The Water Quality Characteristics and Quality Status of Bengkulu River and Nelas River, Bengkulu Province: Conditions for The Last Six Years

I Khalik¹, A Sapei², S Hariyadi³ and E Anggraeni⁴

¹ Natural Resources and Environmental Management Study Program, Graduate School of IPB University, Bogor, Indonesia
² Department of Civil and Environmental Engineering, IPB University, Bogor, Indonesia
³ Department of Aquatic Resources Management, IPB University, Bogor, Indonesia
⁴ Department of Agroindustrial Technology, IPB University, Bogor, Indonesia
⁵ Public Health Study Program, STIKES Tri Mandiri Sakti, Bengkulu, Indonesia

E-mail: idham_khalik_idham@apps.ipb.ac.id

Abstract. The existence of extractive activities around the river has a negative impact on the quality of river water. This study aims to provide an overview of water quality characteristics and water quality status of Bengkulu River and Nelas River in Bengkulu Province. The data used is river quality monitoring conducted by the Environment and Forestry Service of Bengkulu Province from 2014 to 2019. Measurements are carried out twice a year representing the dry season (March to June) and the rainy season (September to December). The observation stations representing upstream, middle and downstream of rivers conditions. The parameters observed were physical, chemical, and biological parameters. The water quality status is determined using the Storet Index. The results show that both rivers have Storet Index >31. It means that these river water are heavily polluted. Parameters that have exceeded the water quality standard are TSS, DO, BOD, COD, Fe, Mn, Cu, and total coliform. The river water quality parameters, especially heavy metals, may be caused by open land being washed and carried into the river body. The existence of population and animal activities as well as industrial waste outlets at upstream also affect the decline of river water quality.

1. Introduction

Water is one of the fundamental elements needed for the survival of living things. Currently, surface water is one of the most important sources of water and is widely used for agricultural, industrial and domestic activities. As one of the surface waters, rivers are also used as the main source of clean water [1]. The increase in population and economy are the factors that trigger an increase in clean water demand. But on the other hand, there is a scarcity of water sources becomes serious problem and challenge faced by various countries [2]. There are many causes of pollution and river water quality degradation, such as changes in land use and land cover, settlement activities, mining, increased use of pesticides and fertilizers, industrial waste [1,2]. Unsafe water is a medium for the transmission of several types of infectious diseases [3]. Disease events caused by water pollution can have a negative impact on economic activity and even lead to death [4]. The availability of drinking water is closely related to adequate clean water. Clean water is a water resource with good quality and is usually used by humans...
for consumption or to support daily activities [5]. It shows the importance of controlling and monitoring surface water quality as a source of clean water [6].

Bengkulu River and Nelas River located in Bengkulu Province are surface water used by the Regional Drinking Water Company (PDAM) as a source of raw water for Bengkulu City. In addition, based on the Local Government Regulation of Bengkulu Province (Peraturan Daerah/Perda) Number 6/2005 regarding Stipulation of Water Quality Standards and Classes of Cross-Regency/City River Water in Bengkulu Province, the rivers are designated as sources of raw water (Class I). The upstream and midstream areas of Bengkulu River are located in Central Bengkulu Regency, while the upstream area of Nelas River is located in Seluma Regency. Both rivers empty into the city of Bengkulu. Bengkulu City is the capital city of Bengkulu Province which is located on the west coast of Sumatera Island. The city has an area of 151.70 km². The population of Bengkulu City in 2020 is 373,591 people, with a population growth rate of around 1.87% per year [7]. This study aims to provide an overview of the characteristics of water quality and water quality status of Bengkulu River and Nelas River, Bengkulu Province.

