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Assessment of Water Quality Indices of Heavy Metal Pollution in Jojari River (Jodhpur) using Multivariate Statistics

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ABSTRACT

The paper mainly aims at critically assessing the quality of different industrial effluents and also the Jojari river water using "water quality index - (WQI) and heavy metal pollution index (HPI)- "statistical analysis. Samples were collected from different locations of the polluted industries of the Jodhpur City and the Jojari river area in the summer of 2019-21. Their WQI ranged between 62.638634 to 164.28797, a very high value for irrigation. And the range of HPI of different sites ranged from 26074.41 to 84547.49. These values of HPI are also very high than the normal standard limits prescribed by WHO and BIS. Further, high concentrations of Cd, Pb and Cr along with Ni, Zn and Cu were also detected. Since this water is openly used by the farmers for irrigation of vegetables, pulses grains, spices, the heavy metal toxicity might be affecting the health of larger population of the Jodhpur city and its surrounding areas. Increasing cases of cancer and neurological disorders could be related to this toxicity.

Key words : *Waste water effluents, Jojari River, Physico-chemical parameters, WQI, HPI*

Introduction

Increased industrial activities have resulted inthe pollution due to heavy metals extensively around the world (Zaidi *et al.*, 2012). Environmental pollution with poisonous metals present in (Zaidi *et al.*, 2012) waste water of industries, is a significant issue of most of the industrial cities of Rajasthan, especiallyJodhpur. Heavy metals found in the wastewater of different industries incorporate lead, chromium, nickel, uranium, zinc, cadmium, arsenic and mercury (Ahalya *et al.*, 2003; Kacholi and Sahu, 2018). Tainting of the climate with harmful heavy metals of industrial effluents is a significant issue. Many fabric and handicraft industries in Jodhpur district release the untreated effluents in the nallah, which finally meet in the Jojari river. A large number of cloths are widely dyed and colored with the help of harmful chemicals daily, which not only pollute the environment, but is also hazardous for the people living in these localities (Himani, 2012). Dyes intensely color wool, nylon, silk and mainly cotton fabrics. A colossal volume of untreated coloured water is released into the Jojari stream. According to the CPCB, one of the most polluted industries is the textile printing and dyeing industry (CPCB, 1990).

During colouring and completing cycles a lot of gushing is created, which is poisonous and contains solid tone, a lot of suspended solids, a profoundly fluctuating pH, high temperature, COD, BOD (Al-Kdasi *et al.*, 2004). It was observed that different industries of the Jodhpur region, release waste water effluents containing very high concentrations of toxic metals like cadmium, chromium, zinc, copper, lead, nickel etc (Zaidi *et al.*, 2012). Most of the industries do not treat water before discharging. The water is collected in the Jojari river and from here, with the help of underground pipes and pumps it is used for irrigation. Due to scarcity of water farmers in the area are using this polluted water for irrigation. This is causing harmful effects to humans, plants and animals. Plants can amass these metals in their tissues as well as in cells, in concentration over the standard levels, which might be a danger to life in a total cycle (CPCB, 1990 and Himani, 2012).

Heavy metals are generally utilized in paints, photographic papers, household appliances, photo chemicals and so forth. Ground water pollution due to the human activities is the main reason for all the ecological problems arising throughout the world (Al-Kdasi *et al.*, 2004). Consumption of heavy metals contaminated food can lessen fundamental supplements in the body, can cause kidney problems, bone diseases, neurology and reproductive system defects and sometimes cancer (Minaxi *et al.*, 2008). Consumption of polluted water by mothers, show critical impacts on the growth of babies and birth weight of a new born child.

In our study we have analyzed the effluent water of the industries as well as Jojari river for physico-chemical analysis and have also determined concentrations of toxic heavy metals in different effluent samples (Agrawal *et al.*, 2011 and Currie *et al.*, 2013). We calculated "water quality index -(WQI) and Heavy metal pollution index- (HPI)" for all the sites. The results would help us in evaluating the state of water pollution today. This water is not only used for irrigation but is also making soil infertile (Mishra, 2012; Mishra and Soni, 2016; Mishra *et al.*, 2020). Thus, future action for its prevention can be planned to protect people of the Jodhpur city from heavy metal toxicity.

