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Original Article

Support Vector Regression (SVR) to Investigate Diurnal Fluctuation in Chromium Concentration in River Amba

Shreeyans Dhamane

Mathematics-Computer Science, University of California San Diego, California, USA

Corresponding Author : sdhamane@ucsd.edu

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Abstract *- In Pali, Maharashtra, petrochemical factories have caused chromium contamination in River Amba, which can cause ulcers, liver damage, and cancer to locals. This study uses Support Vector Regression (SVR) to investigate the non-linear diurnal variation in chromium concentration in River Amba in a 24-hour cycle and its relation to river temperature and river speed. The chromium contamination in River Amba was below the maximum limit of 50µg/L only from 9 p.m. to 6 a.m. Higher chromium concentrations occurred at daylight hours, peaking at 59.5µg/L at 10 a.m., and lower chromium concentrations at night, the minimum being 45.8µg/L at 5 a.m. Similarly, the river temperature was highest (27.6°C) at 10 a.m. and the lowest (20.6°C) at 4 a.m. The diurnal fluctuation in chromium concentration was correlated to the diurnal fluctuation in the river speed, as a positive moderate linear relationship between chromium concentration and river speed with an r2 value of 0.522 emerged. The diurnal variation in river speed, in turn, is likely caused by the fluctuations in the viscosity of heavy oil in River Amba with river temperature, which is influenced diurnally by the River's and the Sun's thermal dynamics.*

Keywords *- Diurnal, River pollution, Regression, River temperature, River speed.*

1. Introduction

Industrialization has increased the number of petrochemical factories near the banks of River Amba [1]. The petrochemical factories dispose of petrochemical waste into River Amba, which includes several heavy metals (hexavalent chromium, lead, and cadmium), hydrocarbons, and heavy oil [2]. It is essential to discover and evaluate the pattern of diurnal fluctuation of heavy metals, such as chromium, in rivers because state and regional governments can use patterns to set up varying minimum chromium concentration levels, design methods to clean chromium-polluted sections of River Amba, and gauge threats to organisms in the river. Pali, located in the Raigad district of Maharashtra, is one of the villages closest to River Amba. It has an estimated population of approximately 12,800 in 2024 [3]. Pali locals use River Amba's water for drinking, cooking, cleaning, and bathing. Since Pali is centred on agriculture, farmers use the River Amba water to irrigate paddy fields. Previous research from industrial regions in India has shown that exposure to water contaminated with hexavalent chromium leads to vomiting, diarrhoea, and liver damage [4]. Hexavalent chromium is also associated with higher risks of cancer [5]. Therefore, the locals of Pali are susceptible to such ailments. Hexavalent chromium may also harm plants and organisms dwelling in rivers. It can rupture the cell membranes of plants, and it can cause hyperglycemia and hyperlactamia in freshwater fish [6, 7]. While many studies had been done on the aforementioned negative effects of chromium pollution on humans, plants, and fishes, there was a lack of investigations exploring how chromium concentration diurnally fluctuates in rivers. Therefore, this study examines how river speed and temperature influence the diurnal fluctuation in chromium concentrations in River Amba. The results of this study can help in planning environmental management strategies for Pali. The petrochemical factories employ locals in Pali and increase their incomes. However, it is essential to find solutions that minimize the impact of chromium pollution in River Amba while concurrently allowing the petrochemical factories to operate. The study provides a solution to the petrochemical factories by analyzing the pattern of diurnal fluctuations of highly toxic chemicals like chromium so the factories can select appropriate waste disposal timings to reduce the impact of chromium pollution on locals and the ecosystem in Pali. This study also aims to determine the time intervals in which the chromium concentrations in River Amba remained within healthy water consumption limits.

2. Literature Review

Previous research has shown that heavy metal concentrations in rivers fluctuate diurnally. Research in 2001 by the USGS in South Fork Coeur d'Alene River shows that the concentration levels of heavy metals showed maximum values at 9 a.m. and minimum values at 7 p.m. diurnally [8]. However, similar research by the USGS conducted at Pricky

Pear Peak in Montana demonstrated opposite results: minimum values at 6 a.m. and maximum values at 9 p.m. diurnally [8]. However, this research did not elaborate on the causes of the diurnal fluctuation of heavy metal concentration in rivers. The discrepancy in the results between the South Fork Coeur d'Alene River and the river at Pricky Pear Peak implies that the diurnal fluctuation pattern of each river differs starkly, and the factors influencing this pattern must be studied. Research in 2012 by S. Rudall et al. links two factors, temperature and pH levels, to diurnally fluctuating heavy metal concentrations in the South Tyne River [9]. The results reported extreme concentrations at 5 a.m. Inductively coupled plasma mass spectrometry was used to measure a 109% difference between the maximum and the minimum concentrations of heavy metals during the day [9].

