Survival at School: An Investigation into Water Resources in Times of Natural Disasters

Children of Makuhari Beach

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1. Abstract

The Great East Japan Earthquake, which occurred in 2011 and permanently damaged Makuhari, a community in Chiba City, Chiba Prefecture, Japan. As our school is located in Makuhari, the area surrounding our school was plagued by liquefaction, in conjunction with severe water shortages due to turbid water and water outages. The disaster prompted us to ask the questions: Is it possible to reduce the damage caused by such natural disasters in Japan, an earthquake-prone country? Is there any way to supply clean water in a more efficient way?

This project will investigate the likely effects on Makuhari's water systems and water supply if another disaster strikes and causes damage to waterworks facilities that results in shortages of water needed to sustain our lives. We aim to prove how it is possible to deal with the effects of natural disasters on the water supply using readily available materials. Our research will involve investigating Makuhari's geographical features, and the impacts past disasters have had on the region. Moreover, we will explore the current disaster-response methods to identify any drawbacks and consider the alternatives that would fix these problems. We will also experiment with manifold methods of water testing in order to ascertain which method is the most practical in times of crisis. Water testing is important when a disaster occurs to determine whether the water is safe to drink.

Key words

the Great East Japan Earthquake, liquefaction, land reclamation, water testing

2. Background of the Research

2.1. The Purpose of the Research

Water can give us life, but it is also capable of destroying our lives. Our research is designed to encourage local citizens to be more aware of water-related dangers in their community. Our goal is to ensure that water resources are protected in the event of a disaster. As was evident from the aftermath of the Great East Japan Earthquake, the powerful earthquake triggered powerful tsunami waves that are known to have reached heights of up to 40.5 meters and which resulted in the deaths of 15,899 people. In the area surrounding Makuhari, the casualties were minimal compared to the casualties caused by the tsunami in other areas, but the impacts of the liquefaction caused by the earthquake are still visible to this day. As many scientists speculate that there will be another large earthquake that will devastate Japan soon, we thought that this project would be the perfect opportunity for us to investigate what is likely to happen to the area surrounding our school in the event of such a disaster and how we may be able to survive by utilizing the very same element that could also kill us: water.

2.2. Method of the Research

This research paper consists of two parts:

1. Natural Disasters and the Effects on the Water Systems
2. Water Testing

In the first part, we looked into research conducted by the Chiba Prefectural Waterworks Bureau and also went to the Sewerage Exhibition to learn about prevention measures for future natural disasters. The Sewerage Exhibition is a comprehensive exhibition of the latest technology and equipment used in a wide range of fields related to sewerage, based on the results of technological development by sewerage-related companies and organizations throughout Japan, and aimed at local governments and other organizations that are the managers of sewerage projects. We also referred to the hazard maps that Chiba City released, especially in part 6 in which we explored the possibility of Makuhari being struck by water-related disasters aside from liquefaction.

In the second part, we tested the water quality of areas surrounding our school using pack tests that were available in our school.

2.3. Result of the Research

Phase one investigates the aftermath of the Great East Japan Earthquake and based on the findings, we made a prediction about what kind of earthquake would hit Japan in the near future. Through analyzing Makuhari's geological features, we discovered that Makuhari is most susceptible to liquefaction in the event of an earthquake. Indeed, the loose sandy soil that covers the reclaimed land makes it ever the more susceptible to liquefaction. It is highly probable that Japan will be struck by an earthquake with a magnitude of nearly 7.3. Such a large earthquake will devastate Makuhari with the effects of liquefaction, which include the tipping and sinking of structures, surfacing of underground tanks, and the upending and sinking of utility poles. The results of the simulation also show the effects on the waterworks system and the drainage system in the Chuo, Hanamigawa, Inage, Wakaba, Midori, and Mihama wards. The results of the simulation of the damage to the waterworks system suggest that all of the seven water supply facilities in the city will experience power outages, but, immediately after a disaster, emergency generators will maintain water distribution functions. As for the drainage system, immediately after the disaster, 4% of the population will experience functional disruption. However, even if sewerage functions are restored, toilets and other facilities will be unusable if the water supply system is not operating. This means that there will be a need to provide sanitary working lavatories in the case of natural disasters. The implementation of manhole toilets is a good solution. Manhole toilets are emergency toilets that can be stockpiled with less space. The benefits of manhole toilets in times of natural disasters is that they are easy to stockpile, and can be used quickly and easily. Moreover, they are hygienic, because urine can be diverted into the sewage pipeline.

We took the research a step further by exploring the possibility of Makuhari being struck by water-related disasters aside from liquefaction. The water-related disaster can be separated into three separate disasters. The first disaster is inundation. Since Makuhari has a low altitude, it is prone to inundation. The two rivers that flow through Makuhari also have a low altitude, which can cause the drainage system to malfunction and increase the possibility of inundation. As a result, the city requires a river embankment that is strong enough to resist the effects of inundation, and which also has an efficient drainage system.

The second disaster is the storm surge. Makuhari is located just next to the ocean, so it is likely to be attacked by a storm surge. A storm surge is a rise in sea levels that occurs during storms.

This figure shows that at the maximum height, waves that reach heights of 2 to 3 meters are expected to hit Mihama Ward. Furthermore, some narrow roads that do not have an efficient drainage system may remain flooded for up to 168 hours, until water levels fall below 0.5m. Although the ocean coast near Makuhari is protected by sea embankments, it is unlikely the embankments will protect residents from all the damage that storm surges bring. Therefore, it is crucial for families that live in Makuhari to prepare emergency items in advance.

The third disaster is the sediment disaster. Since the greater part of Makuhari was constructed from landfill, the possibility of a sediment disaster occurring is quite low. No points in Makuhari have been registered as a sediment disaster alert area or sediment disaster special alert area. The other wards in Chiba City – Chuo, Hanamigawa, Inage, Wakaba, Midori – are presumed to be at low risk of sediment disaster. However, we should not let our guard down and keep up with the latest hazard maps to protect our lives.

Phase two is an experiment that we conducted regarding the water conditions of the bodies of water surrounding our school. We were interested in carrying out this experiment as in times of natural disasters, there may be a period of time when we cannot access clean water and may have to resort to using water from nearby sources of water. In these circumstances, we wanted to investigate which water sources are safe to use and which water resources are not safe to use.

There are seven major types of water testing: COD test, PO_4^{3-} test, NO_2^- test, NH_4^+ test, pH test, turbidity (transparency) test, and hardness test. A COD test is used to measure the number of organic pollutants in a water body as an indicator of water quality. A PO_4^{3-} (orthophosphate) test is added to a water source to prevent lead pipes from leaching, but when in high concentration, it can cause rapid algae growth on surface waters, harming the plants underneath the water. In a NO_2^- test, the presence of nitrite nitrogen in water is an important indicator for estimating water pollution, as it is mainly produced by the oxidation process of ammoniacal nitrogen from various industrial effluents. In a NH_4^+ test, nitrate predominates in unpolluted waters, while dirty water contains high organic nitrogen. In a pH test, the pH scale runs from 0 to 14 and measures the acid or base quality of the water. We collected water samples from areas within and surrounding our school. A turbidity test is often used as a measure of the sanitary quality of water and often indicates that filters are not working properly. A hardness test measures the amount of dissolved calcium and magnesium in the water.

The water samples we examined are as follows: tap water, water from Mihama Ward, water from Hamada River, water from Hanamigawa River, and water from an aquarium. The results show that the pH levels of all of the water samples are 6.2, but the COD levels differ greatly. The COD level of the tap water is a relatively safe 5 mg/L, but the COD level of the water from an aquarium is 20 mg/L, meaning that the water is contaminated. In order to apply the results of phase 2 to the research we conducted in phase 1, we have researched the water quality of the groundwater when the ground is shaken due to an earthquake. It is possible that earthquakes can, at least temporarily, expose groundwater to pollution and change its makeup. In this case, we think that adding a pH adjusting agent will decrease the acidity of the water and make it drinkable. Moreover, in order to purify water after a disaster, boiling the water will disinfect the water enough for us to be able to use it.

Phase 1: Natural Disasters and the Effects on the Water Systems

3. The Dangers Caused by Makuhari's Geological Features

3.1. An Overview of Mihama Ward

1) Location

Mihama Ward is the westernmost of Chiba City's six wards, facing Tokyo Bay. The great majority of Chiba City is made up of reclaimed land. This is also the ward where our school is located.

Figure 1: Location of Mihama Ward

2) Geological Features

The entire area is reclaimed land and does not have many differences in elevation. The area was reclaimed by placing sand and silty soil from the adjacent offshore area on top of the very loose soil that had accumulated on the seafloor, resulting in extremely soft ground. Figure 2 shows that the ground is composed of sand above 8 meters of the ground and the ground is composed of silt below eight meters of the ground. The shallower the soil, the softer the ground.

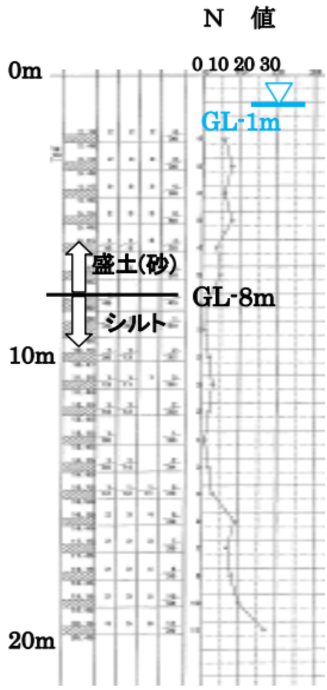

Figure 2: Ground hardness scale

3) Land Usage

The JR Keiyo Line runs through the center of the ward from east to west, and many people commute to central Tokyo, with most of them living in residential areas. The "Makuhari New Urban Center District" in the western part of Mihama Ward is a business, research, and educational district. The "Shinko District" in the eastern part of Mihama Ward is home to a variety of companies involved in the food, port, and transportation industries. Makuhari also has a wide variety of attractions from stadiums to a convention center to malls and homes as well as office buildings.

3.2. History of Land Reclamation of Chiba City

As mentioned in 3.1., the great majority of Chiba City is made up of reclaimed land. As seen in Figure 3, although other regions of reclaimed land surrounding Tokyo Bay were made centuries ago, the land on which Chiba City was built was formed quite recently (1965-1985).

The recent formation of the land under Chiba City correlates to the severity of liquefaction in this exact area in comparison to the other reclaimed land of Tokyo Bay (3.4 & 4.2).

