The impact of earthquake on clean water demand and supply at North Lombok regency, Indonesia

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Abstract: An earthquake of magnitude 6.4 Mw hit Lombok, Indonesia in July 2018, followed by another 6.9 Mw earthquake magnitude in less than a month in August 2018. The earthquake caused fatalities and damage to infrastructures, including the facilities of clean water. The main objective of this study is to know the impact of the earthquake towards clean water facilities damage, and to analyse clean water demand and supply after earthquakes in North Lombok Regency. Another purpose is to propose disaster mitigation to be implemented in the other disaster prone regions of Indonesia. The primary data were collected through field survey and questionnaire samples of 110 respondents. Secondary data regarding the damage of clean water network were collected from the Regional Water Company (PDAM) of North Lombok.

The results of this study show that many clean water facilities were damaged due to earthquake. The amount of clean water demand in Lombok Island after the earthquake was decreased by 19.03%. The number of wells users after the earthquake increased from 22.73% to 57.27%. The potential groundwater for clean water in the Lombok Island is more than sufficient to fulfil the requirement of clean water during disaster. However, further studies are required to realize such idea.

Keywords: earthquakes, pipelines, clean water needs, mitigation.

1. Introduction

Earthquake has become a global disaster, especially for countries that are located between active tectonic plates and Ring of Fire such as Indonesia. Both tectonic earthquake which is caused by the shifting of earth plates and, volcanic earthquake which is caused by magma activities are frequently happen in Indonesia. There are three tectonic plates within Indonesia archipelago, i.e. the Indo-Australian plate, the Eurasian plate, and the Pacific plate [9]. Therefore, Indonesia frequently experiences earthquakes with considerable magnitude. The earthquakes also cause damage to infrastructure, including facilities of clean water. The following are some historical earthquakes in Indonesia that affected clean water facilities.

a. Yogyakarta earthquake

In 2006, Yogyakarta was hit by an earthquake with a magnitude of 6.3 Mw [1]. The earthquake caused the clean water source to shrink and even disappear in some places. Before the earthquake, an
abundant water sources were available throughout the year. After the earthquake, people found difficulties in finding the clean water during the dry season”[16].

b. Palu and Donggala earthquakes

In 2018, Palu and Donggala, Central Sulawesi Indonesia were hit by an earthquake. The earthquake magnitude was 7.5 Mw and caused many fatalities [15]. Similar to that in Yogyakarta, the earthquake also reduced the availability of clean water in Palu and Donggala since, the network of clean water distribution in the area stopped functioning. According to Jannah [8], the earthquake also damaged the pipeline networks due to landslide or soil movement that displaced the pipe line off it tracks. In some areas, the ground conditions in Palu were cracked and collapsed, causing further damage to clean water pipes in Palu. Another contributing factor to the disaster is the cut off of electricity due to the damage of electrical lines. Such damage lead to disability of the Regional Water Company (PDAM) and community wells to function properly. To overcome the issue of clean water availability, the Ministry of Public Works and Public Housing operated public hydrants on artesian wells and groundwater sources [17].

Japan is also one of the countries that prone to earthquakes. Japan's geographical location is similar to Indonesia, which is located between three active tectonic plates, i.e. the Pacific plate, the Philippine Sea plate, and the Eurasian plate. Several major earthquakes have occurred in Japan, and some were followed by Tsunami.

a. Sendai earthquake, 2011

In 2011 Japan was hit by a powerful earthquake on March 11, 2011, at 14:46 local time with a magnitude of 9.0 Mw at the coast of East Japan and followed by a Tsunami. The earthquake caused the disruption of water supply for 2.300.000 households in such a large area, from Tohoku to Kanto [10]. Miyajima also mentioned that in Sendai City, the damage of pipe water supply network can be classified in to two categories namely caused by ground shaking and ground failure such as liquefaction and slope failure. Figure 1 shows a broken connection of pipe with diameter of 240 mm due to ground movement [10]. An underground water tank was uplifted due to liquefaction is shown in Figure 2 [10]. These two failures suggests the scale of destruction the earthquake can do to water distribution network infrastructure.