2. Research Method

2.1. Study area
The research was conducted in Bengkulu River and Nelas River, Bengkulu Province. The Bengkulu River flows from the upstream, which is in the Bengkulu Tengah (Central Bengkulu) Regency region, and downstream in Bengkulu City. Meanwhile, the upstream area of the Nelas River is in Seluma Regency, and the downstream area is in Bengkulu City. These rivers are sources of fresh water in Bengkulu City. The sampling points of each river were carried out representing upstream, middle and downstream areas. In 2014, sampling was carried out at 3 (three) points representing upstream (Rindu Hati village), middle (Kembangseri village) and downstream areas (Rawa Makmur village) for the Bengkulu River; and upstream (Talang Sebaris village), middle (Sukaraja village), downstream (Padang Serai village) for Nelas River. However, since 2016 additional sampling points have been made so that there are 6 (six) locations for the Bengkulu River, and 5 (five) locations for the Nelas River. All sampling location points are presented in table 1 below.

| No | Sampling point       | Coordinate               | Information     |
|----|----------------------|--------------------------|-----------------|
|    | **Bengkulu River**   |                          |                 |
| 1  | Rindu Hati village   | S 03° 40' 54.22"; E 102° 33' 26.96" | Upstream       |
| 2  | Penanding village    | S 03° 45' 52.26"; E 102° 33' 26.96" | Middle stream 1 |
| 3  | Pulau Panggung village | S 03° 48’ 11.12”; E 102° 23’ 38.45" | Middle stream 2 |
| 4  | Kembangseri village | S 03° 47’ 27.12”; E 102° 21’ 47.9” | Middle stream 3 |
| 5  | Nakau village       | S 03° 46’ 38.01”; E 102° 20’ 28.42” | Middle stream 4 |
| 6  | Rawa Makmur village | S 03° 46’ 47.87”; E 102° 16’ 12” | Down stream     |
|    | **Nelas River**      |                          |                 |
| 1  | Talang Sebaris village | S 03° 55’12.5”; E 102° 28’28” | Upstream       |
| 2  | Lubuk Payun village | S 03° 55’22.57”; E 102° 26’10.03” | Middle stream 1 |
| 3  | Sukaraja village     | S 03° 55’9.33”; E 102° 24’9.28” | Middle stream 2 |
| 4  | Jenggalu village    | S 03° 55’03.48”; E 102° 21’56.5” | Middle stream 3 |
| 5  | Padang Serai village | S 03° 54’60.4”; E 102° 19’13.1” | Down stream     |

2.2. Data
The data series used in this study were provided by the Environmental and Forestry Service of Bengkulu Province, the agency responsible for monitoring cross-district/city river water quality. The dataset used covers a period of 6 years from 2014 to 2019. The measurements were conducted twice a year, representing dry and rainy seasons. Measurement for the dry season was carried out between March and
June, while measurement for the rainy season was carried out between September and December every year. Water quality parameters include: physical, chemical, and biological. Physical parameter i.e.: Total dissolved solids (TDS), Total suspended solids (TSS). And chemical parameter, i.e.: pH, Dissolved Oxygen (DO), Iron (Fe), Manganese (Mn), Copper (Cu), Biochemical oxygen demand (BOD), Chemical Oxygen Demand (COD), Sulfate (SO$_4^{2-}$), Nitrite (NO$_2$-N), Oil and grease. While the biology parameter is total coliform. Each of these parameters is presented in table 2 below.