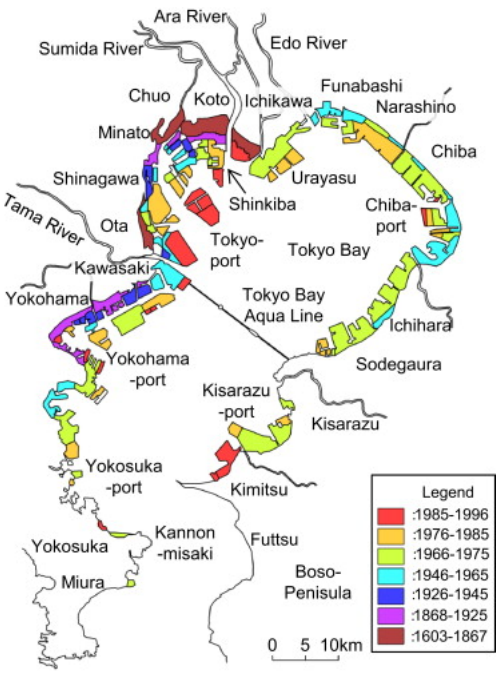

Figure 3: Reclaimed land surrounding Tokyo Bay

3.3. Analysis of Makuhari's Geological Features

3.3.1. Introduction of Makuhari's Geological Features

Makuhari is located in Chiba City in Figure 3.

The reclaimed land in Chiba City was made during 1966-1975. The city comprises an area of 271.77 square kilometers. As the great majority of Chiba City and all of the Makuhari district is made up of reclaimed land, it is considered an artificial flat land.

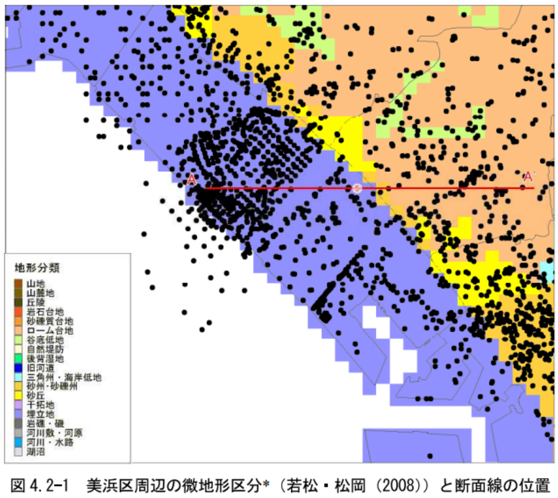

Figure 4: Geographical Landscape of Mihama Ward

Figure 4 shows the geological landscape of Mihama Ward. The area highlighted in purple is reclaimed land and the area highlighted in orange is the Kanto loam foundation. The black dots represent huge lands. As shown from this figure, much of the area surrounding our school is reclaimed land.

3.3.2. The process of the development of reclaimed land in Makuhari

The process of the development of the reclaimed land in Makuhari occurred over a span of 10 years. Figure 5 is a comparison between modern Makuhari and before the land reclamation process started in 1947. [1]

Figure 5: 1947 Makuhari Coastline

The shaded region in Figure 5 shows how big the area of reclaimed land is. What was once the ocean is now land comprising stations, stadiums, office buildings, and schools. Figure 6 shows Makuhari after the reclamation process was completed. Although the landscape had altered dramatically, it was still not the Makuhari of today. The newly built territory then was just acres of empty plots and farms.

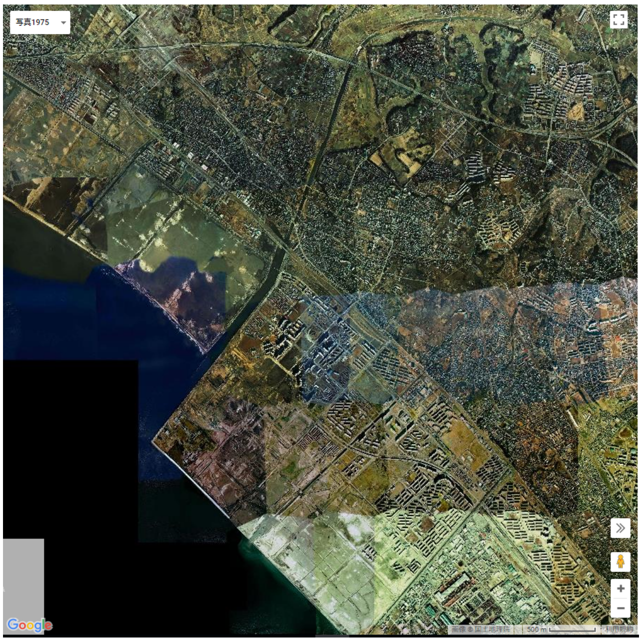

Figure 6: 1975 Makuhari

It was not until the 1980's when this empty land was finally put to use. Even then, there was still a lot of empty land. Importantly, there was nothing that connected this new territory and the surrounding major cities such as Tokyo. In the late 1980's transportation methods, including train lines, made Makuhari accessible. Since then, the amount of infrastructure and the population have increased, transforming Makuhari from a seaside village to a densely populated district.

3.3.3. Poling borehole water level distribution of Makuhari

By examining the geology of Makuhari, specifically the water boreholes, we can see that the depth of these water boreholes correlates to the location of liquefaction.

A water borehole is a modern well that stores the water that we use for our daily needs. Some boreholes exist deep underground, others are dangerously shallow. It is dangerous when a borehole is shallow as it increases the chances of liquefaction.

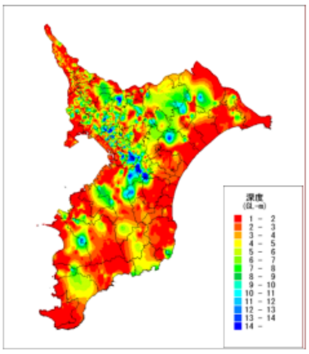

図 5.3-4(1)　ボーリングの孔内水位から求めた地下水位分布（深度表示

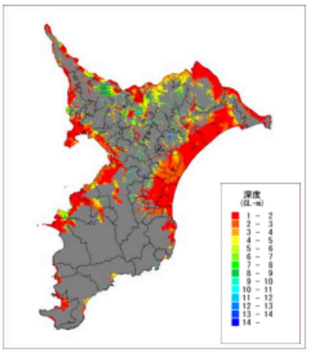

図 5.3-4(2)　ボーリングの孔内水位から求めた地下水位分布
（深度表示・液状化対象層のみ：図の灰色は対象外）

Figure 7: Liquefaction data from boreholes

Figure 7 shows the depth of the locations of these water boreholes around Chiba Prefecture. The red mark, being the shallowest of only about a meter below surface, can be seen around the coast (Tokyo Bay), right where Makuhari is located.

The second map in Figure 7 is the area where liquefaction was seen. These liquefactions can be seen from areas where these water boreholes are dug not too deep underground. Both of these figures show that areas where the water boreholes are not dug deep underground are most susceptible to liquefaction.

3.4. Comparison to other Reclaimed Land

Before examining comparisons between Makuhari and other areas of reclaimed land, a quick overview of liquidation and its impact on reclaimed land is necessary.

Figure 8 shows that reclaimed land is made of sand particles. These particles are connected to each other. In the gaps between sand particles is pore water. When events such as earthquakes occur, these sand particles, which were once together, spread out within the pore water. This pore water will ride above the sand, producing liquefaction. When this pore water rises, the sand particles sink beneath the water. This causes the sand particles to be connected once again, but in such a way that their bonds are stronger than before their separation.

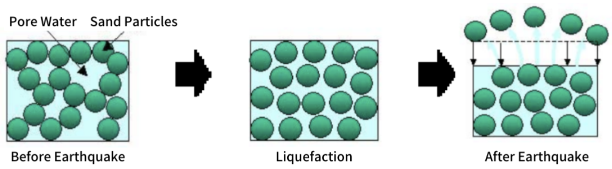

Figure 8: Mechanism of Liquefaction

Hence, the land gets stronger every time liquefaction occurs. Thus, as this process has been repeated, older reclaimed land is stronger than newly developed reclaimed land.

Because Makuhari is built on very newly reclaimed land, it will take multiple liquefactions over the next decades in order for the land to become stronger and more stable. Section 4 will evaluate the negative aspects of liquefaction.

4. Damage Caused by Liquefaction Resulting from the Great East Japan Earthquake

4.1. Definition of Liquefaction

Liquefaction is a phenomenon in which partially saturated soil becomes liquid due to strong seismic shocks applied to loosely deposited ground such as reclaimed land, and low-lying areas between sandbars.[2] In Japan, liquefaction became well known after the 1964 Niigata earthquake, when liquefaction of the ground-supporting structures caused buildings to topple over, sink, or tilt. Phenomena resulting from liquefaction include sand fountains, structural subsidence, uplift, lateral flow (horizontal displacement of the ground due to liquefaction), and subsidence.

4.2. Mechanism of Liquefaction

Liquefaction is a process which occurs when loose sandy soil saturated with groundwater is subjected to repeated and violent shearing by seismic motion.[3] The excess pore water pressure increases and the effective stress decreases, resulting in the sand losing stability. It becomes as if the sand particles are drifting in the water. This phenomenon is known as “sand drift”.

In other words, the sand substrates temporarily and becomes like a liquid due to seismic vibration. When liquefaction occurs in this way, heavy structures built on loose ground will sink and silt. On the other hand, structures that are buried underground and have a low specific gravity will float. On the surface, sand eruptions will occur over a wide area, affecting roads, parks, and residential areas, and the ground will settle after the eruption, causing damage to the surrounding areas. Figure 9 below shows how liquefaction happens.

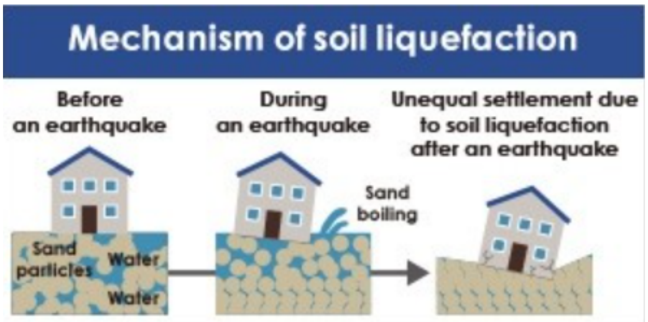

Figure 9: The mechanisms of liquefaction[4]

4.3. Geological Features Susceptible to Liquefaction

Liquefaction does not occur everywhere. It is said to be more likely to occur when the following three factors come together.