However, the study notes that these results do not capture routine river diurnal fluctuations, as the study was conducted over a small duration of 48 hours. Therefore, a research gap exists, and diurnal fluctuations of heavy metals in rivers need to be observed over a more extended period to receive more accurate results. A report by the USGS on heavy metal concentration in the Klamath River Basin shows that the concentration levels of heavy metals in the exact location differ by 20-40% according to waterbody type [10].

Faster-moving waterbodies like rivers have larger heavy metal concentrations than Artesian wells [10]. These results may indicate a relationship between water speed and heavy metal concentration level, which this report has not explored. This relationship may be a factor that influences the diurnal fluctuation of heavy metals like chromium in water. Hence, further research must be conducted to verify this relationship's existence.

3. Materials and Methods

3.1. Study Location

This study was conducted on the Amba River in the city of Pali. This section of the river was selected as petrochemical factories that release chemical waste are present nearby. Therefore, this location will provide a sound understanding of diurnal fluctuations of chromium concentration. No prior study on chromium pollution has been performed in this area, so that this study will provide new insight. Three locations, separated by 10 meters, on the river, were selected. The locations were kept consistent using GPS markers. Moreover, all measurements were taken from the surface of the river.

3.2. Method Overview

The river speed, river temperature, and chromium concentration were measured hourly for a 24-hour cycle at the three locations. This process was repeated for a week (20 May 2024 - 26 May 2024) to reduce random error. The data for each factor was averaged to create a table (Table 1) of diurnal fluctuations of river speed, river temperature, and chromium concentration.

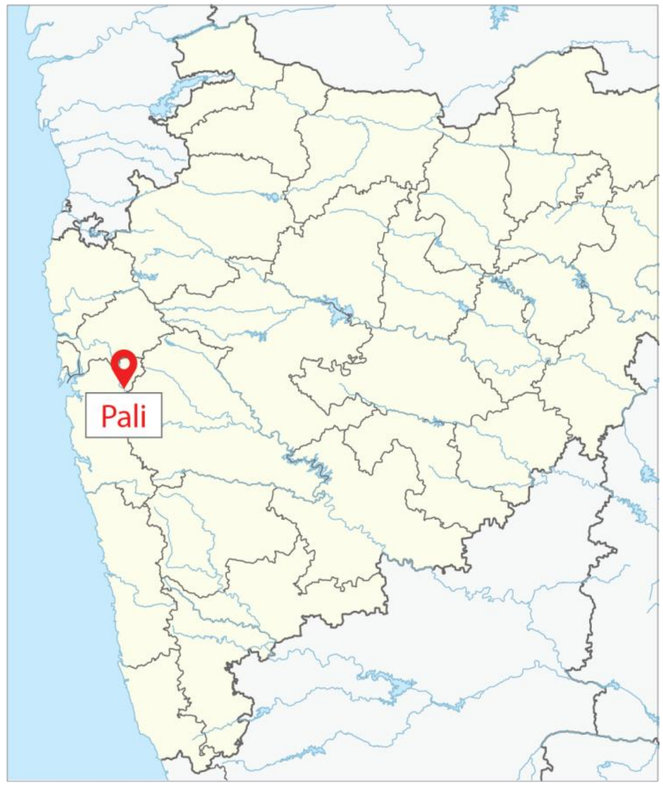

Fig. 1 Location of Pali in Maharashtra, India

3.3. Measurement of Chromium Concentration

The following process was conducted every hour. 3 samples of 50 ml river water were collected in clean, sterilized glass containers. The samples were mixed with 10 ml nitric acid to preserve the chromium. The samples were strained through a fine mesh to remove particles. After the sample was prepared, inductively coupled plasma mass spectrometry (ICP-MS) was used to measure chromium concentration.