**Table 2. Water parameter and quality standard.**

| No. | Parameter                             | Unit     | Class I | Class II | Class III | Class IV |
|-----|---------------------------------------|----------|---------|----------|-----------|----------|
|     |                                       |          |         |          |           |          |
| **Physic** | Total dissolved solids (TDS) | mg/L    | 1.000   | 1.000    | 1.000     | 2.000    |
| 1   |                                       |          |         |          |           |          |
| 2   | Total suspended solids (TSS)          | mg/L    | 40      | 50       | 100       | 400      |
| **Chemical** | pH                                   |          | 6-9     | 6-9      | 6-9       | 6-9      |
| 1   |                                       |          |         |          |           |          |
| 2   | Dissolved oxygen (DO)                | mg/L    | 6       | 4        | 3         | 1        |
| 3   | Iron (Fe)                            | mg/L    | 0,3     | -        | -         | -        |
| 4   | Manganese (Mn)                       | mg/L    | 0,1     | -        | -         | -        |
| 5   | Copper (Cu)                          | mg/L    | 0,02    | 0,02     | 0,02      | 0,2      |
| 6   | Biochemical oxygen demand (BOD)      | mg/L    | 2       | 3        | 6         | 12       |
| 7   | Chemical oxygen demand (COD)         | mg/L    | 10      | 25       | 40        | 80       |
| 8   | Sulfate (SO$_4^{2-}$)                | mg/L    | 300     | 300      | 300       | 400      |
| 9   | Nitrite (NO$_2$-N)                   | mg/L    | 0,06    | 0,06     | 0,06      | -        |
| 10  | Oil and grease                       | mg/L    | 1       | 1        | 1         | 10       |
| **Biology** | Total Coliform                  | MPN/100 mL | 1.000  | 5.000    | 10.000    | 10.000   |

Note: *) Government Regulation (GR) No. 22/2021 regarding Implementation of Environmental Protection and Management.

- Class I, water that allocated to be used for drinking water and/or another usage that required same water quality,
- Class II, water that is allocated to be used for water recreation infrastructure/facilities, freshwater fish cultivation, livestock, irrigate planting, and/or another usage that requires the same water quality,
- Class III, water that allocated to be used for freshwater fish cultivation, livestock, irrigate planting, and/or another usage that required same water quality,
- Class IV, water that is allocated to be used for watering plants and/or another usage that requires the same water quality.

2.3. Data analysis

Data analysis was using the STORET Index method. STORET comes from the word Storage and Retrieval. The method is used to determine water quality based on time series data, including parameters: physical, chemical, and biological [8]. Initially, this method was developed by United States-Environmental Protection Agency (US-EPA). The method is commonly used to determine water quality status as stipulated by the State Minister of Environment Decree No. 115/2003 regarding guidelines to determining water status. This method compares measurement data with water quality standards based on their designation. The method has advantages, namely: calculation is simpler and faster, and it is easier to identify contaminants that cause pollution. However, this method has
weaknesses such as: it requires more than one data set or time series data, so it cannot be applied if it only has one data set [9].

The procedures to water quality determination using Storet Index method were as follow: (i) Collecting data of water quality periodically (time series data); (ii) Comparing the measurement data from each parameter with water quality standard value according to its class; (iii) If the measurement results met water quality standards (measurement result ≤ quality standard) then it scored 0; (iv) If the measurement result did not fulfill the water quality standard (measurement result > quality standard) then score is given (table 3); (v) Then, all of the negative parameters above are counted, and quality status is determined from total score obtained using score system. The minus value for each of the parameters above indicates that measurement results at the time of study have exceeded specified quality standards. River water quality standards are divided into 4 (four) classes as stipulated GR No. 22/2021. Determination of water quality status using a value from the US-EPA by classifying water quality into four classes (table 4).

### Table 3. Score each parameters water quality status.

| Sample quantity | Score Parameter | Physic | Chemical | Biology |
|-----------------|-----------------|--------|----------|---------|
| <10             | Maximum         | -1     | -2       | -3      |
|                 | Minimum         | -1     | -2       | -3      |
|                 | Average         | -3     | -6       | -9      |
| ≥10             | Maximum         | -2     | -4       | -6      |
|                 | Minimum         | -2     | -4       | -6      |
|                 | Average         | -6     | -12      | -18     |

### Table 4. Classification and water quality status.

| Class            | Score   | Water quality status          |
|------------------|---------|-------------------------------|
| Class A : Excellent | 0       | meet quality standards        |
| Class B : good    | -1 to -10 | lightly polluted              |
| Class C : medium  | -11 to -30 | moderately polluted          |
| Class D : bad     | ≥ -31   | heavily polluted              |

### 3. Result and Discussion

#### 3.1. Water quality

Water pollution can occur when substances or pollutants enter water that exceeds its ability to decompose it. Pollution is the entry or inclusion of living things, substances, energy, and/or other components into water. Water pollution is caused by a natural process from the environment itself and the existence of human activities that reduce the quality of water. So, water does not function according to its designation. Water quality is determined by testing its parameters. The parameters are physics, chemistry, and biology.

