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2023
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4th International Symposium of Earth, Energy, Environmental Science, and Sustainable Development (JESSD 2023) 26/08/2023 - 27/08/2023 Jakarta, Indonesia

Accepted papers received: 20 November 2023

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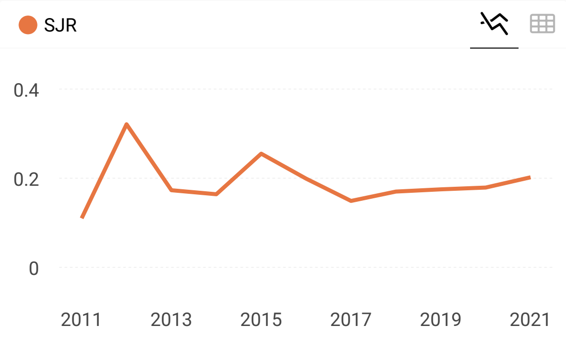

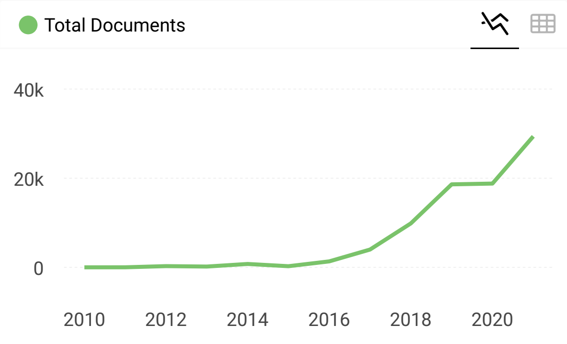

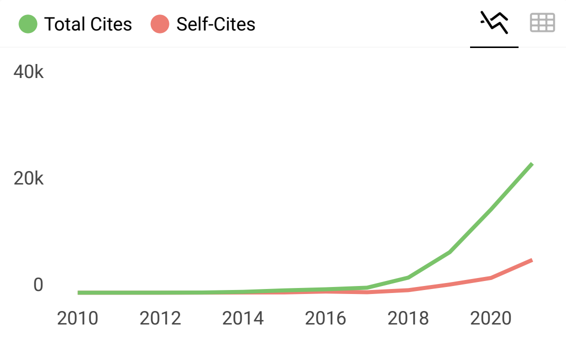

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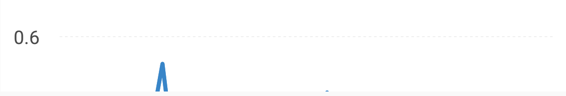

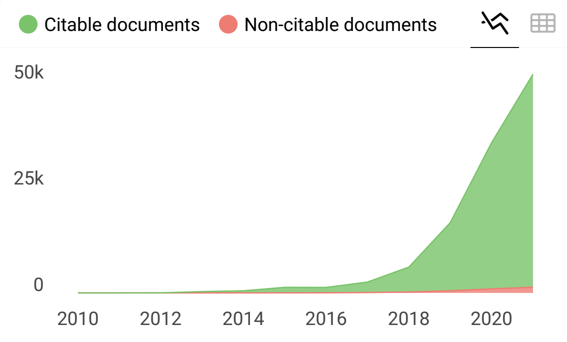

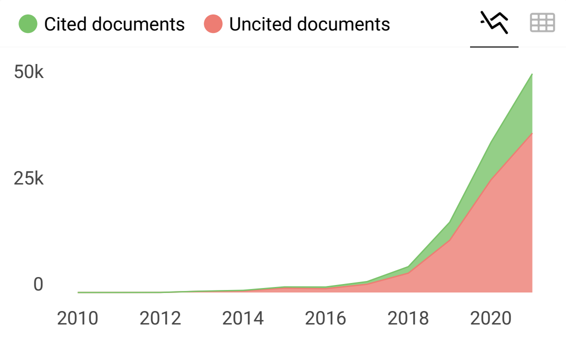

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Assessment of Water Quality Changes Using Physical Parameter and Stable Isotope in Ciliwung River

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Abstract. The Ciliwung River is the potential water source for the people of Jakarta and Bogor. Rapid urbanization and industrial development have sparked severe problems in the water resources of the Ciliwung River. The potential pollutants increase as the river flows through residential, business, and industrial areas, where drainage and sanitation infrastructure are worse. Water is naturally tagged with natural tracers, such as temperature, electrical conductivity, chemical constituents, and environmental water isotopes (δ^2H and δ^{18}O). These proved valuable tracers to identify the origin of the water. This research aims to trace the origin of the Ciliwung River water using a stable isotope approach and physical parameters. Research methods are field surveys, laboratory analysis, and analytical studies—sampling at 12 points of river water for a physical parameter and 5 points for stable isotopes. The research results show that the water origin of Ciliwung's is rainwater. The stable isotopes in the upstream area are smaller than those in the upstream area experiencing enrichment. Factors leading to enrichment are inputs from anthropogenic activities to water bodies from household, agricultural, and industrial pollution. The results of this research are helpful for the government and academics in designing Ciliwung River conservation policies.

1. Introduction

Groundwater is an essential resource for sustaining the existence of organisms and vegetation [1]. Water demand is expected to rise with population expansion, economic advancement, and progress in education, social dynamics, and cultural advancements [2]. In recent years, there has been a significant increase in urbanization and industrialization, leading to the emergence of noteworthy environmental and water resources challenges [3,4]. Water has inherent characteristics known as isotopic fingerprints, specifically stable isotopes of δ^2H and δ^{18}O. These isotopes undergo variations following the hydrologic cycle activities specific to a given water body [5,6]. Water is naturally tagged with fingerprints, i.e., stable isotopes of ^{18}O and ^{2}H, which vary according to the processes of a particular body of water through the hydrologic of hydrologic environment-atmosphere, hydrosphere, biosphere, and above the crust. This change results in isotope fractionation to give isotope "fingerprints" due to differences in physicochemical, biochemical, kinetic, and thermodynamic effects [7]. The isotopes ^{18}O and ^{2}H can be effectively utilized as a reliable tracer for discerning the blending and displacement of water originating from different sources [8]. The utilization of stable isotopes has a wide range of applications in water resources research [9]. The composition of ^{18}O and ^{2}H in water molecules can undergo small changes during phase transitions. Various processes control the behavior of stable isotopes in the hydrologic cycle and observe the distribution of their concentrations in space and time [10].

