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Identification of Water Pollution Sources for Better Langat River Basin Management in Malaysia

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Abstract: The shutdown of drinking water treatment plants (DWTPs) at the Langat River Basin, Malaysia, which provides drinking water to almost one-third population in the basin, is very frequent, especially due to chemical pollution in the river. This study explored the pollution sources in the Langat River based on eight specific water intake points of the respective DWTPs to suggest an integrated river basin management (IRBM). Analysis of Al (250.26 $\pm$ 189.24 µg/L), As (1.65 $\pm$ 0.93 µg/L), Cd (1.22 $\pm$ 0.88 µg/L), Cr (0.47 $\pm$ 0.27 µg/L), and Pb (9.99 $\pm$ 5.38 µg/L) by ICP-MS following the Chelex® 100 column resin ion exchange method found that the mean concentrations except Al were within the water quality standard of the Ministry of Health (MOH) as well as the Dept. of Environment (DOE) Malaysia. However, the determined water quality index based on physicochemical parameters (2005–2015) at the midstream of Langat River was Class III, which needs substantial treatment before drinking. The linear regression model of Al, As, Cd, and Pb suggests that water quality parameters are significantly influencing the increase or decrease in these metal concentrations. Moreover, the principal component analysis (PCA) and the hierarchical cluster analysis (HCA) also support the regression models that the sources of pollution are both natural and man-made activities, and these pollution sources can be clustered into two categories, i.e., upstream (category 1) and mid to downstream (category 2) in the Langat River. The degraded water quality in the midstream compared to up and downstream of the river is mainly due to human activities apart from the natural weathering of minerals. Therefore, the implementation of policies should be effective at the local level for pollution management, especially via the proactive leadership roles of local government for this transboundary Langat River to benefit from IRBM.

Keywords: Malaysia; Langat River Basin; pollution; water quality; multi-stakeholders; integrated water resources management

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1. Introduction

Chemical pollution of the rivers in Malaysia is frequent along with the country's development activities, and the ecological and human health risks are of great concern due to the pollution of these rivers [1–5]. Pollution of the transboundary Langat River in the most populous and fastest developing Selangor state among the states of Malaysia is no different than other polluted rivers in Malaysia [6–10]. The origin of the Langat River is in the hilly area of Hulu Langat, and the Langat River Basin shares the Selangor and Negeri Sembilan states as well as the federal territories of Kuala Lumpur and Putrajaya before falling into the Strait of Malacca. The Langat River is one of the major sources of potable water in the Selangor state and it supplies drinking water to almost one-third of the population in the state [6]. However, the shutdown of drinking water treatment plants (DWTPs) in the Langat River Basin is very frequent due to pollution both from the point and non-point sources of pollution [11,12].

The turbidity in the Langat River changes very frequently, mainly because of the flash floods in the tropical climate, and the pollution from agricultural and industrial zones [6,13,14]. Angelova et al. [15] also reported a significant positive correlation between turbidity and Al concentration in the Iskar Dam of Sofia city, Bulgaria. Therefore, the doses of $Al_2(SO_4)_3$ are very crucial for the treated water disinfection by the drinking water treatment plants (DWTPs) following the conventional flocculation and coagulation methods in the Langat River Basin. For instance, Sungai Semenyih DWTP had to shut down five times in 2016 because of odor pollution from the Nilai and Semenyih industrial areas [16–18]. The Sungai Langat, Cheras mile 11, and Bukit DWTPs experienced several shutdown incidents during the last decade [16,19–21] mainly due to flash floods along with much runoff of mud, industrial effluent, etc., in the Langat River because of huge land clearance activities for palm oil plantation as well as industrialization and urbanization in these areas. Similarly, Sungai Semenyih DWTP halted the operation for some time in December 2021 due to odor pollution [22] as well as in the Hulu Langat area due to severe floods [10]. DWTPs were unable to treat raw water when there was increased mudflow/turbidity in the river during floods because of much runoff resulting from heavy rain [7]. In contrast, the DWTPs were also unable to treat the raw water when there were drought situations because of the higher concentrations of the chemicals in the water [23].

There are several agencies for this transboundary Langat River Basin Management. For instance, the Dept. of Irrigation and Drainage (DID) is in charge of the river basin including pollution sources management, and the Dept. of Environment (DOE), and the Ministry of Health (MOH) are in charge of river and drinking water quality monitoring, respectively. However, the implementation of policies at the local level remains challenging due to the inadequate proactive leadership of multi-stakeholders, especially of the local government. The local authorities are empowered by the Local Government Act 1976 to manage the pollution of the river; however, the coordination among the local authorities in the Langat River Basin remains inadequate due to the absence of an effective multi-stakeholder platform [11,12,24,25]. There is also a state agency, i.e., Selangor Water Management Authority (SWMA) to manage water resources within the Selangor state. However, due to the absence of the same kind of state water agency in Negeri Sembilan state and the Federal Territories of Kuala Lumpur and Putrajaya, SWMA is unable to manage the pollution sources effectively in the transboundary Langat River Basin.

The Institute for Environment and Development (LESTARI), the National University of Malaysia (UKM) as well as other universities and research organizations are conducting research activities, publishing reports and management plans for the UNESCO HELP, (i.e., Hydrology for Environment, Life and Policy) Langat River Basin Management since the 1990s. Similarly, the Academy of Sciences Malaysia (ASM) has also produced reports on integrated river basin management (IRBM) in line with integrated water resources management (IWRM) [26]. There is also the Foresight Institute under the Malaysian Industry-Government Group for High Technology (MIGHT) to facilitate the involvement of the business and industry sector in water resources management along with using the advanced technology [27]. NGOs such as Global Environment Centre [28], the Worldwide Fund for Nature-Malaysia [29], etc., are also active in empowering the community for the IWRM. However, the coordination among the quadruple helix stakeholders, i.e., government, business/industry, academia, and NGOs/ community has been reported inadequate for the Langat River Basin Management, especially the pollution management [11,12,24,25].

Meanwhile, several studies have determined the status of dissolved Al, As, Cd, Cr, and Pb in the Langat River, and in many cases, the parameters exceeded the raw water quality standard proposed by the Ministry of Health Malaysia [8,30–36]. For instance, Al 46.28 $\pm$ 32.71–380 µg/L [33,34,36]; As 4–201.11 µg/L [34–38]; Cd 0.11 $\pm$ 0.12–35.56 µg/L [31,34,37,39]; Cr 0.67 $\pm$ 0.90–70 µg/L [33–36,39], and Pb 0.16 $\pm$ 0.23–57.78 µg/L [34–37,39] concentrations have been reported to be high in the Langat River since 1985. The highest concentration of Al, As, Cd, Cr, and Pb in the Langat River also exceeded the Malaysian standard of drinking water quality—200 µg/L, 10 µg/L, 3 µg/L, 10 µg/L, and 10 μg/L, respectively, by the Ministry of Health, Malaysia [40]. Therefore, this is one of the pioneer studies which aimed to investigate the status of toxic arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and aluminum (Al) in the Langat River. Moreover, the water sampling points were the same points from where the DWTPs in the basin intake raw water for drinking water treatment. Thus, this study aimed to facilitate the decision-making processes of relevant stakeholders, especially the local authorities with the scientific information to manage the pollution sources for the Integrated Langat River Basin Management.

