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River Water Quality Implication after the Earthquake

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Abstract. The earthquake of 6.0 Magnitude occurred in the Ranua district of Sabah lasted for 30 seconds on 5th June 2015. This study investigated the various water quality parameters such as turbidity, color, dissolved oxygen, pH, electric conductivity, total dissolved solids, and so on from two monitoring stations (Bambangan and Kimolohing). The secondary data was requested from the Water Department of Sabah, where the Liwagu river is the downstream system of Mesilau. Through the temporal trace of each parameter, the water quality parameters showed an abrupt change one day before the earthquake. Consequently, around two weeks after the quake, it reached its initial state rapidly. After the earthquake, the mean turbidity is 436.25 NTU with a standard deviation of 1416.86 NTU. Its peak was on 17th June with 5550 NTU, total dissolved solids were 58.68 mg/l, and the electrical conductivity was 122.98 µs/cm at the Bambangan station, while it was 673.00 NTU with a standard deviation of 1869.90 NTU and it peaked on 17th June with 3750 NTU in the Kimolohing. The dissolved oxygen hit the lowest level of 3.27 mg/l on 17th June when 4.19 mg/l. The nitrate concentration increased to the maximum of 0.18 mg/l and 0.15 mg/l in the Bambangan, and the Kimolohing station, respectively. The metal concentrations also increased after the earthquake at both stations. However, alkalinity and hardness had decreased since 30th April before the earthquake and continued to decline until 14th August, when it reached the initial level. The value of pH and chloride did not seem to be affected by the earthquake, as the concentration maintained the average level.

1. Introduction

Water quality change in the vulnerable area, or the location where an earthquake occurred, might significantly disrupt the environmental system and society. Over decades, water quality changed due to earthquakes in numerous regions [1-11]. The shacking impaired the sewage system, infrastructure, and treatment facility. It causes micro-organisms and pathogen indicators with sediment discharge from the raw sewage into the river. That increases the potential risk to human health for those involved in recreational and work-related activities in the river environment. In addition, the impact of secondary hazards such as landslides, debris flow, and sediment liquefaction might cause a disturbance in water quality and take a long time to recover.

Moreover, changing a dominant parameter in water can destroy living organisms and the ecosystem in the catchment. The landslide triggered by the quake brings a hefty amount of sediment into the river deposits in the stream, making the channel shallower and increasing sediment concentration, turbidity, and the flood plain [12]. In addition, it also destroys the landscape vegetation, which boosts the surface runoff and flood velocity [13], the source of nutrient input in the river [14]. The reach-in sediment concentration in water also intrudes the absorbance of oxygen into the water, which is vital for lives in water and might cause the algae to bloom. Further, the high risk of water-borne diseases in water and the limitation of drinking water sources due to pollution concern the public's health [15]. The earthquake resulted from physical changes (drying up of springs, temporary damming of streams, and increase in erosion) and ecosystem services destruction [16]. After the earthquake, water quality changes, such as in groundwater, spring, and surface water, have been well established and documented [1-4, 6-11, 17].

On the other hand, the research paper on the influence of various sources of pollution, such as human activity [18-19], and other natural phenomena, such as climate change and floods, are well produced [20]. However, the research paper on surface water quality degradation caused by earthquakes seemed significantly limited. Moreover, the threat to surface water quality from human activity, earthquakes, or other natural disaster might temporarily or permanently affect living organisms, ecosystems, and humans in catchment areas where surface water is the primary source. Therefore, it is necessary to address this issue by producing more research papers.

Ranau experienced an earthquake of 6.0 Mw on 5th June 2015. This earthquake lasted about 30 seconds. The shaking from the mainshocks and aftershocks triggered the extensive landslide on the very steep slope of Mount Kinabalu, stripping about 1500 hectares (15 Km^2) of vegetarian cover and producing a high amount of loose material. The debris flow wipes away the living organism, and its deposit influences water quality downstream. In addition, it results in increased turbidity, which is unusable for human use for several weeks. To protect the system, the authority needs to close down the water intake for drinking water treatment.

Since the region lies on the blind fault area, the earthquake will possibly trigger again in the future. Therefore, the study aims to evaluate water quality parameters in the Liwagu river before and after the earthquake on 5th June 2015 in Sabah. Hence, this study will provide valuable and additional information for the decision-maker and relevant stakeholders to implement the strategy and follow the river's status to recover and reduce the damage.