Materials and Methods of Analysis

Details of research locations

Jodhpur is important industrial city of Rajasthan where many big and small-scale industries are situated. The textile, tie and dye, printing, gwargum, steel, handicrafts polishing and painting industries release used water and chemicals directly in the naalas.

There are 5 major naalas in Jodhpur which finally meets with the Jojari River.

1. Merti Gate – Paota – Kalyan Singh pyau – Army Area – Digadi to Jojari River
2. Nehru Park – Bhagat ki kothi – Jai Narayan University Jhalamand to Jojari River
3. BhairavBhakher – Khame ka Kooa –

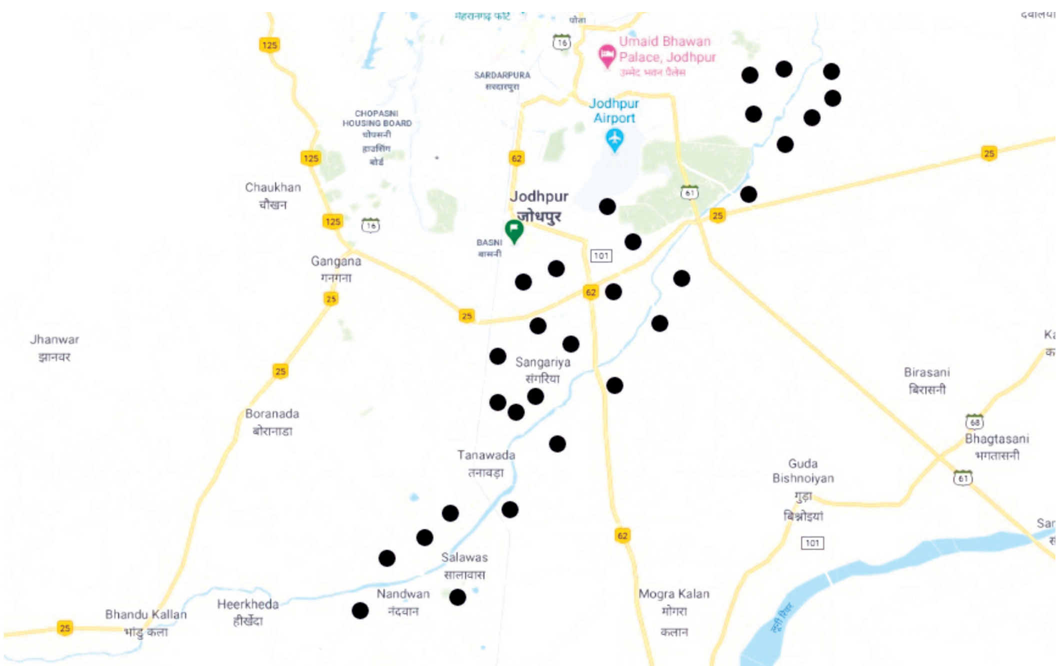

Fig. 1. A Map of Major Industries of Jodhpur (google maps)

Shobhavato Ki Dhani –Derby worker colony – from Bypass RIICO meet to RIICO nallah then to Jojari River

4. Bhadwasia – RTO – Basani bridge – Mata ka than – Central academy school– Khokhariya to Jojari River

Collection of samples

This investigation was done in the long stretch of 2020-2021. Effluent samples were collected from Vinayakiya, Uchiyarda, Kudi, Resham textiles, Basni llphase, Sangariya, Salawas and Shanti textiles. These areas are situatedin the Jodhpur City. Industrial drainage sites, nallah and the Jojari river area were also covered. We have collected four samples from each site and have used mean values for each parameter. These water samples were gatheredin plastic bottles. 10% HCl was used for rinsing all the sample collecting bottles followed by washing with distilled water. After this process, the effluent water samples were finally taken in the plastic bottles (Mishra and Soni, 2016).

All the samples were assessed for the pH, color, alkalinity, chloride, calcium and magnesium hardness, total hardness and TDS . Standard strategies were utilized for the analysis. The metallic elements like Zn, Cr, Cd, Pb, Cu, Ni were determined with the help of AAS. WQI and HPI were also calculated.