The utilization of inherent tracers in water, such as temperature, electrical conductivity, chemical components, and water isotopes, has demonstrated significant efficacy in identifying the origin of water. [11]. Conductivity is considered the most accurate method for directly evaluating water composition [9]. The utilization of the intrinsic meteoric tracker ^{18}O has proven valuable in identifying water sources within the upstream region [12]. Stable isotopes are required to provide information about water origin and mixing [13]. Several scholars have conducted investigations on the association between stable isotopes and the variables of EC, TDS, and DO in surface waters [5,9,13–16]. Generally, the systematic behavior of the isotopic composition of waters is considered relative to their TDS [9]. Most waters are mixtures of meteoric water from the current hydrological cycle and a saline end-member [14]. Further downstream, the water quality decreases due to the accumulation of pollutant loads from the upstream areas. In the upstream region, pollutant materials from agricultural areas are estimated to be pesticides, nitrates, and ammonia [17]. The downstream region experiences the accumulation of garbage from upstream sites and sources of home and industrial origin. Heavy metals are among the markers used to assess river pollution levels. This study aimed to evaluate the isotopic characteristics and physical qualities of the Ciliwung River.

The Ciliwung River possesses considerable potential as a water source for the inhabitants of Jakarta and Bogor [18]. The catchment area of the Ciliwung River is derived from the incline of the Gede Pangrango Mountain, which stands at an elevation of 3000 meters above sea level in West Java. The river originates from elevated regions and traverses Bogor, Depok, before discharging into Jakarta Bay. The Ciliwung River is the largest and most significant of the thirteen rivers crossing Jakarta's coastal region. Its whole length, spanning from the upstream to the estuary, measures around 117 km, including an area of 387 km2 [19]. The Ciliwung River passes through the Jakarta area, and the potential for pollutants to pollute the river increases as the river flows through residential, business, and industrial areas, where drainage and sanitation infrastructure are worse. Organic matter, besides pesticides and the heavy metals industry, is the primary source of household pollution in the Ciliwung River [16,20]. Anthropogenic activities in the vicinity of the Ciliwung River can induce surface water pollution, diminish the river's capacity to transport water, and degrade the overall quality of the river water [18]. The upstream region of the Ciliwung watershed traverses various land uses such as plantations, agriculture, and animal husbandry [21]. On the other hand, the downstream part of the watershed is characterized by industrial operations and residential districts. [22]. The influence of anthropogenic activities around the Ciliwung River can cause surface water pollution, reduce the river’s carrying capacity, and cause degradation of river water quality [18]. The Ciliwung watershed in the upstream area passes through plantations, agriculture, and animal husbandry; in the downstream region, it passes through industry and housing [21].

Previous research on the deterioration of the water quality in the Ciliwung River has been carried out by several researchers on multiple occasions [16,18-31]. The primary objective of this study is to employ a stable isotope methodology and physical factors to investigate the source of the Ciliwung River water. One notable distinction between the present study and other research is examining the correlation between physical parameters and stable isotopes to ascertain the water source. This study can potentially assist governmental bodies, scholars, and environmental planners in managing river water supplies effectively.

2. Materials and Methods

2.1 Study location

This research was conducted at the Ciliwung River, from upstream to downstream. Ciliwung Watershed is one of the watersheds in West Java, located between 06°10'00" - 6°40'12" South Latitude and 106°40'36"-107°00'00" East Longitude (Figure 1). The Ciliwung Watershed covers an area of 347 km^2 with a central river length of 117 km [28], flowing across the administrative regions of Bogor Regency, Bogor City, Depok City, and DKI Jakarta Province [31]. The average monthly rainfall in the area varies from 585 mm to 771 mm in the hilly region of Bogor. Based on 2020 data, the total amount of rainfall is 9,713.5, an increase of 6.35% [30]. Field investigations took 12 water samples and five isotope samples along the Ciliwung River, from upstream in Bogor Regency to downstream in DKI Jakarta Province. Figure 1 shows the location of the Ciliwung River and sampling sites along the river.

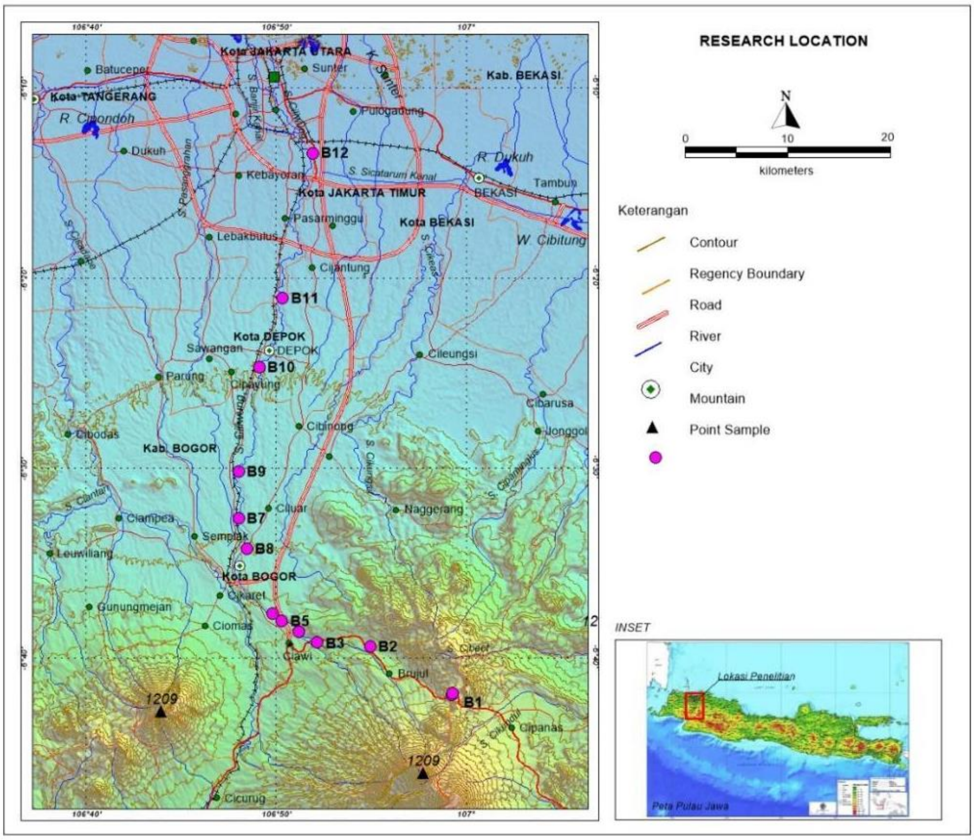

Figure 1. The study region and sampling location in the Ciliwung River were determined for this research (source: [32])