Figure 1.Broken pipe connection with diameter of 240 mm due to ground movement (Source: Miyajima [10])

Figure 2.Water tank lifted to the surface due to liquefaction (Source: Miyajima [10])

b. Kumamoto earthquake 2016

In 2016, Japan was again hit by an earthquake around Kumamoto City. The earthquake occurred on April 14, 2016, with the magnitude of 6.2 Mw and at 11 Km depth. A higher earthquake magnitude of 7.0 Mw again rocked sporadically in 28 hours afterwards, on April 16, 2016 [11]. According to [11], the earthquake caused land movements and geological disaster (landslides, liquefaction, and cracked soils) which resulted in damage to clean water networks. The pipeline network condition in the liquefaction was ten times worse than in the non-liquefaction area [11]. In addition, the earthquake on 14 April with the magnitude of 6.4 Mw caused the operation of clean water distribution in 69 out of 96 wells in Kumamoto City were stopped due to unaccepted turbidity.
As a result, there were 85,000 households that did not get supply of clean water [19]. Later, due to the April 16 earthquake with magnitude of 7.0 Mw, all wells in Kumamoto City stopped functioning due to the same problem of water quality and ultimately 326,000 households were without clean water supply [19].

This study explains further the impact of earthquakes on demand and fulfilment of clean water on the post-earthquake disaster in North Lombok, Indonesia. Previously, the Lombok Island, particularly in the district of North Lombok, was hit by two major earthquakes in Lombok. It happened on July 29, 2018, at 04:47 local time with magnitude of 6.4 Mw, at the direction of 47 km northeast area of Mataram city, with a depth of 24 km [2]. Twenty people died after this earthquake and there were landslides in several points at the climbing area of Mount Rinjani. The second earthquake occurred on August 5, 2018, at 19:46 local time with the magnitude of 6.9 Mw, which was detected at 27 km northeast of North Lombok with a depth of 10 km [2]. There were 506 people died, 1,406 people were injured, and 430,946 people were relocated [13]. The earthquake also caused infrastructure damage, including clean water facilities.

The sources of clean water facilities generally are wells, springs, PAMDES and PDAM (Drinking Water Regional Company). They were not well-functioned after the quake. As a result, most of the affected people could not get clean water from the sources. The objectives of this study are studying the impact of earthquakes on the damage of clean water facilities, the water demand and supply of clean water on post-earthquake in North Lombok. In addition, this study aims to determine some possible forms of mitigation.

2. Research Methods

The study used questionnaires, interviews and field observations as the survey methods. The collected data were categorized into primary and secondary data. Primary data were collected through field survey, interview, and field observation. The number of samples was 110 respondents from the total population of North Lombok Regency of 214,393 people [4]. The sample was selected randomly by considering the sample distribution, thus it was not focused only on one area. The secondary data were obtained from relevant stakeholders. In this case, most of the secondary data, such as the damage of water network data, were collected from PDAM in North Lombok.

![Map of the distribution of respondents](image)

3. Field Survey Results of Effect of Earthquakes in North Lombok

3.1 The Clean Water Network Facilities Damage

The earthquake that hit North Lombok on July 29, 2018, and August 5, 2018, resulted in a serious damage to the clean water facilities including the PDAM's piping network, the supply of
village’s drinking water (PAMDES), and private wells owned by community. As a result of the damage to clean water facilities, it is difficult for the people to get clean water. The facilities such as piping networks for drinking water supply experienced most of the damaged.

The damage caused by earthquakes to drinking water pipe networks was due to several factors including soil movement and slope stability. The major damages were broken transmission pipelines, broken pipe joints, buried intake structures, and the destruction of pump house. Based on the data obtained from PDAM and the results of field observation, the level of damage to the piped network was varied from the water intake, transmission network, distribution network, and the connection to customer's home. Figure 4 shows a landslide material covering the major part of an intake. Figure 5 shows the damage of a galvanized iron (GI) transmission pipe which has a diameter of 2 inches that was crushed by avalanches material including stone with diameters ranging from 50-100 cm. Figure 6 shows the damage of distribution pipes caused by ground movement while, Figure 7 shows the damage of the house connection at PDAM customers’ house which collapsed by the ruins of the house materials.