1) Loose sandy soil

Liquefaction often occurs near seashores, estuaries, reclaimed land, and river fans. The N value of these places, which indicates the hardness of the ground, is less than 20, and the size of the soil particles is 0.03 mm to 0.5 mm. This means that the smaller the size of the particles, the more likely liquefaction is to occur. (※1)

2) Location of groundwater

The groundwater level being within 10m of the ground surface makes the land more vulnerable to liquefaction. In other words, the shallower the groundwater level, the more likely liquefaction is to occur. (※2)

3) Large earthquake mainshocks

The seismic intensity that is required to cause liquefaction is said to be 5 or higher. The longer the shaking time, the greater the damage tends to be. (※3)

※1 The N-value is the number of times a weight must be dropped onto a pile inserted into the ground in a specified manner to drive it to a certain depth, and thus, it indicates the hardness of the ground. As a rule of thumb, soft ground has an N-value of 5 or less, while ground hard enough not to require piles when building a large building has an N-value of 30 or more. Liquefaction does not occur in clay soil. (See Table 1.)

Table 1: The N Value [5]

N Value	Friction Angle, φ' (Deg.)	Relative Density, D_r (%)	Description
Less than 4	25 - 28	Less than 15	Very loose
4 - 10	29 - 32	15 - 60	Loose
10 - 30	33 - 35	60 - 75	Medium
30 - 50	36 - 40	75 - 90	Dense
Over 50	41 - 45	Over 90	Very dense

※2 However, detached houses are light, so if the groundwater level is deeper than 3 meters below the surface, damage to the building itself due to liquefaction is unlikely to occur.

※3 In the Great East Japan Earthquake, large-scale liquefaction occurred in areas where seismic intensity of 5 was recorded. Since the length of shaking is proportional to the magnitude, a large magnitude earthquake will cause a longer shaking time, increasing the likelihood of liquefaction. In addition, if the shaking time is long, liquefaction may occur even with an earthquake of magnitude 4.

4.4. Damage Done to the Area Around Makuhari by Liquefaction

The following is an excerpt from the report prepared by the Research Center for Liquefaction and Fluidization Damage in Tokyo Bay Landfill Areas due to the 2011 Tohoku Earthquake.[6]

(1) Saiwaicho, Mihama Ward:
Damage mainly caused by sand eruptions has been confirmed.

(2) Near Inage-kaigan 2-chome, Takasu 2-chome, Takahama 1-chome, and Shinko near Mihama Ward, Mihama Prefecture:
Significant liquefaction-related damage was observed, including tipping and sinking of structures, surfacing of underground tanks, and tipping and sinking of utility poles. In addition, sand eruptions were extremely large, and subsidence and upheaval of the ground surface were also observed. In Inage Kaigan Park, a very large sand eruption of more than 100 meters was confirmed.

(3) Inage Kaigan 3-chome, Takasu 3-chome, Takahama 4-chome, and Takahama 7-chome in Mihama Ward:

Large numbers of sand eruptions from ground fissures were observed in the vicinity. Many of the cracks were 50-100 mm in diameter. In the Kaihin Park, the extent of damage caused by sand eruptions is remarkable, and in the Lawn Park, a large-scale subsidence of about 50m x 50m occured.

(4) Masago 1-2 chome, Isobe 3-5 chome, Mihama Ward:

The extent of damage north of the Keiyo Line was slightly smaller, but the damage south of the Keiyo Line was significant. In particular, significant subsidence accompanied by a large number of sand eruptions, as well as tilting and sinking of single-family houses, block fences, and utility poles were observed in the Naka-Isobe Park area. In Naka Isobe Park, the large number of sand fountains and fountains have caused significant subsidence of several tens of centimeters to about 1 m in an area of about 30 m wide by 60 m long.

(5) Masago 4-5 chome, Isobe 6-7 chome, Mihama Ward:

The extent of damage north of the Keiyo Line was slightly smaller, but the damage south of the Keiyo Line was significant. In particular, Isobe 7-chome suffered significant damage from subsidence and ground waves caused by sand eruptions.

(6) Wakaba 1-2 chome, Mihama Ward, Kaihin-Makuhari Station area, Makuhari-no-Hama:

This area had a relatively large number of sand eruptions, and roads have been observed to be swollen and sinking.

(7) Hamada 1-chome, Mihama Ward:

Sand eruptions with cracks in the ground have been observed.

(8) Makuhari Nishi, Mihama Ward:

The eruption was confirmed to be caused by liquefaction over the entire reclaimed land, rather than a zonal distribution of eruption sand. The extent of damage was confirmed to be tilt and sinking of utility poles, settling of block walls, and tilt of single-family dwellings.

写真２－２　美浜区幕張西５丁目　（液状化による噴砂）

Figure 10: Damages done to Makuhari Nishi 5 chome

5. Predictions of Damage Caused by Future Earthquakes

5.1. Type of Earthquake

The damage caused by the liquefaction in the Great East Japan Earthquake left a lasting mark on Makuhari, and most of Chiba City. However, it will most likely not be the last large earthquake to devastate Japan. It is estimated that a huge Nankai Trough earthquake will surely occur. To give some sense of the scale, it will be more than 10 times larger than the Great East Japan Earthquake. Therefore, we have conducted research into what the possible type of earthquake that will devastate Japan next will be. Based on the latest national and prefectural scientific findings on earthquakes directly under the Tokyo metropolitan area, as well as past earthquake-damage-estimation surveys conducted by the city, we have summarized the concept of a hypothetical earthquake. In the past, earthquakes of magnitude 8 occurred every 200 to 400 years in the area directly under and surrounding the southern Kanto region. This includes the Genroku Kanto Earthquake of 1703 and the Taisho Kanto Earthquake of 1923. These M8-class earthquakes were preceded by several M7-class earthquakes. As 93 years have already passed since the Taisho Kanto Earthquake, there is a possibility that several M7-class earthquakes will occur in the future before the next M8-class earthquake occurs. On the other hand, the probability of an M8-class earthquake is low for the time being, but the probability of an M8-class earthquake occurring in the next 100 years is high. Based on these considerations, the Central Disaster Prevention Council has assumed an earthquake with a moment magnitude (Mw) of 7.3 directly under Chiba City Hall will occur. The rupture would begin at the rupture initiation point directly below Chiba City Hall, and the earthquake would occur when the inland side of the fault moved northward, and the seaside side moved southward along the fault plane.

The predicted results show that the liquefaction risk is high in Chuo, Hanamigawa, and Mihama Wards. The liquefaction risk is particularly high in Mihama Ward, where liquefaction risk is high in nearly 50% of the area, as is apparent from Figure 11.[7] The liquefaction hazard level varies by location within the landfill site, reflecting the ground structure before the landfill was constructed. In inland valley landfills, the liquefaction hazard is higher due to the thicker liquefaction-prone soil.

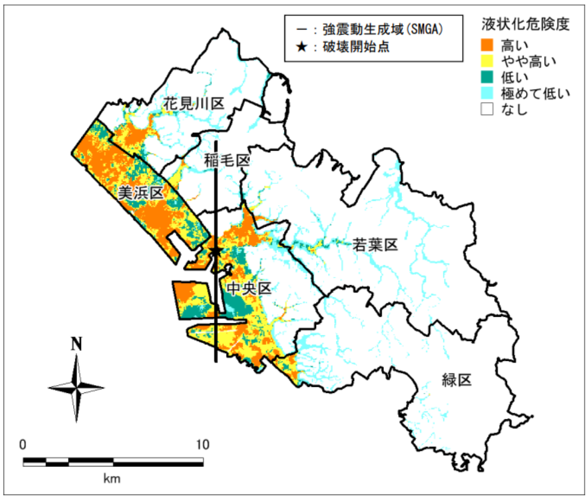

図 5. 3-2　液状化危険度

表 5. 3-2　液状化危険度別・区別の面積割合

区名	総面積 (km²)	高い		やや高い		低い		極めて低い		なし	
		面積 (km²)	割合	面積 (km²)	割合	面積 (km²)	割合	面積 (km²)	割合	面積 (km²)	割合
中央区	44. 70	8. 08	18. 1%	11. 76	26. 3%	5. 33	11. 9%	3. 27	7. 3%	16. 26	36. 4%
花見川区	34. 19	1. 54	4. 5%	1. 79	5. 2%	0. 91	2. 7%	3. 52	10. 3%	26. 43	77. 3%
稲毛区	21. 22	0. 15	0. 7%	0. 61	2. 9%	0. 28	1. 3%	1. 39	6. 6%	18. 79	88. 5%
若葉区	84. 21	0. 20	0. 2%	0. 49	0. 6%	0. 62	0. 7%	6. 20	7. 4%	76. 70	91. 1%
緑区	66. 25	0. 51	0. 8%	0. 85	1. 3%	0. 21	0. 3%	3. 58	5. 4%	61. 11	92. 2%
美浜区	21. 20	9. 96	47. 0%	6. 93	32. 7%	3. 89	18. 4%	0. 40	1. 9%	0. 01	0. 0%
合計	**271. 77**	**20. 44**	**7. 5%**	**22. 43**	**8. 3%**	**11. 24**	**4. 1%**	**18. 37**	**6. 8%**	**199. 29**	**73. 3%**

※四捨五入により、合計が合わない場合がある。

Figure 11: Differences in the susceptibility to liquefaction across wards in Chiba City

Figure 11 is a graph and a table that show the result of a study carried out to determine the susceptibility to liquefaction in Chuo, Hanamigawa, Wakaba, Midori, and Mihama Wards. The areas highlighted in orange are very prone to liquefaction. Much of the area consists of 47.0% of Mihama Ward and 18.1% of Chuo Ward. The areas highlighted in yellow are areas that are prone to liquefaction, but not as prone compared to the areas highlighted in orange. The areas highlighted in green, and blue are not prone to liquefaction.

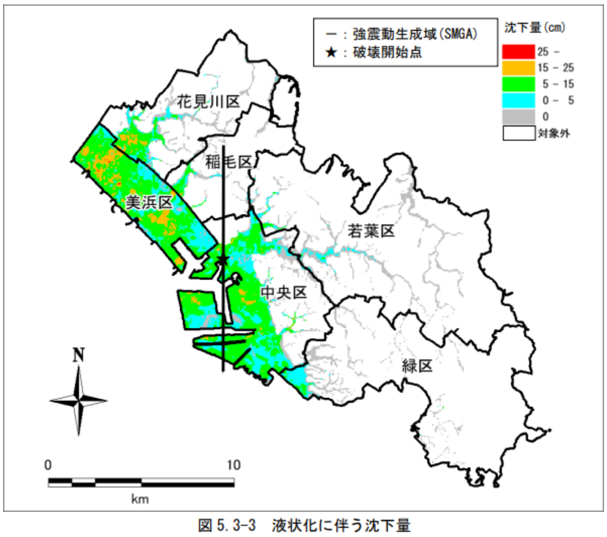

Figure 12: Ground subsidence level

Figure 12 shows the ground subsidence level of the five wards that were also covered in Figure 11. The area highlighted in red will likely subside 25 cm or more due to liquefaction. Although there are only a few spots that are highlighted in red, many of these spots are located in Mihama Ward. The area highlighted in orange will most likely subside 15 to 25 cm due to liquefaction. Most of these spots are located in Mihama, Hanamigawa, and Chuo Wards. The area highlighted in green is predicted to subside 5 to 15 cm due to liquefaction. Nearly the entire area of Mihama Ward is highlighted in green and around half of the area of Chuo Ward is highlighted in green. The area highlighted in blue is predicted to subside 0 to 5 cm due to liquefaction. Some of the areas in Mihama and Chuo Wards are highlighted in blue. The area highlighted in gray is predicted to subside 0 cm should liquefaction occur.

