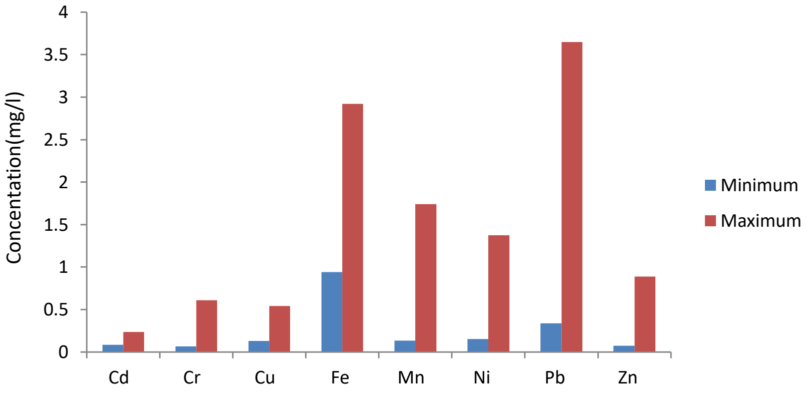

Fig.3. Comparison of heavy metals concentration in post-monsoon 2017.

As from fig. 2 and fig. 3 it is clearly shown that the heavy metal concentration varies with the season. In both the season Cu and Zn shows the concentration which is below the permissible limits. Mn shows large variation in concentration from premonsoon to post monsoon. All the remains heavy metals show large variation in concentration.

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Table.7. Correlation matrix of Heavy metals with HPI in pre-monsoon.

Heavy metals	Cd	Pb	Ni	Cu	Zn	Mn	Fe	Cr	HPI
Cd	1								
Pb	-0.32677	1							
Ni	-0.03557	0.144331	1						
Cu	0.15269	-0.2371	0.361647	1					
Zn	0.085458	-0.05646	0.1573	0.028022	1				
Mn	0.129113	0.162263	0.645002	0.647886	0.225692	1			
Fe	0.172722	-0.06527	0.335077	0.738817	0.330192	0.74399	1		
Cr	0.171806	-0.14805	0.257866	0.864916	-0.33938	0.543326	0.621453	1	
HPI	-0.02415	0.211812	0.142361	0.036846	0.702338	0.421686	0.507488	0.21855	1

The correlation matrix of heavy metals with HPI clearly shows the major influence of Mn, Pb, Cr, Ni, Fe, Cu and Zn on HPI.

Table.8. Correlation matrix of heavy metals with HPI of Post-monsoon season 2017

Heavy metals	Cd	Pb	Ni	Cu	Zn	Mn	Fe	Cr	HPI
Cd	1								
Pb	0.672006	1							
Ni	0.3913	0.430613	1						
Cu	0.430957	0.351267	0.128442	1					
Zn	0.145475	0.000549	0.082852	-0.10532	1				
Mn	-0.58344	-0.59696	-0.40806	-0.26383	-0.11037	1			
Fe	0.82342	0.805357	0.61703	0.472927	0.165026	-0.67961	1		

Cr	-0.008	0.161931	0.176235	-0.3592	0.085978	-0.11576	0.181773	1	
HPI	-0.52179	-0.53977	-0.36126	-0.21468	-0.09968	0.994951	-0.60285	-.10589	1

The correlation matrix of heavy metals with HPI clearly shows the major influence of Mn and Cr on HPI.

