CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106196

Impact of Earthquake on River Water Quality Parameters

Leangkim Kong[a], Aznah N. Anuar[a,*], Ali M. Yuzir[a], Faizah C. Ros[b], Nur F. Said[b], Jun Asanuma[c]

[a]Department of Chemical and Environmental Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[b]Water Quality, Laboratory and Material Testing Branch, Sabah State Water Department, Malaysia
[c]Faculty of Life and Environmental Science, Tsukuba University, Japan
aznah@utm.my

Massive destruction is caused by earthquakes, including building collapse, dam damage, floods, and sewage system failure, which results in landslides and debris flows. Thirteen people died because of the Ranau, Malaysia, earthquake on 5 June 2015, which had a magnitude of 6.0. A dam failure resulted in a flash flood and landslide that swept away the river's living organisms. A lack of clean water was caused by the loose material and debris flow clogging the treatment facility water. The in-depth study of earthquake-related water quality change is still in-bounded compared to other aspects of the literature. This study aimed to evaluate earthquake impact on river water quality. The secondary water quality measurements in Bambangan and Kimolohing of the Liwagu river were obtained from the Sabah Water Department, such as turbidity, electric conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), nitrate (NO_3^-), iron (Fe), manganese (Mn), aluminum (Al), alkalinity, hardness. Daily observation is employed to analyze the variation of each parameter in 2015. Consequently, turbidity was extremely high on 17 June, followed by metal elements such as Al, Fe, and Mn. The concentration of DO declined on 17 June to 3.8 mg/L. About two weeks to two months following the earthquake, the Liwagu river's overall water quality changed until it recovered to its initial state. However, it took more than six months to recover in other parameters, like iron and manganese. The earthquake alone did not dominate the impact; however, it altered the pollution from the existing source to the river. Therefore, researching how earthquakes affect river water quality can help us understand how parameters will react to future earthquakes and help us determine the most effective method to restore the water quality of the Liwagu river.

1. Introduction

An earthquake is a natural disaster that causes enormous destruction. Numerous places have observed changes in water quality brought on by earthquakes during the previous ten years. For example, secondary hazards degrade the quality of water in sources like spring water and groundwater (Makoto et al., 2020), and surface water such as lakes and rivers (Raj et al., 2019). Earthquakes leave unsolved environmental dilemmas in such areas as hydrology, geology, and society. The ground shakes, damaging sewage systems, water distribution, infrastructure, buildings, housing, wastewater, drinking water treatment facilities, and industrial factories, causing the relationship between microorganisms and pathogens to indicate sediment from a river's raw sewage. In addition, the contamination of and lack of access to clean water in disaster zones significantly increases the risk to human health from chemical leaks into water sources, especially for individuals who engage in leisure and employment activities close to the river environments (Ramadhan et al., 2020). Furthermore, the sediment deposited from the mudflow of a stream causes soaring turbidity that damages facilities and disables drinking water treatment (Robert, 2021). The earthquake in Ranau, with a magnitude of 6.0, severely damaged properties, infrastructure, and people's lives. The subsequence of the main shock and aftershock triggered extensive landslides and mudflows, bringing a massive amount of material and sediment from approximately 15 $km^2$of vegetation cover into the river, resulting in the immediate shutting down of the drinking water treatment facility in the Ranau area. Fish species also died of suffocation due to the high levels of turbidity and total

Paper Received: 19 March 2023; Revised: 18 July 2023; Accepted: 30 September 2023
Please cite this article as: Kong L., Anuar A.N., Yuzir A.M., Ros F.C., Said N.F., Asanuma J., 2023, Impact of Earthquake on River Water Quality Parameters, Chemical Engineering Transactions, 106, 1171-1176 DOI:10.3303/CET23106196

suspended solids. Moreover, the sedimentation and gravel settling down have permanently changed the riverbed (Felix, 2016). The debris flow killed the fish and flooded downstream, swiping down the microorganisms. The impact of an earthquake draws researchers' attention to study the impact, such as on building structures, health, the economy, and the environment. The Liwagu River serves as the district of Ranau's main and most dependable water source. However, its water quality is expected to change drastically, especially after the rainfall since the earthquake in 2015. The main issue with water supply is, for instance, high turbidity levels. The water treatment facility at Bambangan Station deteriorated due to the enormous turbidity and flowed into the Liwagu River. Apparently, this condition endangers the microorganisms in the water as it results in a low absorption of oxygen and the slowing down of photosynthesis. In Malaysia, the problem with earthquake research broadly focused on early warning systems, landslides, and the impact of earthquakes on building structures. A limited amount of research has been conducted on the impact of harmful elements released from underground and other pollution sources which are altered by the mainshock. It probably harmful to humans, the ecosystem and water quality. Therefore, the objective of this study is to study the impact on water quality parameters affected by the Ranau earthquake in the Liwagu River. This study brought attention to water quality in the Liwagu River to relevant stakeholders and decision-makers, with the hope of mitigating the consequences and developing management plans. Hence, decision-makers and stakeholders can acknowledge and use the information in this research to support their management activities (Sonja et al., 2016).