The Bengkulu River flows from upstream to midstream at Bengkulu Tengah Regency, and downstream at Bengkulu City. Meanwhile, the Nelas River flows from upstream to midstream at Seluma Regency, and downstream at Bengkulu City. In the downstream area, the rivers are used as a source of raw water for drinking water at Bengkulu City. Based on the Local Government Regulation 6/2005, Bengkulu River and Nelas River are designated as the trans-district/city rivers with water quality criteria of class I, namely water whose designation can be used for drinking water raw and/or same water quality usage.

Based on analysis results, the water quality parameters of Bengkulu River and Nelas River from 2014 to 2019 showed that the water quality continues to decline, and no improvement has been seen. From 13 parameters analyzed, some parameters have not yet exceeded the river water quality standards, namely TDS, pH, sulfate, and nitrite. While the other analyzed parameters have exceeded quality
standards, namely: TSS, DO, BOD, COD, Fe, Mn, Cu, and total coliform. The following are the results of the water quality analysis of the Bengkulu and Nelas rivers from 2014 to 2019.

**Total dissolved solids (TDS).** The TDS value of Bengkulu River water in 2014-2019 is in range of 32 mg/L-352 mg/L. At the same time, the TDS value of Nelas river water ranges from 15 mg/L-492 mg/L. TDS values at all sampling points still fulfilled the quality standard for all classes of river water designation (Class I, II, III, and IV). TDS value is generally higher in the rainy season compared to the results in the dry season measurement.

**Total suspended solids (TSS).** The TSS value in Bengkulu River has a fairly large range from 1 mg/L-4,220 mg/L. A high TSS value that has exceeded quality standards indicates the occurrence of river water pollution. While in Nelas River, it ranges from 1 mg/L-249.5 mg/L. This value meets river water quality standard for class IV is intended for irrigation crops. The existence of coal mining concessions, rubber and palm oil processing factories, and settlements is allegedly the cause of increased TSS value. In addition, the high value of TSS is also estimated to come from fertilizers and pesticides used for plantations and agriculture. It is in line with previous studies which showed high TSS values as a result of mining and rubber processing plants [10,11]. And than, the existence of small and medium-sized industries also contributes to increasing TSS value [12]. The area changes to be developed and agricultural activities significantly increase TSS parameters, thereby reducing river water quality [13]. The high TSS value is influenced by rainfall, slope, soil type, and land-use patterns [14].

**Acidity (pH).** Based on the analysis result, the pH value of Bengkulu River ranged from 5.8-8.4, while for Nelas River, it ranged from 5.8-8.1. Overall, pH values in both rivers still meet quality standards. The pH value indicates that anthropogenic activities around rivers have not had much effect on the acidity of the Bengkulu and Nelas rivers.

**Dissolved oxygen (DO).** In 2014-2019, the DO value of Bengkulu river ranged from 3.1-8.4 mg/L while the DO value of Nelas river went from 2.7-12.9 mg/L. DO quality standard based on GR No. 22/2021 is 6-1 mg/L. Based on DO value, the river waters are met class III (water can be used for aquaculture and/or which requires the same designation). The DO value continues to show a decrease from year to year, which indicates the occurrence of pollution and a decline in the water quality of rivers. The DO decrease was allegedly caused by residential activities at upstream areas [12,15] and indications waste released by rubber factories [10]. The other impact of declined DO will disrupt water organisms.

**Iron (Fe).** Fe values detected in Bengkulu River ranged from 0.0 mg/L-7.1 mg/L, while in Nelas River it was detected from 0.0 mg/L-2.0 mg/L. The maximum Fe value detected in the rivers has exceeded class I water quality standard 0.3 mg/L. In line with previous research that high Fe value in Bengkulu river was caused by coal mining so that mineral content at top-soil cover was washed and carried by rainwater to river body [10].