2. Materials and Methods

2.1. Study Area and Water Sample Collection

The Langat River Basin in Malaysia is a flood-prone area because of heavy rainfall. The geographical location of the basin is in the tropical area and the average yearly rainfall in the area varies from 2000 mm to 3500 mm. Langat River Basin is an important river basin among the four main basins within Selangor and this Langat River Basin is shared by the Selangor state (78.14%), Negeri Sembilan state (19.64%), and federal territories of Putrajaya (1.90%) and Kuala Lumpur (0.33%) [6]. The area of this transboundary river basin is about 1815 square kilometers and the main course of the river is about 141 kilometers. According to the latest census, about 1,184,917 million people are dependent on this river, which is located from latitudes 2°40′152′′ N to 3°16′15′′ N and longitudes 101°19′20′′ E to 102°1′10′′ E [39]. Langat River Basin has also been selected as one of the UNESCO HELP, (i.e., Hydrology for Environment, Life and Policy) basins since 2004 because of the scientific research based on the need of the stakeholders. For this study, water samples were collected at eight points of the Langat River. These water sampling points were exactly the raw water intake points of the respective drinking water treatment plant from upstream to downstream in the basin. These water samples were also collected once in three replicates during 6–14 August 2015. Although the water samples were collected once, however, the analysis of water quality can give initial findings of water pollution sources specifically at the eight raw water intake points of the respective drinking water treatment plant (DWTP) in the Langat River Basin. Moreover, the findings can suggest further studies of water samplings at all the point sources of pollution in the entire Langat River Basin as well as the total maximum daily load (TMDL) studies at the specific sites that are important for drinking water supplies. The locations of the water sampling points were recorded by the Global Positioning System (GPS, GARMIN, GPSMAP 76CSx, Kansas, MO, USA) as illustrated in Figure 1. Calibrated Professional Plus Water Quality Multi-Parameter (6050000, YSI Incorporated, Yellow Springs, OH, USA) was also used to document the status of in situ physicochemical parameters such as dissolved oxygen (DO), electrical conductivity (SPC), pH, temperature, and as such in the Langat River specifically at the eight water sampling points of the river. Moreover, this Professional Plus Water Quality Multi-Parameter also calculated total dissolved solids (TDS) and salinity (ppt) from the measured electrical conductivity.

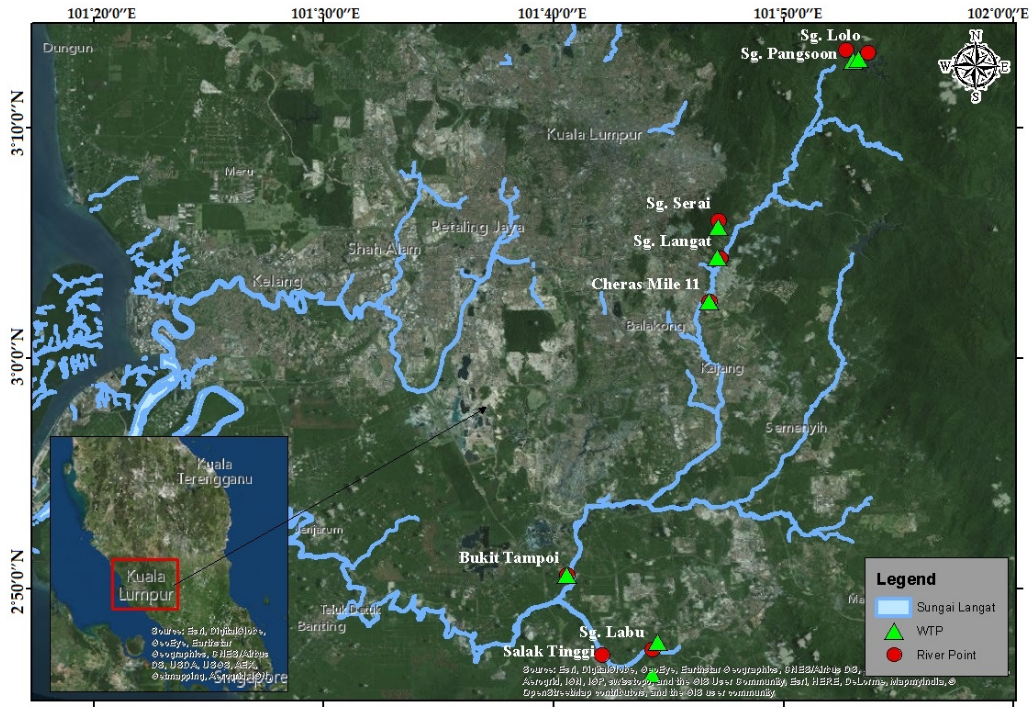

Figure 1. Water sampling points, (i.e., river points) at the Langat River Basin, Malaysia.

2.2. Analysis of Water Parameters

Chelex® 100 column resin ion exchange is a popular method to analyze dissolved concentration of metals and this method was applied in this study to analyze the dissolved concentration of Al, As, Cd, Cr, and Pb (i.e., µg/L) [6,41]. Inductively coupled plasma-mass spectrometry (ICP-MS, ELAN 9000 ICP-MS, PerkinElmer, Shelton, CT, USA) was used to analyze the concentrations of these metals in the Langat River. The calibration of the ICP-MS and analysis of replicates, (i.e., 120) and blanks were performed to ensure the quality of analytical data. Before analyzing the metals' concentrations, the calibration of ICP-MS was performed with the standard of several concentrations of Multi-Element Calibration Standard III (PerkinElmer, Lot # CL7-173YPY1, PE # N9300233, Waltham, MA, USA). The standard curve (r2 = 0.999) of these metals was analyzed to ensure the accuracy in analyzing by the ICP-MS. Similarly, the calculation of relative standard deviation (RSD) of the metals- Al 0.002%, As 5.800%, Cd 0.295%, Cr 0.005%, and Pb 0.003%- was important to ensure the precision of the analytical procedure. Background correction of these metals' concentrations was also completed via analyzing the blanks. Therefore, the mean SRM, (i.e., Multi-Element Calibration Standard III, PerkinElmer, Lot # CL7-173YPY1, PE # N9300233, Waltham, MA, USA) recoveries of these metals were calculated as follows- Al 99.972 ± 0.002, As 75.992 ± 4.408, Cd 94.966 ± 0.280, Cr 99.803 ± 0.005, and Pb 98.762 ± 0.003%.

2.3. Time Series Water Quality Data

Department of Environment (DOE) Malaysia provided the data of physicochemical water quality parameters (2005–2015) to find out the WQI, (i.e., water quality index) of the Langat River [9,42,43]. Therefore, the parameters such as dissolved oxygen (DO%), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3–N), total dissolved solids (TDS), and pH were used following the Equation (1) of WQI by DOE to find out the sub-index values of parameters as well as the overall water quality class of Langat River [42,43]. SIDO refers to the sub-index for dissolved oxygen (DO), SIBOD refers to the sub-index for biochemical oxygen demand (BOD), SICOD refers to the sub-index for chemical oxygen demand (COD), SIAN refers to the sub-index for ammoniacal-nitrogen (AN), and SITDS refers the sub-index for total dissolved solids (TDS).

The water quality Class I defines the water as clean when the WQI value is greater than 92.7. Similarly, Class II defines that the conventional treatment is needed of the raw water before drinking based on the WQI value in the range of 76.5–92.7. Accordingly, Class III defines that extensive treatment is needed of the raw water before drinking based on the WQI value in the range of 51.9–76.5. Moreover, Class IV defines that the water is polluted and can be used for irrigation purposes where the range of WQI is 31.0–51.9. However, the water quality Class V defines that it cannot be used for the purposes of drinking and irrigation, and the WQI is less than 31.0.

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD5) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIpH) \quad (1)$$

2.4. Statistical Analysis

SPSS software (Version 21.0, IBM Corp., Armonk, NY, USA) was used for the descriptive statistical analysis of the water quality parameters. Principal component analysis (PCA) of the water quality parameters was conducted for a meaningful interpretation of pollution sources as well as contribution of each water quality parameter to determine the pollution sources. Hierarchical cluster analysis (HCA) was applied to determine the similarities and dissimilarities among the water quality parameters, as well as the water sampling points, respectively, in the Langat River Basin to cluster them into groups. Regression analysis was also applied to measure the dependent water quality parameters quantitatively through quantitative measuring of the independent water quality parameters.

3. Results

3.1. Water Quality Status of Langat River

The determined concentrations of the water quality parameters (Table 1) in this study were cross-checked with the national water quality standard of the Ministry of Health (MoH) Malaysia [40], the United States Environmental Protection Agency [44,45], and the European Commission [46]. The mean concentrations of As, Cd, Cr, and Pb were within the safe limit based on the comparison with several water quality standards set by several recognized institutions except for the mean concentration of Al in the Langat River. The mean concentration of Al, i.e., 250.26 ± 189.24 µg/L in the Langat River exceeded the safe limit of the toxic reference value, i.e., 87 µg/L set by USEPA [44] and Malaysia 60 µg/L [43].

