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Effect on Humans due to Deposition of Heavy Metals in Weras River and Remediation Techniques

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Abstract**—*This study was carried out to determine the deposition of heavy metals in Weras River and how in turn these metals would affect the lives of people. Heavy metals enter Weras River by natural and anthropogenic activities. Excess accumulation of heavy metals such as Pb, Hg, Cd, Cr, Zn and Cu can cause severe problems in living organisms. To ascertain the harmful effects on humans due to heavy metals deposited in Weras River, water samples were collected from the river, tested, and analysed. Lead concentration exceeded the safety standard specified for aquatic life and, zinc concentration increased over the past years. Through this study the level of contamination of water in Weras River was determined intending to emphasize the harmful effects of heavy metals on humans and to minimize diseases and complications caused by it as there is a serious effect on the long run if heavy metal contamination of water in Weras River is not remediated. Due to the severity of heavy metal contamination in Weras River treatment methods were suggested and a mathematical model to predict heavy metal concentrations in Weras River was developed.*

Keywords**—Heavy metals, Contamination, Bioaccumulation, Treatment, Weras River**

I. INTRODUCTION

With the growing urbanization and industrialization in the past several decades, the environment has been greatly polluted by the excess deposition of heavy metals. Increasing population in Sri Lanka has led to the pollution of waterbodies and these waterbodies undergo heavy metal contamination due to heavy metals released from industrial waste, automobiles, garbage dump sites and human waste. Heavy metals such as Pb, Hg, Cd, Cr, Cu and Zn are extremely toxic and consuming even very low levels of these metals can be harmful to humans.(Pandey & Madhuri, 2014)

Considering human health there are some metals deemed necessary, yet these metals react to cause harmful effects if the safety limits exceed. Heavy metals can enter a human body through ingestion, respiration, and skin. These metals mainly become toxic as they form toxic soluble compounds due to the presence of many minerals and chemicals in the human body. Some heavy metals such as iron and copper are naturally included in the human body and are needed for metabolism. However, soft tissues in the human body easily accumulate heavy metals and cause toxicity hindering the regular functioning of the body.(Jaishankar et al., 2014)

Considering heavy metal contamination, it can be detected by measuring the metal level in water, soil, and biota. Out of all the heavy metals Pb and Hg have a significant effect on humans as they are directly toxic, and the threshold level is low in humans. World Health Organization has studied about the effect of heavy metals to humans and they possess a rather serious threat causing reduction in foetal growth, chronic diseases and even cause cancer.(WHO, n.d.)

Heavy metals mainly enter the human body due to consumption of food fish and by drinking contaminated water. Heavy metals can easily accumulate in fish gills and cause the fish to be poisonous. Some heavy metals can be essential nutrients in the human body. Yet heavy metals like lead, mercury and cadmium have no importance in the role of a living organism and only cause serious health risks. Overall heavy metals are considered to be nonessential elements for humans as most heavy metals are not necessary for the functioning of the human body.(Masindi & Muedi, 2018)

Due to the toxicity of heavy metals treatment methods are used to reduce the metal concentration in water. However, most of these remediation techniques are applied for drinking water and not specifically to surface water. With the development in technology and due to rapid urbanization proper prevention measures should be imposed for natural water bodies and models to predict contamination levels can be designed to obtain the level of contamination in aquatic systems.

II. MATERIALS AND METHOD

2.1 Weras Riverof Sri Lanka

Sri Lanka known as the Pearl of the Indian Ocean lies in the bay of Bengal between 5º55" and 9º51" latitudes north and between 79º41" and 81º53" south east longitude near the equator with an extent of the land area of 65610 km2. Out of many waterbodies that flow in the country, Bolgoda lake located in the Western Province of Sri Lanka is the largest natural freshwater body with a total basin area of 394 square kilometers. The lake is divided into the North Lake and South Lake connected by the BolgodaRiver. The northern end of the Bolgoda Lake is WerasRiver with a total drainage area of 55.5 square kilometers and is divided into seven subbasins.

Two subbasins namely, Thumbowila and Ratmalana-Moratuwa were chosen for the site of the research study. Considering these two subbasins WerasRiver flows passing the Karadiyana dump site and a part of it divides into a sub lake called MedhaLake and flows adjacent to the dumpsite towards Bokundara. This area has been exposed to higher sources of contamination, considering not only the dump site but hospitals, factories and industries and the cluster of houses built along the WerasRiver and therefore can be regarded as a crucial site for the testing of heavy metal contamination of WerasRiver.