The ICP-MS method was chosen because it gives precise outputs, which is essential when plotting minute differences in diurnal fluctuations [11]. The ICP-MS instrument was calibrated with standard chromium concentrations. The ICP-MS instrument outputted the chromium concentration in micrograms per liter for each sample. The results of the three samples for each hour were averaged, and the average value was recorded.

3.4. Method Overview

The river speed and temperature readings were taken immediately before the water samples were drawn out. 3 readings of the river speed and river temperature were taken each hour and later averaged to reduce random error. A current meter measured the river speed in meters per second. The river speed readings were taken after very short intervals of 15 seconds to ensure similar conditions were present during each reading. A digital thermometer was used to measure the temperature of the surface of the river. The thermometer stabilised for 30 seconds for every river temperature reading.

4. Data Analysis

4.1. Support Vector Regression

Support Vector Regression (SVR) was used to generalize the diurnal variation in all three variables: river speed, river temperature, and chromium concentration. The non-linear nature of the diurnal fluctuations was the primary reason SVR was used, as the radial basis function kernel of the SVR algorithm helps transform the data into a space of higher dimension [12]. Moreover, the raw data was noisy and likely influenced by other factors, such as the fish movements within the river and sudden wind gusts.

SVR ensures that only the significant deviations are considered, making SVR a suitable technique for ignoring outliers and providing a smooth general trend for diurnal fluctuations. The data was first normalized by using the StandardScalar function. The epsilon value of the SVR was set to 0.3 to reduce the tolerance for error due to random environmental fluctuations, and the gamma value was set to 0.5 to ensure a balance between capturing the trend without overfitting the data points. Three separate SVR models were used for river temperature, river speed, and chromium concentration, respectively. The r2 score checked each model's validity.

4.2. Linear Regression

The relationships between river temperature, river speed, and chromium concentration were relatively linear. Hence, linear regression was used for these two graphs.

5. Results and Discussion

The subsections analyze how the river temperature affects river speed, which changes the chromium concentration in the river.

5.1. Diurnal Fluctuation in River Temperature

The diurnal fluctuation in the river temperature shown by the SVR model (Figure 2) roughly resembles a sinusoidal graph. The river temperature is the highest (27.6°C) at 10 a.m. and the lowest (20.6°C) at 4 a.m. The peak value is 17.1% above the mean temperature value of 23.6°C, and the minimum value is 12.6% below the mean temperature value. The graph's peak occurs during the daylight hours, and the lower temperatures occur at night without sunlight.

Therefore, the shape of the SVR model adheres to the natural heating and cooling cycle. The radiation from the Sun during daylight hours increases the water molecules' thermal energy at the river's surface. This heating process increases the temperature of water [13]. As radiation intensity from the Sun decreases, the water molecules lose energy to the air, cooling the water molecules down and reducing the river temperature. The SVR model provides a relatively high r^2 value of 0.785, providing adequate evidence of a diurnal variation in river temperature. Moreover, the SVR model's longer right tail suggests that the river stays heated for approximately 3 hours even after the Sun sets. Sunset happens typically at 7 p.m. in India during summer [14]. However, the river reaches its coldest point at 4 a.m.

This delay is because the Amba River is quite deep, with an average depth of 6.7 meters [15]. The depth, coupled with the water's abnormally high specific heat capacity of 4184J/kgK [16], allows the river to retain significant heat energy, which takes 3 hours to dissipate and drop its temperature to substantially below its mean of 23.6°C.

5.2. Diurnal Fluctuation in River Speed

The shape of the SVR model of the diurnal fluctuation in river speed (Figure 3) and that of the diurnal fluctuation in river temperature (Figure 2) is similar. The SVR model of river speed has a reasonable r^2 value of 0.704.

The river speed is the highest (1.13m/s) at 10 a.m. and the lowest (0.81m/s) at 5 a.m. The peak speed value is 19.6% above the mean speed value of 0.94m/s, and the minimum speed value is 14.2% below the mean. This similarity in the shapes of the SVR models for river temperature and river speed can be attributed to the fact that the river temperature might influence river speed. This relationship is further strengthened in the next section.