In addition to the earthquake impacts on piping networks, the ground movement influenced the quality and quantity of water resources from a number of local communities’ wells. The issues were varied, such as the decreased amount of water, the contaminated water quality and the sand that covered part of the wells. Such cases were mostly found on wells own by residents around the coastal area.

Figure 4. An intake was buried by landslide material
Figure 5. The broken transmission pipeline due to the avalanche materials
Figure 6. The damage of distribution pipe caused by ground movement
Figure 7. Home connection was buried by building materials
Figure 8. The location of shallow water wells covered by soil due to the earthquake. (a) A shallow well after being recovered (deepened), the dash line indicates the original soil surface after earthquake (b) A shallow well before being recovered
3.2 Sources of Clean Water, Pre and Post-Earthquake

Table 1 shows some sources of clean water before the earthquake occurred. The survey results show that 71 respondents are customers of PDAM and the remaining 39 respondents are users of other water sources such as wells, water spring, local water supply, and rivers.

| No | Source of water before earthquake | Total | %   |
|----|----------------------------------|-------|-----|
| 1  | PDAM                             | 71    | 64.55 |
| 2  | Wells                            | 25    | 22.73 |
| 3  | Water Spring                     | 12    | 10.91 |
| 4  | Local Water Supply               | 2     | 1.82  |
|    | **Total**                        | **110** | **100** |

Based on the survey, the use of clean water sources can be classified based on geographical zones. For example, springs and local water supply are mostly used in highland areas or around mountainous areas. As for customers, PDAM and wells are generally located in lowland areas, especially around the coast.

After the earthquake, there was a change in the preference of clean water sources usage. This is caused by the damage of the clean water facilities during the earthquake, especially the pipe water distribution system. To meet the needs of clean water after the earthquake, people usually use more than one source.

Table 2 shows that the utilization of wells to meet clean water needs after the earthquake was increased. The survey found that there were 63 respondents (57.27%) who use wells after the earthquake. This was because wells are mostly still available after the earthquake. However, there were a number of wells that cannot be used after the earthquake where the soil inside the wells raised above the water surface of the wells.

The increasing number of wells users was also caused by the operation of several deep wells (drilled) from the Nusa Tenggara River Basin 1 (BWS NT 1) in North Lombok Regency. The wells were originally intended to fulfil irrigation water needs, but then were temporarily operated to fulfil the need for domestic water after the quake. The Ministry of Public Works and Public Housing (PUPR) has added deep wells in several sub-districts. Table 3 shows the number of deep well locations before the earthquake and the additional deep well points after the earthquake in several areas in North Lombok Regency.

| No | sub-district  | Before the Earthquake | After the Earthquake | Total  |
|----|---------------|-----------------------|----------------------|--------|
|    | Amount (point)| Depth (m)             | Amount (point)       | Depth (m)|         |
| 1  | Pemenang      | 2                     | 60 - 90              | 6       | 50 - 150  | 8       |

Table 2. Changes in the usage of clean water sources after the earthquake.

Table 3. The number of drilled well points to meet clean water needs.
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Table 4. Average amount of clean water demand.

| No | sub-district | Before the Earthquake | After the Earthquake | Total |
|----|--------------|-----------------------|----------------------|-------|
|    | Amount (point) | Depth (m) | Amount (point) | Depth (m) |       |
| 2  | Tanjung        | 1         | 90          | 4         | 5     |
| 3  | Gangga         | 3         | 80 - 90     | 4         | 50 - 150 | 7     |
| 4  | Kayangan       | 2         | 50 - 90     | 0         | 0     | 2     |
| 5  | Bayan          | 4         | 80 - 110    | 0         | 0     | 4     |
|    | Total          | 12        | 14          | 26        |       |

Source: ([6] and [5])

The addition of deep well increased the wells users in Tanjung and Gangga. The number of wells users in Tanjung increased by 31.58%, and in Gangga increased by 18.42%. However, in Pemenang, the number was not too large, which was only 7.89%. This is not proportional to the number of additional deep wells in the area. It can be concluded that the determination of location and number of additional deep wells should be conducted carefully. Meanwhile, in Kayangan and Bayan, there were no additional deep well because of its geological conditions which is rocky soil. Nevertheless, the increase of wells users in Bayan was quite large, at 28.95%. In these areas, it was difficult for the resident to obtain clean water, especially those in the highland areas because of the damage of the clean water facilities and the long dry season that happen at the same time. Many rivers in the region dry up, thus people have to find other clean water sources, one of which was from BWS NT 1 drill wells. For those who do not have any vehicle to transport the water, they have to wait for clean water from the water tanker.

