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URBAN WATER SECURITY PROTECTION: IDENTIFYING POLLUTION SOURCES IN JURU RIVER BASIN USING CHEMOMETRICS

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Abstract

The consumption of surface water is becoming increasingly significant as a main solution for Malaysia's issues with water supply, especially in urban areas. The study addresses the protection of urban water security by multivariate analysis, evaluating trends in the distribution of water quality parameters and identifies the primary sources and processes involved in water quality contamination in the Malaysian Juru River Basin. Conventional graphical and multivariate statistical methods HACA and PCA from chemometric techniques were used. The data collected in the Juru River was subjected to this investigation, which recorded 19 physical-chemical and microbiological characteristics at two sampling locations throughout the Juru River Basin. Consequently, the HACA was effectively split into the downstream and upstream areas. Six VFs are displayed by PCA in the high pollution source area (HPS), which represents 81.11% of the variance. The main cause of a decrease in water quality in the downstream areas of the Juru River Basin is anthropogenic pollution, or pollution caused by human activities. The study concludes by demonstrating how chemometric techniques can be used to identify significant details about their capacity to interpret complex data that determines the Juru River Basin's spatial and temporal variation in water quality distribution trends into MPS and HPS areas to ensure the urban water security protection.

Keywords: Urban Water Security; Water Security Protection; Water Quality; Principal Component Analysis (PCA); Chemometrics

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INTRODUCTION

River water pollution is widely known to be a global issue. Malaysia, as a member of The Rio Conventions in 1992, also looked seriously at the issue of river water pollution and made the same efforts to deal with this universal issue (Akhtar-Schuster et al., 2017). In order to respond to Agenda 21, which aims to preserve and conserve the environment, including taking care of river cleanliness, the river water quality monitoring programme is given more serious attention. There are two water quality indicator standard, namely the Water Quality Index (WQI) and National Water Quality Standard (NWQS) have been implement as one of monitoring programme since 1978 until now (Sulaiman et al., 2018).

Thereby, the Department of Environment (DOE) of Malaysia uses WQI and NWQS as standards in assessing the level of cleanliness and quality of water supply that can be used for domestic use, aquaculture, and irrigation (Hasib & Othman, 2020). There are six parameters of WQI, such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), alkalinity or acidity (pH), and Ammoniacal Nitrogen (NH3-N), which have been used by the DOE in calculating WQI. These two indices are usually expressed in the form of classes: I, IIA, IIB, III, IV, and V. WQI and NWQS classifications range from class I, which refers to the best, to class V, which is the worst. Next, WQI is also used to determine the status of river water quality, which is classified into three categories: clean (B), Moderately Polluted (ST), and Polluted (T). These two indices have been used as a good water quality benchmarking tool to carry out river water quality monitoring programmes in this country (DEM, 1991; DEM, 2004).

River water pollution on the west coast of Peninsular Malaysia is very severe, especially in large urban and industrial areas. This is effects of the process of urbanisation and industrial activities due to rapid population growth, which directly increase the release of waste directly into the river without limits or controls. Many rivers that flow through this area are threatened by pollution, including erosion and sedimentation, to the extent that they are no longer suitable for drinking water supply, fishing, irrigation, recreation, and environmental habitat. Therefore, Juru River is no exception in this regard. Juru River is one of the rivers in Malaysia that was reported by DOE Malaysia to be severely polluted based on WQI in 1991 and 2004 (Rahmanian et al., 2015; Fitri et al., 2020).

According Toriman et al., (2011), the distribution trends of Class IV and V water quality have been identified in the Juru River Basin. Industrial waste, untreated home trash, and animal waste, such as pig faeces, are the main contributors to pollution. Additionally, it has been demonstrated that tide phenomena influence pollution in two-thirds of the river. Urbanization, which has the greatest impact on a region's hydrology and water quality of all land use changes, is one of the key causes. It decreases storage capacities and shortens the time needed for concentration, resulting in high peak flows that could cause floods to occur more frequently and with greater intensity. The Juru River is in danger of becoming an open wastewater sewer as more land in the basin becomes urbanized (Karim et al., 2019).

Based on the Zali et al., (2011), for the major manufacturing enterprises at Prai Industrial Estate, the Juru River Basin continues to serve as the primary outflow destination for their effluent. Electronics, textiles, food processing, metal products, the rubber sector, chemical facilities, and transportation equipment make up the majority of the numerous sorts of industries that are still in operation throughout the Juru River Basin (Masthurah et al., 2021).