2. Material and Methods

2.1. Study area and data collection

This study was conducted at the Ligawu river in Ranau district, Sabah, Malaysia. Sabah had been hit by 65 earthquakes since 1973, with magnitudes ranging from 3.3 to 6.5 on a Richter scale [21], located around 1000 Km from the Philippine Trench and 1000 km from the Eurasian-Philippine plate boundary, sitting on the semi-stable South China Sea region. Therefore, the region faults of Sabah are closely related to the active part in the Sulu Sea and Celebs Sea region. The latest earthquake occurred in 2015. The 2015 Mount Kinabalu Earthquake, with a magnitude of 6.0 and a focal depth of 10 km located 6.014°N 116.563°E in the Kinabalu Mountain, Sabah in Borneo, came as follows: a surprise and lasted for about 30 seconds claiming 18 lives. Three aftershocks occurred in the earthquake's immediate aftermath, with the first and second measuring 4.3 magnitudes, while a third was 2.8 Mw. A total of 33 aftershocks have been reported at Ranau, ranging in magnitude from 1.6 to 4.5, recorded by the Malaysian Meteorological Department. Two significant earthquakes occurred earlier at Ranau, with the first recorded in 1966 at magnitude 5.3 and the second at magnitude 5.2 in 1991. Active tectonics of the converging and diverging plate margins are responsible for the occurrence of earthquakes. However, the absence of such an active plate margin in the earthquake location is uncommon [22].

In 2015 (**Table 1**), the secondary water quality data were from the Sabah water department; each parameter is monitored and analyzed following the American Public health Association (APHA) standard. There are two monitoring stations along the Liwagu river, 200km in length, where the river is a downstream system of the Mesilua river. The distance between stations is 1.6 Km, whereas Bamangan and Kimolohing are water intake points for drinking water treatment (**Figure 1**). The river flows eastwards off the southern slope of Mount Kinabalu and then into the Labuk River. The variation pattern of each parameter gives information on water quality variation before and after the earthquake Liwagu river is the primary water source for people in the Ranau district. This river suffered much damage from the earthquake in 2015.

Table 1: List of parameters

Parameters	Units	Limitation[a]
Turbidity	NTU	1000
Color	HU	300
pH	-	5.5-9.0
Electrical Conductivity	µs/cm	-
Total Dissolved solid	mg/l	1500
Dissolved Oxygen	mg/l	-
Ammonia	mg/l	1.5
Nitrate	mg/l	10
Iron	mg/l	1
Manganese	mg/l	0.2
Aluminum	mg/l	-
Alkalinity	mg/l	-
Total-Hardness	mg/l	500
Chloride	mg/l	250
Sulphate	mg/l	-

Limitations following the National Water Quality Standard for Malaysia

Figure 1: Location of water intake stations (Bambangan and Kimolohing)

3. Result and discussion

The water quality data were observed daily from January to December, covering before and after the earthquake on 5th June 2015. The data was divided into the phase before and after the mean and standard deviation earthquake to compare the data variation. **Table 2** and **Table 3** differentiate the mean value of each water quality parameter at Bambangan and Kimolohing stations before and after the earthquake and portray the dispersion of the dataset. The turbidity value was 436.25 NTU ± 37.92 NTU than before the quake, 36.10 NTU ± 1416.86 NTU (**Table 2**). This number indicates the rising of turbidity after the shock.

Similarly, at the Kimolohing station, as shown in **Table 3**, the turbidity level increased after the quake to 309.61 NTU ± 954.49 NTU. From **Figure 2** (a) and (b) Bambangan station and Kimolohing station, turbidity increased quickly from 4th June, the day before the earthquake on 5th June, until around two weeks after the earthquake on 17th June. Thus, the turbidity level remains higher than usual after the aftermath. The color level rose quickly from 4th June to 17th June and decreased to 14th August. The heavy rain causes this increase in turbidity and color after the incident, producing debris flow and mudflow in the stream [22]. Color in water is known to indicate water clarity. It was high compared to before the earthquake in both stations because of the turbidity related to suspended solids in water. Hence, the high level of the suspended substance in water causes the color of the water to be cloudy, affecting the river's living organism if this high level remains for a long time. As a result of reducing the light penetrating water, it also slows down the photosynthesis process. Prompt the eutrophication to release a harmful toxic substance to humans and living organisms.