In highland areas, people used rivers water and clean water from water tankers. The distance from river to evacuation area was between 100 – 2000 meters. Clean water from water tankers comes from river flow and the deep well location of Nusa Tenggara River Basin Area 1 (BWS NT-1).

3.3 Needs and Fulfilment of Clean Water after the Earthquake

The survey results show the decreased amount of individual clean water demand in North Lombok District after the earthquake. Table 4 shows the number of individual clean water demand in North Lombok Regency before and after the earthquake. The reduction of clean water demand after the earthquake was 19.03% (32.81 lt/person/day) from the total demand before the earthquake.

| No | Type of Activity | Before the earthquake | After the earthquake | Difference |
|----|------------------|-----------------------|----------------------|------------|
|    | Amount (lt/p/d)  | (lt/p/d) | (lt/p/d) | (lt/p/d) | (%) |
| a  | 1 Drinking and cooking | 9.70 | 9.05 | -0.65 | -6.70 |
|    | 2 Bathing         | 72.23 | 57.86 | -14.36 | -19.89 |
|    | 3 Washing clothes | 22.77 | 18.86 | -3.91 | -17.19 |
|    | 4 Washing dishes  | 8.85 | 7.92 | -0.94 | -10.60 |
|    | 5 Sanitation      | 45.68 | 38.27 | -7.41 | -16.22 |
|    | 6 Others (watering, drinking supply for livestock, etc.) | 13.17 | 7.64 | -5.53 | -42.01 |
|    | Total             | 172.40 | 139.59 | -32.81 | -19.03 |

Note:
*lt/p/d = litre/person/day

The minus sign (-) in the table shows a reduction of clean water demand. The maximum reduction of water demand was for other activities which include watering, drinking supply for
livestock, washing vehicles, i.e. 42.01% (5.53 lt/p/d) from the original needs before the earthquake. On the other hand, the minimum reduction is happened for drinking and cooking, which equals to 6.70% (0.65 lt/p/d). The reduction of clean water demand after the earthquake was caused by a large number of clean water facilities that was damaged due to the earthquake, hence local residents found it difficult to get clean water.

There is a difference in clean water demand between PDAM customers and Non-PDAM customers. Table 5 shows a comparison of clean water needs between PDAM customers and Non-PDAM customers before and after the earthquake.

| No | Type of activity | Use of Water by PDAM Customers | Use of Water by Non-PDAM Customers |
|----|-----------------|--------------------------------|-----------------------------------|
|    | Before the earthquake (lt/p/d) | After the earthquake (lt/p/d) | Difference (lt/p/d) (%) | Before the earthquake (lt/p/d) | After the earthquake (lt/p/d) | Difference (lt/p/d) (%) |
| a  | b                | c                               | d                               | e=c-d | f=e/c | g                     |
| 1  | Drinking and cooking | 10.88 | 9.90 | -0.97 | -8.96 | 7.55 | 7.49 | -0.06 | -0.76 |
| 2  | Bathing          | 70.49 | 53.45 | -17.04 | -24.18 | 75.38 | 65.90 | -9.49 | -12.59 |
| 3  | Washing clothes  | 23.51 | 19.09 | -4.42 | -18.81 | 21.42 | 18.43 | -2.99 | -13.95 |
| 4  | Washing dishes   | 9.32  | 8.31  | -1.01 | -10.80 | 8.01  | 7.20  | -0.81 | -10.16 |
| 5  | Sanitation Others | 46.48 | 38.24 | -8.24 | -17.73 | 44.23 | 38.33 | -5.90 | -13.33 |
| 6  | Drinking supply for livestock, etc.) | 10.71 | 4.44 | -6.28 | -58.59 | 17.64 | 13.46 | -4.18 | -23.68 |
|    | Total            | 171.39 | 133.43 | -37.96 | -22.15 | 174.23 | 150.81 | -23.42 | -13.44 |