In addition, the studies conducted by Zali et al. (2011) and Idriss & Ahmad (2012) also found that there was a discovery of agricultural waste and metal pollution in this river. Some examples from the DOE's annual report and previous studies show that the pollution of this river occurs continuously due to the higher development of cities and industries along the river. In other words, anthropogenic or human sources of pollution, especially those originating from point sources, are seen as having the potential to affect water quality chemically, biologically, or physically.

Accordingly, this study was conducted with the aim of determining water quality patterns spatially and temporally and identifying the source of water pollution in the Juru River Basin using multivariate analysis. Multivariate analysis using chemometric techniques was performed to analyse water quality data for the years 2009–2013 taken from two sampling stations. This study is expected to predict important differences in water quality after considering the long-term effects of anthropogenic and natural sources along the river.

RESEARCH METHODOLOGY

Juru River is one of the main rivers in the Seberang Perai Tengah district (SPT), which is located in the northern part of Malaysia in Penang. The entire length of the river is about 15.62 kilometres (Toriman et al., 2011). The source of this river starts from Kampung Paya, Kampung Desa Wawasan, Kampung Tanah Liat, Taman Suria Aman, and Taman Berapit nearby from Bukit Mertajam towards the west and ends in the area of Perindustrian Prai (Prai Industrial Estate), where this river flows out into the Straits of Melaka.

Most of the development areas along Juru River Basin have been upgraded into cities and centres of economic activity for urban and sub-urban residents, such as small and medium industries, businesses, and services, as well as government institutions, while some other areas have been maintained as agricultural areas and livestock farms.

A large part of this river basin range covers industrial areas and residential houses. The types of industries that operate include electronics, textiles, metal-based goods and fabrication, food processing and canning, processing of agricultural products and chemical plants, rubber-based industries, wood products, paper products, printing, and transport equipment (MPSP, 2015).

Based on the background characteristics of the study area, there are two selected sampling stations shown in Table 1 and Figure 1, which represent the downstream and upstream areas of the river. 2JR01 (Prai Industrial Area) and 2J12 (Kampung Tanah Liat) are located next to industrial areas reclaimed from mangrove forests.

Table 1: Department of Environment (DOE)'s Sampling Staion in Juru River Basin

River	Sampling Station	Sub River Area	Latitude	Longitude
Juru	2JR01	Downstream	05^{0}19'91.7	100^{0}26'70.4
River	2JR12	Upstream	05^{0}30'86.5	100^{0}24'96.3

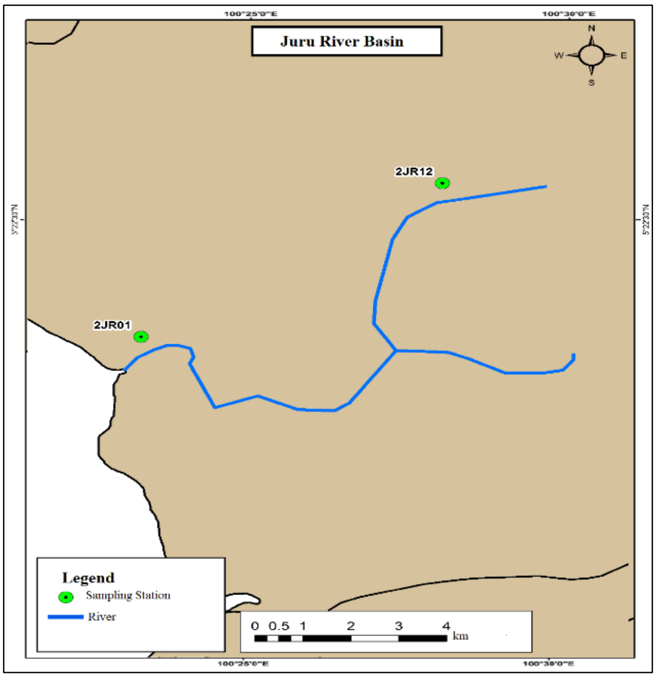

Figure 1: Map of Sampling Station of Department of Environment (DOE) in Juru River Basin, Malaysia

The water quality data in this study was taken from two sampling stations along the Juru River Basin, which are water quality monitoring stations operated by the Department of Environment (DOE), Malaysia. Although there are 30 water quality parameters available, only 19 consistent parameters were selected by focusing on the six main WQI parameters, some physico-chemical and microbial parameters, as well as other heavy metal pollution parameters. Among these parameters are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), alkali or acid (pH), Ammoniacal Nitrogen (NH3-N), temperature (TEMP), conduction (COND), arsenic (As), Turbidity (TUR), salinity (SAL), nitrate (NO3), phosphate (PO4), mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb), Escherichia coli (E-coli), and coli While, for primary data collection, water sampling for COD and SS analysis was done in a laboratory based on American Public Health Association (APHA) standards, pH, NH3-N, DO, and BOD parameters were measured in-situ in the field (Zin et al., 2017; Wahab et al., 2018; Hassan et al., 2022).