The hydrological characteristics of the Ciliwung River exhibit variability in flow rate, which is contingent upon the average annual precipitation within its respective watershed. The quantity of rainfall from the two wind regimes is influenced by two distinct seasons. The northwestern monsoon season, characterized by a low flow rate, spans from May to October and is commonly called the dry season. The southeast monsoon season, which coincides with the rainy season, lasts from November to April. This period is characterized by a significant increase in flow rate [24,26,33].

The elevated positioning of the area frequently results in inundation. The geological characteristics of the Ciliwung watershed are primarily shaped by the presence of volcanic materials originating from two volcanic mountains. Specifically, Mount Pangrango is characterized by tufa breccias, whereas Mount Salak is known for its alluvial deposits and fans. Most surface is predominantly characterized by alluvial deposits, primarily dirt, sand, and gravel. The primary geological makeup gives rise to highly fruitful soil types. The higher portions of the Ciliwung River are characterized mainly by tertiary sediments and intrusive rock components, while the middle sections consist primarily of quaternary sediments [34,35].

2.2 Method

The study employed many methodologies, including field investigations, sampling of river water, quantification of water quality parameters, and subsequent data analysis. The sample process was carried out throughout the temporal setting of the rainy season, specifically in April 2023. The water sample procedure involved using Horiba water checker equipment, DO Meter YSI Pro20, and a digital water quality tester for pH measurement. The parameters that are assessed directly in the field or situ include temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), and oxidation-reduction potential (ORP). The stable isotopes δ^2H and $\delta^{18}O$ are typically sampled by collecting a water sample in a polyethylene bottle with a volume of 100 mL. The bottle is securely sealed to minimize the occurrence of evaporation. The stable isotope analysis was performed in the Bandung Institute of Technology hydrogeochemistry laboratory, utilizing the cavity ring-down spectrometer (Picaro L-2130-i Analyzer) with a diffusion sampler. The data were adjusted to conform to the Vienna Standard Mean Ocean Water (VSMOW) by examining three standard waters with established isotopic compositions. The results of the replicated analyses demonstrate that the analytical precision, represented by the standard deviation ($\pm\sigma$), was ±0.02‰ for the isotopic composition of $\delta^{18}O$ and ±0.23‰ for δ^2H for the isotopic composition of δ^2H. The local meteoric water line (LMWL) equation is derived using the cumulative weighted component [36].

2.2.1 Statistical analysis.

The statistical analysis used is Pearson's Correlation and hierarchical group analysis. Pearson correlation was used to determine the relationship between the independent and dependent variables. Assumptions in Pearson correlation: Data must be normally distributed. Hierarchical group statistical analysis was carried out to analyze homogeneous data with the principle of grouping data with the same characteristics compared to data with other differences [37]—hierarchical group analysis with average linkage.

2.2.2 Stable Isotope Method

Research in isotope hydrology often used deuterium and oxygen-18 [38]. Isotopes lighter (1H) have a relatively greater abundance than other isotopes heavier (^2H), and ^{16}O has a greater quantity than $\delta^{18}O$. Comparison between heavy isotopes with light isotopes determined in ratio differences, such as ^2H /^1H and ^{18}O /^{16}O, for deviation deuterium isotopes are represented by δ^2H and for the deviation of the oxygen-18 isotope is stated with $\delta^{18}O$ [39]. Meteoric Water Line is a linear line relationship between values abundance of δ^2H and $\delta^{18}O$ in rainwater that form a graph, which is generated an equation that shows the relationship between δ^2H and $\delta^{18}O$ worldwide called the Global Meteoric Water Line (GMWL) [40]. The results of $\delta^{18}O$ and δ^2H are expressed in units per mil (‰), showing the ratio of the isotope content of ^{18}O to ^{16}O for $\delta^{18}O$ while δ^2H is the ratio of ^2H to ^1H. Both values are relative to the standard mean ocean water (SMOW-Standard Mean Ocean Water).

$$\delta^2H = 8\ \delta^{18}O + 10\ ‰$$

The GMWL line depicts isotope behavior over time and time in various places worldwide. This value differs for each area—the Local Meteoric Water Line (LMWL). is specific for certain areas. LMWL is the relationship between the concentration ratio of water isotopes of deuterium and oxygen-18 land at different elevations in a particular area of concentration isotopes of deuterium and oxygen-18 standardized in the ocean [41]. Indonesia also has the meteoric water line equation, resulting from

BATAN research through rain collection stations in Indonesia—the Indonesian LMWL graphic equation [29].

$$\delta^2H = 8.28\ \delta^{18}O + 15\ ‰$$

3. Results and Discussion

The origin of river water in the Ciliwung River was determined by measuring hydrogeological objects using the stable isotopes and physical characteristics technique. Figure 2 displays box and whisker charts representing hydrogeological objects. The examination of bivariate and multivariate correlations among several physical parameters of the Ciliwung river water reveals the presence of multiple environmental factors that significantly impact the quality of the river water.