2. Materials and methods

The location of the study area and data collection will be described in the following section.

2.1 Study area

The Liwagu river is located in Sabah's Ranau area, where the current study was carried out. The river is located between 5º43', 5º05', and 110º51'E, 116º85'E, flowing from Kinabalu to the China Sea or to the Sulu Sea. Most of the river's parts are covered by primary and secondary forests, and the upstream river is filled with agricultural activities. The average annual rainfall is recorded at 2,500 mm with an average temperature of 10 ºC at the upper part and 30 ºC at the lower part. Geologically, the district is comprised of a hilly slope and elevation, and the highest peak is on the Kinabalu mountain. The study area is dominated by five lithologies: serpentine, the Crocker formation, the Trusmadi formation, granite, and Pinousok gravel. The Crocker formation consists of strongly folded and faulted sandstone, siltstone, red and grey shale, mudstone, and argillite. The strongly faulted and folded grey and dark grey argillite, slate, siltstone, and sandstone with volcanic inclusions make up the Trusmadi formation. The weakly condensed gravel in the Pinousok gravel, on the other hand, can reach boulder sizes in a sandy to clayey matrix. These lithologies often consist mostly of weathered elements (Haziq et al., 2022).

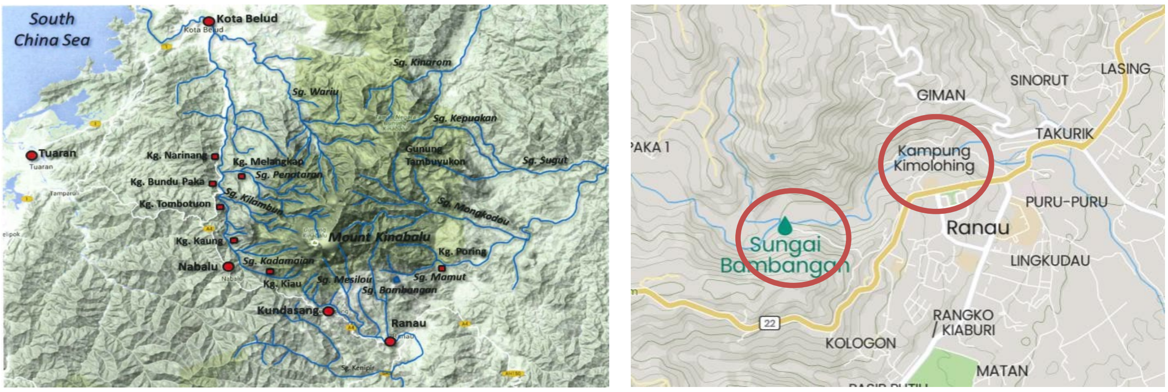

Figure 1: Location of Liwagu river and station of water intake points

2.2 Data collection

The water quality data, namely the turbidity, colour, pH, EC, TDS, DO, NO_3^-, Fe, Mn, Al, alkalinity, and hardness, were obtained from the Sabah Water Department. After that, each parameter was tracked and examined in a lab. The water was sampled in 2015 from January to December. Based on the mean values and standard deviation, as shown in Table 1, the statistical description assessed the interpretation of the data set and its variation before and after the earthquake.

Table 1: Mean ± standard deviation of parameter of pre-earthquake and post-earthquake

Parameter	Bambangan		Kimolohing	
	Pre-earthquake	Post-earthquake	Pre-earthquake	Post-earthquake
Turbidity	36.1 ± 37.92	436.25 ± 17.28	17.28 ± 19.23	309.6 ± 954.49
EC	130.72 ± 33.33	122.98 ± 21.86	124.89 ± 34.99	118.6 ± 22.11
DO	8.28 ± 0.58	7.84 ± 1.48	8.25 ± 0.58	8.11 ± 1.55
NO_3^-	0.04 ± 0.02	0.05 ± 0.04	0.05 ± 0.02	0.05 ± 0.04
Fe	0.25 ± 0.23	1.13 ± 1.11	0.16 ± 0.11	1.07 ± 0.54
Mn	0.03 ± 0.02	0.14 ± 0.15	0.03 ± 0.02	0.15 ± 0.2
Al	0.03 ± 0.01	0.06 ± 0.05	0.05 ± 0.07	0.04 ± 0.04
Hardness	62.14 ±19.37	64 ± 15.53	55.59 ± 18.52	59.83 ± 12.5