Results and Discussion

The various sorts of water impurities can be named as organic, inorganic and biological. Most normal inorganic water contaminants are toxic heavy metals, which are very poisonous and Cancer causing innature (Achmad *et al.,* 2017), besides some of the anions such as nitrates, sulphates, phosphates, fluoride, chloride etc., which can cause serious health hazards. We examined the samples for Physico-chemical parameters like pH, Colour, Total alkalinity- (TA), Chloride, Total hardness- (TH), Calcium hardness- (CaH) and TDS. Standard strategies were utilized for the analysis.

Physico-chemical analysis of effluent water -samples

pH: According to the observation presented in the Table 2, All the effluent water samples pH was observed between 6.2 to 10.3, indicating that most samples are alkaline in nature (Agrawal *et al.,* 2011).

Chloride: Amount of chloride were obtained between 290 to 855, in all the 12 samples. The values were according to the WHO standard limits of effluent water.

Table 2. Permissible limits for effluent water

S. Number	Parameters	Conc. in mg/l
1	pH	8.5
2	TDS	500
3	TA	200
4	TH	300
5	Nitrate	45
6	Sulphate	200
7	Chloride	250
8	Fluoride	1
9	Cadmium	0.003
10	Chromium	0.05
11	Zinc	3.00
12	Lead	0.01
13	Nickel	0.02
14	Copper	1

Table 1. Physico-chemical analysis of industrial effluent water- samples

Parameter	V*1	V*2	V*3	V*4	V*5	V*6	V*7	V*8	V*9	V*10	V*11	V*12
Colour	Pale yellow	Coffee brown	Chocolate brown	Light Yellow	Chocolate brown	Lemon yellow	Green	pink	Indigo	Mustard yellow	Mustard yellow	Orange
pH	7.8	7.9	6.7	6.8	6.5	10.3	6.2	6.8	7.5	6.3	7.5	7.9
TDS	3200	1600	1467	1600	1190	5180	2100	4210	1700	3200	1800	2500
TA	600	300	200	400	530	490	630	555	275	485	325	450
TH	310	396	440	900	350	695	380	370	890	440	490	370
Nitrate	50	47	61	77	60	85	79	58	65	72	49	67
Sulphate	350	310	250	280	322	276	310	300	289	208	320	350
Chloride	290	305	357	459	600	620	855	478	560	620	790	500
Fluoride	1	1.2	0.9	0.8	1.6	1.4	0.7	1.8	1.4	1.5	1.8	1

*All the readings are in mg/l.

* Samples are named as V1 to V12

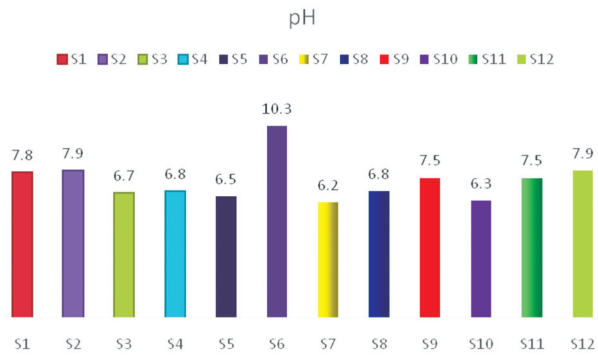

Fig. 2. pH variations in effluent water samples

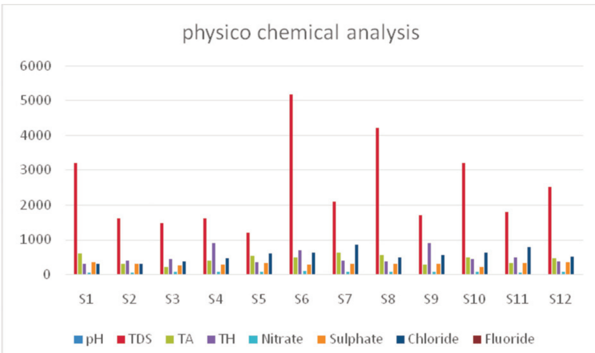

Fig. 3. Analysis of physico-chemical parameters for effluent water samples

Total Alkalinity (TA): The values of TA were between 200 to 630, which was higher than the permissible limits.