Then, the secondary data used involves the collection of water quality data by DOE through water sampling works in the field, which are carried out six times a year according to the specified justification. This study applied the multivariate analysis from the chemometric technique by using additional software, XLSTAT 2015. Basically, this software has various other statistical methods that can be used, but this study uses the chemometric technique, which only involves two analysis methods, namely HACA and PCA. Figure 2 shows a summary of the framework for analysing Juru River Basin distribution trends in water quality data from HACA and PCA.

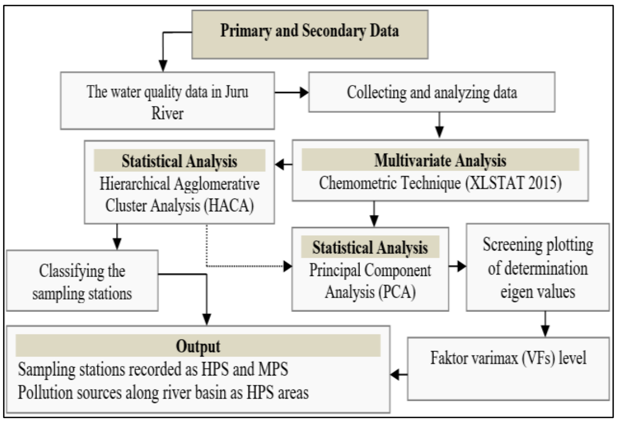

Figure 2: The study framework distribution trends in water quality data using HACA and PCA

The analysis of water quality data in this study basically started by using HACA to determine the pattern of water quality spatially and temporally. HACA is a commonly used method for classification (Hassan et al., 2022) into specific groups with a high level of homogeneity for each group member in a specific class based on pre-determined selection characteristics. Thus, in this study, HACA was used to classify sampling stations from certain groups (clusters) based on homogeneity characteristics that were analysed using the data that had been collected. The use of this method can simplify and speed up the classification process and identify a set of observations that show significant homogeneity ($P<0.05$) (Shafii et al., 2019). The results of HACA will be depicted through a tree diagram, also known as a dendrogram, to show clusters or similarities formed from this procedure (Forina et al., 2002; Shafii et al., 2019). Furthermore, PCA analysis was applied to identify the source type of water pollution for each variable. PCA is a method used to see the relationship between variables (Azhar et al., 2015) and how strong the relationship between each variable is after the HACA classification model is produced. The combination of HACA and PCA can provide information about the most important variables due to spatial and temporal variations that describe the entire set of data (Kamarudin et al., 2017; Juahir et al., 2018). Therefore, PCA also consists of the same data set but has been transformed (19 parameters) separately for different spatial regions. In order to achieve the maximum change in this data set, all the new variables, referred to as principal component scores (PCs), were calculated, while the variables that were not counted into the first new variable underwent a second calculation based on this new variable. If there is a new variable that has not been calculated from the first and second, a third calculation has to be done to get the maximum variable. This method is known as varimax rotation in PCA.

This varimax rotation was used to produce a good interpretation of the data because there are also weighting factor values given by PCA that are unclear and not available for interpretation. Thus, in this study, PCA and varimax rotation were used on new variables to produce new groups of variables with eigenvalues greater than 1 that are considered important. These new groups of variables are named varimax factors (VFs). Only factors with a strong weighting value (weighting factor >0.7) are taken into account in the interpretation of the results (Azaman et al., 2015; Saad et al., 2023). The results of PCA will be illustrated through scree plots of eigenvalue analysis and factor loading tables after varimax rotation. The basic model for this method expressed in the following Equation 1:

$$z_{ij} = a_{f1}x_{1i} + a_{f2}x_{2i} + \ldots + a_{fm}f_{mi} + e_{fi}$$ Equation 1

Where;
z : the component score;
a : the component loading;
x : the measured value of variable;
I : the component number;
J : the sample number;
M : is the total number of variables