**Manganese (Mn).** Mn value detected in Bengkulu River ranged from 0.0 mg/L-1.3 mg/L, while in Nelas River it was detected from 0.0 mg/L-0.8 mg/L. The Mn value has exceeded the river water quality standard for class I, which is 0.1 mg/L. The increased value of Mn is thought to have come from mining activities in upstream areas. It can have a further impact on other species, including human health.

**Copper (Cu).** At the study site, Cu values detected in Bengkulu River ranged from 0.0 mg/L-4.8 mg/L, while in Nelas River it was detected from 0.0 mg/L-3.86 mg/L. In some sampling locations, Cu value has exceeded river water quality standards. Based on GR No. 22/2021, the permissible Cu value is 0.02 mg/L for water class I-III and 0.2 mg/L for class IV. The Cu value was detected relatively high in 2019, which indicates declining the quality of the rivers. Cu is thought to have originated from the opening of coal mines which were then washed and entered the water body. The potential Cu in river waters can also come from activities of rubber and palm oil processing industries.

**Biochemical oxygen demand (BOD).** The BOD of Bengkulu River ranged from 0.3 mg/L-29 mg/L, while Nelas River ranged from 0.6 mg/L-11.8 mg/L. The BOD value is much higher at the middle to downstream sampling point. It is due to the possibility of accumulation of organic materials from various sources at upstream. Land use forms of settlements, factories, agriculture, and animal husbandry have been allegedly caused an increase in BOD value. It is in line with previous research, which showed a link between land use patterns, especially settlements and agricultural activities, with an increase in
BOD [16,17]. In addition, the pattern of settlements that follow the flow of the river can also indicate high BOD parameters [14]. An increase in built-up area is positively correlated with a decrease in water quality. On the other hand, forest and agricultural areas are negatively correlated with decreasing water quality [18,19].

Chemical oxygen demand (COD). The COD value of Bengkulu River was in range of 1 mg/L-300 mg/L, and Nelas River was in range of 3.5 mg/L-64 mg/L. Most of the COD values have exceeded river water quality standard, which is 10 mg/L-80 mg/L. Generally, since 2014-2019, COD values have increased at almost all sampling points. It indicates the occurrence of pollution and degradation of river quality is still happening. Sources of pollution related to COD values are settlements, agriculture, and rubber and oil palm factories. Previous studies showed that the contribution of COD pollutant sources in the Nelas river mostly came from households and livestock [20]. The presence of a factory in the middle also contributes to increasing of COD [11]. It is also supported by another research in which increases of in COD values is positively correlated to industries and settlements [19,21].

Sulfate (SO\textsubscript{4}\textsuperscript{2-}). The analysis results showed that the SO\textsubscript{4}\textsuperscript{2-} value in Bengkulu River ranged from 1 mg/L-290 mg/L, while in Nelas River it ranged from 1 mg/L-400 mg/L. Generally, the average sulfate value detected ranges from 300 mg/L-400 mg/L, this is still below the water quality standard. However, large sulfate values were detected in both rivers in 2019. The increase of sulfate values in both rivers is caused by coal mining activities, industrial waste disposal, and domestic activities. It is supported by previous studies showing a positive correlation of increasing sulfate values with anthropogenic, industrial, agricultural pollution, and coal mining [22].

Nitrite (NO\textsubscript{2}-N). Nitrite values detected in Bengkulu River ranged from 0.0 mg/L-0.02 mg/L, while in Nelas River it ranged from 0.0 mg/L-0.04 mg/L. Generally, nitrite value is still below the quality standard of 0.06 mg/L, but it is close to a quality standard in Nelas River, so that in the future, it needs to get further treatment. In waters, nitrite is generally sourced from industrial and domestic waste [23].