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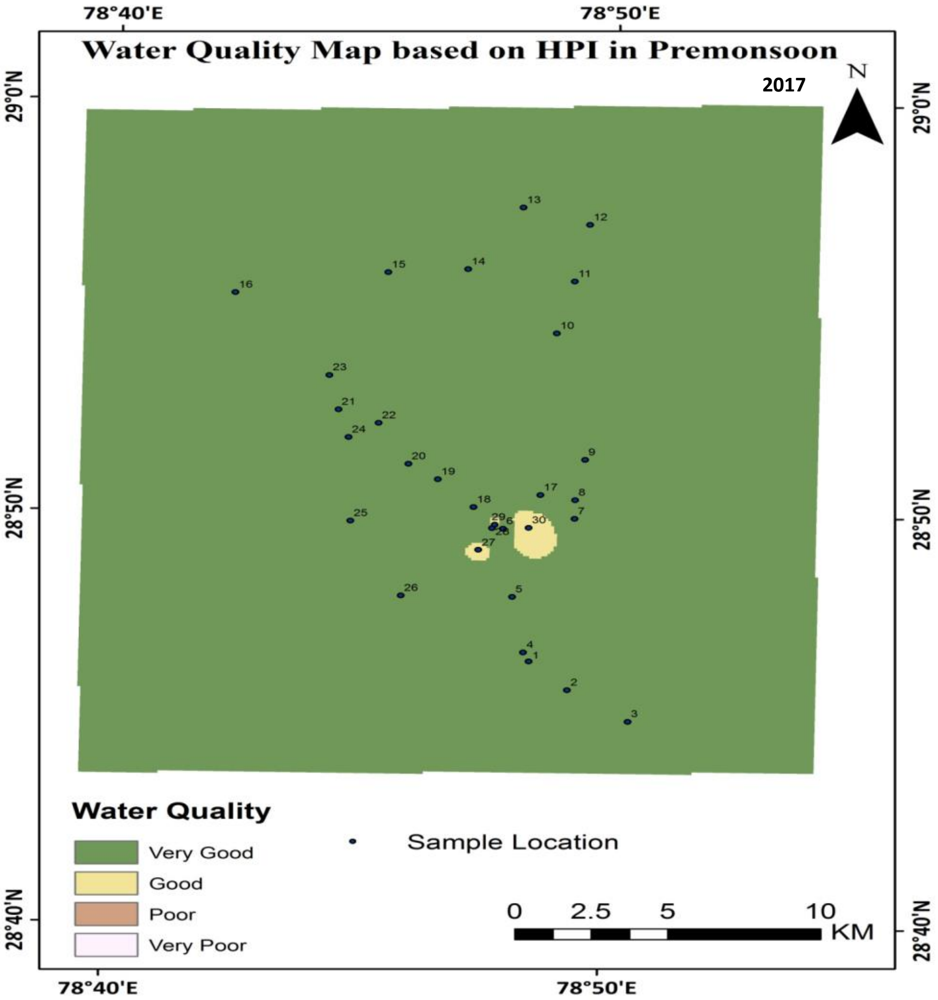

Fig.4. Map showing water quality based on HPI values of Pre-monsoon season 2017.

The water quality is characterized into four classes as appeared in table 1. In the examination area, water quality observed to be very good to good in pre-monsoon2017. Anyway a few patches, as demonstrated orange color in the figure, found in the southern region of the investigation area shows the good quality of water. From fig. 4, it very well explained that water quality in many zones of Moradabad area is observed to be generally good to good during pre-monsoon 2017.