Total Hardness (TH): The values of TH were between 310 to 900, which were very high.

Fluoride: The values of fluoride content were between 0.7 to 1.8, which was within limits.

Nitrate: As shown in the Table 2, the values of nitrate content were between 47 to 85. Nitrate was found in higher concentration in all the samples.

Sulphate: Sulphate content in all the 12 samples were between 208 to 350 .

TDS: All the 12 samples showed their TDS values greater than normal standard limits. TDS values were obtained between 1190 to 5180.

Assessment of "Water Quality Index (WQI)" for industrial wastewater and water of Jojari river

We can determine quality of water by calculating its water quality index (WQI) (Karim and Panda, 2014). This WQI is a number which shows overall quality of water (Karim and Panda, 2014) at a particular location. It is based on some physico-chemical parameters. With the help of WQI, we can compare water quality of different sampling sites.

We used weighted arithmetic index method for calculation of (Zakhem and Hafez, 2014) WQI. The WQI was computed by following three steps -

(i) Calculation of unit weight factors (Wn), for every parameter, by applying the formula (Jain *et al.*, 2021)

Wn = K/ Sn (Kumar and Singh, 2021)

Where value of K is, K= 1/ 1/S1+ 1/S2+1/ S3+.........1/Sn =1/Σ1/Sn (Kumar and Singh, 2021)

Sn= Standard permissible limit of the nth parameter (Kumar and Singh, 2021)

Summation of unit weight factors is equal to unity (Jain *et al.*, 2021)

$$\Sigma Wn=1$$

(ii) Calculation of sub index (Qn) by utilizing the formula (Jain *et al.*, 2021)

Qn= Vn-Vo/ Sn-Vo × 100 (Jain *et al.*, 2021)

Where value of V_n is, V_n = Mean concentration (Observed readings) of the nth parameter (Jain *et al.*, 2021)

Vo= Actual concentration (ideal readings) of the parameters in pure water (Usually Vo= 0 for maximum parameters except the value for pH) (Kumar and Singh, 2021)

So QpH = VpH - 7/ 8.5- 7 × 100 (Jain *et al.*, 2021)

(iii) After merging step-(i) and step-(ii), WQI is determined (Jain *et al.*, 2021)

Overall WQI = ΣWnQn/ ÓWn

WQI Calculations

We have calculated values of unit weight factors (Wn) for each physico-chemical parameter. Values of standard (Sn) and unit weight factor (Wn) are same for each site , which are given in Table 3. Then on the basis of readings(Vn) given in Table 1, we calculated values of sub-index (Qn)(Singh and Hussain, 2016) by using formula Qn=Vn/Sn× 100 and then WnQn for each parameter. After using formula of overall WQI, we got values of WQI for each site, which are given in Table 4. If we compare our results with the WQI standards as given by (Brown *et al.*, 1972), samples from all the 12 sites fell in the very poor category. Samples from site 1,3,4,7 and 12 were in very poor category and samples from site no 2,5,6,8,9,10,11 were in very very poor category. Meaning that this water is unfit for consumption

Table 3. Values of Sn and Wn for each parameter

Parameters	BIS Standards (Sn)	1/Sn	Σ1/Sn	K	Wn
pH	8.5	0.117647059	1.159202614	0.862661961	0.101489642
TDS	500	0.002	1.159202614	0.862661961	0.001725324
TA	200	0.005	1.159202614	0.862661961	0.00431331
TH	300	0.003333333	1.159202614	0.862661961	0.00287554
Nitrate	45	0.022222222	1.159202614	0.862661961	0.019170266
Sulphate	200	0.005	1.159202614	0.862661961	0.00431331
Chloride	250	0.004	1.159202614	0.862661961	0.003450648
Fluoride	1	1	1.159202614	0.862661961	0.862661961
Σ					1

Table 4. WQI for all sites

Sites	WQI	Water Quality Status
1	97.65945025	Very Poor
2	114.279255	Unfit for consumption
3	80.599622	Very Poor
4	74.458219	Poor
5	140.64452	Unfit for consumption
6	151.68280	Unfit for consumption
7	62.638634	Poor
8	160.711251	Unfit for consumption
9	130.31985	Unfit for consumption
10	131.67428	Unfit for consumption
11	164.28797	Unfit for consumption
12	98.84257	Very Poor