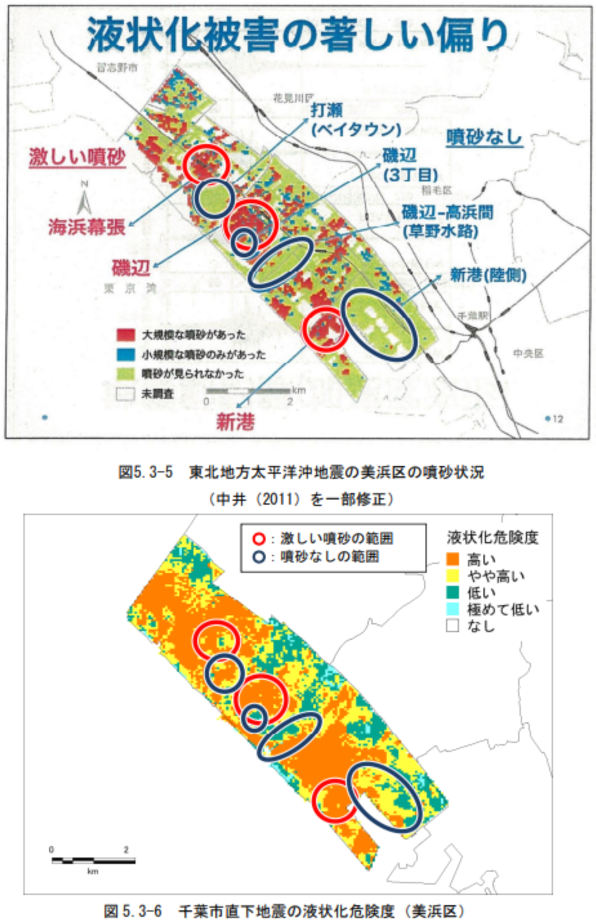

Figure 13: Mihama Ward's susceptibility to liquefaction

Figure 13 shows that many of the major places within Mihama Ward are susceptible to the effects of liquefaction. By comparing Figure 13 and Figure 14, it is apparent that our school (the red dot) is located in a place where liquefaction is highly likely to occur.

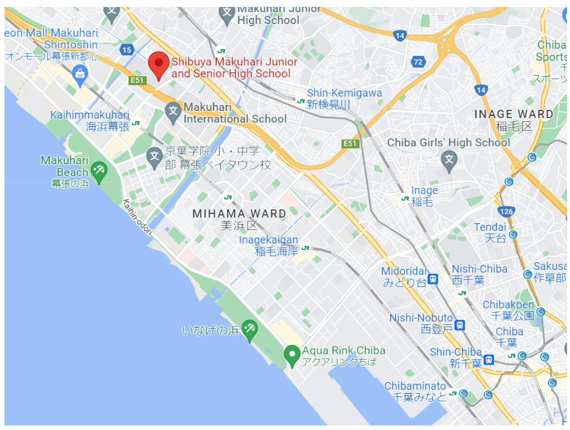

Figure 14: Location of Shibuya Makuhari Junior and Senior High School

As evident from the location of our school in Figure 14, if there is a large earthquake, our school will be affected by liquefaction. Not only that, but also train stations, ward offices, and ward halls will face the effects of the earthquake, as can be suggested from Table 2 below.

Table 2: Effect of liquefaction on major stations, ward offices, and ward halls

Place	Susceptibility to liquefaction
JR Keisei Chiba Station	Low
JR Inage Station	Low
JR Keisei Makuhari Station	Low
JR Kaihin Makuhari Station	Very high
JR Chiba Minato Station	High
JR Soga Station	High
Chiba Ward Hall	Very high
Chuo Ward Hall	High
Hanami Ward Hall	Very High
Inage Ward Hall	Low
Wakaba Ward Hall	Low
Midori Ward Hall	Low
Mihama Ward Hall	High

5.2. Effect on Water Systems

5.2.1. Waterworks System

The tables below (See Tables 3, 4, and Figure 15) show the forecast of the functional disruption of waterworks facilities. [8]

The calculations were based on data from 8 cities in Hyogo Prefecture and 17 cities and 2 towns in Osaka Prefecture affected by the Great Hanshin Awaji Earthquake. The study was proposed by a group led by Professor Nojima of Gifu University in the Metropolitan Area Earthquake Disaster Prevention and Mitigation Project (MEXT 2011).

Table 3: Effect of power shortage on the waterworks system in Chiba City

Facility	Location	Malfunction time due to power outage	Functioning time of emergency generator
Hirakawa water purification plant	2210 Hirakawa-cho, Tadashi Ward	Within 1 day	10 hours
Daikido water purification plant	1417 Okido- cho, Kan Ward	Within 12 hours	14 hours
Doke water purification plant	1635-2, Doke-cho, Midori Ward	Within 12 hours	13 hours
Sashishina water purification plant	1377 Sarai-cho, Wakaba Ward	Within 1 day	24 hours
Chiba research	1170 Kamisenka,	Within 1 day	19 hours

bark water purification plant	Wakaba Ward		
Onodai water pumping station	1-9-14, Onodai. Green Ward	Within 12 hours	10 hours
High-powered water stations	881-70 Takane-cho,Wakaba Ward	Within 1 day	20 hours
		Within 1 day	More than 10 hours
		Within 1 day	1~2 days

Table 4: Waterworks system functional failure rate (%)

Ward name	Right after the disaster	1 day after the disaster	3 days after the disaster	1 week after the disaster	2 weeks after the disaster	1 month after the disaster
Chuo Ward	63	61	55	43	26	7
Hanamigawa Ward	66	63	57	45	27	7
Inage Ward	72	70	64	51	32	9
Wakaba Ward	74	72	66	52	33	10
Midori Ward	45	42	37	28	16	4
Mihama Ward	64	61	55	43	26	7
Total	65	62	56	44	27	8

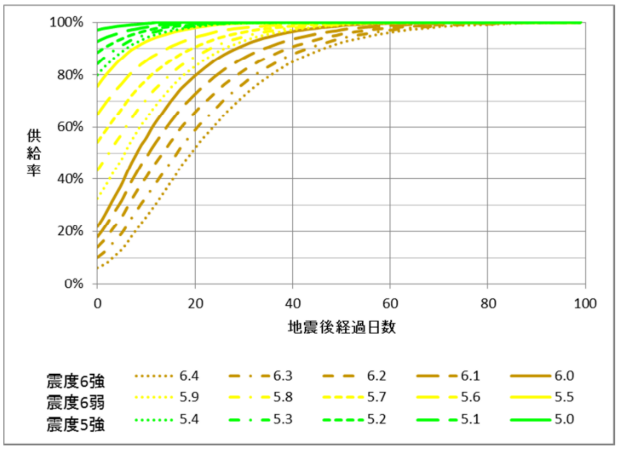

図9. 3-2　震度に対する供給率曲線（上水道）（文部科学省（2011））

Figure 15: Results of Figure 18 shown on a graph

The results of the simulation suggest that all of the seven water supply facilities in the city will experience power outages, but immediately after a disaster, emergency generators will allow the water distribution network to continue to function. However, since the power will be restored within one day at the latest, it is assumed that there will be no interruption of water distribution immediately after the power outage and after one day. In addition, it was assumed that the Chiba Prefectural Waterworks Bureau would be able to operate its emergency generator for approximately 10 hours, and Yotsukaido City would be able to operate its generator for approximately one to two days, and similarly, that there would be no water distribution outages immediately after the earthquake or after one day after the earthquake due to power outages. Based on the above, the functional disruption of the water supply system was calculated using the supply rate curve against the available population (= total water supply population), and the results are shown in Table 4: 65% of the population supplied immediately after the disaster, and 62% after one day. Compared to the predicted results of an earthquake directly under the northwestern part of Chiba Prefecture based on the prefectural survey conducted in 2014 and 2015, the functional disruption rate is slightly higher for an earthquake directly under Chiba City because of the wider area within Chiba City where the seismic intensity would be 6 or higher. In Mihama Ward, the ward in which our school is located, it seems that more than half of the population will have access to water immediately after the disaster, and after one week, only about one third of the population will still suffer from problems with water distribution, according to Table 4. However, the larger the magnitude the earthquake is, the more it will disrupt the progress of water distribution.

5.2.2. Drainage System

Assumptions were made regarding functional disruption of the sewage system (i.e., the situation in which daily life, including activities such as using the toilet, is disrupted due to the loss of treatment functions caused by damage to sewer facilities, etc.). The Central Disaster Prevention Council evaluated the sewerage system, taking into account (1) the impact of power outages at treatment facilities and (2) damage to pipelines (i.e. extension of damage). Chiba City's public sewage treatment facilities include the Central Sewage Treatment Center (Mihama Ward), the Southern Sewage Treatment Center (Chuo Ward), and the Hanamigawa Termination Treatment Plant (Chiba Prefecture-owned facility, Mihama Ward). All these facilities have emergency power generators that can operate for 12 to 24 hours, so it was assumed that power outages would not disrupt treatment plant functions.

Based on the pipe damage rates by liquefaction hazard, seismic intensity, and pipe type, the unrepaired pipe length immediately after the disaster was estimated, and assuming that this will be repaired by sewer restoration workers daily, the ratio of the pipe length to be repaired to the total pipe length was multiplied by the population that needed treatment. Sewer restoration crews include support from other cities.