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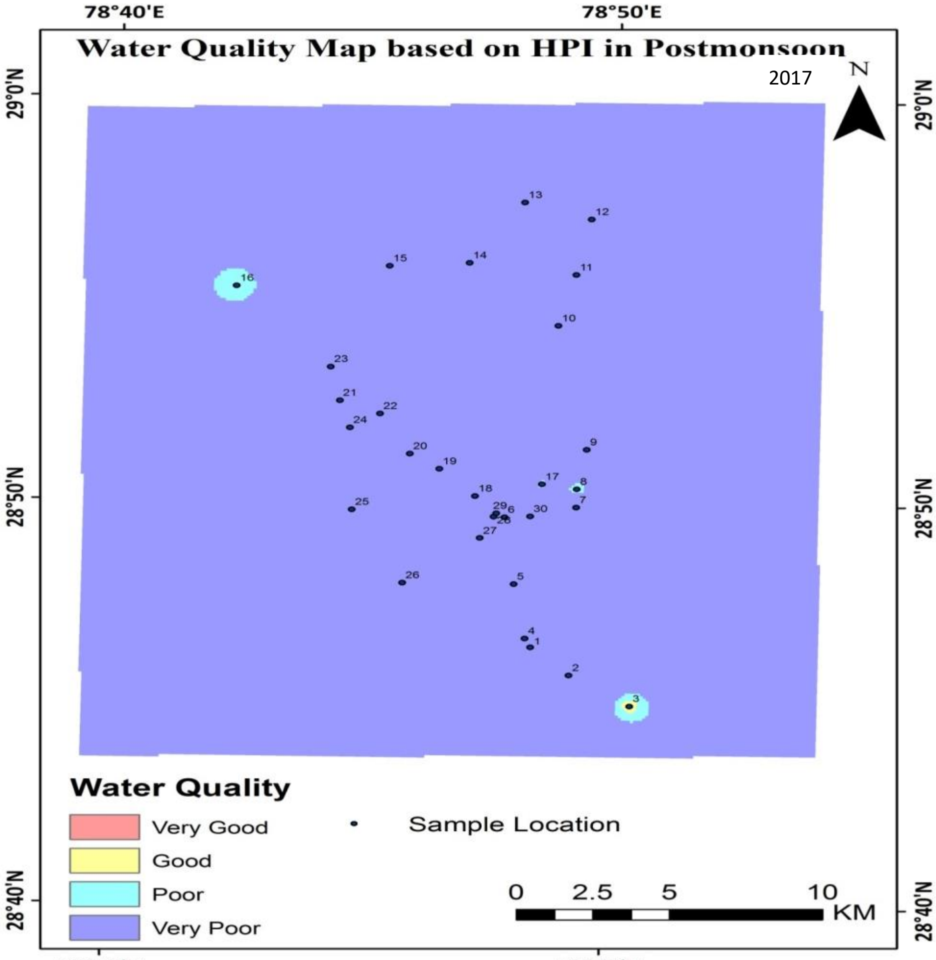

Fig.5. Map showing water quality based on HPI value of post-monsoon season 2017.

During post-monsoon 2017, water quality observed to be poor to exceptionally poor. As demonstrated by few patches of cyan color, found in northwestern and southern edge of the study area reveals poor quality of water. Therefore from fig.5, it very well may be presumed that water quality in many regions of Moradabad area is observed to be poor to very poor amid during post-monsoon 2017 and recommending contamination and defilement of groundwater. The defilement of groundwater in the investigation region is because of fast urbanization, the untreated release of industrial wastes and effluents.

3.1 Geochemistry of Heavy metals

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Status of trace elements in the study region has been considered concerning standards prescribed by WHO 2012 and BIS 2012. Study reveals that Ni, Cd, Fe, Cr, Pb and few samples of Mn are in higher concentration than the permissible limits in Pre-monsoon 2017. While Cd, Mn, Cr, Ni, Fe, and Pb are exceeded the permissible limits in the post-monsoon 2017.

3.1.1 Manganese (Mn)

The concentration of Mn extended from 0 to 0.087 in pre-monsoon season 2017 and 0.134 to 1.741 in post-monsoon season 2017. The value of Mn concentration 30% of water samples in the pre-monsoon season is surpassed as far as possible, while in post-monsoon 2017the concentration in all the samples is more than the permissible limits. Study uncovers the higher concentration of manganese (Mn) in the investigation region is expected to electroplating and production of batteries. Manganese in groundwater may enhance iron microorganisms in groundwater.

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3.1.2 Cadmium (Cd)

Cadmium is extremely risky components and is taken as a cancer-causing agent. By increasing its permissible concentration in water, it can cause damage to the nervous system and furthermore can lead to kidney failure **[23].** Cadmium value fluctuates from 0.35 to 0.60 and 0.08 to 0.23 in pre and posts monsoon seasons 2017 respectively. The highest permissible limits for Cd in groundwater is 0.003mg/l **[24,25].** All the water samples in the investigation zone exceeded the prescribed limit in both the seasons. The principal reason for the higher concentration of cadmium in water is because of its occurrence as a contaminant in zinc galvanized pipes, water heaters, solders in fittings, water cooler, and taps. High level of cadmium concentration in water may result from industrial and domestic discharge.Long haul introduction to cadmium can make harm the kidney, liver, bone and blood. Consequently, cadmium ought to be expelled from waste water before release into the groundwater. It is utilized as a coating layer to a ferrous material, metal, and aluminum. Every one of these sources is the fundamental element of high cadmium concentration in groundwater.