Table 5. Standards of WQI given by (Brown *et al.*, 1972)

WQI	Water Quality Status
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unfit for consumption

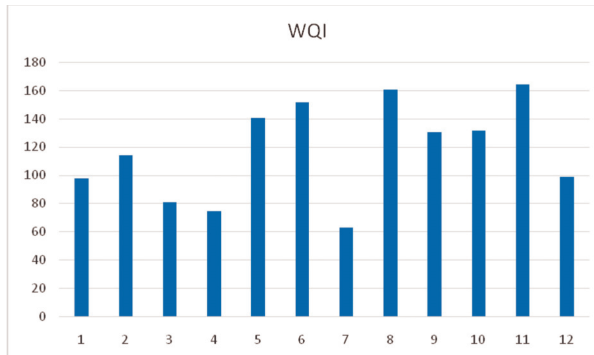

Fig. 4. WQI for 12 different sampling sites

and also not fit for the irrigation. It will also affect the soil fertility and cause health hazards.

Heavy toxic metal analysis of effluent water -samples

All 12 samples were evaluated for toxic heavy metals with the help of atomic absorption spectrophotometer. According to our results, six heavy harmful metals namely Pb,Cu, Ni, Cd, Cr, Zn were detected in all the effluent water samples, with the help of atomic absorption spectrophotometer (AAS).

Cadmium

It is one of the most harmful heavy metals after lead. It can enterin humans through the food chain. High Cd concentrations if found in plants can result in theirreduced growth, some changes may take place in the chloroplast ultra-structure. Cadmium causes queasiness, diarrhoea, muscle cramps, sensory disturbance, liver damage and renal failure. It was found between 0.89 to 3.54 ppm. The values are very high for the effluent water as given by the WHO and BIS (Agrawal *et al.*, 2011). When values compared with the earlier study (Mishra and Soni, 2016) cadmium concentration has increased in the last four years.

Chromium

Cr is mainly used in the steel processing plants (Minaxi *et al.*, 2008) as component ofalloys which are mainly iron based. Chromium is also used in the implants for dental and other medical implants (Minaxi *et al.*, 2008). Chromium causes respiratory diseases in humans. It blocks respiratory organs. Due to its oxidation property, it causes kidney damage, liver failure, blood anaemia and sperm damage. In our samples, the values of Cr were between 1.574 to 3.742 mg/l. Seven samples showed higher concentration of chromium than standard limits. Even chromium concentration has increased since 2016 study (Mishra and Soni, 2016).

Nickel

Nickel can cause severe bronchitis, reduction in lung function and sometimes it can cause cancer of the lungs. High intake of nickel can also cause stomach diseases, blood and kidney disorders. Ni concentration was obtained between 0. 274 to 0. 97 mg/l. The values were within permissible limits.

Lead

Lead is a veryharmful heavy metal for the living beings. Lead ingestion can cause very serious health issues. Some persistent impacts of lead harming are alimentary stoppage, colic and anaemia (Chambial *et al.,* 2015 and Mark Manuel *et al.,* 2018) Pb toxicity causes a decrease in the hemoglobin synthesis (Chambial *et al.,* 2015), kidney disorders, joint pain, conceptive and cardiovascular disorders and persistentharm to the CNS (Mark Manuel *et al.,* 2018). All the samples showed a very high concentration of lead than the permissible limits (Ravikumar *et al.,* 2011). The values of Pb were between 2.431 to 4.081 mg/l. This is very dangerous as in earlier study (Mishra and Soni, 2016) only two samples were found with higher concentration of lead.

Zinc-

Zinc is one of the essential element for human health. They also increase our immunity and because of that one is running for the zinc supplements. Excess amount of zinc can cause stomach cramps, skin irritation, anaemia, pancreas damage, arteriosclerosis and respiratory disorders. Higher amount of Zn can cause hindrance to reproduction and development. It was found between 0. 273 to 3.791 mg/l, which was within permissible limits.