Table 1. Diurnal fluctuations of river temperature, river speed, and chromium concentration of river amba

Time (Hours)	River Temperature (°C)	River Speed (m/s)	Chromium Concentration (μg/L)
0	22.5	0.84	49.2
1	21.5	0.84	48.8
2	21.3	0.87	47.5
3	22.4	0.93	48.1
4	20.6	0.89	49.2
5	22.9	0.81	45.8
6	21.3	0.86	47.1
7	24.3	0.87	53.7
8	25.5	1.03	53.3
9	24.3	0.94	58.1
10	27.6	1.13	59.5
11	26.5	1.05	53.3
12	25.2	1.06	57.1
13	26.2	1.02	56.3
14	24.7	1.01	56.8
15	23.8	0.98	50.4
16	24.1	0.97	52.2
17	23.8	1.03	50.7
18	24.7	0.91	53.5
19	22.7	0.96	53.6
20	23.4	0.92	52.7
21	22.9	0.95	48.4
22	21.2	0.91	47.2
23	22.5	0.89	47.5

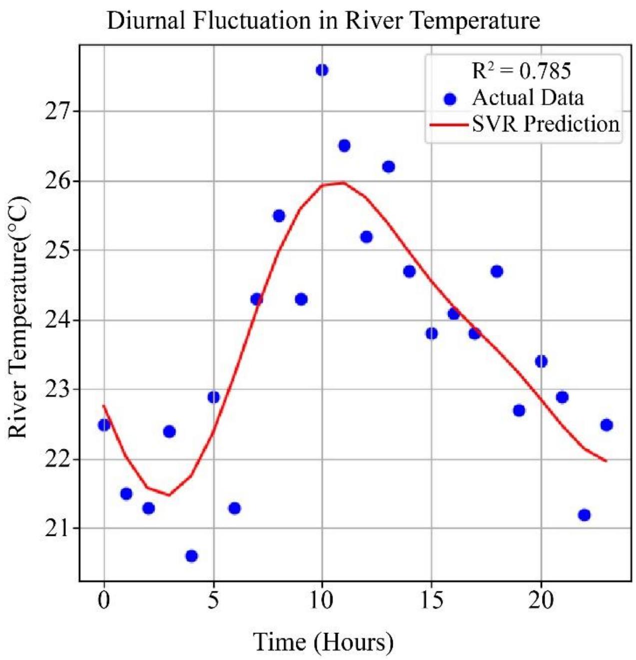

Fig. 2 Diurnal Fluctuation in River Temperature

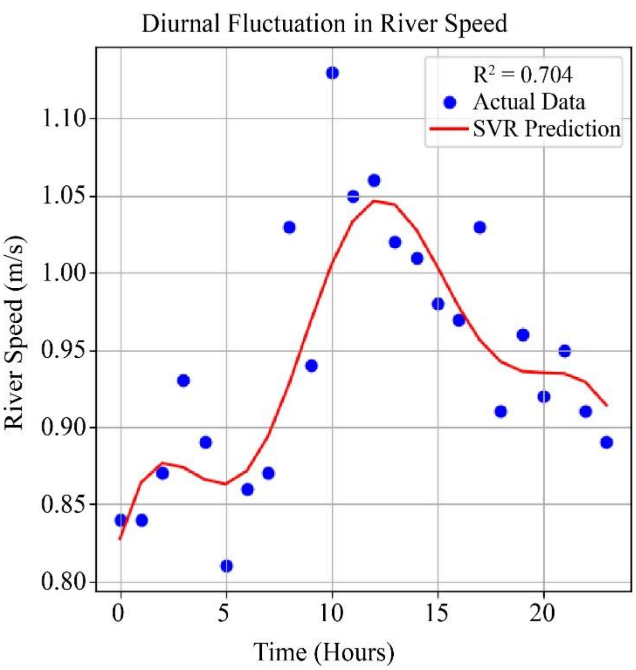

Fig. 3 Diurnal Fluctuation in River Speed

5.3. River Speed vs River Temperature

A positive linear relationship between the river speed and river temperature arises (Figure 4). The r^2 value of 0.629 suggests a moderate positive linear relationship between river temperature and river speed despite other unpredictable variables affecting the data. A plausible explanation for this moderate positive linear relationship is the significant presence of heavy oil due to chemical pollution by petrochemical factories in the Amba River [17].