Oils and greases. Oil and grease value in Bengkulu River ranged from 0.0 mg/L-4,998 mg/L, while Nelas River ranged from 0.0 mg/L-897 mg/L. The average oil and grease value in rivers has exceeded the water quality standard, 1 mg/L-10 mg/L. The high content of oil and grease allegedly comes from household activities along the river. In addition, the presence of palm oil and rubber processing factories is suspected to be because of increased oil and grease. Previous studies have also shown that the high value of oil and grease is caused by factory activities in Kolkata, settlements, agriculture, plantations, and palm oil processing factories [24].

Total Coliform. Total coliforms in Bengkulu River ranged from 33-16,000 MPN/100 mL, and in Nelas River, it went from 95-18,980 MPN/100 mL. Based on the results, there is an increasing number of total coliforms every year. It indicates that river water pollution is still occurring. The contributor to this pollutant is the disposal of organic waste and sewage directly into rivers [25]. Increased domestic activities, agriculture and plantations, factories around rivers are strongly indicated as a cause of total coliforms increase. It is in line with previous studies that showed built-up areas, increasing population, and agricultural activities led to total coliforms increase [13].

3.2. Water quality status
Generally, there has been a decline trend Storet Index of Bengkulu River and Nelas River in the last six years for all classes of water usage (see figure 1). Water quality has deteriorated over time due to a large number of nutrients entering water bodies. It indicates that pollution and degradation of rivers’ water quality are still happening. In the last few years, both rivers have been the Storet Index value ≥ −30, so that classified as heavily polluted. It means that the rivers are not suitable for a source of drinking water usage. Some parameters still meet the water quality standard (based on GR 22/2021), namely: TDS, pH, sulfate, and nitrite. Meanwhile, other parameters were detected to have exceeded the quality standard, namely: TSS, DO, Fe, Mn, Cu, BOD, COD, oil and grease. These parameters’ value has increased as an indicator that the quality of river water continues to decline. However, pollutant concentrations constantly fluctuated over time. It is in line with previous studies that Bengkulu River in upstream,
middle, and downstream has been heavily polluted [10], as well as Nelas River, which has also been heavily polluted [20].

![STORET Index of Bengkulu River](image1.png)

![STORET Index of Nelas River](image2.png)

**Figure 1.** Status of water quality in Bengkulu River based on Storet Index all season (a) Bengkulu River and (b) Nelas River.

Pollution and water quality declining of Bengkulu and Nelas rivers occurred both naturally and due to anthropogenic activities. Naturally, the decline in river water quality occurs due to the natural interaction of rainwater that falls upstream with rocks and soil. On the other hand, various anthropogenic activities such as settlements, coal mining, agriculture and plantations, land clearing as well as the presence of palm oil and rubber processing factories operating along the river have a very significant influence on the occurrence of river water pollution. These have been supported by several previous studies at different locations, but generally show the same conditions [26,27]. Land cover changes in the Bengkulu watershed area into critical land have a positive impact on erosion and decreasing water quality of Bengkulu River [20,28,29]. Based on Local Government Regulation No. 6/2005, the two rivers were designated as raw water sources for drinking water, but until now, they are still experiencing a decline in water quality. Figures 2 and 3 have compared the Storet Index values of the Bengkulu River and the Nelas River in the dry and rainy seasons. Based on the Storet Index, in general, the water quality in the two rivers has been better in the rainy season than in the dry season. It is likely in the rainy season, the amount of water entering the river body is more so that it affects the concentration of pollutants in the river water flow. During the rainy season, there is an increase in rainfall and outflow affecting river flow so that the water quality looks better [30].

Based on the Storet Index, it can be seen that both rivers continue to experience pollution and a decrease in river quality. For this reason, efforts or management of the watershed is needed. The following strategies are needed: increasing the participation of the communities and industries to control river water pollution; factories operating in the upstream and midstream areas must manage the resulting waste before being discharged into the river. In addition, other things that are needed closely monitoring by related parties; rehabilitate protected areas and water catchment areas by planting vegetation in open areas; conduct environmental audits for all activities that can damage watersheds such as mining; control pollutant sources related to the socio-economic activities of the community around the river.
Figure 2. Status of water quality in Bengkulu River based on Storet Index (a) Dry season and (b) Rainy season.