Copper

Copper is also an essential element but its higher concentration can cause headaches, stomach-pains, nausea, diarrhoea and vomiting. High consumption of copper is harmful for kidney, liver and brain.In our study copper was found within permissible limits. It was found between 0.768 to 3.9 mg/l. Only two samples showed higher concentration than 3 ppm.

Evaluation of "Heavy Metal Pollution Index" (HPI) for industrial wastewater and water of Jojari river

"Heavy metal pollution index (HPI)"(Gad and El-Hattab, 2019) shows the water quality with regard to heavy metals (Gad and El-Hattab, 2019). We calcu-

Table 6. Heavy metal ions in effluent water samples

Metal ions	V*1	V*2	V*3	V*4	V*5	V*6	V*7	V*8	V*9	V*10	V*11	V*12
Zn	0.44	_	_	2.11	3.79	0.41	0.40	0.52	0.31	_	0. 27	_
Cd	2.73	2.47	3.35	2.26	2.39	2.56	1.23	1.44	0. 89	3.28	2.98	3.54
Cr	2.45	2.03	1.97	1.88	2.17	2.24	2.97	2.13	3.74	2.06	1.57	1.87
Ni	_	0.30	0.52	_	_	0.97	0. 43	0. 27	0. 96	_	0. 32	_
Pb	2.77	3.28	4.08	2.96	3.93	2.87	2.56	2.43	2.88	3.10	2.98	3.26
Cu	0.83	0.97	1.72	1.53	2.13	1.67	4.79	2.01	3.96	0. 76	1.49	1.68

*All the readings are in mg/l.

Table 7. Values of Sn and Wn for each metal

Metals	Max. Allowed Conc. (Sn) (Kurakalva *et al.*, 2021)	1/Sn (Kurakalva *et al.*, 2021)	Σ1/Sn	K(Kurakalva *et al.*, 2021)	Wn=K/Sn (Kurakalva *et al.*, 2021	Ideal value (Vo) (Kurakalva *et al.*, 2021)
Zn	3	0.333333333	504.6666667	1	0.333333333	0
Ni	0.02	50	504.6666667	1	50	0
Cd	0.003	333.3333333	504.6666667	1	333.3333333	0
Cu	1	1	504.6666667	1	1	0
Pb	0.01	100	504.6666667	1	100	0
Cr	0.05	20	504.6666667	1	20	0
Σ		504.6666667			504.6666667	