Table 1. Trace Metals in Langat River in comparison with several standards.

Parameter	N	Min.	Max.	Mean	MOH [1]	USEPA [2]	EC [3]	DOE [4]
Al (µg/L)	24	38.09	648.52	250.26 ± 189.24	-	-	-	60
As (µg/L)	24	0.33	3.04	1.65 ± 0.93	10	150	-	50
Cd (µg/L)	24	0.39	3.43	1.22 ± 0.88	3	0.72	0.2	10
Cr (µg/L)	24	0.12	1.22	0.47 ± 0.27	50	11	-	50
Pb (µg/L)	24	4.76	24.93	9.99 ± 5.38	50	2.5	1.3	50

Notes: [1] Malaysian Raw Water Quality Standard [40]; [2] Criteria Continuous Concentration by United States Environmental Protection Agency [45]; [3] Annual Average set by European Commission [46]; [4] Raw water quality standard set by Department of Environment Malaysia [43].

Moreover, according to the national water quality standard of Malaysia [43] Pb and Cd status in Langat River belong to Class III, whereas Al is ranked Class IV which requires extensive treatment before drinking (Table 2).

Similarly, the determined WQI (water quality index) of the Langat River based on physicochemical parameters was Class IIA that needs conventional treatment before drinking. However, the raw water intake points at the midstream of Langat River such as Langat, Cheras and Bukit points belong to Class III which requires extensive treatment before drinking (Table 3).

Table 2. Determined metal's status in Langat River (2015) (n = 24).

Location	Al (μg/L)	As (μg/L)	Cd (μg/L)	Cr (μg/L)	Pb (μg/L)
Pangsoon	231.17 ± 128.59	1.59 ± 0.30	1.60 ± 0.66	0.60 ± 0.56	9.57 ± 1.82
Lolo	529.96 ± 70.45	2.62 ± 1.00	1.78 ± 1.43	0.66 ± 0.36	20.72 ± 3.67
Serai	556.90 ± 95.54	1.82 ± 0.15	2.54 ± 0.02	0.60 ± 0.04	14.45 ± 1.13
Langat	214.48 ± 2.92	2.00 ± 0.65	1.25 ± 0.09	0.31 ± 0.14	7.33 ± 1.70
Cheras	144.18 ± 36.68	2.24 ± 1.18	1.23 ± 0.73	0.57 ± 0.32	11.46 ± 1.45
Bukit	104.09 ± 66.91	1.78 ± 1.14	0.43 ± 0.03	0.32 ± 0.12	5.88 ± 1.12
Salak	143.68 ± 46.45	0.67 ± 0.07	0.50 ± 0.04	0.36 ± 0.02	5.52 ± 0.02
Labu	77.65 ± 41.42	0.44 ± 0.03	0.47 ± 0.04	0.31 ± 0.12	5.03 ± 0.27
Average	250.26 ± 61.12	1.65 ± 0.93	1.22 ± 0.38	0.47 ± 0.21	9.99 ± 1.40
Overall Class [1]	IV	I	III	I	III

Note: [1] National Water Class of Malaysia based on Metal Concentration [34].

Table 3. Determined water quality index of Langat River, Malaysia (2005–2015).

Location	WQI	Class	Class Range	Category	Category Range
Pangsoon	92.23 ± 6.60	II	76.5–92.7	Clean	81–100
Lolo	91.51 ± 7.68	II	76.5–92.7	Clean	81–100
Serai	92.25 ± 6.63	II	76.5–92.7	Clean	81–100
Langat	64.15 ± 32.12	III	51.9–75.5	Slightly Polluted	60–80
Cheras	69.20 ± 26.20	III	51.9–75.5	Slightly Polluted	60–80
Bukit	60.77 ± 29.39	III	51.9–75.5	Slightly Polluted	60–80
Salak	84.65 ± 13.51	II	76.5–92.7	Clean	81–100
Labu	84.49 ± 13.36	II	76.5–92.7	Clean	81–100
Average	79.91 ± 16.94	II	76.5–92.7	Clean	81–100

3.2. Source Identification of Water Pollution

The correlation matrix in the principal component analysis (PCA) represents both the positive and negative correlation among the water quality parameters based on the water sampling data of 2015. Several positive and negative correlations among the water quality parameters indicate more than one component solution in PCA. It also represents the range of variables in a standardized format. Moreover, the determinant greater than zero, (i.e., 5.62×10^{-8}; Table 4) also suggests conducting a PCA to find out the correlations among water quality parameters.

The Kaiser–Meyer–Olkin (KMO) and Bartlett's test is a justification of the data reduction procedure. The significant result (p = 0.000; Table 5) of Bartlett's test of sphericity interprets that at least there is a significant correlation in the correlation matrix, and the correlations are not near zero. The Kaiser–Meyer–Olkin measure of sampling adequacy, (i.e., 0.687; Table 2) also measures the effect size of the data to conduct the PCA. The accepted value of the Kaiser–Meyer–Olkin measure of sampling adequacy is > 0.4.

The communalities also explained the highest 96.5% (Table 6) variance extracted from the parameter Cr, followed by 96.4% and 92.4% from Cd and Pb, respectively, as well as the lowest 71.3% from DO. However, the extraction of variance >20% from the data was good for the PCA. The total variance explained three components solution (Table 6). The first three components show the eigenvalues greater than one (Table 6 and Figure S1), and the first component explained about 61.727% (Table 6) of the total variance, and cumulatively, the rotated component matrix explained about 85.363% of the total variance although cumulatively >60% of the explained total variance was accepted for the component rotation.

Table 4. Correlation matrix [a] among water quality parameters using principal component analysis.

Parameters	Al (μg/L)	As (μg/L)	Cd (μg/L)	Cr (μg/L)	Pb (μg/L)	DO (mg/L)	SPC (μS/cm)	TDS (mg/L)	SAL (ppt)	pH	Temp (°C)
Al (μg/L)	1.000										
As (μg/L)	0.351 **	1.000									
Cd (μg/L)	0.689 *	0.431 *	1.000								
Cr (μg/L)	0.468 *	0.501 *	0.598 *	1.000							
Pb (μg/L)	0.781 *	0.565 *	0.735 *	0.541 *	1.000						
DO (mg/L)	0.626 *	0.533 *	0.650 *	0.375 *	0.582 *	1.000					
SPC (μS/cm)	−0.759 *	−0.306 *	−0.719 *	−0.345 **	−0.586 *	−0.808 *	1.000				
TDS (mg/L)	−0.739 *	−0.190 *	−0.679 *	−0.367 *	−0.536 *	−0.729 *	0.923 *	1.000			
SAL (ppt)	−0.786 *	−0.323 **	−0.731 *	−0.403 *	−0.627 *	−0.810 *	0.994 *	0.926 *	1.000		
pH	−0.341 **	0.269	−0.143	−0.183	−0.241	0.132	0.093	0.163	0.110	1.000	
Temp (°C)	−0.729 *	−0.445 *	−0.678 *	−0.469 *	−0.752 *	−0.850 *	0.824 *	0.758 *	0.841 *	0.307 *	1.000

Notes: [a] Determinant = 5.62×10^{-8}. Correlation measures the strength of the linear relationship between two variables. It has a value between −1 to 1, with a value of −1 meaning a total negative linear correlation, 0 being no correlation, and +1 meaning a total positive correlation. High degree: if the coefficient value lies between ±0.50 and ±1, then it is said to be a strong correlation. Moderate degree: if the value lies between ±0.30 and ±0.49, then it is said to be a medium correlation. Low degree: when the value lies below +0.29, then it is said to be a small correlation. * Significant at 0.01 level. ** Significant at 0.05 level.

Table 5. Kaiser–Meyer–Olkin (KMO) and Bartlett's Test.

Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy		**0.687**
Bartlett's Test of Sphericity	Approx. Chi-Square	308.847
	Sig.	0.000

Table 6. Rotated component matrix for the water quality parameters.