Table 5: Length of the water pipes

Ward name	PVC and ceramic pipes	Other pipes	Total
Chuo Ward	340	570	910
Hanamigawa Ward	350	340	690
Inage Ward	280	220	500
Wakaba Ward	400	390	790
Midori Ward	360	540	900
Mihama Ward	130	300	430
Total	1870	2360	4220

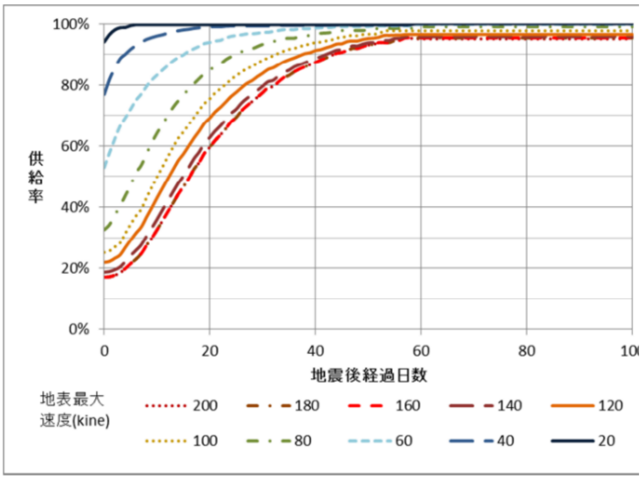

図9. 4-2　地表最大速度に対する供給率曲線（下水道）

Figure 16: Supply rate of sewage system

Table 6: Functional disruption rate of the sewage system (%)

Ward name	Right after the disaster	1 day after the disaster	3 days after the disaster	1 week after the disaster	2 weeks after the disaster	1 month after the disaster
Chuo Ward	3	2	2	2	1	0
Hanamigawa Ward	4	4	4	3	2	1
Inage Ward	5	5	4	4	2	1
Wakaba Ward	4	4	4	3	2	0
Midori Ward	2	1	1	1	0	0
Mihama Ward	3	3	3	2	1	0
Total	4	3	3	2	1	0

Table 6 shows the results of the extent of the damage caused by potential disruption of the sewage system. The number of people is approximately 930,000, and immediately after the disaster, 4% of the population will experience functional disruption. However, even if sewerage functions are restored, toilets and other facilities cannot be used if the water supply system is not available. The functional disruption rate is high in Hanamigawa, Inage, and Wakaba wards, where the proportion of PVC and ceramic pipes with high damage rates is large, as shown in Table 5.

5.3. Liquefaction Danger Zone Map

While the previously mentioned research dealt with the results of a simulation of a 7.3 magnitude earthquake that has a high chance of occurring, by using the same ground model developed in the study, the susceptibility to liquefaction was estimated for all prefectures when shaking occurs at uniform intensities of 5 and 6 on the Japanese seismic intensity scale. Two types of seismic motion were considered: earthquakes with normal duration, such as earthquakes directly under the ground, and earthquakes with long duration, such as the Tohoku District-off the Pacific Ocean Earthquake. For normal duration earthquakes, the length of shaking is assumed to be several seconds to several tens of seconds, and the magnitude of the earthquake is assumed to be about M6 to M7. On the other hand, for long duration earthquakes, the length of shaking is assumed to be a few minutes, and the magnitude of the earthquake is assumed to be M8 to M9. The maximum acceleration corresponding to seismic intensity of 5 (weak), 5 (strong), 6 (weak), and 6 (strong) was calculated. The results are shown in Figure 17 and Figure 18.

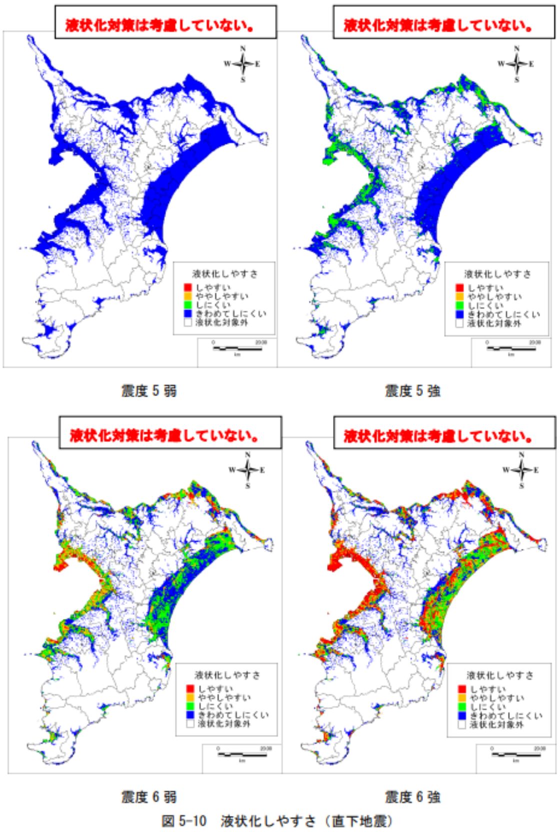

Figure 17: Liquefaction levels caused by normal duration earthquakes

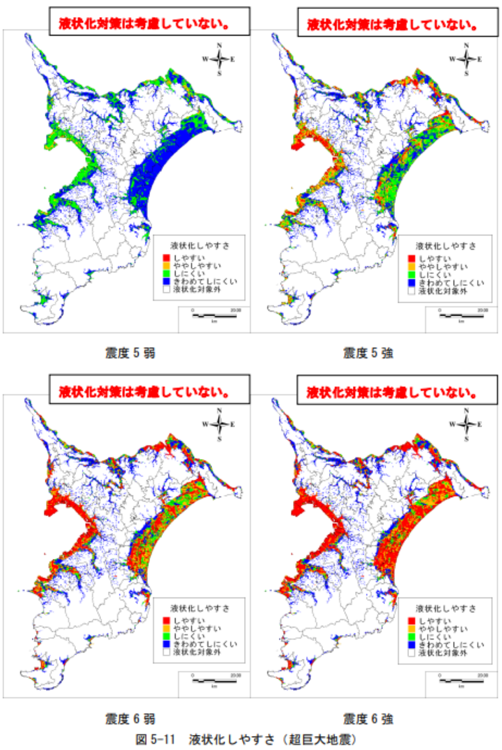

Figure 18: Liquefaction level of long duration earthquakes

The results of the experiment show that for earthquakes directly under the city, some reclaimed land is slightly liquefied at an intensity of 5 or higher. In addition, a seismic intensity of 6 or higher would cause liquefaction across a wide area, mainly in reclaimed land and low-lying areas along the Tokyo Bay coastline. In the case of a very large earthquake, liquefaction is more likely to occur in reclaimed and low-lying areas along the coastline. Even in the case of a seismic intensity of 5 or lower, there are some landfill areas that are slightly prone to liquefaction when hit by a massive earthquake. In the case of an earthquake of intensity 5 or higher, liquefaction is likely to occur across a wide area centered on landfill sites along the coastline. In this way, very large earthquakes tend to cause liquefaction even when the seismic intensity is one magnitude lower than that of earthquakes directly under the ground.

5.4. Prevention Measures

In order to apply the lessons of the Great East Japan Earthquake to the future, it is necessary to clearly identify what can be done to protect lives and what cannot be done. At the time the earthquake occurred, there were many reports of problems with disaster prevention information and evacuation responses and actions. We must carefully address these issues. Table 7 organizes the issues with the disaster response task. Many of our solutions come from information that we obtained from the Sewerage Exhibition that we attended.

Table 7: Problems with measures taken in the Great East Japan

Earthquake [9]

List of emergency measures	Problem
Information gathering and transmission	Emergency measures are based on information from local governments. However, local governments were forced to take emergency measures without any information because of the damages caused to their own government and staff.
Rescue	It was difficult to coordinate rescue operations among working organizations.
Disaster medical care	Medical services to hospitalized patients in disaster-stricken areas had been disrupted.
Emergency transportation systems	The emergency traffic routes caused confusion amongst users.
Transportation of goods and speed control	It was not always enough to deliver fuel and other necessary supplies at the right time.
Operation and management of evacuation centers	In evacuation centers, various kinds of assistance and services were not able to meet demands.
Establishment of cooperation system	It was difficult to request support from the local governments affected by the disaster.
Public relations	There was a lack of public relations activities regarding the local government’s response.
Support from overseas	Confusion arose in accepting overseas assistance.
Consideration for women and those in need of assistance in the event of a disaster	There was a lack of consideration for women, disabled people, and the elderly.

1A) Information gathering and dissemination

In the affected municipalities, not only were communications disrupted, but also government buildings were damaged, making it impossible to assess the damage and report and transmit information. In the beginning, the government could not even grasp the fact that some of the municipalities had lost basic functions. In severely affected regions, it was difficult to gather information on the extent of the damage, and it was not clear who to contact in the affected areas for assistance.

1B) Our proposed solution

Meidensha, a Tokyo-based company, has delivered a sewer water level information system to the city of Yokohama that utilizes the "manhole antenna", an IoT device for sewer pipelines, and began providing water level measurement information to citizens on June 28, 2021. [10] The purpose of this the system is to collect and organize sewer water level information from manhole antennas installed around the west exit of Yokohama Station, and provide the information to underground mall managers, citizens, etc., as well as to use the information to support flood prevention activities. This is the first time that sewer water level information has been made available to the general public by utilizing manhole antennas delivered by the company. In this system, water level sensors are installed under four manholes around the west entrance of Yokohama City to create a water level observation system for monitoring flooding. The water level information collected in the sewage pipes will be managed and organized on the cloud, and underground mall managers, citizens, and others will be able to access the sewage water level information site via the Internet from PCs, smart devices, cell phones, etc. to view the water level information in real time. This will be beneficial in the sense that people can take action earlier if they have access to such information.

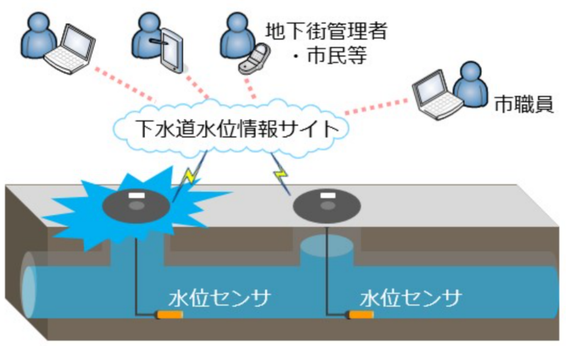

Figure 19: Image of manhole antenna

Figure 20: Real image of the manhole antenna in use

2A) Manhole surfacing

During the Niigata Chuetsu Earthquake, which occurred in 2004, and the Great East Japan Earthquake, which occurred in 2011, sewer manholes surfaced due to liquefaction of the ground. The interruption of sewer drainage functions and the impact on transportation functions interfered with the emergency and reconstruction efforts of the affected residents, causing enormous damage.

2B) Our proposed solution

In order to prevent the effects of manhole surfacing, an inner weight construction method is considered to be one of the best solutions.[11] It can be installed only inside the manhole. Relatively easy installation is possible even on arterial roads with heavy traffic and urban roads with many surrounding buried objects. The principle is simple: simply weigh the manhole so that its apparent specific gravity is approximately equal to the unit volume weight of the liquefied ground. The simplicity of the principle and design makes it easy for sewerage operators, road administrators, and the surrounding community to understand, enabling easy adoption.