The total dissolved solids and electrical conductivity decreased by comparing both stations' mean and standard deviation. **Figure 4** (a); (b), the total dissolved solids and electric conductivity concentration dropped on the same day, from 30th April to 21st May, rose on 4th June, and fell again on 17th June. These two parameters are reported as significant changes related to seismic activity in the groundwater system [6, 23]. Additionally, total dissolved solids and electric conductivity have a substantial relationship. Therefore, the increase of total dissolved solids also increases the concentration of EC, and diluted rainwater volume into the stream is probably a reason.

Dissolved oxygen, the most vital element to support the living organism, dropped slightly in both stations despite the mean value. According to **Figure 3** (c) and (d), the dissolved oxygen concentration in the Bambangan station gradually decreased from 21st May until 17th June. Unlikely, dissolved oxygen in the Kimolohing station rapidly reduced from 4th June until 17th June. Plus, a high turbidity level might intrude the absorbance of oxygen from the atmosphere into water. However, there is an agreement of the lowest concentration of dissolved oxygen on the same day (17th June) in both stations, which indicates the change in dissolved oxygen level. The pH level remains at the mean value of around 7.0 before and after the earthquake. The pH level remains exact before and after the quake (**Figure 3**). Therefore, no significant change could indicate the event's impact.

The mean concentration of ammonia was 0.03 mg/l at Bambangan, before the earthquake, 0.06 mg/l. In comparison, in the Kimolohing station, it is 0.03 mg/l less than before the earthquake, 0.04 mg/l, and the limit of its concentration in water is 1.5 mg/l. Therefore, it is still at the safe level. **Figure 5** (a); (b) demonstrate the conflict of the variation pattern of ammonia between the stations of concentration changing related to the earthquake's impact. The nitrate concentration in Bambangan station **Figure 5** (c) increased from 4th June until 17th June. The nutrient concentration in the river usually contains fertilizer from agriculture fields or soap and detergent from the household. Other nitrogen sources have in the soil, discharge into the river, surface runoff, and soil erosion.

In the Bambangan station (**Table 2**), the mean concentration of nitrate is 0.04 mg/l ± 0.02mg/l (**Table 3**), while in Kimolohing is 0.05 mg/l ± 0.02 mg/l before the earthquake. After the earthquake, its concentration was 0.05 mg/l ± 0.04 mg/l. In Kimolohing **Figure 5** (d), nitrate concentration rapidly increased from 4th June until 17th June. A previous study by Sato *et al.* [24] found the change in the nitrate concentration due to the rainfall after the incident, which transported the nitrate into the river's catchment. Therefore, the transportation of sediment and material from the upstream and nearby catchment triggered by an earthquake might be the factor that makes it increases.

The metal concentration of aluminum, iron, and manganese increases according to the mean value and standard deviation except for aluminum in Kimolohing. Before the earthquake, the mean concentration is 0.05 mg/l; after the quake, is 0.04 mg/l. Therefore, aluminum concentration quickly increased from 4th June until 17th June and after the concentration of aluminum reached the initial state as shown in **Figure 6** (a); (b). Likewise, the concentration of iron rapidly increased from 4th June until 17th June and decreased until 14th August **Figure 6** (c); (d). The increase in manganese concentration started on 4th June until 17th June and dropped again on 11th September **Figure 7** (a); (b). A previous study [25] stated that the overall random increasing or decreasing trends in primary heavy metal contents after the earthquake portrayed that this imbalance might be due to mingling of the soil of multifarious composition caused by land sliding. The alkalinity level decreased after the quake at 60.97 mg/l ± 17.82 mg/l, 57.93 mg/l ± 23.24 mg/l before and after the earthquake. However, the average hardness level increased in both stations.

The alkalinity concentration in the Bambangan station **Figure 8** (a) decreased from 30th April until 14th August and rose again on 25th September. The Kimolohing **Figure 8** (b) showed a similar decreasing pattern except on 17th June, when it increased, even though it remained at an equivalent level of the Bambangan station. The hardness level in each station was decreased from 14th May until 4th June and increased again until 17th June. A report of rock falling from Mount Kinabalu during the shaking, where the small gravel and stone were transported into the river [22]. A similar study by Qian et al. [9] also found that the Wenchuan earthquake reduced the decrease in hardness in China. Besides, the chloride and sulfate concentration remains the same in both stations.