Water Quality Parameter	Component			Communalities
	1	2	3	Extraction
SPC (μS/cm)	0.967	−0.172	0.003	0.802
SAL (ppt)	0.956	−0.224	0.029	0.868
TDS (mg/L)	0.935	−0.116	0.106	0.739
DO (mg/L)	−0.816	0.353	0.282	0.713
Temp (°C)	0.797	−0.431	0.154	0.802
Al (μg/L)	−0.720	0.434	−0.308	0.869
Cd (μg/L)	−0.640	0.564	−0.105	0.964
As (μg/L)	−0.159	0.809	0.434	0.899
Cr (μg/L)	−0.184	0.806	−0.172	0.965
Pb (μg/L)	−0.505	0.714	−0.195	0.924
pH	0.079	−0.069	0.956	0.844
Initial Eigenvalues	6.790	1.398	1.202	-
% of Variance Extraction	61.727	12.710	10.926	-
Cumulative % Extraction	61.727	74.437	85.363	-

Notes: Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation converged in 4 iterations.

The scree plot (Figure S1) determined how many components should be extracted in this PCA. The scree plot also showed that after the first two-component values, the difference among the eigenvalues declined, and then the curve flattened. The values less than zero were not accepted for the component analysis, and the values close to one also could not interpret the data meaningfully. Hence, the scree plot analysis also suggests a three-component solution, although the third component was very poorly defined, relating to only a strong factor loading, i.e., pH (Table 6).

The varimax rotation method produced an orthogonal factor rotation, and it forced the factor solution to be orthogonal as well as the factors were not highly correlated to each other. If the factors were uncorrelated orthogonal, then the varimax with Kaiser normalization factor rotation would yield a more orthogonal factor solution. There would be some correlation among the factors and the varimax with the Kaiser normalization rotation procedure would measure it. Moreover, the factors sorted by size also helped to interpret the rotated component matrix efficiently.

The first component explained about 61.727% (Table 6) of all water quality data and observed adequate positive loadings of specific conductance (SPC)/ electrical conductivity, (i.e., SPC = 0.967), total dissolved solids, (i.e., TDS = 0.935), salinity, (i.e., SAL = 0.956) as well as temperature, (i.e., temp = 0.797). However, dissolved oxygen, (i.e., DO = −0.816) and aluminum, (i.e., Al = −0.720) have strong negative loadings. Although the strong loadings indicated that they were strongly influencing each other, the negative loadings suggested an opposite trend to the positive loadings in the same group.

Similarly, the second component explained about 12.71% of the total variance, and the observed adequate to moderate positive loadings of arsenic (As = 0.809), chromium (Cr = 0.806), lead (Pb = 0.714), and cadmium (Cd = 0.564) indicated inorganic pollution in the Langat River both from the natural and anthropogenic sources. These strong loadings of inorganic metals in the second component also suggested that they were in the same group and were strongly related to each other. Strong factor loadings of Cr in the second component also indicated the high concentration of Cr in the river mainly from the weathering of oxisols, which come from the lithogenic serpentinite rock underneath the peninsular of Malaysia [47]. In addition to the natural weathering process, the corrosion inhibitors and pigments in the industrial effluents also contribute to increasing the concentration of Cr in the river.

Similarly, the third component observed a strong positive loading of pH (0.956) indicating an intrusion of saline water in the Langat River and this third component explained the 10.926% variance. The dissolved metals are largely influenced by the physicochemical parameters such as pH, electrical conductivity, water residence time, and changing bedrock lithology from granite bedrock upstream to the quaternary sediments downstream. Moreover, mildly alkaline river water under oxidizing conditions favors adsorption of Cd, Pb, and As possibly onto the secondary oxides of Fe, Al, and Mn [48]. Therefore, the dissolution of As, Cd, and Pb with the high pH (alkaline) condition can be predicted well through the multiple regression model. While the rotated component matrix contains all loadings (even those <0.3) for each component, and the component plot (Figure 2) gives a visual representation of the loadings.

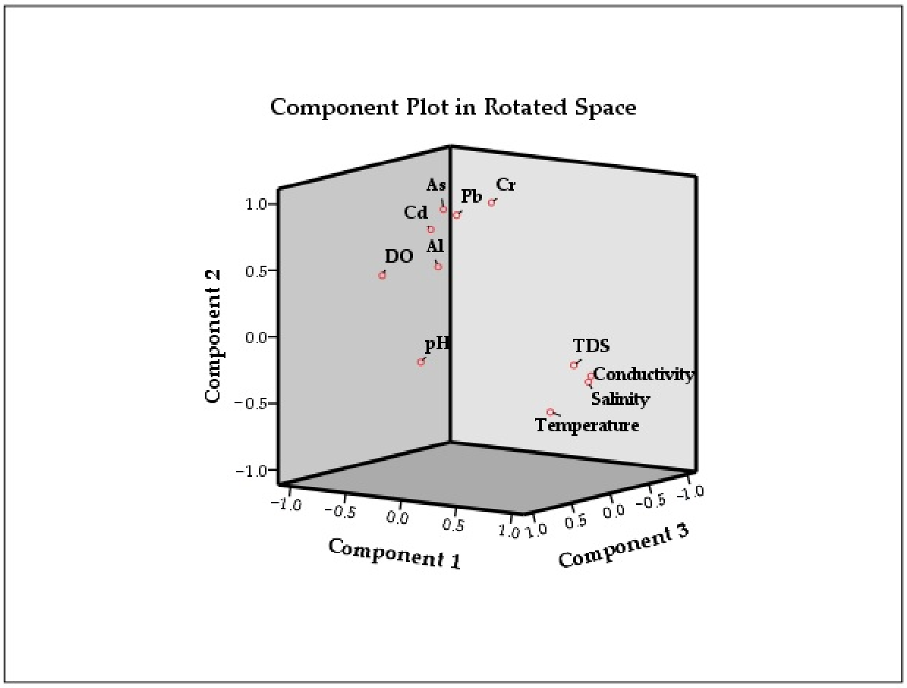

Figure 2. Component plot in rotated space.

The hierarchical cluster analysis (HCA) supported the findings of principal component analysis (PCA) because the graphical representation of HCA found the similarities among the water quality parameters within a cluster as well as dissimilarities among the clusters. The agglomeration schedule coefficients also verified the graphical representation of clusters through a dendrogram. Two main clusters (Group 1 and Group 2) were specified based on the water quality parameters through HCA (Figure 3). Group 1 consisted of salinity (SAL), pH, dissolved oxygen (DO), temperature (temp) as well as metals i.e., As, Cd, Cr, and Pb. The selected metals in Group 1 are also like the loadings of metals in the factors loading in Group 2 of the principal component analysis (PCA). The presence of metals, i.e., As, Cd, Cr, and Pb in the same cluster is also supported by the Pearson correlation analysis. The Pearson correlation (Table 7) among the dissolved metals indicated significant and strong affirmative correlations, e.g., between Al-Pb ($r = 0.781$, $p < 0.01$), As-Pb ($r = 0.565$, $p < 0.01$) Cd-Pb ($r = 0.735$, $p < 0.01$) and Cr-Pb ($r = 0.582$, $p < 0.05$).