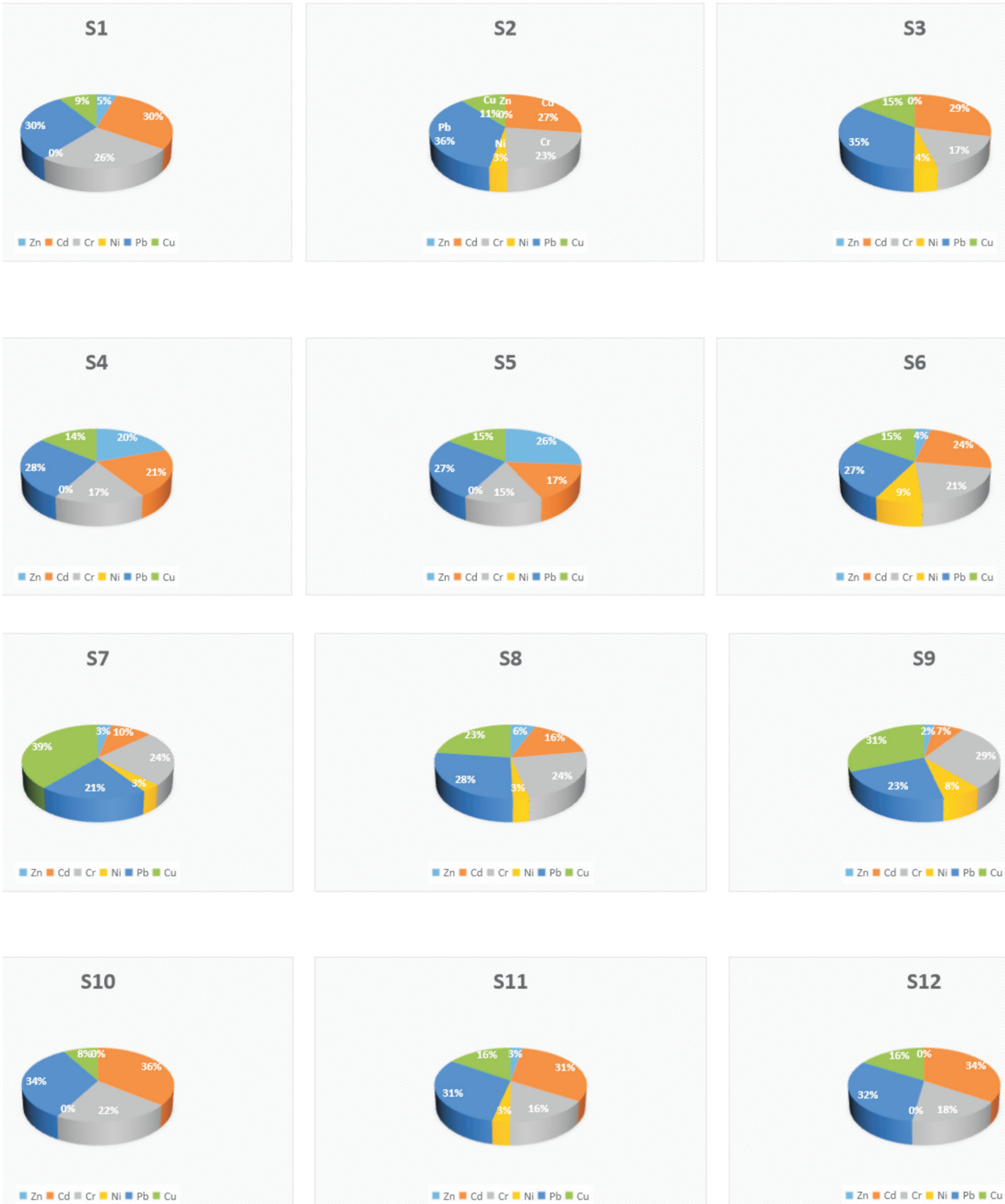

Fig. 5. Analysis of heavy metals according to samples

lated HPI for different sampling sites and after comparison of these values, we can determine water quality and pollution load at different sites.

HPI was calculated by following three steps -

(i) Calculation of unit weight factors -(Wn), for every metal by applying the formula (Jain *et al.*, 2021)

$$Wn = K / Sn$$ (Kumar and Singh, 2021)

Where value of K is, K= 1/ 1/S1+1/S2+1/ S3+........1/Sn= 1/Σ1/Sn (Kumar and Singh, 2021)

Sn= Standard permissible limit for the metal (Kumar and Singh, 2021)

(ii) Calculation of sub index (Qn) by utilizing the formula (Jain *et al.*, 2021)

$$Qn = Vn - Vo / Sn - Vo \times 100$$ (Jain *et al.*, 2021)

Where value of Vn is, Vn= Mean concentration (Observed readings) of the metal (Jain *et al.*, 2021)

Vo= Real concentration (ideal readings) of metals in pure water (Usually Vo= 0 for pure water) (Jain *et al.*, 2021)

(iii) After merging step(i) and step(ii), HPI is determined (Jain *et al.*, 2021).

$$\text{Overall HPI} = \Sigma WnQn / \Sigma Wn$$

HPI Calculations

We have calculated values of unit weight factors (Wn) for each metal. Values of Sn and Wn are same for each site, which are given in Table 7. Then on the basis of readings given in Table 6, we calculated values of Qn and WnQn for each metal. After using formula of overall HPI, we got values of HPI for each site, which are given in Table 8.

HPI is also important tool for determination of overall pollution of different sampling sites with regard to heavy toxic metals (Krampah *et al.*, 2019). We have calculated HPI for 12 sites. The range of HPI was 26074.41 to 84547.49. All the twelve sites have shown very high HPI, far above than normal standard limits. This clearly indicates that industries are discharging their effluents directly without primary and secondary treatment, which is collected in to the Jojari river, making it highly polluted with heavy metals and poisonous. This water is totally unfitted for irrigation but still farmers are freely using this water for irrigation.