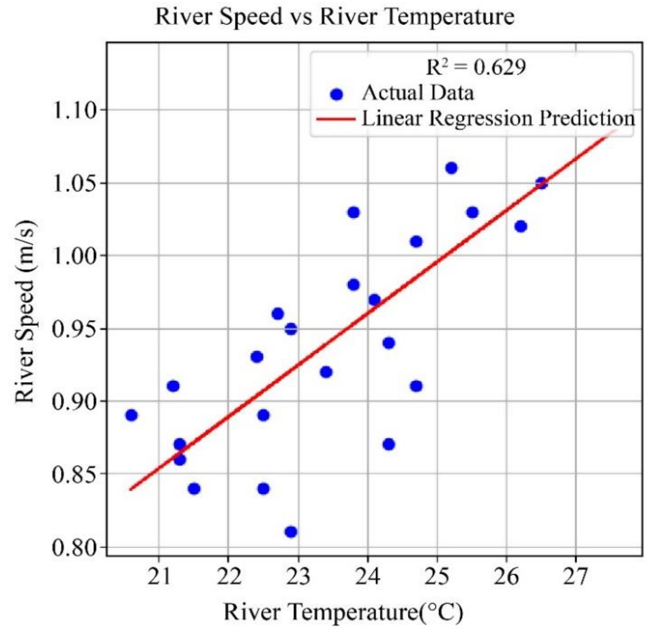

Fig. 4 Graph of River Speed vs River Temperature

The viscosity of heavy oil and medium temperature have a steep inverse relationship. This relationship is especially steeper in the Amba River's temperature interval. At 20°C, the oil viscosity is about 600000mPa·s, and at 30 degrees, it is significantly lesser at about 400000mPa·s [18]. The drastic change in oil viscosity occurs because higher medium temperatures increase the mobility ratio of heavy oil to water [18]. Therefore, higher river temperature during daylight hours may reduce heavy oil viscosity, making it easier for the river currents to flow, resulting in river speeds from 8 a.m. to 6 p.m. greater than the mean river speed of 0.94m/s.

5.4. Chromium Concentration vs River Speed

A moderate positive linear relationship exists between chromium concentration and river speed (Figure 5), with an r^2 value of 0.522, which is statistically sufficient for modelling an ecological relationship. This linear relationship may be explained as follows.

During higher river speeds, the water molecules have higher momentum. With higher momentum, the water molecules exert a greater force on chromium pollutants than usual. This phenomenon causes water molecules to drag greater-than-usual amounts of chromium from the source of chemical waste disposal into the river, increasing chromium concentration in the Amba River compared to slower river speeds.

5.5. Diurnal Fluctuation in Chromium Concentration

The trend of the SVR modelling the diurnal fluctuation in chromium concentration (Figure 6) adheres to the results discussed in the previous sections. The chromium concentration is the highest (59.5µg/L) at 10 a.m. and the lowest (45.8µg/L) at 5 a.m.