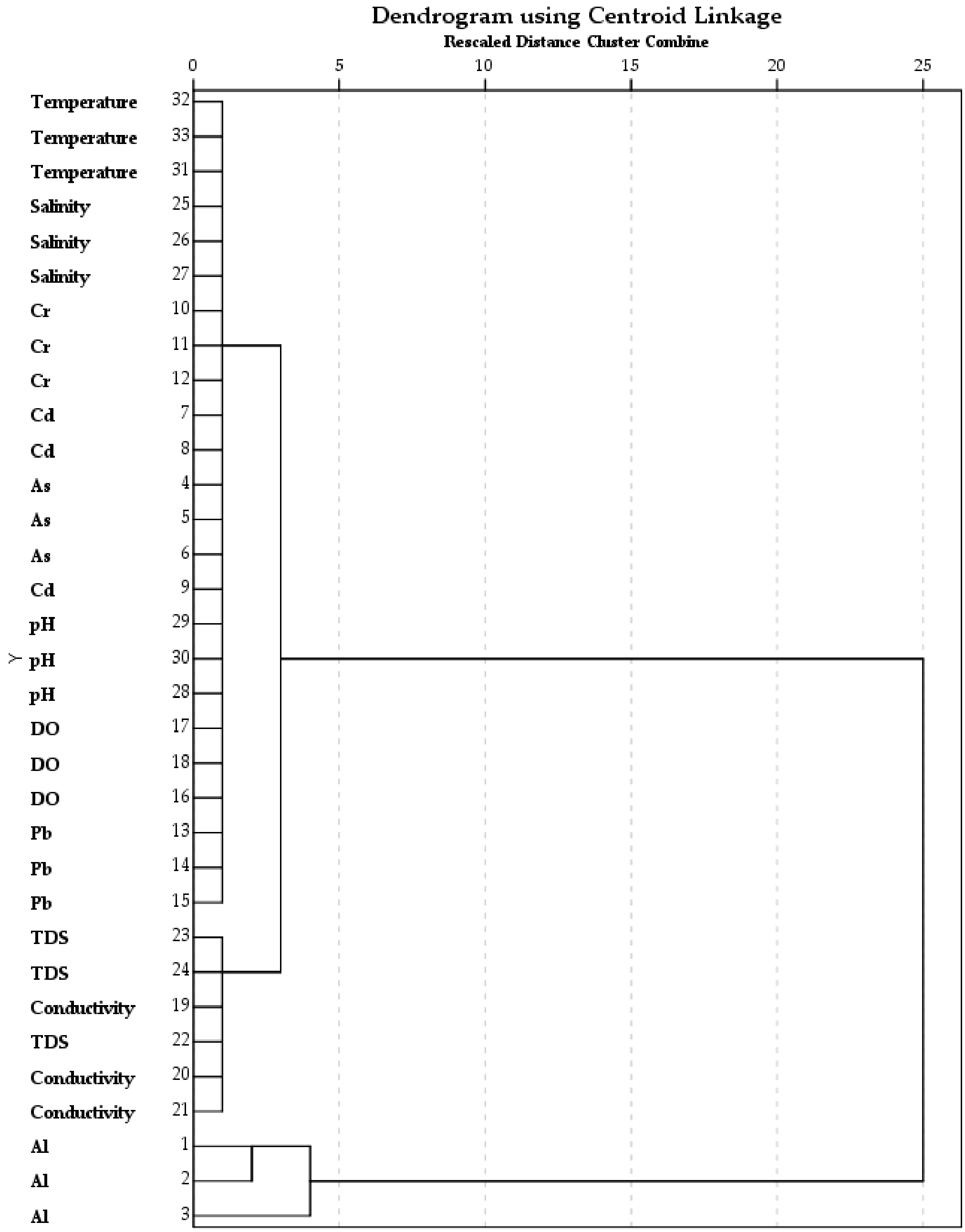

Figure 3. Clustering of metals and physicochemical parameters in the Langat River.

Table 7. Pearson correlation among metals and physicochemical parameters.

Parameter	Al (µg/L)	As (µg/L)	Cd (µg/L)	Cr (µg/L)	Pb (µg/L)	DO (mg/L)	SPC (µS/cm)	TDS (mg/L)	SAL (ppt)	pH	Temp °C
Al (µg/L)	1										
As (µg/L)	0.351	1									
Cd (µg/L)	0.689 **	0.431 *	1								
Cr (µg/L)	0.468 *	0.501 *	0.598 **	1							
Pb (µg/L)	0.781 **	0.565 **	0.735 **	0.541 **	1						
DO (mg/L)	0.626 **	0.533 **	0.650 **	00.375	0.582 **	1					
SPC (µS/cm)	−0.759 **	−00.306	−0.719 **	−00.345	−0.586 **	−0.808 **	1				
TDS (mg/L)	−0.739 **	−00.190	−0.679 **	−00.367	−0.536 **	−0.729 **	0.923 **	1			
SAL (ppt)	−0.786 **	−00.323	−0.731 **	−00.403	−0.627 **	−0.810 **	0.994 **	0.926 **	1		
pH	−00.341	00.269	−00.143	−00.183	−00.241	00.132	00.093	00.163	00.110	1	
Temp °C	−0.729 **	−0.445 *	−0.678 **	−0.469 *	−0.752 **	−0.850 **	0.824 **	0.758 **	0.841 **	00.307	1

Notes: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

The physicochemical parameters, i.e., salinity, pH, temperature, and dissolved oxygen (DO) are related to each other and have significant negation correlation with the studied metals except for DO (i.e., Al-DO = 0.626, $p < 0.01$; As-DO = 0.533, $p < 0.01$; Cd-DO = 0.650, $p < 0.01$; Pb-DO = 0.582, $p < 0.01$; Table 7) indicated their strong influence on the presence of dissolved metals in the Langat River. Although electrical conductivity and total dissolved solids are related to other parameters in Group 1, they are dissimilar to other parameters in the same group. For example, TDS and electrical conductivity have a negative significant correlation with metals (Table 7). Similarly, the significantly opposite correlations between pH and metals, (i.e., Al, Cd, Cr, Pb) in the Langat River are also supported by the study of Aris et al. [49]. Therefore, Group 1 indicated that the metals in the Langat River are mainly via natural weathering of granite rock underneath the entire basin [47–51] as well as effluent discharges from the domestic, industrial, and runoff from the urban and agricultural sources. Moreover, Liu et al. [52] also reported the presence of dissolved Pb from the atmospheric sources in the river.

However, in the HCA, Group 2 only represents the dissolved Al (Figure 3) indicating the large attribution from man-made sources to increasing the concentration of Al in the river. However, the cluster of Al is also related to other metals and physicochemical parameters in the Langat River. Hence, the Pearson correlation (Table 7) between Al and other metals in the Langat River found significant and strong positive relations, i.e., Al-Pb ($r = 0.781$, $p < 0.01$), Al-Cd ($r = 0.689$, $p < 0.01$) and Al-Cr ($r = 0.468$, $p < 0.05$). Therefore, the HCA clustered the river sampling points broadly in two groups (Figure 4) for their similarities within locations and dissimilarities among locations based on the water quality parameters to identify specific pollution sources in the Langat River. Group 1 comprised of Pangsoon, Lolo, and Serai areas, which are the upstream area with undisturbed forests, while Group 2 consisted of Langat, Cheras Mile 11, Bukit Tampoi, Salak Tinggi, and Sungai Labu areas, which are situated in mid to downstream of the basin, and these findings are similar to the study of Yap [53].

The four drinking water treatment plants (DWTPs), i.e., Sungai Pangsoon, Sungai Lolo, Sungai Serai, and Sungai Langat are situated upstream (Figure 4). The upstream of Langat River Basin is a hilly area along with the dense tropical forest. The inhabitants are mainly the native people of this Hulu Langat area. Therefore, there are few human activities in the upstream area except for a small number of campaign sites. Thus, the water was clean at the upstream water sampling points, especially at the Sungai Pangsoon, Sungai Lolo, and Sungai Serai points compared to the Sungai Langat point [53]. The water quality was slightly polluted at the Sungai Langat point based on the observation, which might be due to the land clearance, agricultural, and logging activities as well as discharges of effluent from the industries in a few places.