*Correlation is significant at the 0.05 level

2.3 Data analysis

To identify the impact of the earthquake, the water quality data set were split into two phases, namely pre-earthquake (January to 4 June) and post-earthquake (6 June to December). Shapiro-wilk test was utilized to test the normality distribution of variables that the hypothesis is the distribution of dataset is normal. When the *p*-value is greater than 0.05 then the hypothesis is accepted. In contrast, *p*-value is less than 0.05 then the hypothesis is accepted. Table 2 demonstrated result of Shapiro-wilk test of each variable. Most of the variable obtained with the *p*-value which less than 0.05, then the variable is non-normal distributed. Consequently, Kruskal-Wallis was applied to compare datasets where the hypothesis is that the water quality would be different before and after the earthquake. If *p*-value is less than 0.05, then the hypothesis is accepted. On the other hand, if *p*-value is greater than 0.05, then the hypothesis is rejected. All analyses were processed by the application package IBM SPSS 27.0.

Table 2: Result of Shapiro-wilk test that will be utilised to test the distribution of variables

Parameter	Bambangan station			Kimolohing station		
	Statistic	df	*p*-value	Statistic	df	*p*-value
Turbidity	0.37	12	0.000*	0.322	13	0.000*
EC	0.914	12	0.238	0.959	13	0.741
DO	0.74	12	0.002*	0.777	13	0.004*
NO_3^-	0.786	12	0.006*	0.67	13	0.000*
Fe	0.705	12	0.001*	0.774	13	0.003*
Mn	0.742	12	0.002*	0.534	13	0.000*
Al	0.741	12	0.002*	0.727	13	0.001*
Hardness	0.961	12	0.796	0.907	13	0.168

*Correlation is significant at the 0.05 level

3. Result and discussions

3.1 Variation of water quality parameters

Figure 2 demonstrated the variation of turbidity, DO, hardness and EC at Bambangan station and Kimolohing stations. Both stations experienced an exceptionally high level of turbidity on 17 June, approximately two weeks after the main earthquake, then the level returned to its initial level. Generally, the rise in turbidity of a river disruption primarily originates from the large discharge of sediment and suspended solids. This could have been brought on by the earthquake's immediate severe rain, which resulted in debris and mudflow in the stream (Felix, 2016). If the high amount of the suspended substance persists for a long time, the hazy colour of the water and effect on the river's living organisms will result. Reduced light penetration of the water also inhibits photosynthesis, causing eutrophication and the production of poisonous compounds that are detrimental to humans and other living things. Also, the depletion of oxygen levels causes fish suffocation, leading to death and affecting their reproduction. On June 17th, the dissolved oxygen concentration was at its lowest, and it resumed its normal pattern on August 14th. Despite the mean value, DO, the element that supports life the most, decreased marginally in both stations.

A high turbidity level could prevent water from absorbing oxygen from the air. Additionally, chlorides (salt) have an impact on the oxygen saturation concentration in water by lowering the saturation concentration. Between May 14 and June 4, each site's hardness level fell, then it climbed until June 17. However, in both places, the average hardness level rose. The sources of hardness are from the reaction of limestone of rock type (Omer, 2019). A prior investigation found that little pebbles and stones that might have included limestone were carried into the river by the rocks that fell from Mount Kinabalu during the earthquake. Such phenomena might reduce the river's flow from upstream, the concentration of alkalinity, and hardness. Additionally, a prior study by Feng et al. (2013) discovered that the Wenchuan earthquake in China decreases hardness.

The concentration of EC showed a decreasing pattern from 30 April until 25 September. In the groundwater system, the prior investigation revealed that these two metrics were documented as substantial alterations connected to seismic activity (Maurizio et al., 2021). In addition, the debris flow triggered by the landslide upstream affected the flow of the river (Felix, 2016), associated with the volume of a tremendous amount of rainwater in the stream, causing dilution, which is the reason for decreasing EC concentration in the Liwagu river.