3.1.3 Chromium (Cr)

Chromium mostly found in nature in 2 oxidation state, i.e., Cr+6 and Cr+3. The hexavalent condition of chromium is mobile and is additionally extremely dangerous. Its concentration in groundwater in the investigation region changes from 0 to 0.41 mg/l and 0.06 to .61 mg/l in premonsoon and post-monsoon. All the water samples in the investigation area exceeded the highest permissible limits according to standards that are 0.05 mg/l **[24,25].** Study reveals that the fundamental cause of chromium in groundwater is from paints, colors, papers, and electroplating ventures **[20]**The rise in the level of chromium in water causes ulceration of nasal septum and dermatitis sickness.

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		Trace Element Pre-Monsoon 2017 (mg/l)									Trace Element post-monsoon 2017 (mg/l)								
S. No	Locations	Cd	Cr	Cu	Pb	Mn	Ni	Fe	Zn	HPI (Pre)	Cd	Cr	Cu	Pb	Mn	Ni	Fe	Zn	HPI (Post)
1	Kharagpur baze	0.604	0	0.12	0.043	0	1.508	0.704	0.184	21.5	0.094	0.159	0.211	0.338	1.741	0.489	0.941	0.075	558.68
2	Milak Kuttunwali	0.354	0.026	0.17	0.537	0	1.607	0.955	0.237	13.96	0.087	0.32	0.14	1.193	1.061	0.418	1.371	0.49	346.21
3	Badepur	0.4	0.069	0.166	0.506	0.004	1.545	0.701	0.262	19.84	0.099	0.066	0.193	0.631	0.155	0.508	1.157	0.118	42.91
4	Milak Rustampur	0.449	0.104	0.195	0.566	0.001	1.674	0.909	0.218	14.7	0.118	0.235	0.281	1.391	1.189	0.44	1.298	0.152	387.16
5	Kaliyanpur2	0.457	0.134	0.2	0.908	0.002	1.563	0.801	0.153	17.38	0.158	0.609	0.354	1.661	0.46	0.519	2.286	0.197	176.54
6	Near RamGanga Bridge	0.425	0.189	0.199	1.65	0	1.554	0.896	0.172	15.37	0.169	0.489	0.348	1.532	0.184	1.22	2.252	0.14	84.73
7	Bhainsiya	0.37	0.185	0.196	1.594	0	1.492	0.759	0.105	19.27	0.132	0.498	0.246	1.708	0.348	1.047	2.176	0.498	134.65
8	BarwalaMazra	0.398	0.209	0.182	1.48	0	1.508	1.014	0.089	12.21	0.133	0.421	0.264	1.977	0.135	0.826	2.111	0.443	63.91
9	Got	0.362	0.182	0.198	1.323	0.006	1.657	0.813	0.058	15.76	0.121	0.26	0.189	1.774	0.806	1.198	2.067	0.184	282.69
10	Laluwala	0.46	0.209	0.206	0.961	0.019	1.551	1.028	0.048	5.35	0.156	0.533	0.296	1.127	0.413	1.047	2.432	0.185	164.67
11	Pipalsana	0.412	0.216	0.191	1.633	0	1.451	0.834	0.049	17.21	0.207	0.61	0.233	2.148	0.38	1.118	2.162	0.211	145.63
12	BhojpurDharampur	0.379	0.23	0.206	1.306	0.008	1.603	1.062	0.08	8.0	0.129	0.552	0.314	2.281	0.901	0.86	2.241	0.354	319.99
13	Ahmadpur	0.444	0.239	0.206	1.422	0.011	1.461	1.045	0.12	7.49	0.185	0.563	0.166	2.444	0.603	1.174	2.201	0.181	219.47
14	Khaiya khaddar	0.474	0.243	0.198	2.507	0.014	1.617	1.001	0.133	7.48	0.141	0.361	0.164	2.222	0.204	1.265	2.266	0.21	90.45
15	Islam Nagar	0.42	0.266	0.196	2.348	0.087	1.772	1.081	0.069	18.42	0.131	0.463	0.341	2.806	0.189	1.079	2.231	0.254	85.73
16	Sheruachauraha	0.403	0.271	0.223	0.302	0.014	1.581	1.001	0.051	7.6	0.171	0.417	0.185	2.563	0.158	0.732	2.171	0.262	72.43
17	BarbalaMazra	0.434	0.369	0.225	0.915	0.043	1.67	1.227	0.104	8.33	0.185	0.549	0.132	2.675	0.135	0.902	2.458	0.753	72.54
18	GIC Faizganj	0.408	0.373	0.228	0.541	0.01	1.551	1.066	0.055	7.04	0.15	0.578	0.164	2.656	0.516	1.333	2.577	0.207	201.44
19	Shankar Nagar Deputyganj	0.507	0.398	0.241	0.728	0.012	1.628	1.123	0.075	4.65	0.187	0.542	0.162	2.874	0.161	1.072	2.778	0.34	90.33
20	Civil Lines	0.505	0.376	0.259	0.019	0.013	1.543	1.194	0.075	2.16	0.213	0.42	0.156	2.605	0.227	1.18	2.844	0.184	113.83
21	Harthala	0.44	0.38	0.25	0.07	0.01	1.52	1.14	0.04	3.51	0.18	0.08	0.49	2.38	0.13	1.25	2.50	0.17	76.7