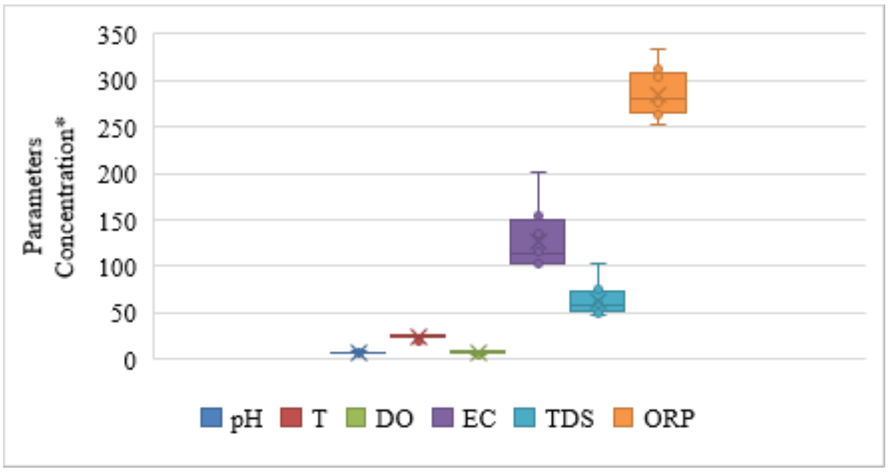

Figure 2. Box and whisker plots of the physical parameters (source: data analysis,2023) (*The unit used depends on the type of parameter: pH is no unit; T is °C; DO and TDS are mg/L; EC is µS/cm; ORP is mV)

The researchers compared the physical parameters of the study location with the guideline levels for drinking water and human consumption supplied by the World Health Organization (WHO) [42]. The WHO provides these levels as recommendations for drinking water and human consumption. The descriptive statistical results obtained from the in-depth computations carried out on water quality parameters during both the wet and dry seasons are presented in Table 1. These results can be seen in both tables.

Table 1. Summary statistics of analytical data in the Ciliwung River

Parameters	Min	Max	Average	St.Dev	Water Standard
pH	6.95	8.2	7.63	0.30	6-9
T (°C)	19.7	27	24.42	1.90	-
DO (mg/L)	5.5	9.21	7.65	1.05	6
EC (µS/cm)	102	201	126.38	29.22	-
TDS (mg/L)	47	104	62.92	15.75	1000
ORP (mV)	253	333	285.42	23.23	-

Source: The result of in-situ measurement, 2023
*Water quality standard for drinking water in Indonesia (Government Regulation Number 22 of 2021 -Appendix VI)

3.1 Statistical Analysis

The Pearson correlations conducted in the Ciliwung River revealed the associations between many factors within a particular correlation. Table 2 displays the correlation matrices, each representing a distinct set of variables. The findings exhibited positive and negative correlations, indicating a direct association with all hydrochemical variables. The data that underwent Pearson's Correlation analysis had 99% and 95% confidence levels, respectively.

Table 2. Pearson correlations for water samples in the Ciliwung River

	pH	T	DO	EC	TDS	ORP
pH	1					
T	-.679*	1				
DO.	.812**	-0.574	1			
EC.	-.864**	0.530	-.864**	1		
TDS	-.899**	.591*	-.848**	.991**	1	
ORP	-.724**	.586*	-.624*	.851**	.844**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
Source: data analysis, 2023

There is a substantial association between pH and several other variables, including electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and oxidation-reduction potential (ORP). Additionally, pH has a modest correlation with temperature. The pH level does not directly impact the environment, but it is a significant parameter that defines the appropriateness of water for different purposes [43]. A moderate correlation exists between temperature and pH, EC, TDS, DO, and ORP variables. Water temperature is a significant characteristic crucial in assessing its appropriateness for various human and industrial purposes and the functioning of aquatic ecosystems [44]. While it is not employed for directly assessing potable water, it plays a crucial role in governing the presence and behavior of several biological organisms and influencing the rate of their activities.

Furthermore, it significantly impacts most chemical processes within natural water systems and the solubility of gases [45]. The electrical conductivity (EC) exhibits a significant correlation with pH, total dissolved solids (TDS), dissolved oxygen (DO), and oxidation-reduction potential (ORP). The association between TDS and EC is influenced by the composition and characteristics of the dissolved cations and anions in the water [46]. There is a substantial correlation between total dissolved solids (TDS) and the variables of pH, electrical conductivity (EC), dissolved oxygen (DO), and oxidation-reduction potential (ORP). This significant correlation demonstrates a strong relationship between TDS and these factors.

Additionally, the relationship between TDS and these variables can be moderately strong. The relationship between temperature and the dissolution of rock minerals has been found to impact groundwater's geochemistry (Reference 36) significantly. The concentration of Dissolved Oxygen (DO) exhibits a significant positive correlation with pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC). In contrast, it demonstrates a moderate positive correlation with Oxidation-Reduction Potential (ORP). The concentration of dissolved oxygen (DO) plays a significant role in assessing surface water quality since it is subject to several physical, chemical, and biological elements in river water [47]. The oxidation-reduction potential (ORP) measures the comparative inclination of a solution to conduct either oxidation or reduction reactions. Therefore, the oxidation status of chemical species in the solution can be influenced [48].

A hierarchical group analysis was employed to examine a homogenous data set by categorizing data with similar features in contrast to data with dissimilar attributes [49]. The hierarchical dendrogram analysis of the volcanic hills along the Ciliwung River was conducted based on the Euclidean distance. The resulting dendrogram revealed the presence of two distinct major groups, namely Group A and Group B (refer to Figure 3).