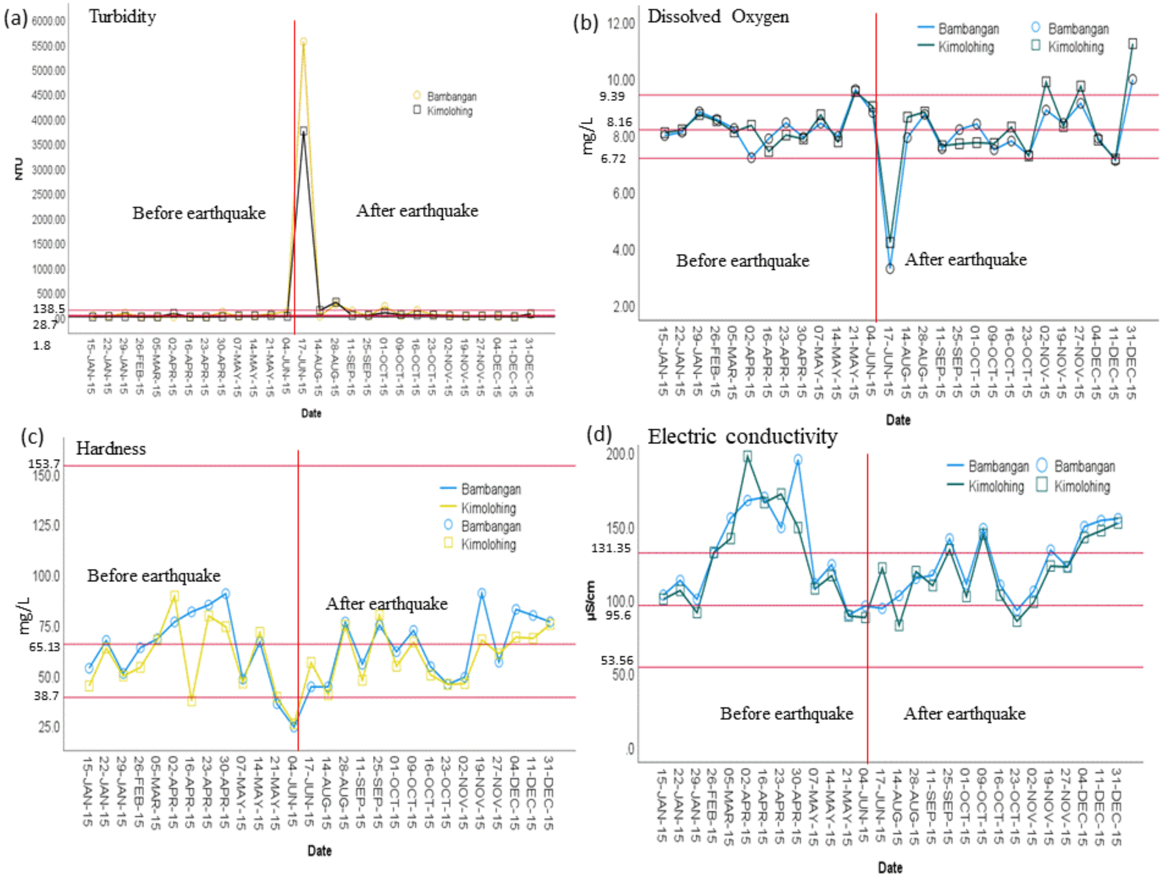

Figure 2: Variation pattern of (a) turbidity, (b) dissolved solids, (c) hardness, (d) electric conductivity; (the vertical line is the earthquake's date on 5 June 2015; the horizontal line is the minimum, average, maximum in 2014)

According to Figure 3, at Kimolohing station, there were two peaks of Al concentration before the earthquake, 15 January and 26 February, and the third peak was on 17 June, about two weeks after the earthquake. While in Bambangan station, a peak was recorded on 17 June, and another peak was on 19 November. The highest concentration of Fe was on 17 June. However, the average concentration after the main shaking was higher. Likely, Mn concentration was also high on 17 June, and another peak was on 10 October. According to a prior study (Mirza et al., 2015), the overall imbalance of raising or lowering trends in primary metal levels following the earthquake suggests that the land sliding, which is a result of the earthquake, mixed soil with a variety of compositions. When metal solubilities are lower at near-neutral pH than in acidic or extremely alkaline fluids, environmental conditions and metal solubility may be considerably influenced by pH, temperature, and salinity. High quantities of Fe, Al, and Mn were therefore found following the earthquake. Additionally, there are other processes that can lead to metal accumulation in water bodies, including weathering of soils and rocks, atmospheric deposition, volcanic eruptions, as well as human activities like mining and industrial use. When metal solubilities are lower at near-neutral pH than in acidic or extremely alkaline fluids, environmental conditions and metal solubility may be considerably influenced by pH, temperature, and salinity. High quantities of Fe, Al, and Mn were therefore found following the earthquake. Additionally, there are other processes that can lead to metal accumulation in water bodies, including weathering of soils and rocks, atmospheric deposition, volcanic eruptions, as well as human activities like mining and industrial use (Chin, 2013). A recent review paper by Haziq et al. (2022) stated that the landslide and rock falling event in June during the Ranau earthquake was linked to the high intensity of rainfall. This finding might support the assumption of the source of metal presence in the Liwagu river. With the minimal level of chloride change, the impact of the quake might be limited.