RESULT AND DISCUSSION

This section discusses the results of the overall study on spatial and temporal water quality distribution patterns based on the classification of sampling stations using HACA analysis. The HACA performed on the water quality data set showed that the sampling station classification was successfully divided into two different clusters, such as cluster 2 and cluster 3, as shown through the Juru River Basin dendrogram in Figure 3 and the sampling station classification map in Figure 4. Cluster 3 from station 2JR01 shows HPS classified as the downstream area of the Juru River as an industrial area (Prai Industrial Area), which is growing rapidly, while station 2JR12 is in cluster 2 as MPS in the upstream area, which is heavily populated in the suburban (Bandar Bukit Mertajam) and is also an agricultural area that is maintained. The results obtained from these two clusters showed HACA is useful in classifying reliable sampling stations for the downstream and upstream areas of the Juru River Basin based on the background characteristics of the same area and water pollution.

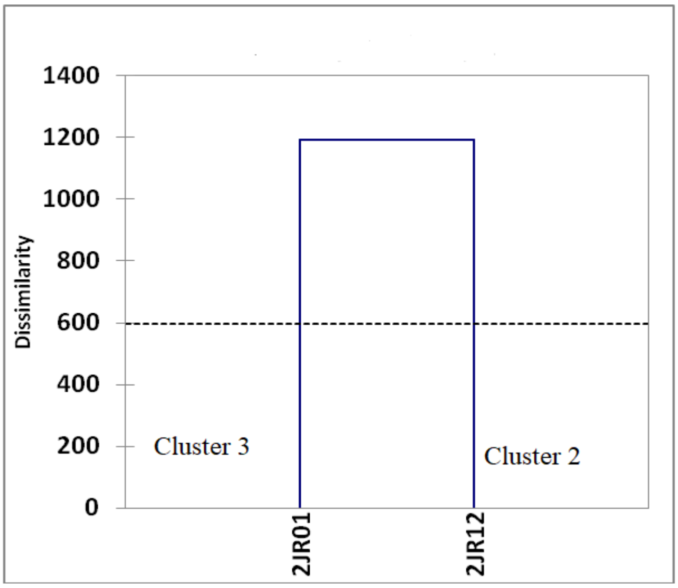

Figure 3: Sampling station classification based on HACA model

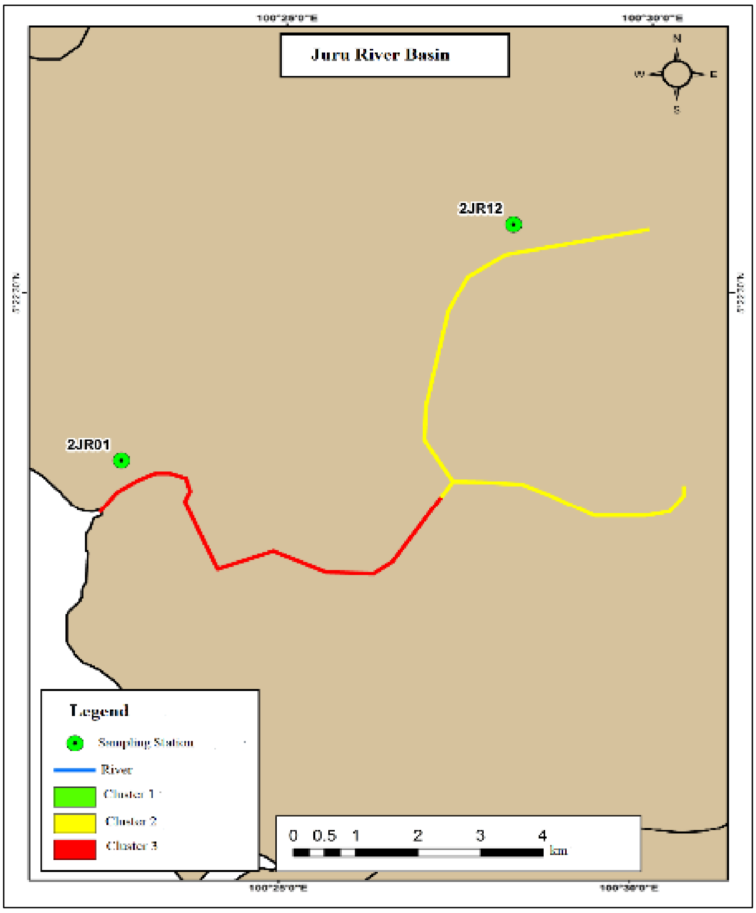

Figure 4: Map of sampling stations classification along downstream and upstream areas of Juru River Basin based on HACA model