Figure 21: Image of inner weight construction method

3A) Unsanitary lavatories

Let us now consider the toilet problem in the Great East Japan Earthquake. One of the characteristics of the Great East Japan Earthquake is that it was a disaster that damaged all of Japan. While support can be concentrated in a narrow disaster area, in a wide-area disaster, support is dispersed, resulting in the problem of inadequate delivery. The provision of temporary toilets is a good example. The results of a survey, shown in Figure 22, show that amongst the municipalities affected by the Great East Japan Earthquake, 34% of the municipalities took 3 days or less, 17% took 4-7 days, 28% took 8-14 days, 7% took 15-30 days, and 14% took one month or more to distribute temporary toilets to evacuation centers in the affected municipalities.[12] The municipality that took the most time took 65 days. Even if temporary toilets are deployed, the number of days until they arrive varies. Many evacuation centers were unable to use flush toilets due to water and power outages, and temporary toilets were not delivered, resulting in unsanitary conditions in many evacuation centers.

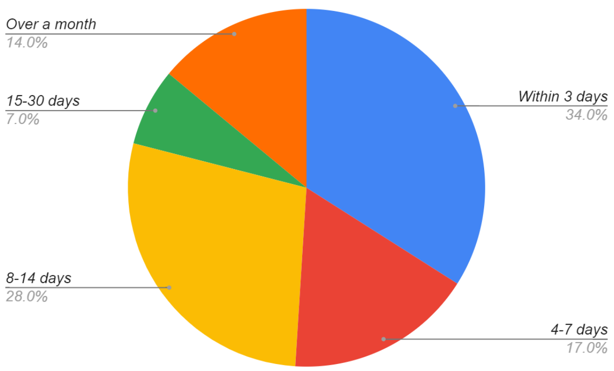

Figure 22: Days taken by local municipalities to supply temporary toilets to evacuation centers

Figure 23: Conditions of the public restrooms in the Great East Japan Earthquake

3B) Our proposed solution

Manhole toilets are valuable as easily stockpiled disaster toilets. Manhole toilets can be divided into three parts: the upper structure (panels, tent, toilet seat, and toilet bowl), the steel lid, and the lower structure.[13] The main line direct connection type and flow-through type manhole toilets can be used when the downstream sewage pipelines and treatment plants have not been damaged. In recent years, the construction of earthquake-resistant sewer pipelines has progressed to a certain degree, and the damage to sewer pipelines in the event of a disaster has been approximately 1.5 times greater than that of the Great East Japan Earthquake.

However, the number of toilet users should be predicted in advance and attention should be paid to the storage capacity. In addition, both flow-down and retention manhole toilets must have a water source for flushing urine from the drainage pipe and a water supply for transporting urine. The benefits of manhole toilets in times of natural disasters is that they are easy to stockpile, and can be used quickly and easily as is evident from Table 8. Moreover, they are hygienic because urine can be diverted into the sewage pipeline. Using manhole toilets also minimizes the number of steps at the entrance, making them easier for people with disabilities to use.

Table 8: Table that shows the benefits and problems of three types of restrooms

Emergency Restrooms	Feature	Points to remember
Portable toilet	Even if the water supply is cut off, there is power outage, and the drainage system is malfunctional, portable toilets can be used once it is set. Since portable toilets can be created from toilets that already exist, there is no need to create a new toilet.	There is a need to secure a place of secretion. There is also a need to find ways to eliminate the smell coming from the excretion.
Manhole toilet	It is just as easy to secure and flush as normal toilets. It is hygienic because it allows the urine to flow through the sewer pipes, effectively getting rid of the odor. As it can be placed on an entrance, people with disabilities can also use it.	Safety measures need to be taken regarding the placement of keys and lights. The way to use the toilet is not widely known. The applicability varies based on the capacity of the water supply and the resistance to earthquakes.
Temporary toilet	It can easily be transported from one place to another and it can also be used more than one time. It is currently used at events or construction sites, so people know how to use it. Some temporary toilets have functions that separate urine from feces.	It may take time to secure a place to place the temporary toilet. Most temporary toilets need to have the urine content removed.

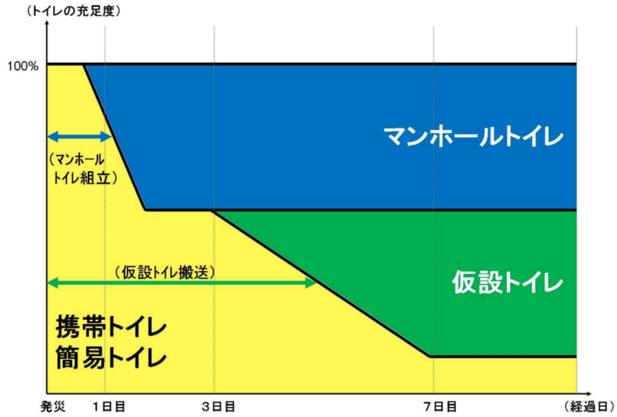

Figure 24: Supply rate of each type of restroom in the case of an emergency

4A) Guerilla rainstorms

Chiba has suffered from a few heavy rainstorms in the past, most recently the heavy rainfall on October 25, 2019. It was caused by Typhoon No. 21, resulting in damage mainly in Chiba Prefecture. This caused 27 rivers to overflow, along with landslides and floods in many areas. In the event of such disasters, it is important to know what measures can be taken to prevent the damage from getting worse.

4B) Our proposed solution

Aronkasei, a company based in Japan, has developed the backflow prevention mass, which prevents countercurrents. Since the valve plug is open under normal conditions, no solids adhere to it and it does not obstruct the flow of drainage.[14] The valve plug closes by buoyancy only when backflow occurs. Combined with an overflow lid, a continuous backflow deterrent effect can be achieved.

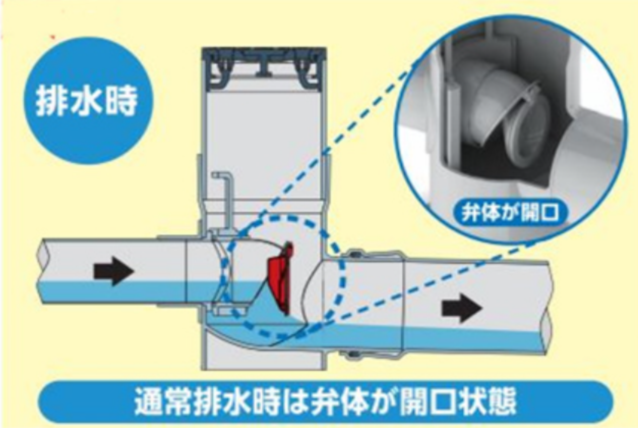

Figure 25: Image of backflow prevention mass (1)

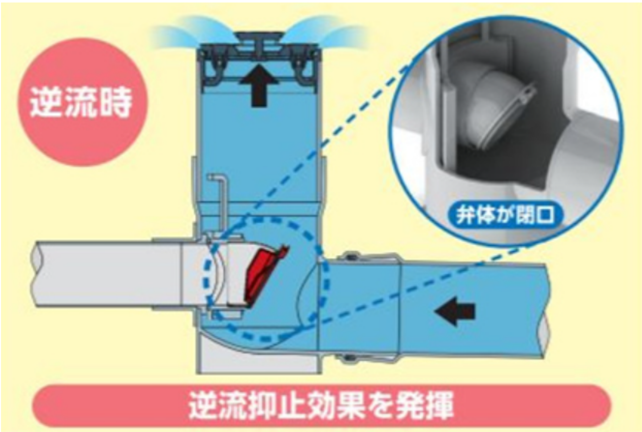

Figure 26: Image of backflow prevention mass (2)

6. Predictions of Damage Caused by Water-Related Disasters

In the previous section, we focused on liquefaction and made inspections about the damage on Makuhari, and researched possible prevention methods.

However, it would be ignorant to deny the possibilities of Makuhari facing water disasters other than liquefaction, just because Makuhari is built on reclaimed land.

In this section, we will investigate the possibilities of Makuhari suffering from water-related disasters other than liquefaction.

6.1. Types of Water-Related Disasters

6.1.1. Our Classification of Water-Related Disasters

There are a lot of types of water-related disasters that happen in Japan, such as flooding and landslides, which are mainly caused by strong typhoons.

We categorized those water-related disasters into three types, identified as (1) to (3) below.

(1) Inundation

- Inundation induced by river
- Inundation inside the levee

(2) Storm surge

(3) Sediment disaster

6.1.2. Definition of Each Disaster

(1) Inundation

There are two types of inundation.

1. Inundation induced by river

Inundation induced by a river is a type of inundation which happens when river water overflows, or when levees collapse because of the river water overflowing.

Since a huge amount of river water will break out of the broken levees, areas nearest to the river are presumed to suffer the biggest damage as a result of this type of inundation. Houses and automobiles will quickly be swept away by flood. Disabled people, seniors, and children will have a difficult time escaping from floodwaters. Moreover, the river water delivers sand and soil to the area, which causes more damage to the cities compared to inundation inside the levee, which will be described below.

2. Inundation inside the levee

Inundation inside the levee is the other type of inundation. It happens when the precipitation amount exceeds the acceptable level for the city's drainage system and the system malfunctions. This causes houses and roads to become submerged. Such inundation is likely to occur when the city is located at a low elevation. Valleys, basements and underground malls are more likely to be inundated than other areas built on higher grounds. Furthermore, asphalt roads don't allow water to penetrate as soil roads do, so urban areas where roads are paved with asphalt are also more likely to be inundated.

(2) Storm surge

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides.
It can sweep homes off their foundations, flood riverside communities miles inland, and break up dunes and levees that normally protect coastal areas against storms.

(3) Sediment disaster

Sediment disaster is a form of disaster in which houses, roads, agricultural lands are buried, and human lives are lost because of the collapse of sediment (soil, sand, stone) on slopes of mountains and hillsides, or because of the increased flow of the mixture of such sediment with rain water and river water. Places where sediment disasters are likely to happen are steep rivers, which have crumbling soil and sand at the source of the river. There is a possibility for these areas to become fast-flowing rivers when heavy rain strikes, even in areas where no rivers previously existed.

Below, we will explain the kind of damage Makuhari is likely to face if each water-related disaster happens, and the conceivable counterplans to alleviate the damage.