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		6		6	1	3		7	7		8	9	5	7	4	8	3	1	0
22	Ramganga vihar phase2	0.459	0.41	0.27	0.245	0.01	1.558	1.308	0.052	4.85	0.238	0.221	0.395	3.034	0.165	0.1541	2.543	0.167	87.11
23	MohraMustakam	0.472	0.387	0.275	0.396	0.025	1.636	1.135	0.079	0.26	0.212	0.324	0.164	3.128	0.195	1.373	2.632	0.213	97.40
24	Adarsh Colony	0.51	0.403	0.304	0.571	0.034	1.583	1.152	0.109	3.97	0.176	0.413	0.496	3.3	0.165	1.141	2.752	0.303	93.94
25	Majhaula Mandi	0.422	0.401	0.316	0.252	0.042	1.626	1.043	0.098	3.63	0.192	0.158	0.469	3.261	0.21	1.114	2.883	0.151	112.12
26	Transport Nagar	0.448	0.362	0.293	1.112	0.043	1.562	1.22	0.141	8.75	0.232	0.101	0.432	1.668	0.407	1.245	2.775	0.887	173.69
27	Hanuman Murti (Derhigaon)	0.441	0.379	0.295	1.109	0.056	1.659	1.751	0.181	28.02	0.222	0.331	0.373	2.687	0.251	1.169	2.869	0.635	124.46
28	HMIC Near Mandir	0.451	0.361	0.304	1.107	0.053	1.808	1.224	0.127	12.25	0.207	0.297	0.541	3.649	0.198	1.186	2.915	0.104	109.77
29	Barbalan	0.452	0.364	0.31	0.719	0.067	1.651	1.84	0.309	34.30	0.208	0.249	0.536	2.571	0.251	1.217	2.828	0.133	124.71
30	Gulab bari Waste Site	0.472	0.361	0.311	1.013	0.078	1.624	2.215	0.256	48.50	0.203	0.341	0.458	2.764	0.243	0.907	2.92	0.125	123.97

Table.9. Analyzed value of Heavy Metals concentration in the samples

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3.1.4 Copper(Cu):
Copper concentration ranges from 0.12 to 0.36 and 0.13 to 0,54 mg/l in premonsoon and post-monsoon. The prescribed limits of Cu are 2 mg/l **[24,25].**The value of copper in the study region is under permissible limit. Copper is a fundamental component for human health, and its appearance in low concentration can affect the formation of human blood. The main sources of copper in the investigation territory are Brassware enterprises.