2.2 Data Collection

Preliminary actions were taken by studying previously collected data, to obtain the best sample locations in order to collect data. The number of heavy metals to be tested and selected was decided upon learning the most toxic and abundantly available heavy metals in Sri Lanka. Thereby, six heavy metals such as Pb, Hg, Zn, Cu, Cd and Cr were selected as the heavy metals to be tested.The site was analyzed regularly to detect the areas where people were gathered frequently and where sources of contamination were located.

Fig.1- Contaminated Water in Medha Lake

Table 1- Sample Locations

Location	Co-ordinates (Northing, Easting)	Description
1	6.8170612, 79.8994751	Location selected from the small lake created by water flowing from Weras River and MedhaLake
2	6.818050, 79.898571	Point selected towards the North of WerasRiver close to the Borupana bridge
3	6.8102016, 79.9030317	Point towards the South of WerasRiver
4	6.8146683, 79.9006791	Towards the middle of WerasRiver in front of the Karadiyana dumpsite
5	6.8141183, 79.9026264	Point selected from the MedhaLake

After selecting the sample locations, five water samples of 300ml were collected to polyethylene (PE) bottles from the selected five locations each. Sample collection process was carried out from 7.30 a.m. to 9.00 a.m. and the locations selected were accessed by a boat and the water was collected from the bow of the boat. Prior to collecting, the water was muddled to obtain a maximum concentration considering the whole water column. The muddled water was collected at a depth of about 1m. As soon as the water was collected to the PE bottles it was then transferred to an ice box to avoid any changes to the original composition of the samples. Thereafter, the collected samples were immediately transferred to the National Water Supply and Drainage Board in Thelawala. The transferred samples were stored in a refrigerator at 4℃ in the chemical laboratory of the Water Supply and Drainage Board until the samples were tested. Then the samples transferred were tested using the icap 7400 Inductively Coupled Plasma Optical- Emission Spectrometer (ICP- OES).

Then, the results obtained from testing were analysed with safety standards specified by the Central Environmental Authority and Sri Lanka Standards Institution. After analysing the results, treatment methods were suggested for Weras River, and a mathematical model was built to predict the heavy metal concentration in water in Weras River using MATLAB Software.

2.3 Treatment and Prediction of Heavy Metals

Due to the increase in contamination many methods have been implemented to remediate heavy metal pollution. However, some of these approaches cause the pollutant to be destroyed rather than averting the heavy metals entering the food chain. There are methods adopted to minimize the toxic substances entering the food chain. Phytoremediation, microbial culture, rhizofilteration and other remedial methods can be used without causing disturbances to the environment.(Mishra et al., 2019)

With the development in technology, empirical formulas can be used to predict the concentration of pollutants in a system. This can be applied to heavy metal contamination in water bodies. Data needs to be measured initially that can be used as variables in a predictive model that can relate to the concentration of a metal present in water. When a mathematical model is developed it should be developed such that it will have a minimum error maximizing the predictive variables accuracy.(Lindstrom, 2000)

III. RESULTS AND DISCUSSION

3.1 Heavy Metal Concentration in Weras River

Results of concentrations of Pb, Hg, Cd, Cr, Cu and Zn were obtained and graphically analysed to determine the heavy metals with the higher risk.

Table 2- Heavy Metal Concentration in Weras River- 2020

Heavy Metal	Concentrations of Sample Locations (µg/l)				
	1	2	3	4	5
Lead	17.00	6.00	11.00	8.00	7.00
Cadmium	-	0	2.00	0	0
Chromium	4.00	-	1.00	1.00	-
Copper	5.00	0	4.00	1.00	-
Zinc	48.00	17.00	39.00	28.00	29.00
Mercury	0.155	0.017	0.063	0.030	-