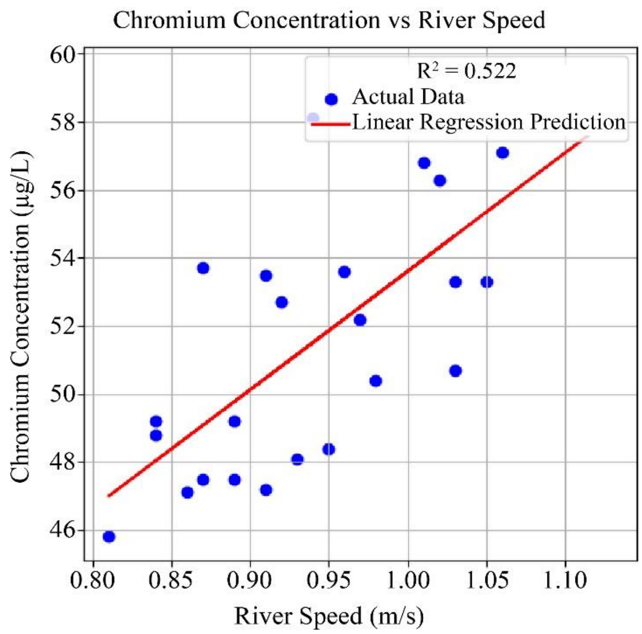

Fig. 5 Graph of chromium concentration vs River speed

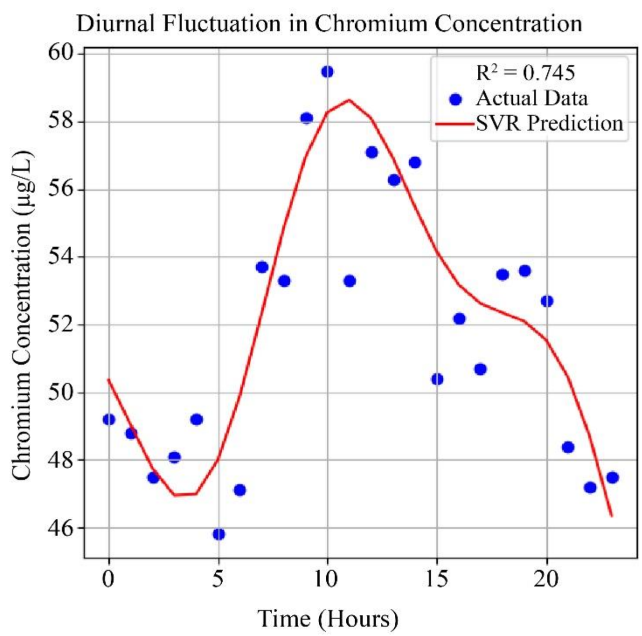

Fig. 6 Diurnal fluctuation in chromium concentration

The peak chromium concentration is 15.2% above the mean chromium concentration of 51.7µg/L, and the minimum chromium concentration is 11.4% below the mean. The SVR model of chromium concentration has a reasonable r^2 value of 0.745. The Government of India states that the maximum permissible healthy range of chromium concentration in drinkable water should be 50µg/L [19]. However, from 7 a.m. to 9 p.m., the chromium concentration is above this limit. This discovery poses severe short-term and long-term threats to the health of locals who consume this water. In the short run, ingesting water from the Amba River from 7 a.m. to 9 p.m. can lead to temporary ulcers and holes in the nasal septum [20]. Repeated consumption of water from the Amba River can cause liver and kidney damage and infections in the gastrointestinal tract [21]. Despite only hexavalent chromium present in the Amba River, it can transform into trivalent chromium as it enters cells, and trivalent chromium can cause DNA alternation [20]. The similarity between the shapes of the three SVR models (Figures 2, 3, and 6) suggests that the diurnal fluctuation of chromium concentrations occurred due to the changes in river speed, which, in turn, was caused by the varying river temperature due to the thermal cycle between the Sun and the river.

5.6. Comparing with Existing Literature

This research shows a difference of 29.9% between the maximum value of chromium concentration at 10 a.m. and the lowest value at 5 a.m. Compared to the difference of 109% in the previous research by S. Rudall et al. in the South Tyne River, the value of 29.9% offers a more generalized view as this research has been conducted over 192 hours (one week) rather than 48 hours. The sporadic, higher fluctuations are evened out due to the longer time frame in this research. The difference value of 29.9% is significantly lower than 109% because the diurnal temperature difference range is 7°C in River Amba compared to the 14°C in the South Tyne River. Also, this research confirms a reasonable relationship between river speed and the heavy metal concentration result implied by the study by USGS. This research even adds further to the relationship by strongly suggesting the role of the viscosity of heavy oil in it. Moreover, the unique support vector regression technique used in this study provides a smoothed-out view of the diurnal fluctuations of chromium concentrations, providing firms and governments with a consistent trend to make environmental decisions.

5.7. Implication of the Results on the Farmers of Pali

The river speed is the lowest at 5 a.m. (Figure 3), and the chromium concentration is also at the minimum at 5 a.m. Therefore, if the chemical waste, which contains chromium, by the petrochemical factories is disposed of only during the timeframe of 5 a.m. to 6 a.m., it will have minimal impact on the environment. The slower river speed at 5 a.m. would mean that water molecules with lower momentum exert a lesser-than-usual force on chromium pollutants, so the rate at which chromium pollutants are dragged into the river will decrease. Petrochemical factories releasing chemical waste during slower river speeds at 5 a.m. would also reduce the spread of chromium pollutants into the nearby paddy fields of local farmers. The lower kinetic energy of the river currents would reduce the ability of the chromium-contaminated river water to penetrate the soil and groundwater ways that lead into the paddy fields. Suppose the spread of chromium pollutants into farms is not managed well. In that case, it can have consequences not only for the health of the crops but it would also carry the toxic hexavalent chromium into the bodies of the people all over India who consume the distributed crops.