3.1.5 Iron (Fe):
Iron is a chief component for the formation of hemoglobin in human blood, but its excess may cause hemochromatosis, while its deficiency leads to anemia. The concentration varies 0.70 to 2.21 mg/l and 0.94 to 2.92 mg/l Premonsoon and post-monsoon respectively. Prescribed limits of iron in water are 0.3 mg/l **[24,25].** and all the samples exceeded this limit in both seasons. The higher concentration of iron in Moradabad is because of filtering of leaching of organic matter, corrosion of metal pipes and interaction of iron-bearing minerals.

3.1.6 Nickel (Ni):
Nickel concentration varies from 1.45 to 1.80 and 0.54 to 1.37 mg/l premonsoon and post-monsoon 2017 respectively. Water samples exceeded the permissible limits in the area for both the seasons, which is 0.07 mg/l **[24,25].** Nickel is present as enzymes in plant and microorganism. Leaching pipes and fitting can be considered as the prime key of nickel concentration in the Moradabad district.

3.1.7Lead (Pb):
Lead concentration in the study area ranges from 0.09 to 2.50 mg/l and 0.33 to 3.64 mg/l in premonsoon and post-monsoon. The highest permissible limit of lead in water is 0.01 mg/l **[24,25].** The concentration of lead exceeded the permissible limits in both the seasons. The sources of lead contributing higher concentration of lead in water includes Lead pipes, brass fixtures, Lead-based copper piping solders. The possible sources of lead are diesel fuel from farmlands discarded batteries.

3.1.8 Zinc (Zn):
Zinc is essential for all living being. Its concentration varies from 0.04 to 0.30 mg/l and 0.07 to 0.88 mg/l in premonsoon and post-monsoon 2017. The highest permissible limits of zinc are 3 mg/l **[24,25].**Concentration in all the samples found under the permissible limits. Study reveals that water samples indicating a deficiency of zinc in the study area and may causes dermatitis, loss of taste disease.

CONCLUSION

Based on average values, the heavy metal concentration is in the following order Ni>Fe>Pb>Cd>Cr>Cu>Zn>Mn in pre-monsoon season 2017, While in the Post-monsoon period heavy metals are in order of increasing values Fe>Pb>Ni>Mn>Cr>Cu>Zn.Cd. The correlation matrix analysis of mean concentrations of heavy metals reveals that good to strong positive correlations between Zn, Ni, Zn, Fe, Pb, Cd, Cu, and Cr, propose that these metals have a common source. Status of heavy metals in the study area has been considered concerning standards prescribed by **[24,25].** Study reveals that Cd, Cr, Fe, Ni, Pb and few samples of Mn are in higher concentration than the permissible limits in Pre-monsoon season 2017. While Cd, Cr, Fe, Mn, Ni, and Pb are also found in higher concentration than the allowable limits in the post-monsoon season 2017.The immense production of industrial solid waste in Moradabad city and its improper disposal in the form of heap piled outside the city areagenerates leachate. Heavy metals leaching from these disposal points may contaminate thegroundwater as well as surface water resources.

Commented [K21]: Add the > between Zn and Cd

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The poisonous metals are not just seriously influencing human wellbeing by causing extreme sicknesses yet additionally making the unbalance of the aquatic system of river Ramganga. In this manner, the protection and supervision methodologies are proposed for the tainted sites of Ramganga and also there is an urgent need for appliance of the preservation and awareness plan. Heavy metal pollution index is an effective technique to mark the groundwater pollution.Continuous examination of groundwater quality concerning their heavy metals content is needed, taking into review the sharp increase of the socioeconomic activities inthe city area.