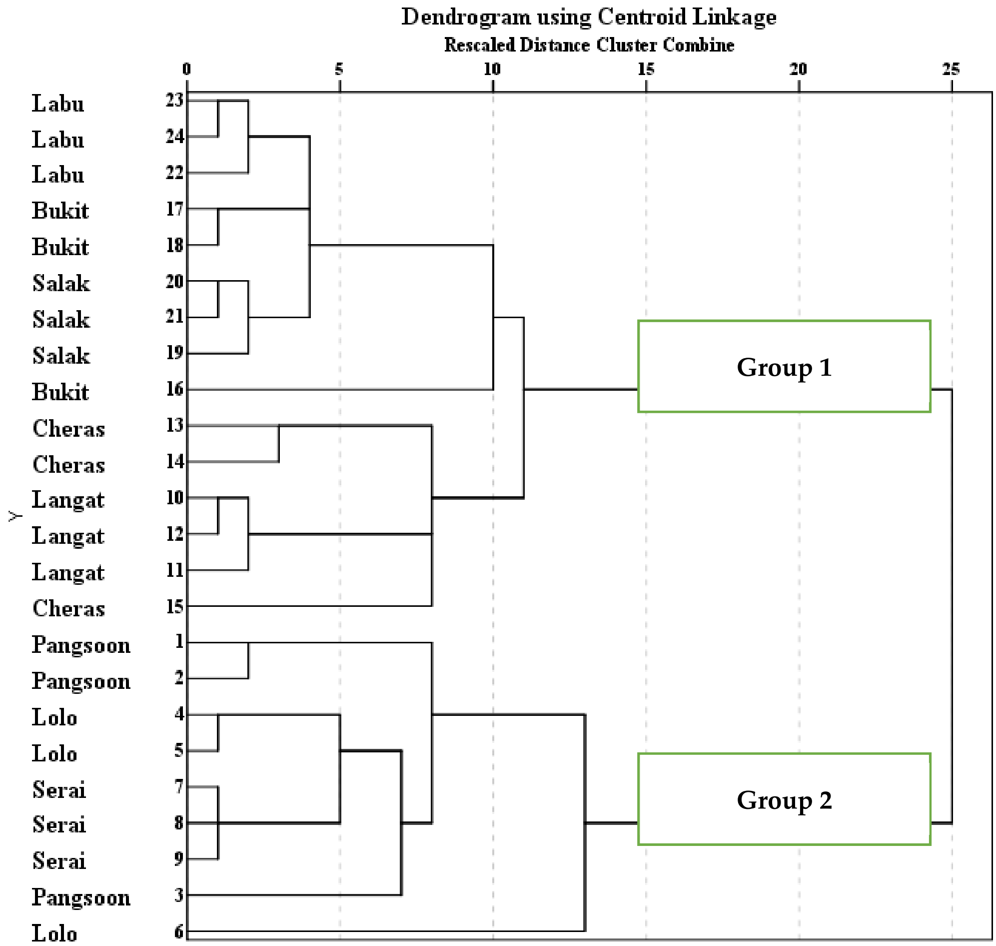

Figure 4. Clustering of river sampling points based on water quality parameters in Langat River, Malaysia.

However, the remaining four drinking water treatment plants, i.e., Cheras Mile 11, Bukit Tampoi, Salak Tinggi, and Sungai Labu from midstream to downstream of Langat River Basin experience moderate to high water pollution incidents. The Cheras Mile 11 DWTP is situated in the midstream of the Langat River Basin. The midstream of Langat River Basin is a built-up area and pollution in the river is mainly from the residential and industrial discharges apart from the agricultural activities such as oil palm plantation and rubber cultivation. Hence, the pollution level downstream is higher compared to the up and midstream because it accumulates all the pollution occurring in the up to midstream. The chemical pollution from the industrial zones is happening frequently [54] apart from the agricultural, animal husbandry, and residential waste discharge activities, etc.

The watercolor of the Langat River from midstream to the downstream was observed light brownish to deep brownish. The reason for the brownish watercolor might be due to the excessive run-off from the oil palm plantation and rubber cultivation. The land use map of Langat River Basin also indicates the oil palm plantation in these areas (Figure 5). The discharge of sewage might have also contributed to the pollution of the Langat River [53]. Many manufacturing, metal finishing, and paper-based industries as well as ex-mining, and sand and gravel extraction activities in the mid to downstream areas have contributed largely to the pollution of Langat River [54].

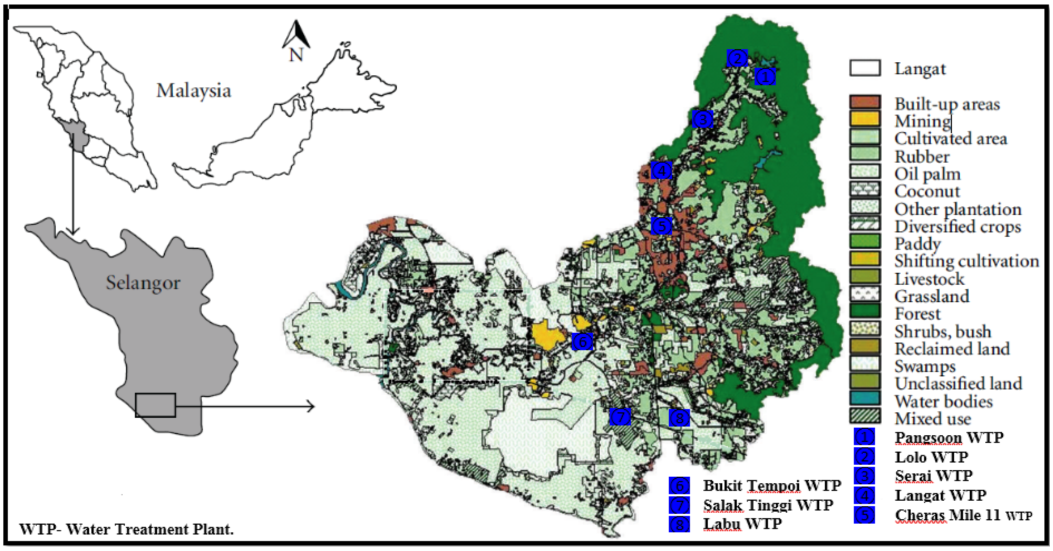

Figure 5. Land use map of Langat River Basin, Malaysia. Source: Modified from Lim et al. [33].

3.3. Predicting Metal Concentration in Langat River

The multiple linear regression model is proved very useful to predict the water pollution in the Langat River. Therefore, the Shapiro–Wilk normality test was performed to justify the suitability of data to run the regression model. The Shapiro–Wilk normality test at the 0.05 level ensured that the metals and physicochemical data had normal distribution; however, the data of As (p = 0.593), and DO (p = 0.081) were log-transformed to run the regression model (Table 8). The increase, as well as decreased concentration of water quality parameters based on the regression model, were appropriate to predict the metal's concentration in the Langat River.

Table 8. Linear regression model for the metal's concentration in Langat River, Malaysia.

Predictors	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	961.968	−2.609	0.151	1.406	5.403
	−1.64	(−2.303) *	−0.038	−0.821	−0.283
Al (µg/L)		0.0003	−0.002	0.0004	0.02
		−0.503	(−1.089)	−0.569	(3.434) *
Log (As)	62.252		−0.228	0.403	2.069
	−0.503		(−0.298)	−1.234	−0.558
Cd (µg/L)	−43.95	−0.026		0.198	2.572
	(−1.089)	(−0.298)		−1.923	(2.403) *
Cr (µg/L)	52.89	0.229	0.997		−1.43
	−0.569	−1.234	−1.923		(−0.511)
Pb (µg/L)	22.082	0.01	0.108	−0.012	
	(3.434) *	−0.558	(2.403) *	(−0.511)	
Log (DO)	469.581	0.633	1.835	−0.561	−13.226
	−1.965	−1.196	−1.161	(−0.777)	(−1.814)
SPC (µS/cm)	−2.605	−1.943	−0.012	0.002	0.065
	(−3.779) *	−0.002	(−2.349) *	−0.854	(2.729) *
pH	−316.037	0.327	−0.734	0.026	6.045
	(−3.286) *	−1.326	(−0.974)	−0.076	−1.751
Temp °C	55.311	−0.032	0.203	−0.042	−1.731
	(2.897) *	(−0.668)	−1.478	(−0.657)	(−3.092) *
Adjusted R^2	0.791	0.6	0.634	0.229	0.766
F value	11.851	5.321	5.976	1.856	10.433
p Value	0.00003	0.003	0.002	0.144	0.0001

Notes: Model 1, 2, 3, 4, and 5 represents Al, As, Cd, Cr, and Pb, accordingly through Enter Method. * Significant at the 0.05 level.

The multiple linear regression Model-1 represents the concentration of dissolved Al in the Langat River, estimated that around 79.1% of data, (i.e., adjusted R^2) were used to justify the model. The ANOVA was also found significant (F = 11.851; p = 0. 00003) for Model 1 (Al) to predict the linear relation between the dissolved Al concentration and the other independent variables. Model 2 (As), represents the dissolved As, which estimated that about 60% of the variance was used to calculate the model. The significant ANOVA (F = 5.321; p = 0.003) for Model 2 also indicates a linear relationship between As and other independent variables. Similarly, Models 3 (Cd), 4 (Cr), and 5 (Pb) also explained the regression model via calculation of 63.4%, 22.9%, and 76.6% of data, (i.e., adjusted R^2), respectively. The significant ANOVA test of the Model 3 (F = 5.976; p = 0.002), and Model 5 (F = 10.433; p = 0.0001) also indicated the linear relationships among the water quality parameters.