Figure 3. Status of water quality in Nelas River based on Storet Index (a) Dry season and (b) Rainy season.

4. Conclusion and Recommendation
Based on Storet Index, from 2014 to 2019 water quality of Bengkulu River and Nelas River have been polluted. The water of rivers did not meet quality standards for drinking water and/or other designations that same requirement as stipulated GR No. 22/2021. Water quality parameters that exceeds quality standards is total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), iron, manganese, copper, and total coliform. Anthropogenic activities are caused by declining water quality parameters, i.e.: domestics/settlements, minings, palm oil and rubber processing factories, agriculture, and plantations. Land cover changing and increasing open land cause a decrease in river water quality. Several strategies can be implemented in watershed management to prevent pollution and degradation of river water quality, including involving the participation of the communities and industries to control river water pollution, rehabilitating and reforesting open areas, conducting environmental audits. In the future, we suggest further studies on the impact of heavy metals
on bio-accumulation and histology on aquatic biota. In addition, study on the effect of land cover changes on river discharge.

**Acknowledgment**
The author would like to thanks to the Head and Staffs of the Environment and Forestry Service of Bengkulu Province whose have provided serial data of river water quality monitoring.

**References**

[1] Ullah KA, Jiang J and Wang P 2018 Land use impacts on surface water quality by statistical approaches *Glob J Environ Sci Manag.* 4 231–50

[2] Evans AE V, Hanjra MA, Jiang Y, Qadir M and Drechsel P 2012 Water pollution in Asia: The urgent need for prevention and monitoring *Int J Water Resour Dev* 28 195–216

[3] Ali SA and Ahmad A 2019 Analysing water-borne diseases susceptibility in Kolkata Municipal Corporation using WQI and GIS-based Kriging interpolation *GeoJournal* 3

[4] Reddy VR 2018 Economic analysis of health impacts in developing countries *Encyclopedia of Environmental Health 2nd ed.* (Elsevier Inc.) p 10

[5] Kemenkes [Kementerian Kesehatan] 2019 *Profil Kesehatan Indonesia 2018* Jakarta (Kementerian Kesehatan RI) p 207 (Indonesian)

[6] Osmi SFC, Malek MA, Yusoff M, Azman NH and Faizal WM 2016 Development of river water quality management using fuzzy techniques: a review *Int J River Basin Manag.* 14 243–54

[7] BPS [Badan Pusat Statistik] 2021 *Kota Bengkulu Dalam Angka 2021* (Bengkulu Municipality In Figures 2021 Bengkulu)

[8] Mudjiardjo ASU, Moersidik SS and Darmajanti L Analysis of water pollution using the STORET method in the Upper Citarum Watershed *IOP Conf Ser Earth Environ Sci.* 716 1–8

[9] Jubaedah D, Hariyadi S, Muchsin I and Kamal MM 2015 Water Quality Index of Floodplain River Lubuk Lampam South Sumatera Indonesia *Int J Environ Sci Dev.* 6 252–8

[10] Supriyono and Utya S 2019 Study of quality changes and determination of water pollution index at river watershed *Sumatra J Disaster, Geogr Geogr* 1 20–33

[11] Belladona M 2017 Analisis Tingkat Pencemaran Sungai akibat Limbah Industri Karet di Kabupaten Bengkulu Tengah *Proceeding Seminar Nasional Sains dan Teknologi* (Jakarta: Fakultas Teknik Universitas Muhammadiyah Jakarta) p 7 (Indonesian)

[12] Effendi H, Muslimah S and Permatasari PA 2018 Relationship between land use and water quality in Pesanggrahan River *IOP Conf Ser Earth Environ Sci.* 149 1–9

[13] Hua AK 2017 Land use land cover changes in detection of water quality: A study based on remote sensing and multivariate statistics *J Environ Public Health* 1–12