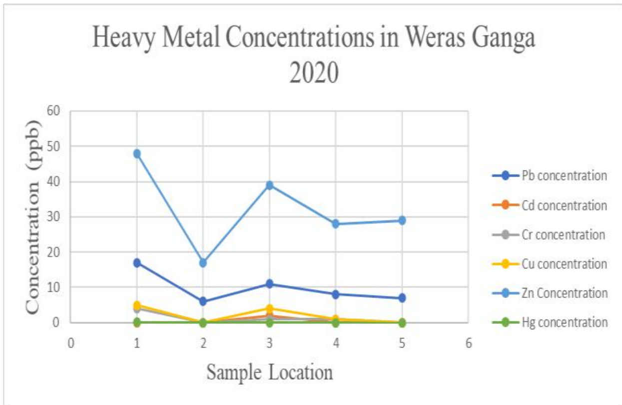

Fig.2- Analysis of Heavy Metals in Weras River

The above graph depicts the concentration of metals varying with the location tested. By analysing, it is evident that zinc has a higher concentration deposited in water of Weras River compared to the other metal levels. The metal levels in water deposited follow the order Zn> Pb> Cu> Cr> Cd> Hg.

The highest concentrations of metals were detected in sample location 1, where a small lake was formed by water flowing from Weras River and Medha Lake. Location 2 has relatively the lowest concentrations of metals deposited compared to all other locations. It is important to notify that the concentration at location 1 is high because this location was selected due to the fact that locals engage in fishing activities on a regular basis. Overall analysis showed that zinc and lead were detected from all five locations while chromium was detected in three locations, and cadmium has been detected from only one location but in low concentrations. However, mercury which is the most toxic metal considered in the study was detected from four locations in minute concentrations.

3.2 Analysis of Past Data and Safety Standards

Metal levels of lead, chromium, cadmium, zinc, and copper present in water in the year 2007 were tabulated and analysed with results obtained by testing water samples in the year 2020.

Table 3- Results of Heavy Metal Concentrations- 2007 vs 2020

Metal	Average Heavy Metal Concentrations in Weras River- 2020 (ppb)	Highest Heavy Metal Concentration detected in Weras River- 2020 (ppb)	Heavy Metal Concentrations in Weras River- 2007 (ppb)
Pb	10.0	17.00	29.5
Cd	2.0	2.00	8.3
Cr	2.0	4.00	6.3
Cu	3.0	5.00	21.9
Zn	32.0	48.00	29.3

The data obtained in the year 2007 was obtained during the dry season while the metal levels of the year 2020 was obtained during the rainy season. When the analysis was carried out by considering the average concentration obtained in Weras River in 2020, it was identified that zinc level has increased over the years. However, lead, cadmium, chromium, and copper has decreased in the deposited amounts. Yet copper is the element that has a significant reduction in its metal concentration.In contrast to the analysis of the average metal concentrations, it was identified that the highest concentrations obtained in 2020 does not have a significant or even noteworthy reduction in heavy metal concentrations over the 13 years that have passed by. In this case the zinc level has increased by a large concentration and the lead and chromium concentrations have no striking reductions in concentrations.

As there is a 13-year long gap between the two years of the comparative study it would have been expected that the reduction in metal concentrations were a remarkable reduction rather than only a notable difference due to the samples being collected during the rainy season and due to the reduction in contamination levels due to the COVID-19 pandemic in 2020.

Table 4- Safety Standards of Heavy Metals in Water

Heavy Metal	Highest Heavy Metal Concentrations in Weras River -2020 (µg/l)	Water Acceptable for Aquatic Life (µg/l)
Pb	17.0	2
Cd	2.0	5
Cr	4.0	20
Cu	5.0	100
Zn	48.0	1000
Hg	0.155	1

By obtaining the safety standards specified in Sri Lanka it was learned that there are no particular safety limits specified for bathing and contact recreational water except for mercury. Likewise, agriculture and irrigation has been specified standards for zinc and mercury, however standards have been specified for all metals when considering water suitability for aquatic life.

When considering standards specified for aquatic life, lead has exceeded the safety limit specified. With a notable difference of 15µg/l lead contamination has taken place in Wears River to a great extent. Cadmium concentration levels detected during the rainy season are comparatively high with only a 3µg/l difference in concentration specified for the safety of aquatic animals. This depicts probability for hazardous situations concerning health of aquatic species and humans during the dry season or when contamination rates increase. Also, analysis of these metals as bathing or recreational water signifies that the water is contaminated and is not suitable for the use of people as the WHO signifies that heavy metals can easily enter a human body and that the presence of heavy metals itself is toxic to a human.