Model 1 explains that Pb ($p < 0.05$), electrical conductivity ($p < 0.05$), pH ($p < 0.05$) and temperature ($p < 0.05$) were significantly related to the dissolved concentration of Al in the Langat River. Therefore, if there was an increase in a unit, (i.e., 1 µg/L) of dissolved Pb, then there would be an increase of 22.082 µg/L of dissolved Al in the river. However, if there was an increase of 1 °C in temperature, then there would be an increase of 55.311 µg/L of dissolved Al in the Langat River. However, a 1 unit decrease in electrical conductivity and pH will significantly decrease 2.605 µg/L and 316.037 µg/L, respectively, of the Al concentration in the Langat River. The As and Cr models suggest that these metals are primarily from natural sources and the concentrations of these metals do not significantly depend on other water parameters. Pb ($p < 0.05$) can significantly increase the concentration of Cd, (i.e., Model 3) in the Langat River. It is determined that an increase in Pb by a unit has the potential to increase Cd levels by 0.108 µg/L. On the other hand, a unit of electrical conductivity decrease in the Langat River has the potential to decrease the Cd concentration by 0.012 µg/L. Accordingly, it was calculated that the concentration of Pb, (i.e., Model 5) in the Langat River significantly depends on the concentrations of Al (p < 0.05), Cd ($p < 0.05$), electrical conductivity ($p < 0.05$) and temperature ($p < 0.05$). Therefore, an increase in Al, Cd, and electrical conductivity by a unit have the potential to increase the concentration of Pb by 0.020 µg/L, 2.572 µg/L, and 0.065 µg/L, respectively, in the Langat River. Contrarily, the decrease in a unit of temperature will significantly decrease the concentration of Pb by 1.731 µg/L in the Langat River.

The multiple linear regression model for the selected dissolved metals:

$$Al = \beta_0 + \beta_1 \log(As) + \beta_2 Cd + \beta_3 Cr + \beta_4 Pb + \beta_5 \log(DO) + \beta_6 SPC + \beta_7 pH + \beta_8 Temp + \varepsilon_i \tag{2}$$

$$log(As) = \beta_0 + \beta_1 Al + \beta_2 Cd + \beta_3 Cr + \beta_4 Pb + \beta_5 \log(DO) + \beta_6 SPC + \beta_7 pH + \beta_8 Temp + \varepsilon_i \tag{3}$$

$$Cd = \beta_0 + \beta_1 Al + \beta_2 \log(As) + \beta_3 Cr + \beta_4 Pb + \beta_5 \log(DO) + \beta_6 SPC + \beta_7 pH + \beta_8 Temp + \varepsilon_i \tag{4}$$

$$Cr = \beta_0 + \beta_1 Al + \beta_2 \log(As) + \beta_3 Cd + \beta_4 Pb + \beta_5 \log(DO) + \beta_6 SPC + \beta_7 pH + \beta_8 Temp + \varepsilon_i \tag{5}$$

$$Pb = \beta_0 + \beta_1 Al + \beta_2 \log(As) + \beta_3 Cd + \beta_4 Cr + \beta_5 \log(DO) + \beta_6 SPC + \beta_7 pH + \beta_8 Temp + \varepsilon_i \tag{6}$$

where: β = Coefficient; ε_i = Error.

4. Discussion

The strong positive loadings of electrical conductivity (SPC), and the calculated TDS and salinity from the measured electrical conductivity by the Professional Plus Water Quality Multi-Parameter via principal component analysis (PCA) suggested the seawater intrusion in the Langat River along with the anthropogenic activities in the river basin and similar findings were also reported by Aris et al. [34]. TDS was also responsible for the high salinity and electrical conductivity in the Langat River possibly due to the geology and soil erosion effects at the basin [55]. Angelova et al. [15] also reported a significant positive correlation between turbidity and Al concentration in the Iskar Dam of Sofia city, Bulgaria. Moreover, increased salinity along with high TDS influenced the desorption of heavy metals from sediment, in consequence, increasing the heavy metal concentrations in the water because of the ion-exchange mechanism [34]. TDS and salinity are reactive compounds and quantitatively influence the status of inorganic pollutions [38]. Contrarily, the strong negative loading of DO also indicate the high salinity and temperature in the river, as well as the strong negative loadings of Al, which indicated the dissolution of Al concentration with the increasing salinity through flocculation [56], authigenic aluminosilicate formation, and adsorption mechanism. Moreover, hydrous aluminum in the clay mineral of the basin [49] and erosion of ferralsols, (i.e., oxisols and ultisols) enriched with Al [57] attributes to the strong loadings of Al in the first component indicated high dissolved concentration of Al. In addition to the natural weathering mechanism, the discharge of Al enriched sludge by the drinking water treatment plants (DWTPs) in the Langat River also largely contributed to increasing the Al concentration [58]. The strong loading of DO also suggest the organic and nutrient pollution in the Langat River might be due to the decomposition of natural organic matter when there were drought situations [59] as well as higher photosynthesis function in the upstream undisturbed forest area. Organic materials mainly from the densely residential area of Cheras, Kajang, and Bangi within the basin have been attributed to the DO concentration [55]. Several positive and negative factor loadings suggested that it required more than one component solution. Therefore, it can be concluded from the first component that the Langat River is contaminated both by organic and inorganic pollutants.

The use of fertilizers such as arsenal herbicides in cultivating palm oil, rubber, etc., [34,57], as well as mining of minerals such as tin [37,60] are the contributing factors to increasing the concentration of As and Pb in the river. Similarly, the use of phosphate fertilizer [61] as well as the mining activities and automobile exhausts through direct atmospheric transport and rainfall are the possible reasons for the high Pb concentration in the river [32]. Heavy shipping traffic contributes to the Pb and As pollution [62], whereas steel and metal industries in the basin, especially in the Dengkil area, are the potential sources of high concentration of Al, Pb, Cr, etc., in the river [34,57,63]. Moreover, intensive dredging, reclamation, and construction activities in the main course of the river as well as in the branches of the river might have re-suspended and reintroduced the sediments enriched with several trace metals in the river water [34,64]. In addition, the use of antifouling paints in the basin is one of the important sources of Pb in the Langat River [57]. Teallite ($PbSnS_2$), Galena (PbS), Franckeite ($(PbSn)_6FnSn_2Sb_2S_{14}$) minerals are the main origin of Pb in the river, especially via natural weathering and these minerals are present in the hydrothermal veins of the Main Range Granite of the central belt along the Langat Basin [48,50] in peninsular Malaysia. The electroplating, etching, and preparation of metal components are also responsible for releasing Cd in the river [57]. Leaching from the dumping of rechargeable batteries at the landfill in the region, as well as effluent discharges from metal and fertilizer industries, sewage treatment plants, atmospheric deposition [48], and urban runoff, are the important sources of Cd in the Langat River [32]. Therefore, the second component of PCA indicated the presence of inorganic metals in the Langat River.

The multiple linear regression model confirms the findings of principal component analysis (PCA) and the hierarchical cluster analysis (HCA) that pollution sources are from both man-made and natural sources, and it is clustered into two groups, i.e., upstream and mid-downstream. The upstream is comparatively cleaner than the mid-downstream of Langat River, mainly because of human activities such as oil palm plantation, discharges of industrial effluents, dumping of household waste, etc. Moreover, the weak implementation of policies by the relevant agencies, especially by the local government, also contributes to the pollution of the river because of the illegal dumping of chemical waste.