[14] Rahman MW, Purwanto MYJ and Suprihatin 2014 Status kualitas air dan upaya konservasi sumberdaya lahan di DAS Citarum Hulu, Kabupaten Bandung *J Pengelolaan Sumberd Alam dan Lingk.* 4 24–34 (Indonesian)

[15] Dunea D, Brestcan P, Tanislav D, Serban G, Teodorescu R, Iordache S, Petrescu N and Tuchiu E 2020 Evaluation of water quality in Ialomita River Basin in relationship with land cover patterns *Water* 12 1–20

[16] Lee JY, Yang JS, Kim DK and Han MY 2010 Relationship between land use and water quality in a small watershed in South Korea *Water Sci Technol.* 2607–15

[17] Azhar A and Dewata I 2018 Studi kapasitas beban pencemaran sungai berdasarkan parameter organik (BOD, COD dan TSS) di Batang Lembang Kota Solok, Provinsi Sumatera Barat *J Pengelolaan Lingk Berkelanjutan (Journal Environ Sustain Manag.)* 2 76–87 (Indonesian)

[18] Effendi H, Permatasari PA, Muslimah S and Mursalin 2018 Water quality of Cisadane River based on watershed segmentation *IOP Conf Ser Earth Environ Sci.* 149 1–7

[19] Ogbozige FJ and Alfa MJ 2019 Land use-land cover effects on surface flowing water quality: A statistical approach *Niger J Technol Dev.* 16 25–35

[20] Arnop O, Budiyanto and Rustama 2019 Kajian evaluasi mutu Sungai Nelas dengan metode Storet
dan Indeks Pencemaran J Naturalis 8 15–24
[21] Permatasari PA, Setiawan Y, Khairiah RN and Effendi H 2017 The effect of land-use change on water quality: A case study in Ciliwung Watershed IOP Conf Ser Earth Environ Sci. 54 1–7
[22] Zhou M, Li X, Zhang M, Liu B, Zhang Y, Gao Y, Ullah H, Peng L, He A and Yu H 2020 Water quality in a worldwide coal mining city: A scenario in water chemistry and health risks exploration J Geochemical Explor 213 1–12
[23] Effendi H, Romanto and Wardiatno Y 2015 Water quality status of Ciambulawung River, Banten Province, based on Pollution Index and NSF-WQI Procedia Environ Sci. 24 228–37
[24] Ghosh S, Majumder S and Roychowdhury T 2019 Assessment of the effect of urban pollution on surface water-groundwater system of Adi Ganga, a historical outlet of river Ganga Chemosphere 237 1–9
[25] Badgley BD, Steele MK, Cappellin C, Burger J, Jian J, Neher TP, Orentas M and Wagner R 2019 Fecal indicator dynamics at the watershed scale: Variable relationships with land use, season, and water chemistry Sci Total Environ 697 1–11
[26] Risal A, Parajuli PB, Dash P, Ouyang Y and Linhoss A 2020 Sensitivity of hydrology and water quality to variation in land use and land cover data Agric Water Manag 241 1–12
[27] Tahiru AA, Doke DA and Baatuwue BN 2020 Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana Appl Water Sci 1–14
[28] Supriyono 2018 Critical land detection watershed River Bengkulu and effect of coastal area using Geographic Information System Sumatra J Disaster, Geogr Geogr Educ. 2 30–7
[29] Satmaidi E, Muthia AA and Wulandari 2018 Konsep hukum pengelolaan tambang batubara berkelanjutan berdasarkan pendekatan daerah aliran sungai (DAS) di Provinsi Bengkulu J Bina Huk Lingk. 2 198–241 (Indonesian)
[30] Eljaieek-Urzola M, Romero-Sierra N, Segrera-Cabarcas L, Valdelamar-Martínez D and Quiñones-Bolaños É 2019 Oil and grease as a water quality index parameter for the conservation of marine biota Water (Switzerland) 11 1–20