At the Bambangan station **Figure 7** (c), the sulfate concentration increased from 4th June until 17th June, increased again until 14th August, and decreased until 11th September. However, there is a disagreement between both stations; in the Kimolohing station **Figure 7** (d), there was no peak concentration before and after the earthquake. Therefore, the level of chloride change is minimal (**Figure 9**), which means the quake perhaps does not have the majority impact on its concentration in water [26].

The Liwagu river falls into Class I - Class II based on Water Quality Standard for Malaysia (NWQSM) and Water Quality Index [27]. Therefore, the longest variation time is around three months before the earthquake, and the shortest period is one day before the earthquake, which can considerably change rapidly. The recovery time is around two weeks after the quake until it returns to its initial condition. The 120 aftershocks were reported three months after the earthquake, and only five were considered significant [22]. Parameters such as sulfate, alkalinity, hardness, chloride, total dissolved solids, and electric conductivity fluctuated during the aftershock period. Nevertheless, the lack of information to verify if this aftershock has an impact. Conversely, a report of electric conductivity and total dissolved solids in underground water fluctuated during the aftershock in another region [6].

Moreover, heavy rain was recorded on 17th June. Thus, it might make sense that parameters such as turbidity, color, and metal concentration increase at the mentioned time in the river. The review of the water quality status in Malaysia by Garba *et al.* [28] stated that the primary sources of pollution in Sabah are logging and deforestation. In another aspect of the earthquake indicator, the temporal and spatial variation of water quality and human activity must be the factor to be considered. It must reduce the impact on the dataset, such as the location of the monitoring point, to eliminate the unrelated pollution of nearby activity of humans and distance from the epicenter [29]. The interaction of groundwater and surface water is a phenomenon to deliberate that the discharge from groundwater during seismic activity may cause a change in surface water such as dissolved matter, and salinity. Indeed, the series of earthquake events may provide more evidence and information on impending earthquakes' influence on river water quality and groundwater because groundwater is known to interact with the ground movement of seismic activity [30-31]. Thus, any assumption is not strongly justified by just one earthquake episode.

Table 2: Mean and standard deviation of parameters in Bambanganstation

Parameters	Before earthquake		After earthquake	
	Mean	Standard d.	Mean	Standard d.
Turbidity	36.10	37.92	436.25	1416.86
Color	91.54	79.72	760.00	2283.69
pH	7.55	0.40	7.53	0.12
EC	130.72	33.33	122.98	21.86
TDS	62.23	16.05	58.68	10.49
DO	8.28	0.58	7.84	1.48
NH3	0.06	0.07	0.03	0.03
NO4	0.04	0.02	0.05	0.04
Fe	0.25	0.23	1.13	1.11
Mn	0.03	0.02	0.14	0.15
Al	0.03	0.01	0.06	0.05
Alkalinity	60.97	17.82	57.93	23.24
Hardness	62.14	19.37	64.00	15.53
Cl	8.15	7.85	7.93	5.27
SO4	4.92	2.72	5.33	3.50

Table 3: Mean and standard deviation of parameters in Kimolohingstation

	Before earthquake		After earthquake	
Parameters	Mean	Standard d.	Mean	Standard d.
Turbidity	17.28	19.23	309.61	954.49
Color	58.93	67.77	673.00	1896.90
pH	7.53	0.23	7.55	0.10
EC	124.89	34.99	118.63	22.11
TDS	59.42	16.86	55.87	11.08
DO	8.25	0.58	8.11	1.55
NH3	0.04	0.04	0.03	0.04
NO4	0.05	0.02	0.05	0.04
Fe	0.16	0.11	1.07	0.54
Mn	0.03	0.02	0.15	0.20
Al	0.05	0.07	0.04	0.04
Alkalinity	59.51	18.20	54.79	23.02
Hardness	55.59	18.52	59.83	12.50
Cl	7.00	3.57	7.07	3.59
SO4	5.00	2.77	4.73	4.20