3.3 Analysis of Effect on Humans

Heavy metal contamination is a known problem in the world due to the health risks heavy metal poisoning causes. Therefore, countries have taken measures by relative organizations to specify threshold levels for humans in order to prevent various diseases. However, as discussed in the review the World Health Organization emphasizes on the importance of preventing heavy metals entering a human body as these metals are toxic to the body in minute concentrations.(Rajeshkumar & Li, 2018)

When the present data was analyzed it was determined that lead was present in water exceeding the safety limit specified for aquatic life. Bioaccumulation of heavy metals take place in fish and since fish is a source of food for humans, lead contamination has been convinced to be a problem for human health. Starting from one producer, elements start accumulating in the food chain succeeding up to predators. Therefore, with the accumulation and the chemical decomposition that takes place in consecutive links of the chain, when a food source reaches a human it contains extremely high concentrations of elements and this phenomena will apply to humans in undergoing heavy metal poisoning.(Toxicity et al., n.d.)

As heavy metals enter the human body in various ways, such as through food, water, inhalation and by pores of skin, presence of heavy metals itself has been considered a threat to human health. It was established that although the heavy metals Hg, Cd, Cu, Cr, and Zn did not exceed the safety standards, some of their concentrations were marginal to the safety limits and zinc has increased in concentration over the past years while lead concentration has passed the specified safety standard.(Masindi & Muedi, 2018)

However, these metal concentrations are marginal to the safety standards and due to having high accumulation rates they cannot be adjudged to not cause harm to humans.

To emphasize on the wide ranging difference in concentrations obtained from the test results and the SLS standards specified for potable water it is evident that water in Weras River is extremely contaminated. Therefore, since the degree of contamination is high in relation to water that can be used by humans, heavy metal contamination level of Weras River is undeniably harmful to humans.

Moreover, Weras River flows from the south of Bolgoda Lake up to the North Lake thereby discharging into the Indian Ocean. The lake branches out and flows to other water bodies in the area including Kalu River. Ground water intrusion can take place polluting well water used by residents around the Weras River basin. With a total estimated number of households of 22,3000 in the Bolgoda Basin there is a high level of risk in heavy metal poisoning due to the contamination of water

3.4 Methods of Treatment

When considering Weras River, water flows over a large area and this water is not used as drinking water. Therefore, it is rather difficult to provide a treatment method for the water contamination due to heavy metals in Weras River. However, the contamination rate of water can be reduced by method of aeration. For this purpose, eutrophication of the lake needs to be prevented to maintain a maximum oxygen content in the water. Even though, the water body as a whole cannot be treated what can be done is to prevent heavy metals entering the water body from the sources of contamination. Soil contamination by heavy metal play a key role in water contamination. Therefore, soil can be treated to prevent the entry of heavy metals into the water body. Remediation method depends on the characteristics and level of contamination of pollutants of the site considered. (Lindstrom, 2000)

Generally, an aquatic system needs to be cleaned and the surrounding needs to be kept in an unpolluted state as water bodies are habitats for many living things. A long-term solution can be proposed for this problem either by moving the dumpsite to a more isolated area or constructing a method of proper disposal by transporting solid waste collected to a landfill with proper treatment. Also, as sediments are a main source of contamination in an aquatic system, dredging can help reduce the rate of contamination as it reduces the sediment content deposited in the river.

Generally, membrane filtration has been adopted as an effective method of treatment of heavy metals. In this technique, heavy metals get filtered through a membrane which can either undergo microfiltration, ultrafiltration or nanofiltration depending on the membrane that has been used. Most membranes used for this method are made of synthetic polymers. These membranes can be permeable, semi-permeable and impermeable depending on its polymer structure. Apart from these, geo textile membranes can be used to prevent the entry of suspended solids into a water body. Out of the filtration techniques ultrafiltration is the most effective due to the less usage of space, accelerated removal of toxic matter and ease of operation. (Mulligan et al., 2009)

Therefore, method of filtration can be used in treating water of Weras River by using these techniques. Membrane filtration method can be used in effluent discharge pipes so as to prevent the entry of suspended solids to the water body. Conventional method of sand filtration can be used by applying a technique of shoring using sandbags along the banks of the Weras River near the sources of contamination to maximize the filtration method by preventing any contaminant entering the water through ground water and even surface runoff. On the side of the Medha Ela, gabion walls have been constructed on either end. The water tested from this part of the River depicted lower concentrations. Prior to construction of gabion walls geotextile membranes can be laid in the area surrounding the Karadiyana dumpsite to prevent heavy metals getting added to the water body through ground water penetration.