The highest NO_3^- concentration was recorded on 17 June and returned to a lower increasing pattern than before the primary vibration. In a prior study, Tsutomu et al. (2020) discovered that the rains that followed the earthquake caused a shift in the nitrate concentration by bringing nitrate into the river's catchment, as well as sediment and other materials from the upstream and neighbouring catchment. He suggests that the shacking causes cracks in the ground and damages plants, resulting in a decrease in nutrient uptake. This is notable in most of the vegetation and forest areas along the Liwagu river. Additionally, the river's nutrient concentration frequently includes household soap and detergent or fertiliser from agricultural areas. Obviously, there is no clear evidence distinguishing between non-point-source, point-source, and earthquake, but an earthquake might enhance the exposure of pollution sources to the river or create a new source of pollution.

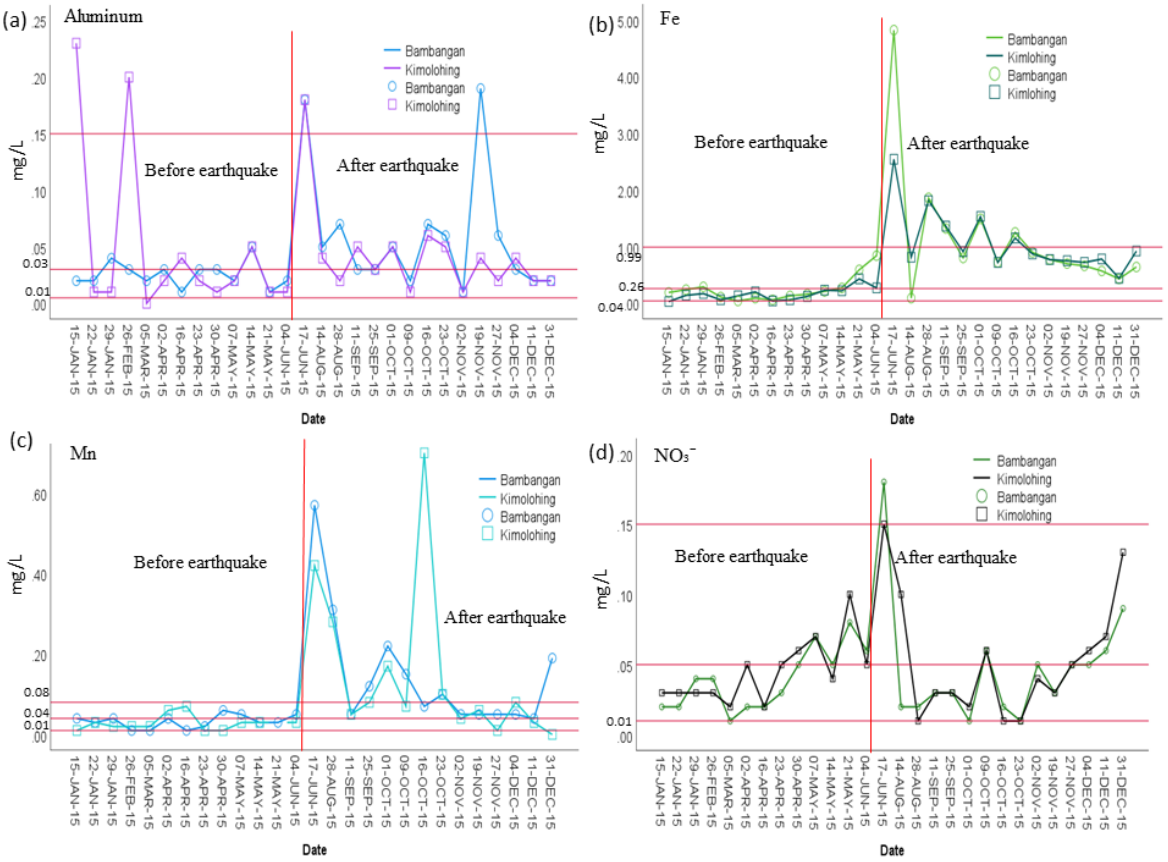

Figure 3: Variation pattern of (a) Al, (b) Fe, (c) Mn, (d) $NO3^-$; (the vertical line is earthquake's date on 5 June 2015; the horizontal line is the minimum, average, maximum in 2014)