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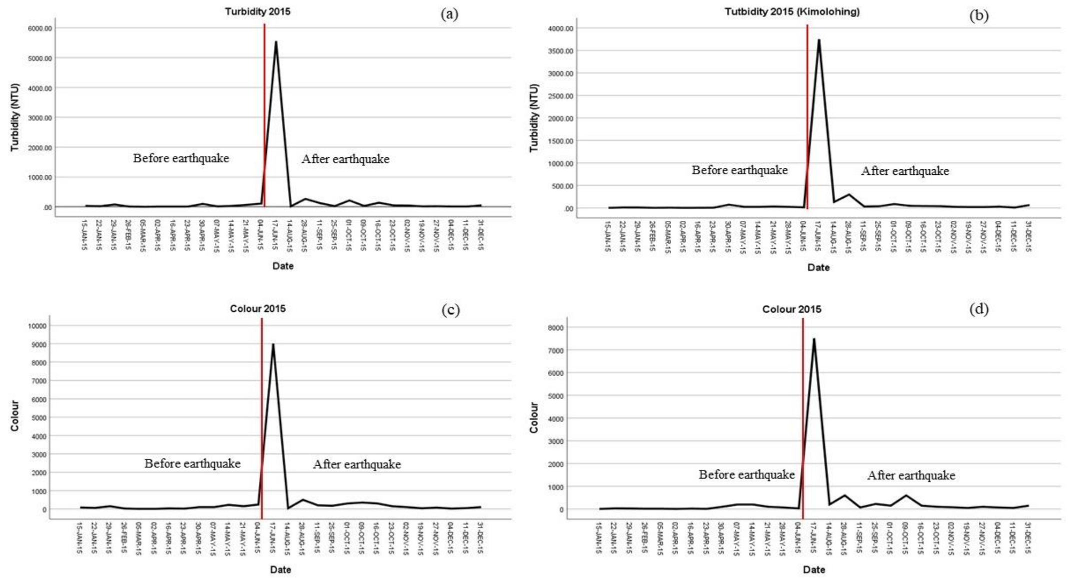