Another method of treatment that can be used is by adsorption. Weras River which is located adjacent to the karadiyana dumpsite has gabion walls built along the riverbanks. These walls are cages filled with rocks, and rocks are a type of minerals that have adsorption properties to a certain extent. These walls help adsorb heavy metals but is not as effective. Therefore, buffer zones can be constructed by refilling the soil using clay minerals such as kaolinite, vermiculite, halloysite and, etc. with high adsorption properties. More rock minerals can be used such as slate or gneiss, but this technique will be expensive to be adopted for a large area. Therefore, most efficient method of using adsorption material is by creating buffer zones filled with clay minerals and biomass depending on the depth of groundwater intrusion.

Another treatment technique can be treatment using plants and is generally termed as phytoremediation. This technology can be categorized further into phytoextraction, rhizofiltration, phytostabilization, phytodegradation and phytovolatilization depending the mechanism adopted for remediation.(Mishra et al., 2019)

The best option for remediation is by preventing the entry of heavy metals into the river by hindering the flow of contaminants to the river via ground water. Buffer zones with effect of phytoremediation can be used as an effective remediation technique. After these zones are filled with clay minerals that have adsorption properties, plants with phytoremediation abilities can be planted on the topsoil layer of the buffer zone. Out of the plants available for this technique most effective kind to be used in Sri Lanka are the well-known kinds of plants that are naturally grown in mangroves and across the coastal line as a natural remediation technique. Some such plants are phragmites karka, azolla (mosquito ferns), eichchornia, or types of grass such as couch grass and false oat grass, mugwort, ferns, cabbage and many more plants that can even be used as medicinal plants.(Mulligan et al., 2009)

Therefore, as an overall solution of the heavy metal contamination of Weras River techniques such as dredging of sediments, filtration, adsorption, and phytoremediation can be adopted to obtain more purified and unpolluted water that will in turn cause less harmful effects and health risks to humans.

3.5 Prediction of Heavy Metal Concentration

A mathematical model was designed using MATLAB, where an equation was obtained using the concentration of the heavy metal and the rate of flow of water in the sample location. This model was designed for lead, zinc and mercury as results obtained needed a minimum of three decimal places for accurate functioning of the software. These three metals selected were the critical heavy metals as lead exceeded the safety standard specified for aquatic life, zinc concentration had exceeded over the past years and mercury was the selected heavy metal with the highest toxicity as specified by health organizations.

The concentrations of heavy metals tested were used as the response or dependent variable while the flowrate was used as the predictor or independent variable. The flowrate was calculated by measuring the velocity of flow and obtaining other necessary data such as width and depth of the Weras River from past research carried out to determine stormwater drainage plan for the Metro Colombo Region.(Study et al., 2003)

Table 5- Data Required for Mathematical Modelling

Sample Location	Flowrate (m^3/s)	Heavy Metal Concentration		
		Pb (mg/l)	Zn (mg/l)	Hg (µg/l)
1	1.56	0.017	0.048	0.155
5	17.28	0.007	0.029	0.000
4	36.71	0.008	0.028	0.030
2	66.2	0.006	0.017	0.017
3	79.1	0.011	0.039	0.063

Lead

Table 6- Variables for Concentration vs Flowrate Graph for Lead

Flowrate (m3/s)	Independent Variable-x	1.56	17.28	36.71	66.2	79.1
Concentration (mg/l)	Dependent Variable-y	0.017	0.007	0.008	0.006	0.011

Fourth Order Polynomial

- $f(x) = 7.139e\text{-}09 \times x^4 - 1.21e\text{-}06 \times x^3 + 6.985e\text{-}05 \times x^2 - 0.001596 \times x + 0.01932$
- Sum of Squared Errors (SSE): 5.559e-33

Second Order Polynomial

- $f(x) = 5.311374e\text{-}06 \times x^2 - 4.971676e\text{-}04 \times x + 0.01671809$
- SSE: 1.541e-05

Using Matlab, two graphs were plotted, and the best fit was obtained for the fourth order polynomial graph. It also has a lesser sum of squared errors (SSE) compared to the second order polynomial graph obtained. The SSE obtained for the second order fit was 1.541e-05. But the error obtained for the fourth order polynomial fit valued at 5.559e-33 which is extremely low and has a comparatively large gap with the second order polynomial curve error.