Table 5 shows that the amount of clean water demand for PDAM customers after the earthquake decreased by an average of 22.15% (37.96 lt/p/d) from the total demand before the earthquake. As for non-PDAM customers, there was a decrease of 13.44% (23.56 lt/p/d) from the total clean water demand before the earthquake. Overall, based on the type of activities related to water requirement shown in Table 5, the maximum decrease of water requirement was from PDAM customers because after the earthquake, most vital pipes of PDAM system was damaged which caused ineffective clean water distribution. Therefore, to meet the daily needs of clean water, customers should search for other sources of clean water. After the earthquake, PDAM customers carefully use the clean water until the PDAM water system become functional. On the other hand, the water demands of non-PDAM customers only slightly reduced, as the clean water sources, such as wells, were mostly still available.

4. Analysis and Discussion

Based on the analysis of the data obtained by questionnaire, the earthquake impact on the demands of clean water in North Lombok Regency was very significant. As a result of the earthquake, most of the damage of the clean water facilities in North Lombok Regency caused difficulties of people to get clean water. Table 6 shows the damage of clean water facilities due to an earthquake which occurred in several regions. Types of damage due to the earthquake are grouped into 9 groups. Group (1) Damaged pipe, group (2) Separated pipe connection, group (3) Malfunction of Intake, group (4) Damaged house connection (SR), group (5) Buried pipe because of landslide, group (6) Underground tank water rises to the surface, group (7) Clean water sources discharge shrinks/disappears, group (8) Damage of pump houses, and group (9) Decreased of the quality and quantity of clean water in wells.
Table 6. The damage to clean water facilities due to earthquakes in several regions.

| No  | Location          | Year | Magnitude (Mw) | Type of Damage for clean water facilities | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|-----|-------------------|------|----------------|------------------------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | Yogyakarta        | 2006 | 6.3           |                                          | √    |     |     |     |     |     |     |     |     |
| 2   | Japan (Sendai)    | 2011 | 9.0           |                                          |     |     |     |     |     |     |     |     |     |
| 3   | Japan (Kumamoto)  | 2016 | 6.4 and 7.0   |                                          |     |     |     |     |     |     |     |     |     |
| 4   | Palu              | 2018 | 7.4           |                                          |     |     |     |     |     |     |     |     |     |
| 5   | Lombok            | 2018 | 6.4 and 69    |                                          |     |     |     |     |     |     |     |     |     |

Table 6 shows that in general, the impact of earthquakes on the clean water facilities in North Lombok District were similar to those in other places. The main factors of destruction are due to soil movement and slope stability. In damage group (9), most type of damages to clean water facilities occurred in North Lombok Regency. The damage to clean water piping system in North Lombok Regency was mostly caused by landslides or material, such as the damage groups (1), (2), (3), and (5). The damage that was caused by liquefaction (group damage 6) that was occurred in Japan was not found in this study.

The process of fulfilling clean water demand, especially in Indonesia, were mostly conducted by distributing the water with water tankers. The sources were from wells, artesian drill wells, and the nearest river flow. However, this distribution method was ineffective because the number of water tankers was not sufficient to serve the community. According to [18], in Selengen Village, since the population was large in comparison with the water tankers availability, the residents had to queue to get clean water. In addition, people also had to find other clean water sources which were quite far, if the water tankers were not available in their location.

Figure 9. The residents of Selengen Village were queuing for clean water
(Source: Viva [18])

Since Indonesia’s geographical location is between three tectonic plates (Indo-Australia, Eurasia, and the Pacific plate), the earthquake disaster may happen again at any time. During the earthquake disaster that happened in North Lombok Regency, the number of affected people was less than the total number of people in the whole Lombok Island. It means that, it is possible that another earthquake may affect even more people Lombok Island. More detail information about the population of Lombok Island is shown in Table 7.