Besides that, this section discusses the source of water pollution based on varimax rotation using PCA. The water quality data set was rotated using varimax rotation on new variables to produce groups of new variables with eigenvalues greater than one that are considered important and can be adopted, as shown in Figure 5. There are six VFs in the HPS produced after varimax rotation, contributing as much as 81.11% of the total variance in the water quality data set, as shown in Table 2. The first varimax factor (VF1) contributed 32.48% of the total variance with positive values strongly weighted against TEMP, COND, and SAL. Many physical characteristics of river water are affected by temperature and each other (Hua, 2015).

The main factor in the occurrence of high water temperatures in the downstream area of the river is likely to be related to pollution of inorganic substances from the industrial area, leading to changes in conductivity in the river water. The increase in high SAL concentration was found to occur when the water temperature around the area also increased due to a high evaporation rate, and this area is also more prone to high tide events resulting in seawater salinity mixed with freshwater salinity as observed in other areas (Salam et al., 2019).

VF2 contributed 16.74% of the total variance, with a positive value strongly weighted to SS and TUR. The influence factor of a high concentration of SS is also the level that increases the turbidity of river water. This is because water turbidity caused by the presence of organic and inorganic substances such as mud and waste from certain surfaces causes river water to become cloudy (Wahab et al., 2018). All of these materials are suspended solids that flow into the water from areas that are open for development and upstream areas. The critical pollution of SS is actually related to anthropogenic or human and natural sources, among which are soil erosion due to unplanned land use development and natural processes such as bedrock erosion and river bank erosion (Rani et al., 2009; Suratman et al., 2013; Mustaffa et al., 2023).

However, in this area, there is an increase in high concentrations of SS, most likely related to the movement of suspended sediment from the upstream areas. As a result, river sedimentation also occurs due to the transport process of various types of loads from the upstream areas (Ata et al., 2016; Wahab et al., 2019). Furthermore, this area is an industrial sector region that is experiencing an increase in industrial areas through land reclamation. This uncontrolled development project caused problems such as sediment deposition, and this result is also consistent with what has been observed in the same area (Kamarudin et al., 2020). Then, VF3 contributed 10.08% of the total variance, with positive values strongly weighted against E. coli and Coliform. The source of Coliform bacteria is found in the faeces of all warm-blooded animals and humans.

According to Tururaja & Mogea (2010), domestic waste is categorised as a source of high Coliform bacteria reproduction in densely populated areas. The high concentration of Coliform bacteria in this area indicates a critical pollution level due to the presence of domestic waste from factories or warehouses in addition to rural housing that also drains this waste into concrete ditches near the river (Ateshan et al., 2020) Next, biological pollution, such as animal faeces, causes the emergence of E. coli bacteria. The factor that increases E. coli bacteria is the release of animal faeces near the river, as observed in the same area (Wong et al., 2020).

VF4 contributed 7.96% of the total variance, with a strong positive value towards Cr. Factors that increase the high concentration of Cr metal in this area most likely occur as a result of industrial activities such as textile and paint factories, as observed in other areas (Muneer et al., 2010). The impact of industrial development housing more of these factories contributed industrial-based waste such as chromium metal in uncontrollable amounts. This metal waste was believed to have been channelled into the river without being processed first or without exceeding the set quality standards (Ahmed et al., 2020). Then, VF5 contributed 7.37% of the total variance, with strong positive values for BOD and COD. An increase in BOD means that there is more organic matter that can be decomposed by microorganisms and more oxygen being used.

The increasing COD concentration occurs because the decomposition of organic matter also takes place through chemical factors. Therefore, the factor increasing the high BOD and COD concentrations in this area is most likely due to domestic sewage waste from factories or warehouses and rural housing. Another factor expected to contribute to the increase in COD concentration in water is agricultural waste processed in agriculture-based factories (Wahab et al., 2018; Maulud et al., 2021). VF6 contributed 6.47% of the total variance, with a strong positive weighted value towards NO3. The presence of nitrates in water is usually caused by agricultural activities that use inorganic fertilisers and nitrogen fertilisers to increase yields. Therefore, the main factor expected to contribute to the increasing concentration of NO3 in this area is the flow of agricultural crop waste processed in agriculture-based factories (Tavakoly Sany et al., 2019).