6.2. Makuhari and Inundation

6.2.1. Previous Research

Figure 27 and Figure 28 are the inundation hazard maps of Mihama ward, released in the official website of Chiba city.[15] Figure 27 shows the presumed planned scale damaged area, and the colored area shown on Figure 28 is the presumed maximum scaled damaged area. From Figure 27 and Figure 28, there are only a few areas that are colored when it is a presumed planned scale damaged area, but when it is a presumed maximum scaled damaged area, the area that is colored expands. The area colored in pink shows the area that is expected to have an inundation damage of up to 0.01 to 0.5 meters high, the area colored in green shows area that is expected to have an inundation damage with 0.5 to 1 meters high, and the area colored in red is presumed to have an inundation damage of up to 1 to 2 meters high.

Figure 27: Inundation hazard map of Mihama Ward (1)

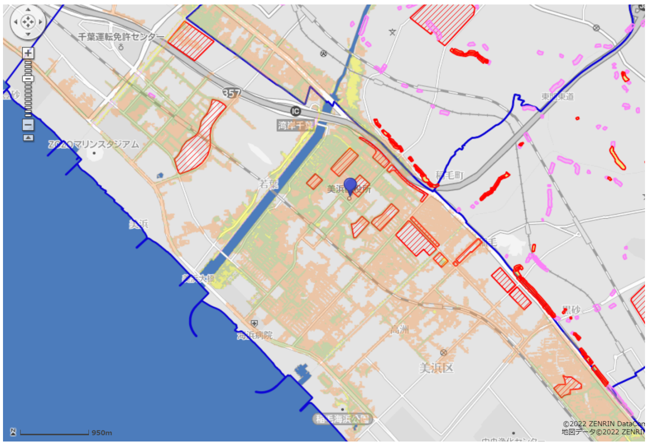

Figure 28: Inundation hazard map of Mihama Ward (2)

When we see the map that shows the presumed maximum scaled damaged area, we know that the colored area is frequently appearing around the HanamiRiver. So, we inspected the area around the two rivers that flow through Makuhari; Hanamigawa river and Hamada river, using ICT disaster prevention hazard maps. ICT disaster prevention hazard map offers us the information of all the places that had suffered from Inundation previously, in addition to the information that is on the hazard map from Chiba city.[16] We will call this map "ICT map" from now.

In the ICT map, the area colored in pink shows the low-land area, which has a lower elevation compared to the area around it and has worse drainage.

Figure 29 is the area around Makuhari shown by an ICT map. According to this figure, especially the area around Hamada River and Hanamigawa river are shown as low-lands areas. In the Hanami River, the area around the upstream of the river is a low-land area while the area around the downstream of the river is not. The probability of an inundation is higher in the upstream of the river.

When we go up to the Hamada River, the upstream of the river disappears. So, it is unlikely for the original river to swell and for inundation to occur. However, since the water is thin, even in the downstream area of the river, when there is a sudden heavy rain, there is a possibility for the river to not be able to drain efficiently and for inundation to occur. Low-lands areas that are located near Hanami River and Hamada River touch both rivers.

The blue points and the red points in the ICT map each show the history of road floods and the history of building floods. When we focus on the area around Hamada River, even though there are only a few points, we can see that the area has a history of inundation. The inundation in 2012 near Makuhari Marine Stadium and the inundation caused by local heavy rain in 2001 near Hamada are some of the recent examples of inundation that occurred in the area. These are shown in Figure 29 and Figure 30.

Especially in the area that is far away from the ocean coast, the number of dots increases. The typhoon that occurred in the 2010s seems to have caused the most damage to this area.

When we focus on the area around Hanamigawa River, the red and blue points are gathered inside the pink colored area, and if we go upstream of the river, the points start to appear at almost equal intervals. The year of the damage varies depending on the location of the points, which shows that the flood damage occurs periodically near Makuhari.

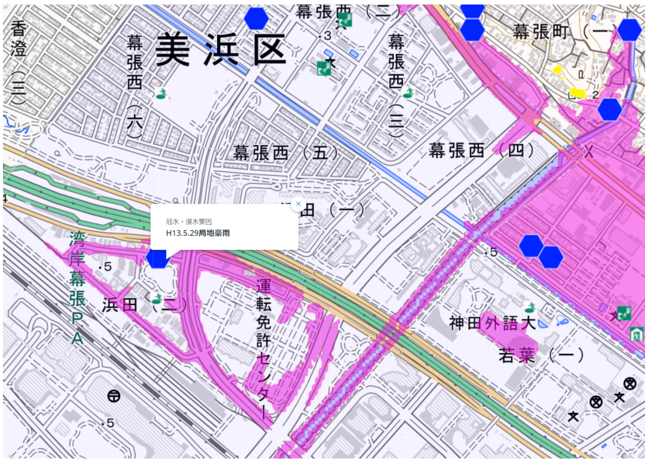

Figure 29: ICT map of Makuhari (1)

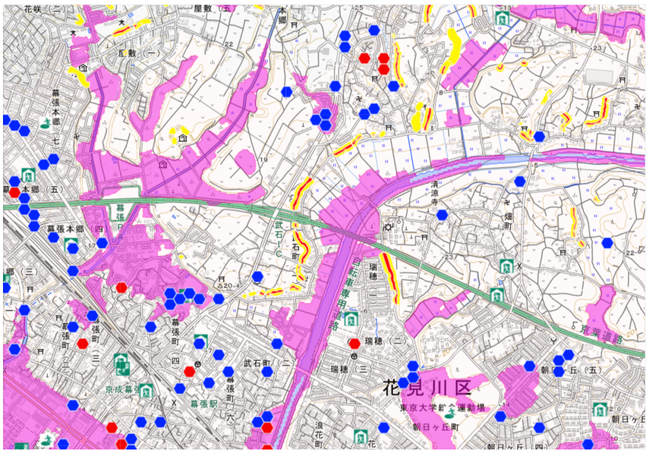

Figure 30: ICT map of Makuhari (2)

6.2.2. Our Proposed Solution

Due to our research findings that the flood damage in the upper stream increases compared to the flood damage in the lower streams, we speculated that counterplans such as embankments for flood control are not enough in the upstream compared to that of the downstream. As most of the damage is concentrated in the upstream area of the river, in order to alleviate the damage from inundation, it is required to make river embankments with solid materials and an efficient drainage system. We should use more of our effort into paving the upstream area before a disaster occurs.

6.3. Makuhari and Storm Surge

6.3.1. Previous Research

The Japanese Flood Control Act was revised in May 2015 in an effort to prepare for possible storm surges and to take preventive measures. The government has disclosed information of the places around seacoasts to the public as it has a high likelihood of being damaged.

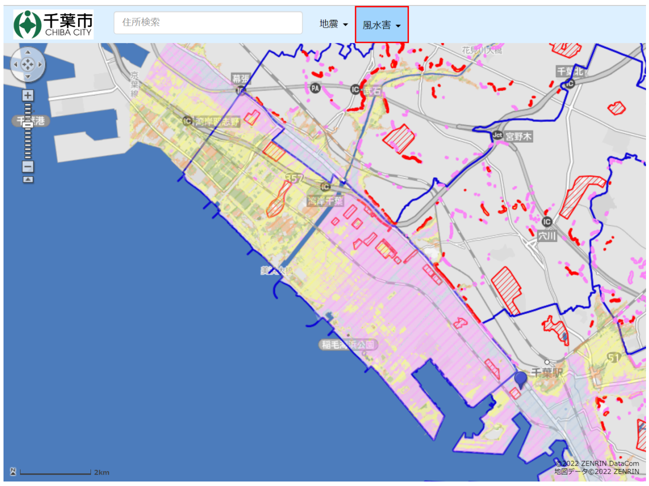

Figure 31: Storm surge hazard map of Mihama Ward (1)

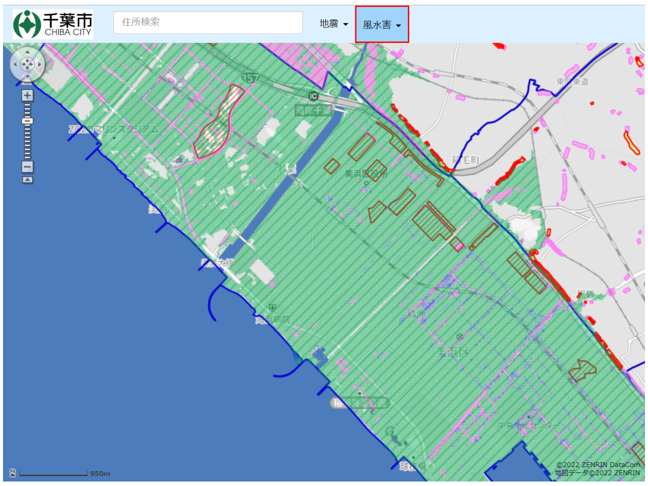

Figure 32: Storm surge hazard map of Mihama Ward (2)

Figure 31 and 32 are storm surge hazard maps of Mihama Ward in Chiba City. [17]

Figure 31 shows how high the assumed maximum scale wave reaches. This figure shows that at the maximum height, waves that reach heights of 2 to 3 meters are expected to hit Mihama Ward. The area is highlighted in pink.

Figure 32 shows the inundation duration due to storm surge. Inundation duration is the estimated time from when the water depth reaches 0.5m or more until it finally falls below 0.5m. This can be seen in the event of inundation caused by a storm surge that occurs once every 1,000 to 5,000 years. In Figure 31, most of the area is colored green, indicating an inundation duration of less than 12 hours. However, in places that are likely to be inundated such as narrow roads are colored pink, indicating an inundation time of between 168-336 hours. This means that floodwaters on roads will not likely be cleared quickly, making it difficult for people to evacuate in an emergency.

6.3.2. Our Proposed Solution

In Japan, the building of sea embankments is required in areas that are prone to storm surge, in order to protect the coastal areas from damage caused by storm surge. When building sea embankments, the upper limit of the tide level is set as a standard height. However, storm surges and high waves that exceed the upper limits cause damage to those embankments. The sea coasts surrounding Makuhari already have sea embankments and seawalls, but regular safety checks conducted by public authorities are essential. Moreover, since Makuhari is adjacent to the ocean, it is difficult to prevent all damage only using sea embankments and seawalls. Residents living near Makuhari should prepare for the coming disasters in advance. They have to be prepared to flee whenever a storm surge is likely to come.

For example, people can make efforts to understand the storm surge risk at home and work by using hazard maps, by learning the location of evacuation sites and evacuation routes, and by preparing emergency items. When you visit the official website of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), you can get a list of the emergency items that are necessary. The website is open to the public. It is important that you have access to any information about the emergency in advance and prepare by yourself when you live in a coastal area.