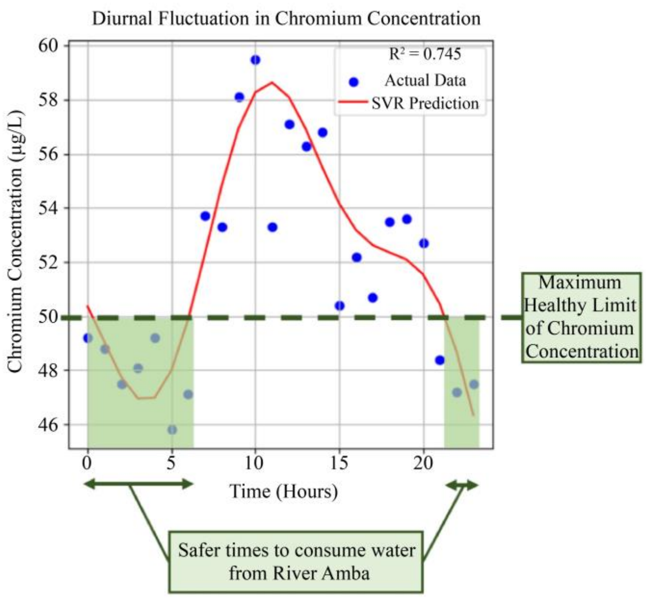

Fig. 7 Safer times for locals to consume water from River Amba

Excess amounts of chromium decrease the germination percentage of paddy crops, which would have future consequences of lower yield [22]. Hexavalent chromium weakens paddy crops by reducing shoot length by as large percentages as 30% [22].

Lower-quality crops may reduce the revenue for local farmers in Pali, affecting their incomes negatively. Since Pali is an agrarian village, protecting the local farmers from excess chromium concentrations is of utmost importance.

6. Conclusion

6.1. Conclusion

The study concludes that there exists diurnal fluctuation in the chromium concentration in the Amba River, consisting of a narrow peak and a long trough, modeled by Support Vector Regression. Higher chromium concentrations occur at daylight hours, peaking at 59.5µg/L at 10 a.m., and lower chromium concentrations occur at night time, the minimum being 45.8µg/L at 5 a.m.

The diurnal fluctuation in chromium concentration draws from the diurnal variation in the river speed. A probable cause of the diurnal variation in river speed is the varying viscosity of heavy oil in the Amba River, which is influenced by the thermal dynamics of the river and the Sun.

6.2. Policy Recommendations

To reduce the severity of chromium contamination to farmers' paddy crops in Pali, the study recommends that petrochemical factories dispose of the waste from 5 a.m. to 6 a.m. when the speed of River Amba is minimal. Till the time that the petrochemical factories fail to regulate their pollution, the study also recommends that the locals of Pali consume the water of the river only between the time interval between 9 p.m. to 6 a.m., as this is the only period in which the chromium concentration in the river is below the healthy maximum limit of 50µg/L.

6.3. Limitations

The mean r^2 value score of the three SVR models was 0.744. This suggests a reasonable 25.6% error in modelling the diurnal variations in river speed, river temperature, and chromium concentration. Moreover, the linear relationships between river temperature and river speed, and the river speed and chromium concentration were not perfectly linear. This suggests that other factors, such as wind speed and groundwater flow rate, may have influenced the results. Correlation does not necessarily imply causation; however, the well-proven inverse relationship between oil viscosity and medium temperature provides a suitable explanation for the varying river speeds that caused the diurnal fluctuation in chromium concentration in the Amba River.

6.4. Future Research

The results of this study may also vary on a seasonal basis. Monthly samples can be collected in future research, and those readings are averaged throughout the year. This would give a broader understanding of how the chromium concentration diurnally fluctuates in River Amba across a year. Future studies can also examine how the diurnal fluctuation in chromium concentrations specifically affects quantifiable features of the paddy crops of farmers near River Amba. This would help measure the loss in revenue to farmers in Pali due to chromium damage to the ecosystem.

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