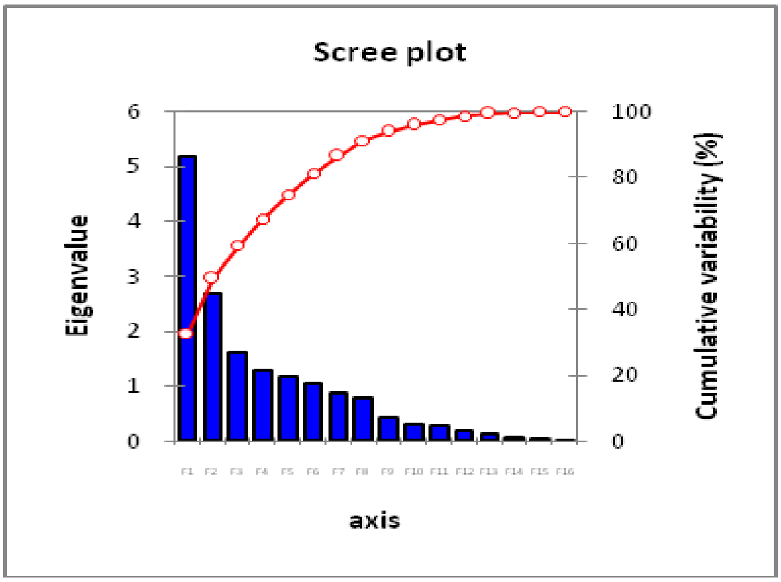

Figure 5: The screening plotting of determination eigenvalues based on PCA

Table 2: Varimax Factor (VF1) based on water quality parameters

Parameter	Higher Pollution Sources					
	VF1	**VF2**	**VF3**	**VF4**	**VF5**	**VF6**
DO (mg/l)	-0.115	0.447	-0.132	0.278	0.244	0.247
BOD (mg/l)	0.092	0.309	0.174	-0.147	**0.835**	0.052
COD (mg/l)	0.182	0.418	0.021	0.245	**0.706**	-0.016
SS (mg/l)	0.104	**0.917**	-0.034	0.063	0.155	-0.043
pH (unit)	0.683	0.063	0.051	0.278	0.198	-0.071
NH_3-N (mg/l)	0.655	0.049	-0.031	0.557	0.334	-0.131
TEMP (Deg C)	**0.870**	-0.037	0.140	-0.111	0.097	0.190
COND (uS)	**0.938**	0.026	-0.017	0.064	0.095	-0.163
SAL (ppt)	**0.943**	0.017	-0.025	0.050	0.057	-0.159
TUR (NTU)	-0.095	**0.939**	-0.071	-0.057	0.061	0.029
NO_3 (mg/l)	-0.193	0.007	-0.096	-0.114	-0.094	**0.885**
PO_4 (mg/l)	0.433	-0.116	-0.209	0.231	0.635	-0.289
As (mg/l)	0.560	-0.279	-0.186	-0.146	0.593	-0.202
Hg (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
Cd (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
Cr (mg/l)	0.052	0.010	-0.048	**0.953**	-0.043	-0.070
Pb (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
E-coli (cfu/100ml)	-0.059	-0.111	**0.738**	-0.008	0.057	0.399
Coliform (cfu/100ml)	0.069	-0.056	**0.885**	-0.064	-0.002	-0.285
Eigenvalue	5.197	2.678	1.613	1.274	1.180	1.036
Varience (%)	32.483	16.738	10.079	7.961	7.373	6.472
Cumulatif (%)	32.483	49.222	59.301	67.262	74.635	81.107

CONCLUSION

This study discussed the overall assessment of water quality distribution trends in the Juru River Basin using multivariate analysis adapted to chemometric techniques. Based on the data analysis, HACA has successfully classified the sampling stations into two different clusters by showing the HPS for the downstream area and the MPS for the upstream area. Then, PCA, which is also responsible for the spatial and temporal variation of Juru River water quality, determines the sources of pollution in the HPS area.

The main source of this pollution problem is more exposed to anthropogenic or human effects that come from point sources such as industrial waste, domestic sewage, and agricultural waste, which are mostly produced in factories. The results of this analysis are very useful as a reference and guide for the Department of Environment (DOE) in collecting physico-chemical data and water quality indices, in addition to being able to identify the source of pollutants. These data are also expected to help other government departments and agencies, such as the Department of Irrigation and Drainage (JPS), the Town and Country Planning Department (JPBD), and the National Water Services Commission (SPAN), carry out river and water resource management work in the future.

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