Zinc

Table 7- Variables for Concentration vs Flowrate Graph for Zinc

Flowrate (m3/s)	Independent Variable - x	1.56	17.28	36.71	66.2	79.1
Concentration (mg/l)	Dependent Variable - y	0.048	0.029	0.028	0.017	0.039

Fourth Order Polynomial

- $f(x) = 1.948e\text{-}08 \times x^4 - 2.983e\text{-}06 \times x^3 + 0.0001525 \times x^2 - 0.003214 \times x + 0.05265$
- Sum of Squared Errors (SSE): 1.748e-31

Second Order Polynomial

- $f(x) = 1.364623e\text{-}05 \times x^2 - 0.001273914 \times x + 0.04983643$
- SSE: 0.0001409

As in the results obtained for lead, the fourth order polynomial obtained for zinc also has the least error compared to that obtained from the second order polynomial equation (Second order- 0.0001409 > Fourth order- 1.748e-31). Therefore, the most effective equation that can be used to predict the concentration of zinc using the flowrate of Weras River is the polynomial equation obtained from the fourth order fit graph.

Mercury

Table 8- Variables for Concentration vs Flowrate Graph for Mercury

Flowrate (m3/s)	Independent Variable- x	1.56	17.28	36.71	66.2	79.1
Concentration (µg/l)	Dependent Variable- y	0.155	0.000	0.030	0.017	0.063

Fourth Order Polynomial

- $f(x) = 1.01e\text{-}07 \times x^4 - 1.794e\text{-}05 \times x^3 + 0.001082 \times x^2 - 0.02494 \times x + 0.1913$
- Sum of Squared Errors (SSE): 1.998e-30

Second Order Polynomial

- $f(x) = 7.149604e\text{-}05 \times x^2 - 0.006620097 \times x + 0.143222$
- SSE: 0.004135

Like in the previous cases, the equation generated from the second order polynomial fit has a SSE of 0.004135 which is much greater than the error obtained for the fourth order polynomial fir valued at 1.998e-30 which is extremely less compared to that of the second order polynomial. Therefore, the equation obtained for mercury using the fourth order polynomial fit curve will be used to predict mercury metal levels deposited in Weras River Water.

Table 9- Past Data for Validation

Heavy Metal	Year	Flowrate (m^3/s)	Concentration (mg/l)
Zinc	2005	82.4	0.0358
Lead	2007	94.0	0.0293

The model was validated by substituting to the equation obtained for lead, for the above flowrate a concentration of 0.03mg/l was obtained. However, there is a minute error of 0.005mg/l. In considering the equation obtained for zinc, a calculated value of 0.042mg/l was obtained for a flowrate of 82.4m^3/s. However, as in the case of lead there is a small error of 0.006mg/l. The model for mercury was developed using concentration measured in micrograms per litre, the equation holds a high accuracy level with a minimum error of 1.998e-30.

However, the model developed has limitations due to the lack of availability of long-term data, the variation of flow rate due to climatic factors and the rate of contamination of the water in Weras River.

IV. CONCLUSION

Heavy metal concentrations of lead, mercury, cadmium, chromium, copper, and zinc were tested to determine the effect heavy metal contamination has on humans. Results obtained by testing water samples for metal levels were analysed with safety standards specified for bathing and contact recreational water, water suitable for agricultural and irrigational activities, water suitable for prevailing aquatic life and potable water. The tested heavy metal levels in Weras River varied in concentration in the order of Zn> Pb> Cu> Cr> Cd> Hg.

In consideration to the hypothesis and null hypothesis it was proved that heavy metal contamination of Weras River will affect humans in negative way resulting in serious health effects. Remediation methods were suggested to treat the water in Weras River either by using a method of membrane filtration, treatment by adsorption or by adopting a treatment method using plants. The mathematical model developed for lead, zinc and mercury can be used to obtain approximated metal concentration in the Weras River by determining the flowrate of Weras River.

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