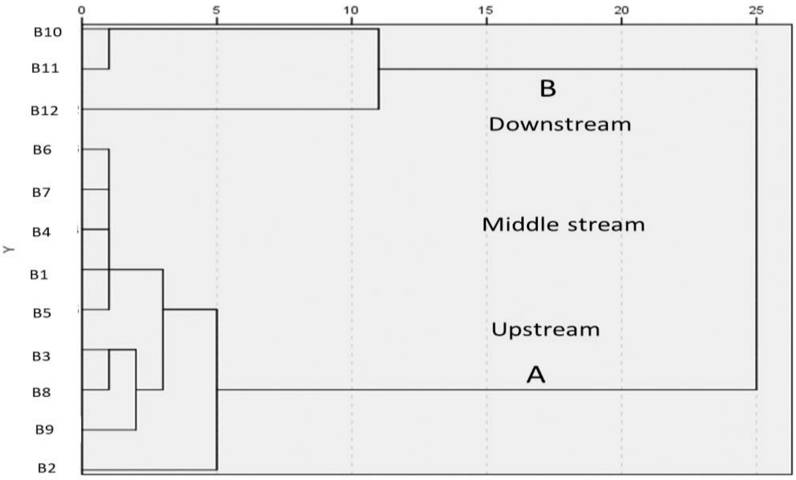

Figure 3. The dendrogram presented herein illustrates the results of a hierarchical group analysis conducted on the Ciliwung River (source: data analysis,2023)

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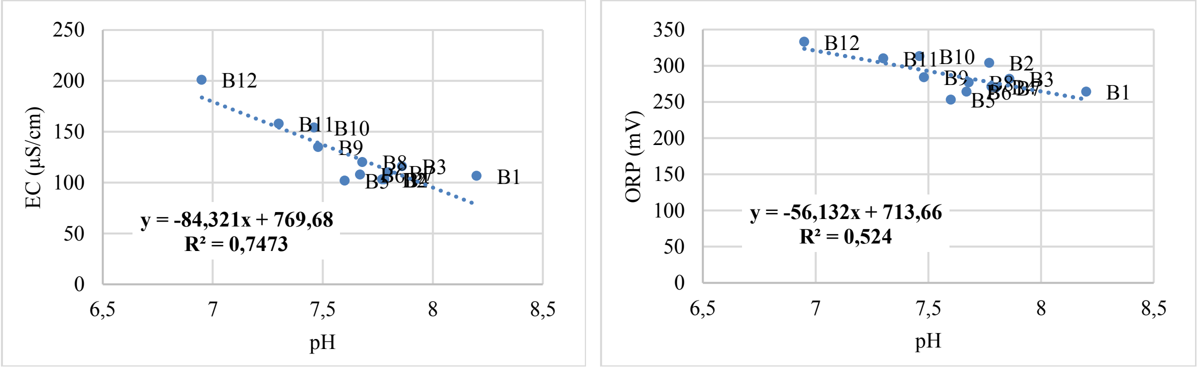
Group A refers to rivers in the upstream and middle regions, characterized by moderate to medium physical parameter values. The input of anthropogenic origin is assessed to be at a medium level. Group B refers to the rivers located in downstream areas, characterized by elevated physical parameter values and a substantial contribution from anthropogenic sources. The grouping analysis results indicate that the river water's characteristics remain consistent as one moves from the upstream to the downstream.

3.2 Bivariate correlation analysis of several physical parameters

The investigation of the source of water and toxins within river systems necessitates the utilization of various methodologies and the implementation of tracers across different levels of analysis. Various scientific methods are employed to ascertain the source of river water, including isotopes, physical factors, and heavy metals. The bivariate correlation study conducted on multiple physical parameters of the Ciliwung River water reveals several environmental factors that impact the quality of the river water. The investigation of the association between several physical parameters reveals multiple ecological influences in the Ciliwung River, as depicted in Figure 4. Alterations in water temperature within river systems are among the most noteworthy environmental transformation indicators. Water temperature shapes river systems' physical characteristics and chemical processes [50]. The pH of a solution has a direct relationship with dissolved oxygen (DO), meaning that as the DO increases, the pH also increases. Conversely, the pH demonstrates an inverse relationship with electrical conductivity (EC), total dissolved solids (TDS), and oxidation-reduction potential (ORP). This implies that as EC, TDS, or ORP increase, the pH decreases. Figure 4 illustrates that a high dissolved oxygen (DO) value indicates favorable river water quality, whereas a low DO value suggests the opposite.



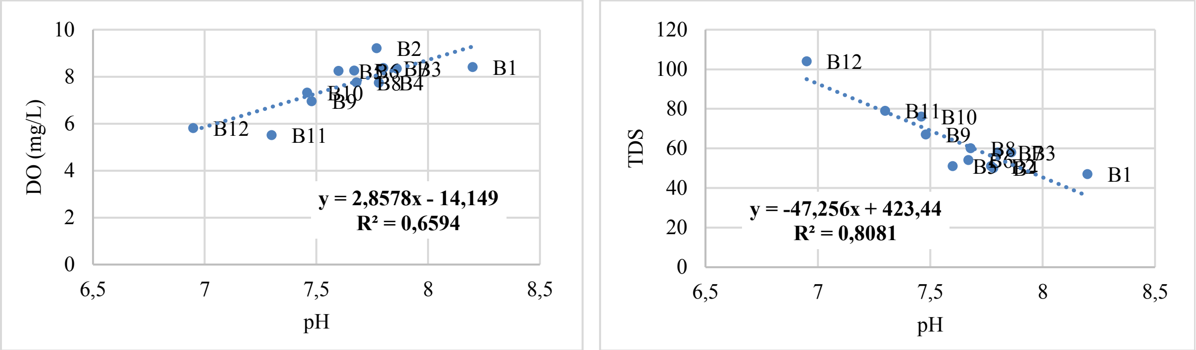


Figure 4. Correlation pH with TDS, EC, ORP, and DO (Source: data analysis,2023)

The examination of the association between several physical characteristics reveals multiple environmental influences in the Ciliwung River, as depicted in Figure 5. Alterations in water temperature within river systems are among the most notable ecological transformation indicators. Water temperature shapes many physical features and chemical and biological reactions within river systems [50]. The bivariate correlation study conducted on multiple physical parameters of the Ciliwung River water reveals the presence of various environmental factors that influence the quality of the river water. The pH level is a significant factor in assessing the appropriateness of water for different purposes [43]. Hydrochemical fluctuations were visualized by creating plots of pH concerning electrical conductivity (EC) and oxidation-reduction potential (ORP) [51]. The upstream area exhibits a lower oxidation-reduction potential (ORP). The redox potential is enhanced by dissolved oxygen (DO) and oxidation ions, as stated in reference [52].