Langat River Basin Management

The scientific findings of this study about the chemical contamination levels and identification of those pollution sources in the Langat River can be well utilized for the better Langat River Basin Management, if the local government or the state water agency takes the proactive leadership roles in the form of Langat River Basin Management Authority (LRBMA) (Figure 6) to coordinate for better river basin management activities. Selangor State government's water agency 'Lembaga Urus Air Selangor (LUAS)/ Selangor Water Management Authority' is in the charge of water resources management within the state. Similarly, the local authorities are supported by the 'Local Government Act 1976' to enforce the water policies at the local level. Therefore, the coordination among the seven local authorities (Table 9) at the Langat River Basin is very important for integrated Langat River Basin Management, which is a UNESCO HELP, (i.e., Hydrology for Environment, Life and Policy) river basin since 2004. This LRMBA model can also be adopted in a total of 189 major river basins, (i.e., river basin >80 km^2) [65] throughout Malaysia for better-integrated river basin management (IRBM) in line with the integrated water resources management (IWRM). The IWRM has already been mainstreamed by the Malaysian government through the national water sector transformation 2040 (WST) initiative in the Twelfth Malaysia Five Year Plan (2021–2025) to accelerate the implementation of IWRM [66]. This IWRM has also aspired within the scope of the Shared Prosperity Vision 2030 (SPV2030) of the country as well as the sustainable development solutions network (SDSN) in Malaysia and Asia to contribute towards achieving sustainable development goals (SDGs) well before 2030 [67]. This Langat River Basin Management Authority (LRBMA) model has followed the modified theory of transformational leadership by James MacGregor Burns [68] as well as the behavioral theory of leadership by John B. Watson [69,70]. The transformational leadership theory has been used by researchers on political leaders, organizational psychology, sustainable development, etc., to explore how leaders can create valuable and positive changes in their followers to encourage them for proactive leadership roles [71–75]. Similarly, the behavioral theory has been used by researchers to explore individuals' technical, human, and conceptual skills towards motivating proactive leadership roles to promote green growth [69,70,76].

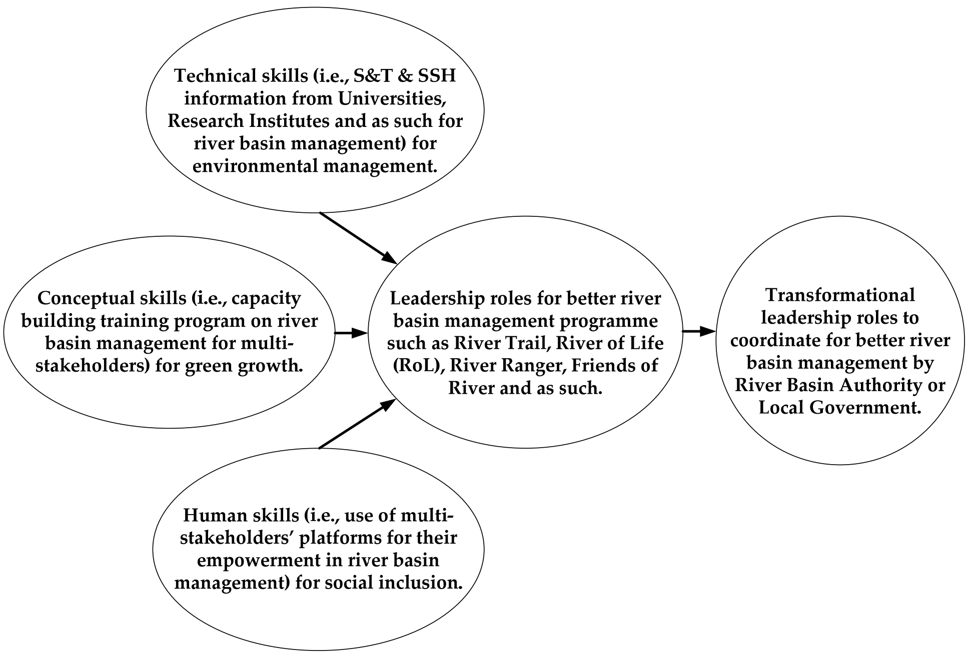

Figure 6. Conceptual framework of better Langat River Basin Management Authority (LRBMA) following modified transformational [66] and behavioral leadership [67,68] theories. Note: S and T = science and technology; SSH = social science and humanities.

Table 9. Local authorities and its administrative areas at Langat River Basin, Malaysia [77].

State	District	Area (km^2)	Local Authority
Selangor	Klang	71.87	Majlis Perbandaran Klang (MPK)
	Kuala Langat	706.93	Majlis Daerah Kuala Langat (MDKL)
	Sepang	333.25	Majlis Perbandaran Sepang (MPS)
	Hulu Langat	809.34	Majlis Perbandaran Kajang (MPKj)
Negeri Sembilan	Seremban	445.12	Majlis Perbandaran Nilai (MPN)
W.P. Putrajaya	-	39.21	Perbadanan Putrajaya (PPj)
W.P. Kuala Lumpur	-	3.67	Dewan Bandaraya Kuala Lumpur (DBKL)
	Total Area	2,409.39	

Therefore, following the Langat River Basin Management Authority (LRBMA) model (Figure 6), the local authority or state government agency can take the proactive leadership role in coordinating not only the multi-stakeholders within the Langat River Basin but also use the S and T, (i.e., science and technologies) as well as SSH, (i.e., social science and humanities) data and information from the universities and other research institutions in managing the Langat River. The identification of pollution sources at Langat River via this study well fits under the technical skills of this LRBMA model and the 'Pollution Control Taskforce' of the Selangor State Agency—LUAS, as well as the enforcement unit of the local authorities, can use the findings of this study about the higher pollution from midstream to downstream than the upstream of the river to monitoring and managing the pollution sources of the Langat River. Already, the government has proposed the capacity development of multi-stakeholders on IWRM via the water sector transformation 2040 (WST2040) initiatives in the Twelfth Malaysia Five Year Plan (2021–2025). The Malaysian government is also keen to use the existing multi-stakeholder platforms for the river basin management in line with the WST2040 initiative as well as the policy on the Shared Prosperity Vision 2030 (SPV2030) of the nation. Hence, there are many initiatives such as the National River Trail [78], River of Life (RoL) [79], Friends of Environment/Rakan Alam Sekitar Programme [80] by the government, Friends of River voluntary activities by the communities, River Ranger Program by the NGOs for community empowerment [81,82], CSR, (i.e., Corporate Social Responsibility) activities by the business and industry sector [83], etc., are important for better Langat River Basin Management. Thus, the transformational proactive leadership roles of local authorities and state water agencies can contribute better to managing the Langat River Basin towards contributing to green growth via monitoring and managing the pollution sources as well as supplying safe drinking water at the household level.

5. Conclusions

The determined As, Cd, Cr, and Pb levels were within the Malaysian National Water Quality Standard except for the mean concentration of Al 250.26 ± 189.24 μg/L, which exceeded the maximum level of 60 μg/L as proposed by the Department of Environment Malaysia. The high concentration of Al in the Langat River is mainly from the natural weathering of minerals at the granite belt underneath the basin. The concentration of Al indicates that it belongs to Class IV and Cd and Pb belong to Class III, respectively, according to the National Water Class of Malaysia. Similarly, the Class II water quality index (WQI) of Langat River indicates the river is clean and only conventional treatment of raw water will be enough before drinking. However, the raw water intake points by Langat drinking water treatment plant (DWTP), Cheras DWTP, and Bukit Tempoi DWTP at the midstream of the Langat River belong to Class III, which requires extensive treatment before drinking.

Therefore, the deteriorated water quality at the mid-downstream of the Langat River indicates pollution mainly from man-made activities apart from the natural reasons such as natural weathering of minerals, runoff due to floods, etc. Moreover, the illegal dumping of household waste and industrial effluent mainly due to the inadequate enforcement of policies by the relevant stakeholders especially local government also contributes to the deteriorating water quality of the river. Therefore, the scientific findings of this study will help the relevant multi-stakeholders, especially the local government to facilitate their decision-making processes, especially for the pollution management in the entire basin. Moreover, frequent studies on the total maximum daily load (TMDL) are required from up to downstream because of fast development activities at the Langat River Basin. The TMDL studies will further help decision-makers, especially local authorities to manage the pollution of the river following the concept of integrated river basin management (IRBM). Moreover, capacity building of multi-stakeholders is essential via a special training program on IRBM for the effective implementation of policies, especially for the point and non-point sources of pollution management at the Langat River Basin.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14121904/s1, Figure S1. Scree plot of eigenvalues for the Principal Component Analysis (PCA).

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