3.2 Significant parameter

Table 3 demonstrates the output of Kruskal-Wallis test, testing the hypothesis that the water quality variable was significantly different. Significant parameters are Fe (0.01) and Mn (0.01) at both stations, turbidity (0.01) in the Kimolohing station, and Al (0.027) in the Bambangan station. Thus, an assumption is drawn on turbidity, and metal content such as Al, Fe, and Mn are the significant parameters which were impacted by the earthquake.

Table 3: The summary output of Kruskal Wallis test at significant value 0.05

Parameter	p-value	
	Bambangan station	Kimolohing station
Turbidity	0.093	0.001*
DO	0.300	0.541
EC	0.596	0.896
Al	0.027*	0.162
Fe	0.001*	0.001*
Mn	0.001*	0.001*
Hardness	0.908	0.371
NO_3^-	0.889	0.895

*Correlation is significant at the 0.05 level

4. Conclusions

Overall, the significant outcome of the present study is that the primary parameter assumed to be highly impacted by earthquakes, such as turbidity, colour and light metal such as Fe, Al, Mn and nutrient content, nitrate as well as alkalinity. In addition, the unstable change in the overall water quality happens for approximately two weeks and its recovery time takes more than six months, for some parameters.

Acknowledgements

This work is funded by the AUN/SEED-Net Grant no: R.K130000.7343.4B403 under Collaborative Education Program for Sustainable Environmental Engineering Network (CEP-SEEN).

References

Chin D.A., 2013, Water engineering in natural system, 2nd Edition, John Wiley & Sons, Inc., United States.

Felix T., 2016, The 2015 Ranau earthquake: Cause and impact, Sabah Society Journal, 32, 1–28.

Feng Q., Bo H., Jun L.J., Wei. L., Biao X.M., 2013, Analysis of the relationship between river flow and water quality before and after the wenchuan earthquake, Advanced Materials Research, 664, 164–168.

Haziq R.M., Musa M.H., Nurmin B., Herayani H.N.S., 2022, An overview: Relationship of geological condition and rainfall with landslide events at East Malaysia, Trends in Sciences, 19(8), 3464–3464.

Makoto K., Kiyoshi I., Takahiro H., Kei N., Jun S., 2020, Describing coseismic groundwater level rise using tank model in volcanic aquifers, Kumamoto, Southern Japan, Journal of Hydrology, 582, 124464.

Maurizio B., Stefania F., Domenico B.M., Andrea B., Tiziano B., Livio G., Francesca G., Sigurjón J., Marco P., Alasdair S., Gabrielle S., 2021, Changes in groundwater trace element concentrations before seismic and volcanic activities in iceland during 2010–2018, Science of the Total Environment, 793, 148635.

Omer, N. ,2019, Water quality parameters, water quality—science, assessments and policy, Kevin Summers, IntechOpen. In.

Raj P.B., Shree R.D., Kanchan T., Man S.S., Rashmi K., Raj P.D., 2019, Post-earthquake water quality in Bhaktapur district, Nepal, Journal of Water Security, 5, 1–7.

Ramadhan H.A., Radianta T., Intan S., 2020, The impact of earthquake on clean water demand and supply at north lombok regency, Indonesia, IOP Conference Series: Earth and Environmental Science, 426, 012001.

Robert O.O., 2021, The influence of urban land use on the water quality of Otamiri river for municipal supply, International Journal of Engineering Applied Sciences and Technology, 6(2), 184–191.

Behmel S., Damour M., Ludwig R., Rodrigue M.J., 2016, Water quality monitoring strategies—A review and future perspectives, Science of the Total Environment, 571, 1312–1329.

Sato T., Takahashi H.A., Kawabata K., Takahashi M., Inamura A., Handa H., 2020, Changes in the nitrate concentration of spring water after the 2016 Kumamoto earthquake, Journal of Hydrology, 580, 124310.