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REFERENCES

1. Ayotte JD, Gronberg JM, Apodaca LE (2011) trace elements and radon in groundwater across the United States: US geological survey scientific investigations report 5059, p 115.
2. Siraj Ahmad, Shadab Khurshid (2018), heavy metals pollution in groundwater of ghaziabad district, western uttarpradesh, india: groundwater quality constraint ijrat*vol.6, no.8, august 2018 e-issn: 2321-9637.*
3. Abdul Jameel and J. Sirajudeen(2006) risk assessment of physico-chemical contaminants in groundwater of pettavaithalai area, tiruchirappalli, tamilnadu – indiaEnvironmental Monitoring and Assessment (2006) 123:299–312.
4. M. R. G. Sayyed, G. S. Wagh, An assessment of groundwater quality for agricultural use: a case study from solid waste disposal site SE of Pune, India, Proceedings of the International Academy of Ecology and Environmental Sciences, 2011, 1(3-4):195-201.
5. D. Sujatha, B. Rajeswara Reddy, Quality characterization of groundwater in the south-eastern part of the Ranga Reddy district, Andhra Pradesh, India, Environmental Geology August 2003, Volume 44, Issue 5, pp 579–586.
6. S M wasim*, S Khurshid, Z A Shah and d Raghuvanshi, Groundwater Quality in Parts of Central Ganga Basin, Aligarh City, Uttar Pradesh, India Proc Indian Natn Sci Acad 80 No. 1 March 2014 pp. 123-142.
7. Ankit Mishra & Lata Kumari & Rishikesh Singh, Assessment of ground and surface water quality along the river Varuna, Varanasi, India, Environ Monit Assess (2015) 187-170.
8. Simge Varol Aysen Davraz, Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey) Environ Earth Sci 2014.
9. Elango, L., Kumar, S. S., & Rajmohan, N. (2003). Hydrochemical studies of ground water in Chengalpet Region. *Indian Journal of Environmental Protection*, *23*(6), 624-632.
10. Madhavan and Subramanian 2007, Fluoride concentration in river waters of south Asia May 2001 Current science 80(10):1312-1319.
11. Vasil Simeonov Assessment of the Surface Water Quality in Northern Greece November 2003 WaterResearch 37(17):4119-24.
12. Madhuri et al.2004, Status of subsurface water quality in relation to some physico-chemical parameters-A study in Visakhapatnam, JECET; December 2014-Febuary 2015; Sec.A Vol.4. No.1, 221-233.
13. Vasil Simeonov Assessment of the Surface Water Quality in Northern Greece November 2003 WaterResearch 37(17):4119-24.
14. Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice- Hall, Inc., Englewood Cliffs, NJ.604 pp.
15. Chapman, J.B**.**, Gehrels, G.E., Ducea, M.N., Giesler, N., Pullen, A., 2016, A new method for estimating parent rock trace element concentration from zircon: Chemical Geology, v. 439, p.59-70.

16. Akhilesh jinwal, Some Trace Elements Investigation in Ground Water of Bhopal &Sehore District in Madhya Pradesh: India, J. Appl. Sci. Environ. Manage. December, 2009.

17. CGWB (2008) District brochure of Moradabad District, UP Davis NS (1964) Silica in streams and groundwater. Am J Sci 262:870–891
18. N. Saba et .al, Hydrogeochemical assessment of Moradabad city, an important industrial town of Uttar Pradesh, India, Sustain. Water Resour. Manag. (2016) 2:217–236.
19. Salman Ahmed, Shadab Khurshid, Heavy metals and geo-accumulation index development for groundwater of Mathura city, Uttar Pradesh, Desalination and Water Treatment, 138 (2019) 291–300 January.
20. S Venkata Mohan, P. Nithila Estimation of heavy metals in drinking water and development of heavy metal pollution index, Journal of environmental science and health. Part A, Environmental science and engineering & toxic and hazardous substance control A31(2):283-289.
21. Bably Prasad and JM Bose, Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas, November 2001 Environmental Geology 41(1):183-188.
22. Lazhar Belkhiri andTahooraSheikhyNarany, Using Multivariate Statistical Analysis, Geostatistical Techniques and Structural Equation Modeling to Identify Spatial Variability of Groundwater Quality, Water Resources Management April 2015, Volume 29, Issue 6, pp 2073–2089.
23. Ayotte JD, Gronberg JM, Apodaca LE (2011) trace elements and radon in groundwater across the United States: us geological survey scientific investigations report 5059, p 115
24. BIS (2012) Indian standard specifications for drinking water. IS:10500, Bureau of Indian Standards, New Delhi.
25. WHO (World Health Organization) (2012) Guidelines for drinking water quality; I recommendation. World Health Organization, Geneva.

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