Table 7. Population, PDAM customers, the volume of water distribution, and clean water infrastructure based on districts/cities in Lombok Island

| No  | Regency / City  | Population (people) | PDAM customers (SR) | Volume of water distribution (m³) | Water Springs (point) | Drill Well BWS NT-1 (point) | Dam (point) |
|-----|-----------------|---------------------|---------------------|-----------------------------------|-----------------------|-----------------------------|-------------|
| 1   | West Lombok     | 675,222             | 52,836              | 10,198,584                        | 41                    | 6                           | 3           |
| 2   | Central Lombok  | 930,797             | 51,592              | 11,471,310                        | 101                   | 25                          | 14          |
| 3   | East Lombok     | 1,183,204           | 23,816              | 508,931,000                       | 242                   | 251                         | 14          |
| 4   | North Lombok    | 216,515             | 11,909              | 2,632,688                         | 50                    | 149                         | 1           |
| 5   | Mataram         | 469,509             | 74,090              | 17,467,772                        |                       |                             |             |
| **Total** |                  | 3,474,247           | 214,243             | 550,641,354                       | 434                   | 431                         | 32          |

(Source: [3] and [5])
Table 7 shows that the population mostly resides in East Lombok Regency, which is equal to 34.06% of the total population in Lombok Island, while the population in North Lombok Regency is only 6.23% of the total population in Lombok Island. In East Lombok Regency, there are a lot of infrastructure facilities of clean water that can be used to serve the need of clean water demand after an earthquake. On the other hand, the population and customers of PDAM in Mataram City at West Lombok are quite large, but the source of clean water from rivers, small reservoir is not sufficient. The rivers that flow in the area are the downstream part of the rivers originated from West Lombok Regency. The river water has been polluted mainly because of household waste from around the river flow. This condition requires a form of mitigation plan to fulfill the clean water demand when the facilities cannot function well.

Many countries that are prone to earthquake tried to mitigate the risk of earthquake disaster, including Japan and Taiwan. Hu, N [7] stated that the same efforts must be taken in Taiwan to reduce the impact of clean water facilities damage due to earthquakes by improving water supply plans in highland areas, developing smart water system, conducting seismic and geological hazard surveys throughout the system, replacing old pipes to maintain its work, capacity building and institutional strengthening to reduce water loss, and improving training for management during emergencies situation.

In Japan, in order to overcome water scarcity in Tokyo, earthquake resistant buildings are promoted for water purification and clean water storage building, promoting earthquake resistant pipe joints, establishing water supply system for emergency condition for example by providing temporary hydrants, conducting promotion and training for local communities, and cooperating with other cities and organizations [12].

5. Mitigation Plan

A mitigation plan for sustaining clean water distribution in Lombok Island may be conducted by for example providing more drill wells in several strategic places. This is because drill wells have proved to be effective in providing required clean water after the earthquake disaster as explained above. There are two Groundwater Basins (CAT) in Lombok Island. Tanjung-Sambalia, with an area of 1.124 km² with a potential groundwater about 224 million m³/year and a depressed groundwater at 22 million m³/year. The other groundwater basin is Mataram-Selong with an area of 2.366 km². The potential groundwater is 662 million m³/year and the potential of depressed groundwater is 8 million m³/year [14]. These potent of ground water should be more than enough in term of volume to cater the need of the population. As for the areas in the highlands, the water may be served by water tankers. The proposed mitigation of increasing the number of wells should be studied with regard to water quality and the best locations with regard to optimization of water distribution. Therefore, it is necessary to do further research to implement this proposed mitigation efforts.

Another mitigation plan can be conducted by strengthening the pipe network infrastructure and reducing the risk of pipe damage impact. The pipe network should be studied carefully to define the hydraulics index of each important pipe along the network. When the hydraulics index of a pipe (pipe A) is higher than certain number (for example 25%) an alternative pipe should be installed. The alternative pipe should be able to replace whenever pipe A is broken.

Learning from the fact that people were queuing for water, it is also important to prepared more truck for transporting water. In area, where the number of people is not so many, truck is not efficient. Therefore, light vehicle (motor tricycle) is a good alternative. These facilities should be prepared and ready whenever required.

6. Conclusion

The study conclude as follows:

a. Clean water supply with a piping network system has a greater risk of damage due to the earthquake,
b. The earthquake caused a decrease in the amount of clean water demand.

c. After the earthquake, people use more wells (shallow and deep) to meet their daily clean water demands. Therefore, the existence of shallow wells is needed to fulfill the needs of clean water.

d. The bore wells have contributed significantly to provide clean water after an earthquake. According to the survey, 57.27% of respondents used wells after the earthquake, where the number of wells users is only 22.73% before the total respondents.

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