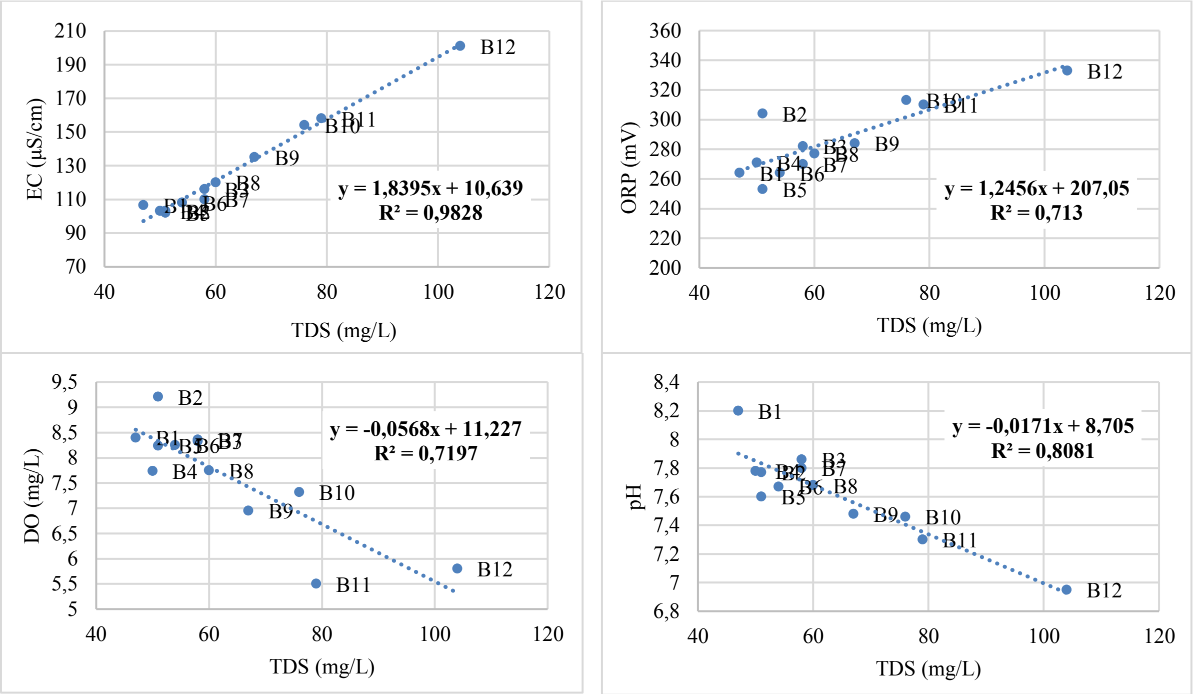


Figure 5. Correlation TDS with pH, EC, ORP, and DO (source: data analysis,2023)

The dissolved oxygen (DO) concentration exhibits elevated levels in the upstream region, indicating minimal impact from chemical, biological, and anthropogenic factors on the Ciliwung River. Oxidation-reduction potential (ORP) is the quantitative measure of a liquid's capacity to eliminate bacteria inside a water system. The downstream duration required for bacterial eradication is directly proportional to the magnitude of the oxidation-reduction potential (ORP) value. The observed relationship between pH and dissolved oxygen (DO) suggests an inverse association, wherein higher DO levels correspond to lower pH values. This phenomenon is particularly evident in alkaline environments characterized by elevated solid content, which can be attributed to the mineral composition of mountainous regions. Water sources in the areas represented by frigid temperatures are known to have elevated quantities of dissolved oxygen (DO). Total Dissolved Solids (TDS) serve as an indicator of groundwater quality, specifically the presence of contaminants. These contaminants are characterized by organic and inorganic substances that can dissolve in water. The concentration of total dissolved solids (TDS) in water exhibits significant variation in geological regions due to disparities in mineral solubility [53]. The concentration and composition of total dissolved solids (TDS) in natural waterways are influenced by various factors, including geological conditions, drainage patterns, atmospheric precipitation, and evaporation-deposition processes [54]. The total dissolved solids (TDS) exhibit a direct relationship with electrical conductivity (EC) and oxidation-reduction potential (ORP) while displaying an inverse relationship with pH and dissolved oxygen (DO). A high total dissolved solids (TDS) concentration indicates a diminished water quality in the river. Water characterized by a high total dissolved solids (TDS) concentration will result in a correspondingly low dissolved oxygen (DO) concentration, and conversely, water with a low TDS value will lead to a higher DO concentration. This state is associated with the process of eutrophication resulting from the dumping of waste and the utilization of surfactants containing phosphorus [55]. The elevated levels of total dissolved solids (TDS), electrical conductivity (EC), and entropy (ent) in the aquatic environment are indicative of heightened toxicity to the organisms.

3.3 The Stable Isotopes and Determination of Water Origin in the Ciliwung River

Stable isotope compositions δ^2H and $\delta^{18}O$ have been collected from 5 locations in the Ciliwung River. Hydrochemical and heavy metal investigations were conducted in March 2023, and samples were taken from various river locations (Table 3).

Table 3. Stable isotope composition of δ^2H and $\delta^{18}O$ in the Ciliwung River

Sample Code	$\delta^{18}O$ (‰)	δ^2H (‰)	pH	T (°C)	DO (mg/L)	EC (µS/cm)	TDS (mg/L)	ORP (mV)
B1	-8.161	-48.64	8.2	19.7	8.4	106.5	47	264
B5	-7.522	-44.92	7.6	23	8.24	102	51	253
B7	-7.484	-44	7.8	24	8.36	110	58	270
B9	-7.316	-42.8	7.48	24	6.95	135	67	284
B12	-6.937	-41.23	6.95	27	5.8	201	104	333

Source: The result of laboratory analysis, 2023

Previous research indicated that the groundwater catchment area for the Jakarta basin is south of Bogor [27]. The results of the $\delta^{18}O$ and δ^2H analysis for Ciliwung River water are shown in Figure 4. According to BATAN research, the local meteoric water line (LMWL) used in this diagram is the LMWL graphic equation of $\delta^2H = 8.28\ \delta^{18}O + 15$ [29]. The slope of the trendline (6.21) is significantly less than the slope of LMWL (8.28), indicating the influence of evaporation [56,57].