Table 8. HPI for all sites

Sites	HPI	Degree of pollution
1	65788.81352	High
2	61190.37274	High
3	82254.67812	High
4	55772.43241	High
5	60579.80978	High
6	62708.15588	High
7	32602.6092	High
8	36822.14025	High
9	26074.41546	High
10	78520.97842	High
11	71798.01145	High
12	84547.49273	High

Table 9. Standards of HPI given by (Bhuiyan *et al.*, 2010)

International Standards	HPI Values	Degree of pollution
HPI	<300	Low
HPI	300-600	Medium
HPI	>600	High
Indian Standards		
HPI	<200	Low
HPI	200-400	Medium
HPI	>400	High

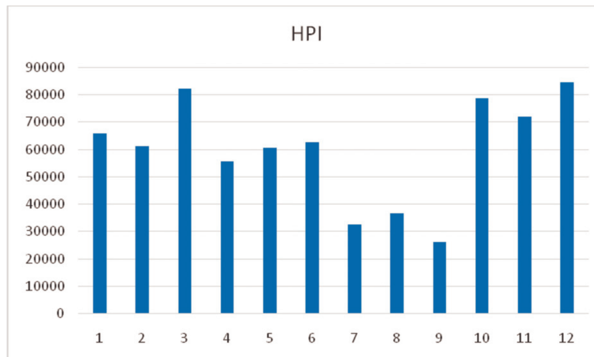

Fig. 6. HPI for 12 different sampling sites

Conclusion

The studies were carried out in 2019-2021. At that time even NGT had already imposed ban and closed few industries and asked them to set up CETP. In our studies, most of the samples were found to be heavily contaminated with toxic heavy metals. We compared the concentrations with the WHO and BIS standards. All our samples contained a very high concentration of lead and cadmium. Chromium was found in excess in seven samples, but it was moderately high. Nickel, zinc and copper were within limits. The order was Pb>Cd> Cr>Cu> Zn>Ni. We have also calculated HPI ("Heavy metal pollution index"). We calculated HPI on the basis of metal ion concentrations. The values of HPI were far above than standard limits for all the 12 sites. The values of HPI were between 26074.41 to 84547.49 which are represented in the Table 8.

Physico-chemical parameters like TDS, TH, TA, nitrate, pH, Sulphate, chloride and fluoride were assessed and water was found alkaline at six sites and at five sites it was slightly acidic in nature. TH, Total Dissolved Solids and nitrate concentrations were found very high at most of the sites. TDS was towards higher range with highest 4210 at site 8. TH, alkalinity and nitrate was found in higher concentration at all the 12 sites. WQI values were also very high as compared to the standard limits for all the 12 sites. WQI was calculated on the basis of physico-chemical parameters TDS, TH, TA, nitrate, Sulphate, chloride and fluoride. According to table number'4', the "water quality index" (WQI) of our sample collecting areas ranged between 62.638634 to 164.28797. Water quality of site 1,3,4,7 was very poor and for site 2, 5, 6, 8.9, 10, 11 was even worst.

On the basis of all our results, we can conclude that high concentrations of lead, chromium and cadmium in the industrial effluent water, which is used for the irrigation may cause breathing disorders, sensory disturbance, liver injury and renal failure, neuropsychological problems, gastrointestinal problems and cancer in the people of Jodhpur city who are eating vegetables, grains and pulses grown with this water. It is very obvious that these heavy metals which are harmful in nature, can enter the food chain. They can easily get accumulated in the different plant parts like leaves, fruits, roots and seeds. When such edibles are consumed by us, they will result in dangerous health issues. Very high WQI and HPI vales are also suggestive that most of the industries in the Jodhpur city are discharging their effluent water directly without any treatment, into the Jojari river through drains.

We strongly recommend immediate stoppage of use of this polluted effluent water for the irrigation. We also suggest regular monitoring of the water quality, compulsory setting up of CETP and imposition of heavy penalties to safeguard people of Jodhpur city from heavy metal toxicity.

Acknowledgement

We are thankful to the Pollution Control Board, Jodhpur and Defense Laboratory,Jodhpur. The samples were analyzed in their lab. We would also like to thank Department of Chemistry, JNVU, Jodhpur for facilitation.

Conflict of Interest

There is no conflict of interest and the main purpose of our research is to bring public awareness.

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