Figure 2: Turbidity and Colour (a), (c) Bambangan; (b), (d) Kimolohing

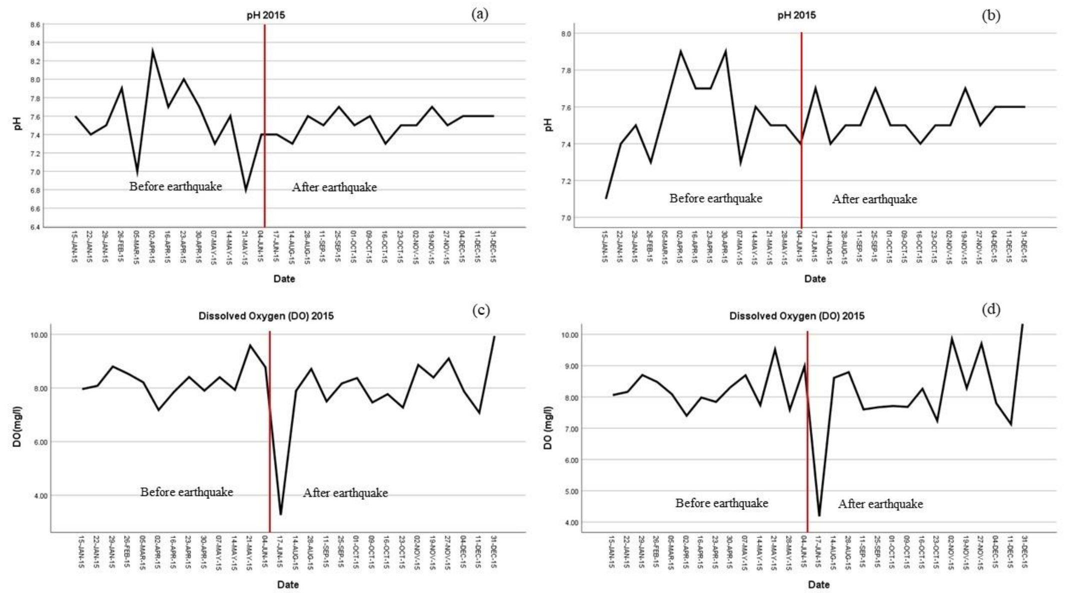

Figure 3: pH and DO (a), (c) Bambangan; (b), (d) Kimolohing

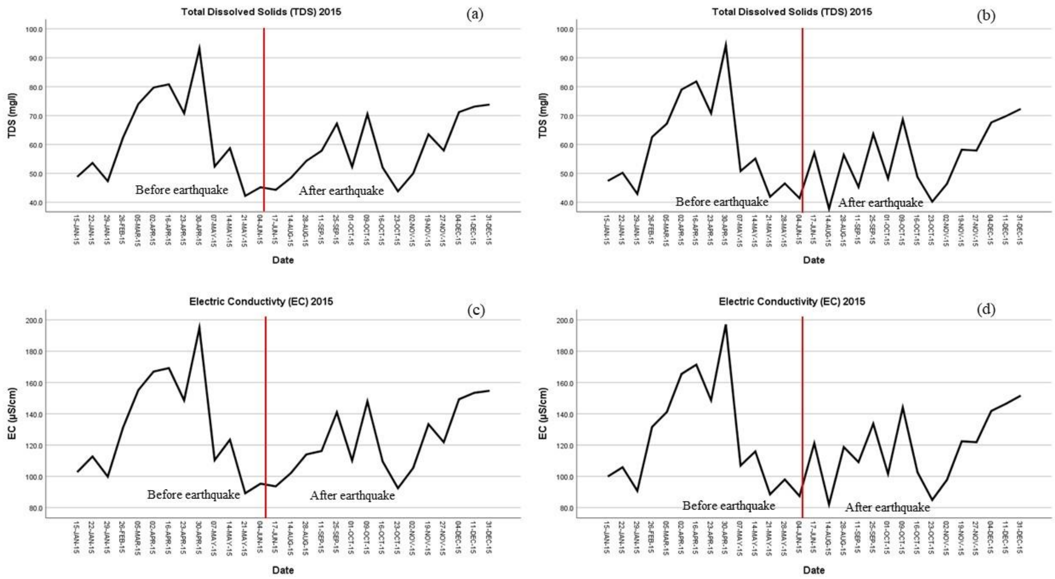

Figure 4: TDS and EC (a), (c) Bambangan; (b), (d) Kimolohing

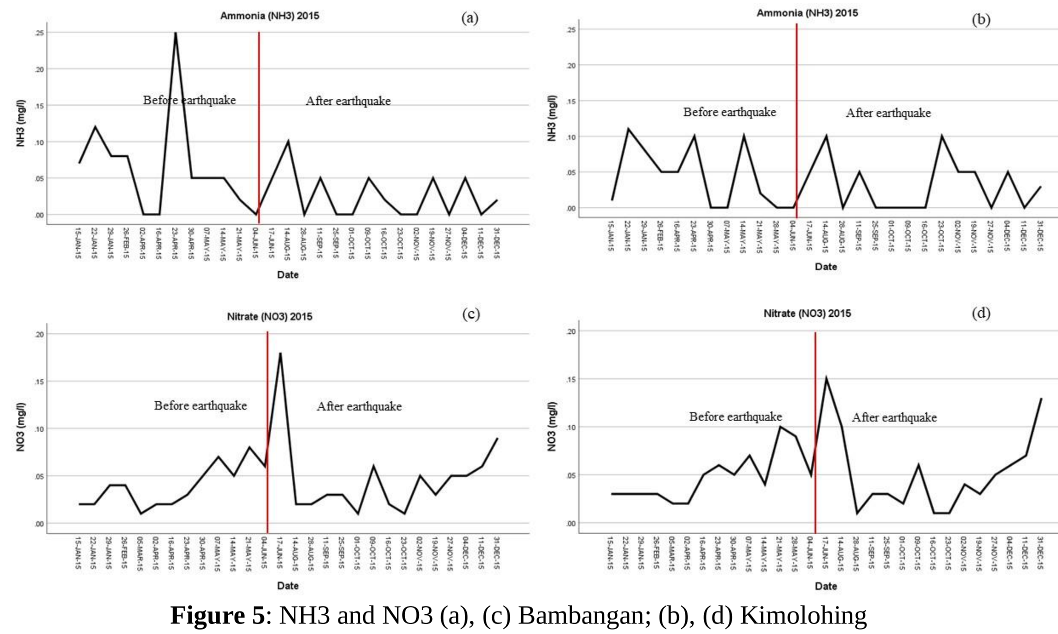

Figure 5: NH3 and NO3 (a), (c) Bambangan; (b), (d) Kimolohing

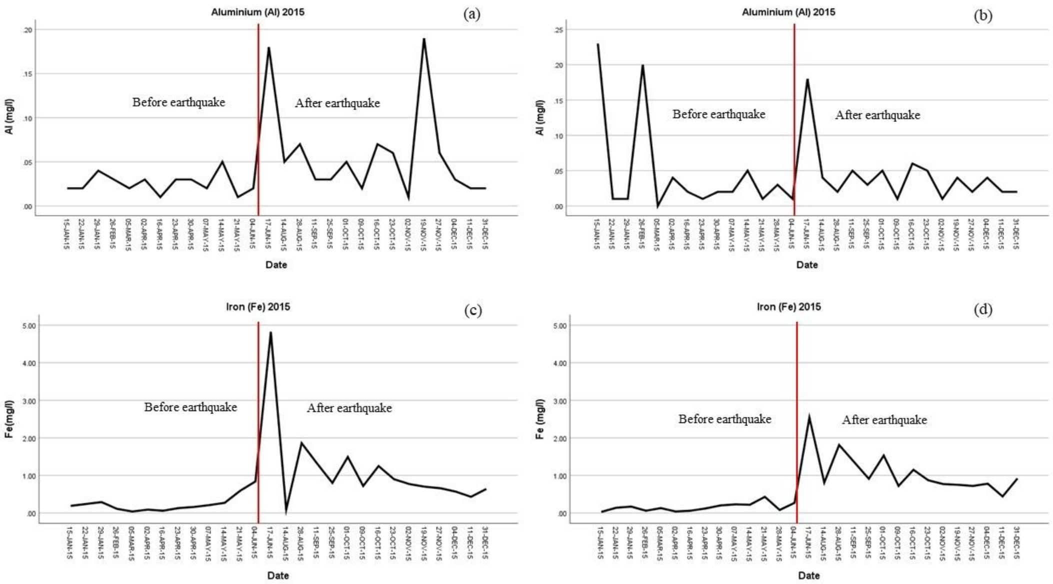

Figure 6: Al and Fe (a), (c) Bambangan, (b), (d) Kimolohing

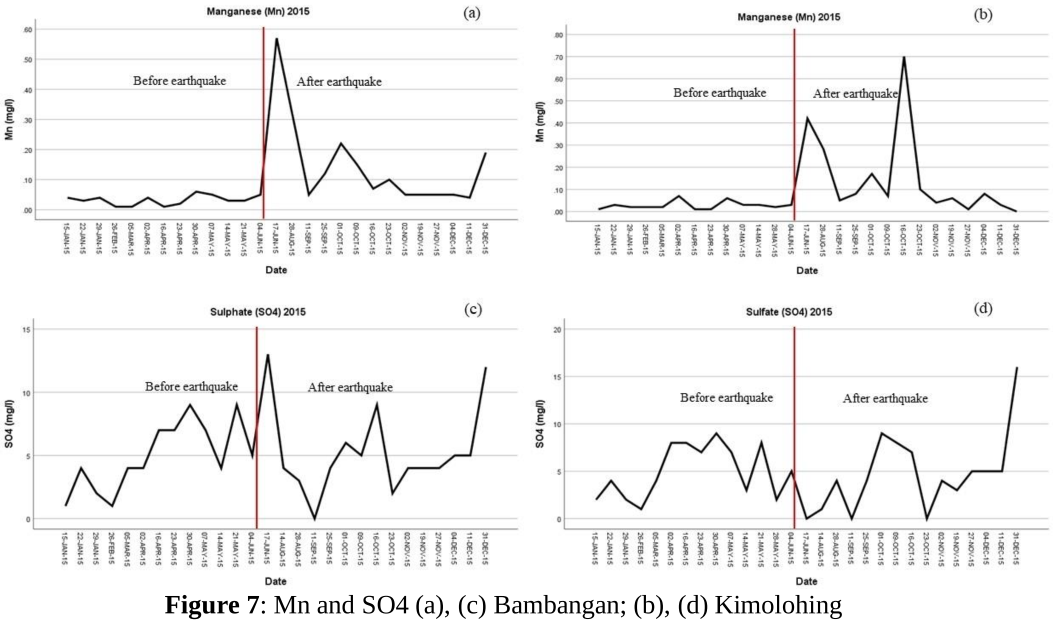

Figure 7: Mn and SO4 (a), (c) Bambangan; (b), (d) Kimolohing

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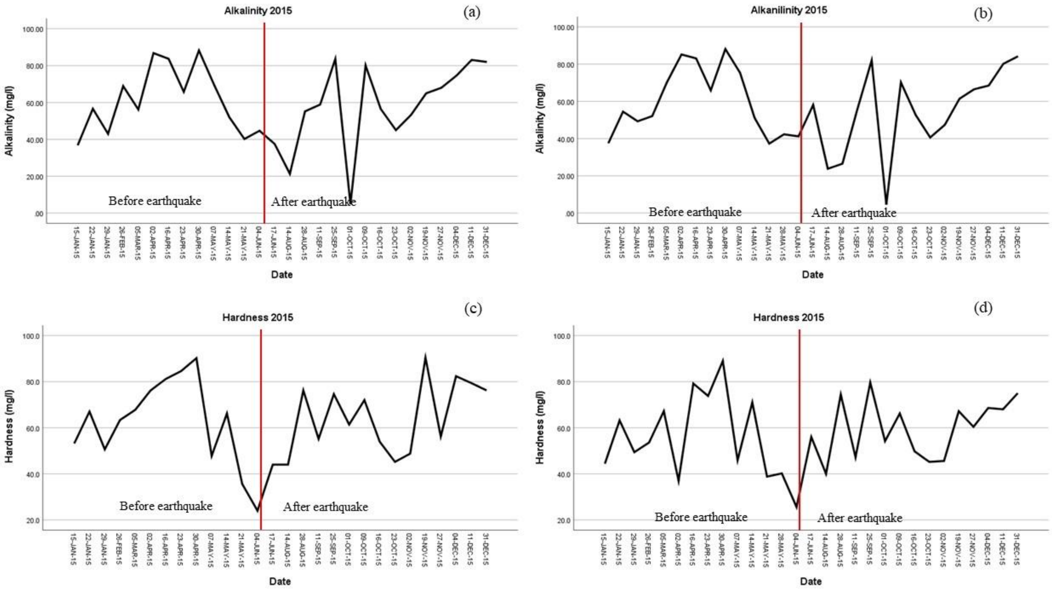

Figure 8: Alkalinity and Hardness (a), (c) Bambangan; (b), (d) Kimolohing

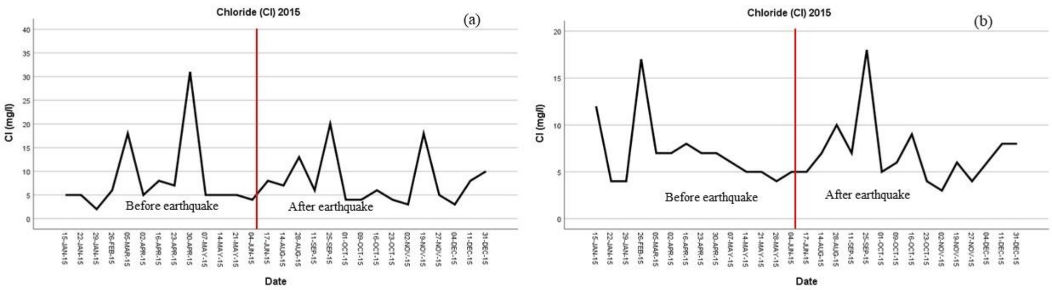

Figure 9: Cl (a) Bambangan; (b) Kimolohing

4. Conclusion and Recommendation

In conclusion, the earthquake has not only brought fatalities and damaged infrastructure but also has a significant disturbance to water quality on the surface and underground. The excessive total suspended solids cause damage to drinking water treatment and limit the accessibility of safe and clean water. The 5th June 2015 earthquake had a remarkable influence on the water quality of the Liwagu river. Through observing water quality in 2015, several river water quality parameters such as turbidity, color, total dissolved solids, electric conductivity, nitrogen content, and metal concentration were changed from one day to three months before the earthquake and still around two weeks later. Even though the fluctuation was detected, according to the national standard, it still follows the safe level, excluding turbidity and color showing higher values levels during and after the earthquake. These two parameters are the most vulnerable and highly affected; the debris and mudflow triggered by the earthquake might be the reason for the high turbidity and color level. It is advised to study a series of earthquake events to investigate the behavior of river water quality response to the earthquake process. The monitoring location is also a factor for future work to reduce the influence of point source and non-point source pollution. Plus, the relationship analyses between the parameters are recommended further to investigate the effect between the parameters. Water quality indexes are suggested to classify the status and impact in future circumstances.

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