The points distribution in the local meteoric water range is $\delta^2H = 6.2157\ \delta^{18}O + 2.2$, indicating that river water is dominantly derived from rainwater (Figure 6). The natural isotope for the Ciliwung River, especially δ^2H and $\delta^{18}O$, tends to be enriched downstream. This condition is caused by the altitude influence of the Ciliwung River, which flows from around 1500 m in Puncak to 0 m in Jakarta. Isotope $\delta^{18}O$ ranges from -8.161 ‰ to -6.937, and deuterium ranges from -48.64 ‰ to -41.23 ‰.

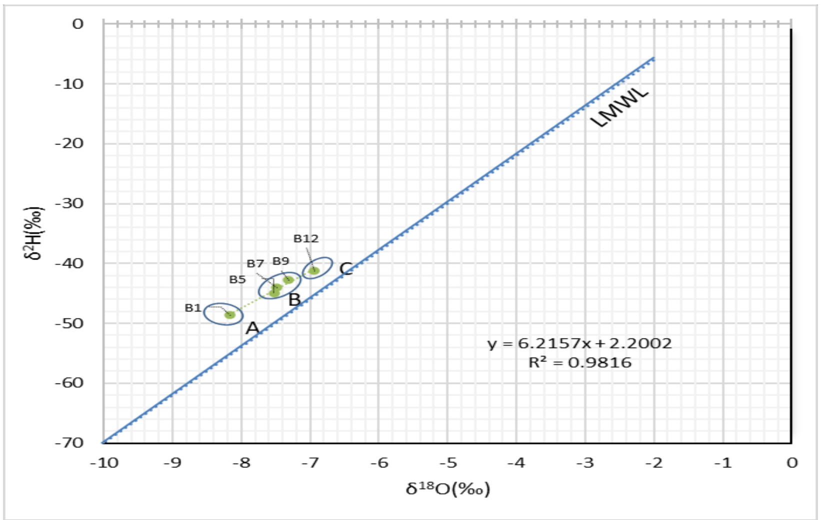


Figure 6. The Stable Isotopes in the Ciliwung River (source: data analysis,2023)

Group A represents the river water sample denoted as B1. This particular sample originates from the recharge area, characterized by its higher elevation. The primary source of water in this location is predominantly derived from rainwater. Group B refers to the river water in the middle part at B5, B7, and B9. This river water originates from the recharge area situated at the top. It is worth noting that the river water in Group B has undergone a discernible alteration in the isotope composition of δ^2H and δ^{18}O compared to its original design. Compared to the surrounding groundwater, isotope enrichment has been observed in Group C, which is downstream (B12). The presence of this particular site can be attributed to the interplay between river water and water containing physical compounds and heavy metals, wherein the exchange of 2H isotopes occurs between H_2O (groundwater) and H_2S. The H_2S chemical is formed as a byproduct of the waste breakdown process. In this study, B12 is regarded as either an end-member or a contaminant. The analysis of δ^2H and δ^{18}O graphs depicting the properties of river water in the Ciliwung River reveals that a significant majority of the samples originate from a shared recharge location. Groundwater is situated inside the meteoric pathway, signifying that it undergoes minimal isotope exchange with the surrounding geological formations it traverses.

3.4 Correlation of stable isotopes and physical parameters

The findings from stable isotope research indicate that rainwater constitutes the primary water source in the Ciliwung River. Multiple correlations between stable isotopes and physical factors suggest a robust association between these variables. The quantity of dissolved oxygen in surface waters indicates water quality and the influence of pollution loads from different discharge sources [58]. The levels of dissolved oxygen and δ^{18}O in river water are influenced by gas exchange with the environment, respiration, and photosynthetic production [59]. The correlation between dissolved oxygen (DO) and the stable isotope δ^{18}O exhibits a moderate correlation (R^2 = 0.663), while the correlation between DO and the stable isotope δ2H also demonstrates a moderate correlation (R^2 = 0.629). The dissolved oxygen (DO) value exhibits an inverse relationship with the isotopes δ2H and δ^{18}O. The downstream region shows an increase in the enrichment of stable isotopes while concurrently experiencing a reduction in dissolved oxygen (DO) values. The relationship between pH and δ^{18}O has a significant correlation (R^2= 0.9282), whereas the link between dissolved oxygen (DO) and δ^2H also demonstrates a substantial association (R^2= 0.895). There exists an inverse relationship between the pH value and the isotopes δ^2H and δ^{18}O. The downstream region exhibits a reduction in pH value while concurrently experiencing an enrichment of stable isotopes, as depicted in Figure 7.

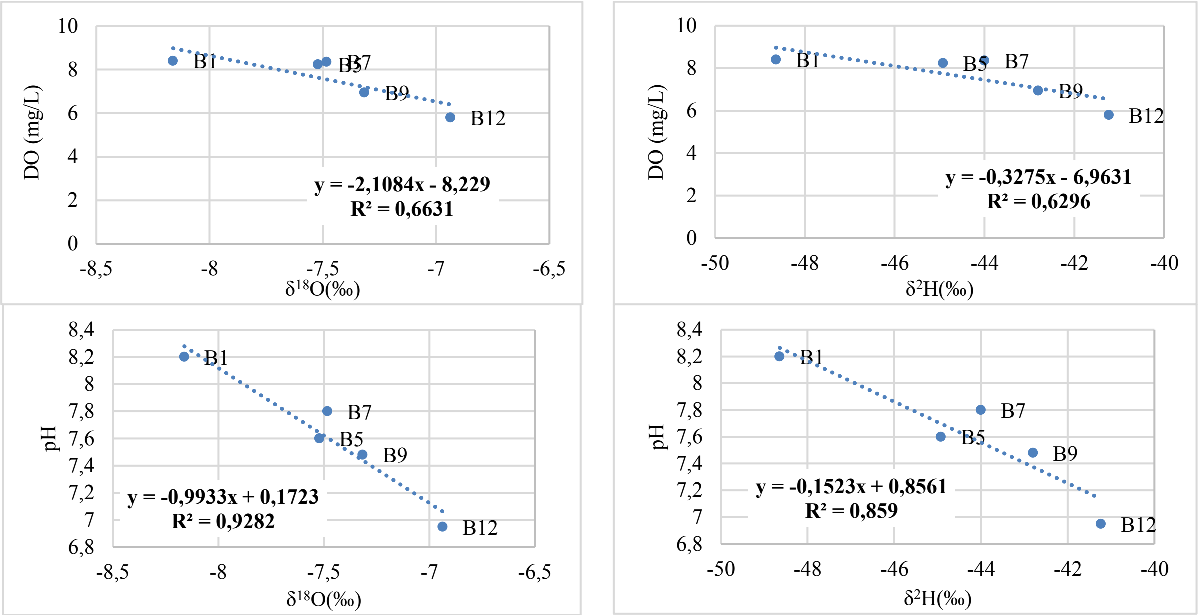


Figure 7. Correlation of stable isotopes with pH and DO (source: data analysis,2023)

The relationship between Total Dissolved Solids (TDS), Electrical Conductivity (EC), Oxidation-Reduction Potential (ORP), and stable isotope values exhibits a direct proportionality. The isotopic values in the upstream region exhibit depletion, while the downstream region demonstrates enrichment (see Figures 8a and 8b). Anthropogenic factors influence the physical properties of the Ciliwung River. Downstream, there is a tendency for the physical water parameters to become enriched. This situation can be attributed to utilizing fertilizers, while the deposition of home and industrial waste on agricultural land exacerbates the proliferation of contaminants.

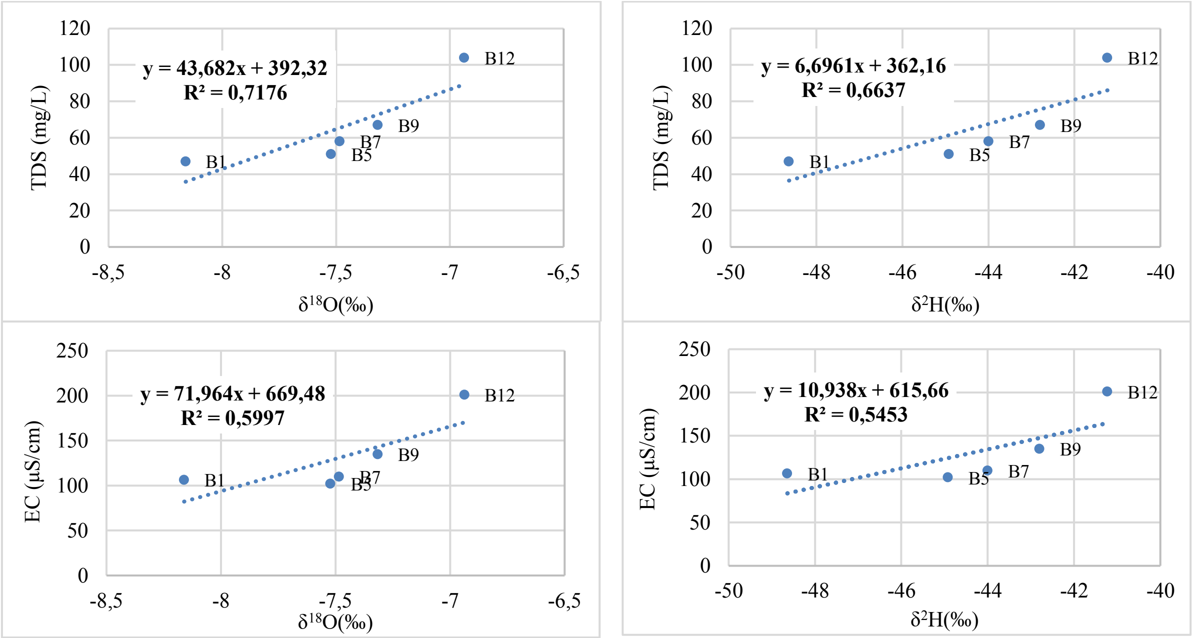


Figure 8a. Correlation of stable isotopes with EC and TDS (source: data analysis,2023)

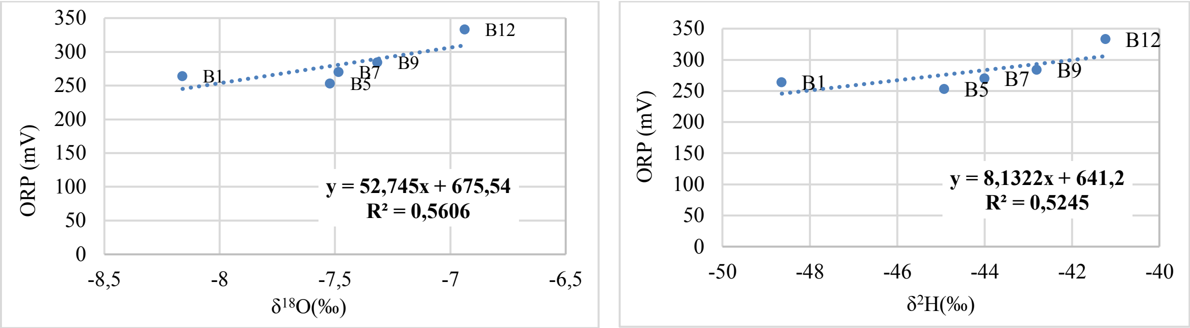


Figure 8b. Correlation of stable isotopes with ORP (source: data analysis,2023)

4. Conclusions

The findings indicated that the source of Ciliwung water primarily consists of precipitation. The upstream area exhibits lower concentrations of physical characteristics such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Oxidation-Reduction Potential (ORP) in comparison to the downstream area, which is undergoing enrichment. This situation exhibits an inverse relationship with the dissolved oxygen (DO) and pH levels associated with the oxygen content of the water. The findings mentioned above are corroborated by the correlation analysis outcomes between physical characteristics and stable isotopes, which suggest an increase in enrichment in the river's water downstream. The enrichment of water bodies can be attributed to inputs from anthropogenic activity, namely, home, agricultural, and industrial pollutants. The findings of this study hold significant value for governmental entities and scholars alike, as they inform the development of conservation strategies for the Ciliwung River. Further refinement of the research is essential, as a more extensive examination is needed to analyze the environmental isotopes in the Ciliwung River thoroughly.

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