6.4. Makuhari and Sediment disaster

6.4.1. Previous Research

Table 9 is an overview of sediment disaster alert areas and sediment disaster special alert areas that were registered by MLIT, in each ward of Chiba Prefecture.

Table 9: Sediment disaster alert area of Chiba Prefecture

Ward	Sediment disaster alert areas	Sediment disaster special alert areas
	As of May 28, 2020	As of May 28, 2020
Chuo-ku	44 places	37 places
Hanamigawa-ku	52 places	49 places
Inage-ku	25 places	19 places
Wakaba-ku	88 places	81 places
Mihama-ku	0 places	0 places
Midori-ku	75 places	75 places
Total	**284 places**	**261** places

Mihama Ward, which is the ward that Makuhari is located in, has zero places that have been registered as either sediment disaster alert areas or sediment disaster special alert areas. This shows that Mihama Ward does not have landscapes that are prone to landslides. The reason for this lies in the geographical landscape of Makuhari. As mentioned in 3.1, the great majority of Chiba City is made up of reclaimed land, so there are only a few differences in elevation throughout the ward.

Table 10: Elevation level of cities in Mihama Ward

Ward	Elevation(m)	Ward	Elevation(m)
Isobe 1Cho-me	3.7	Takahama 4Cho-me	3.8
Isobe 2Cho-me	2.7	Takahama 5Cho-me	2.9
Isobe 3Cho-me	3.9	Takahama 6Cho-me	3.5
Isobe 4Cho-me	4	Takahama 7Cho-me	4
Isobe 5Cho-me	3.8	Toyosago	3.8
Isobe 6Cho-me	4.2	Nakase 1Cho-me	4.4
Isobe 7Cho-me	3.7	Nakase 2Cho-me	3.4
Isobe 8Cho-me	7.6	Hamada 1Cho-me	4.9
Inagekaigan 1Cho-me	3.3	Hamada 2Cho-me	3.6
Inagekaigan 2Cho-me	3.5	Hibino 1Cho-me	4.1
Inagekaigan 3Cho-me	3.4	Hibino 2Cho-me	3.6
Inagekaigan 4Cho-me	3.6	Makuharinishi 1Cho-me	3.4
Inagekaigan 5Cho-me	3.3	Makuharinishi 2Cho-me	3.3
Utase 1Cho-me	4.7	Makuharinishi 3Cho-me	4.2
Utase 2Cho-me	4.7	Makuharinishi 4Cho-me	2.9
Utase 3Cho-me	3.8	Makuharinishi 5Cho-me	3.8
Saiwaicho 1Cho-me	3	Makuharinishi 6Cho-me	3.7
Saiwaicho 2Cho-me	3.8	Masago 1Cho-me	3.1
Shinko	3.2	Masago 2Cho-me	3.4
Takasu 1Cho-me	3.3	Masago 3Cho-me	3.1
Takasu 2Cho-me	3.1	Masago 4Cho-me	3.3
Takasu 3Cho-me	2.9	Masago 5Cho-me	3.6
Takasu 4Cho-me	3.4	Mihama	3.7
Takahama 1Cho-me	3.6	Wakaba 1Cho-me	3.8
Takahama 2Cho-me	3.5	Wakaba 2Cho-me	3.9
Takahama 3Cho-me	3.4	Wakaba 3Cho-me	5.3

Table 10 shows the elevation of all cities in Mihama Ward. According to this table, the minimum elevation is 2.7m in Isobe 3 cho-me, and the maximum elevation is 7.6m in Isobe 8 cho-me, a difference of only 4.9m. The average elevation is about 4.3m, which shows us that Mihama Ward has a low elevation. Sediment disasters cannot happen on flat land, and this is the reason why there were no sediment disaster alert areas and sediment disaster special alert areas in Mihama Ward. However, we need to consider the possibility of Mihama Ward being struck by a sediment disaster that originates in another ward.

We can see a sediment disaster hazard map when we visit the official website of Chiba City, which is open to the public. From those hazard maps, we can know the places that have a high risk of a sediment disaster occurring.

Figures 33, 34, and 35 are sediment disaster hazard maps of the wards around Mihama Ward.

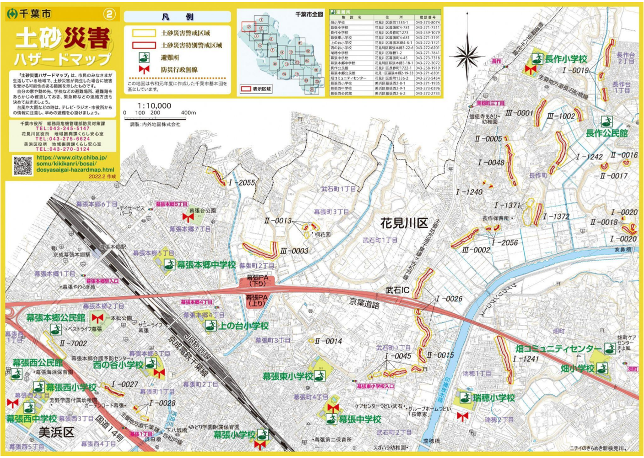

Figure 33: Disaster hazard maps of the wards around Mihama Ward (1)

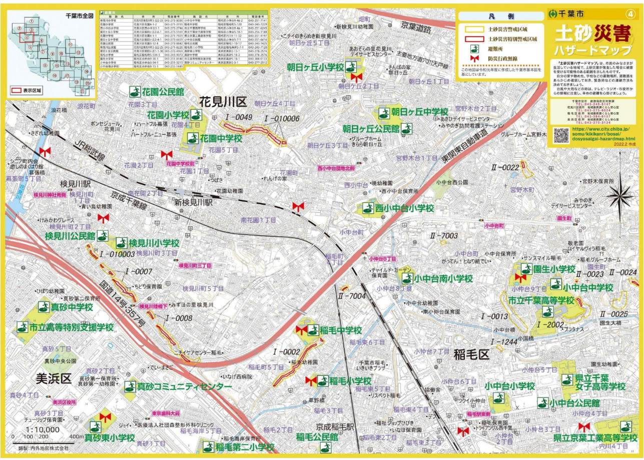

Figure 34: Disaster hazard maps of the wards around Mihama Ward (2)

Figure 35: Disaster hazard maps of the wards around Mihama Ward (3)

In the hazard maps, there are few areas that are colored yellow and red compared to Figure 36, a hazard map of Hiroshima-shi Chuo-ku, where a large sediment disaster happened in 2014.

Figure 36: Hazard map of Hiroshima-shi Chuo-ku

The nearest sediment disaster alert areas and sediment disaster special alert areas that are located outside of Mihama Ward, which we can see in Figure 36, are mostly located on the boundary of Mihama Ward and Chuo Ward. If a sediment disaster occurred in this area, it is most likely that there would be some effects on Mihama Ward. However, since the area is quite small and since National Route 14 blocks the area from Mihama Ward, the damage that Mihama Ward would face would be minimal.

6.4.2. Our Conclusion

We have to continue gathering information about the connection between Makuhari and sediment disasters that could occur in other areas in order to be prepared in the event that a sediment disaster strikes.

7. Experiment Method

7.1. Purpose of the Experiment

The general purpose of the tests is to measure the state of the water and see whether the water is dangerous to living beings or not. We were interested in carrying out this experiment because in the event of a natural disaster, there may be a period of time when we cannot access clean water and may have to resort to using water from nearby bodies of water. In these circumstances, we wanted to investigate which water sources are safe to use and which water resources are not safe to use. There are seven major types of water testing: COD test, PO_4^{3-} test, NO_2^- test, NH_4^+ test, pH test, turbidity (transparency) test, and hardness test.

Here are the specific purposes of each test.

1) COD test

COD is the acronym of ‘chemical oxygen demand’. COD is the amount of oxygen consumed to chemically oxidize organic water contaminants in inorganic end products. A COD test is often used as a measure of water treatment plant efficiency. There is also a type of test called a BOD (biochemical/ biological oxygen demand) test, which measures all organic contaminants, including biodegradable contaminants. Unlike for the BOD test, toxic compounds (such as heavy metals and cyanide) in the samples to be analyzed do not have an effect on the oxidants used in the COD test. Unlike for the BOD test, toxic compounds such as heavy metals and cyanide in the samples do not affect the oxidants measured in the COD test.

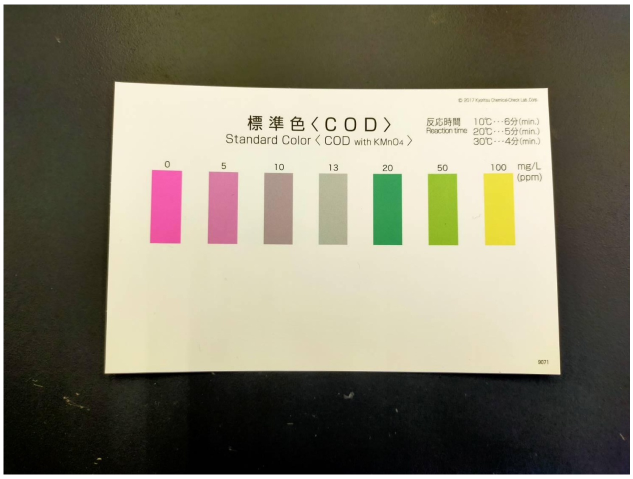

Figure 37: COD level

This is the COD level chart that we used in our experiment.

Table 11: COD level correlation to water quality [18]

0mg/L	Clean water than has not been eutrophicated
Below 1 mg/L	Clean water
1 mg\L~2 mg/L	Rain water
2 mg/L~5 mg/L	Slightly eutrophicated water
2 mg/L~10 mg/L	Water from the downstream area of rivers
Below 3 mg/L	Eutrophicated water that

	salmons live in
Below 5 mg/L	Eutrophicated water that carps and kois live in
Below 10 mg/L	Sewage water
1 mg/L~3 mg/L	Water quality standards
Below 160 mg/L	Existing wastewater standard

Table 11 shows that water that has a COD level of 0~2 mg/L is considered to be relatively clean, but water that has a COD level of more than 2 mg/L is considered to be slightly eutrophicated. Water that has a concentration level of over 10 mg/L is considered to be severely eutrophicated.

2) PO_4^{3-} test

First, orthophosphate can be displayed in two different ways: PO_4^{3-} defined as 'orthophosphate' and PO4-P spoken as 'orthophosphate as phosphorus'. The difference between the two is very important. The results of orthophosphate tests consider both the phosphorus and the oxygen in the compounds, whereas the results of orthophosphate as phosphorus tests only consider the phosphorus in the compounds. Those tests are used to understand how badly the ecosystem may be harmed. Although phosphate is not harmful to humans, it is well known to have significant impacts on the ecosystems of rivers and lakes.

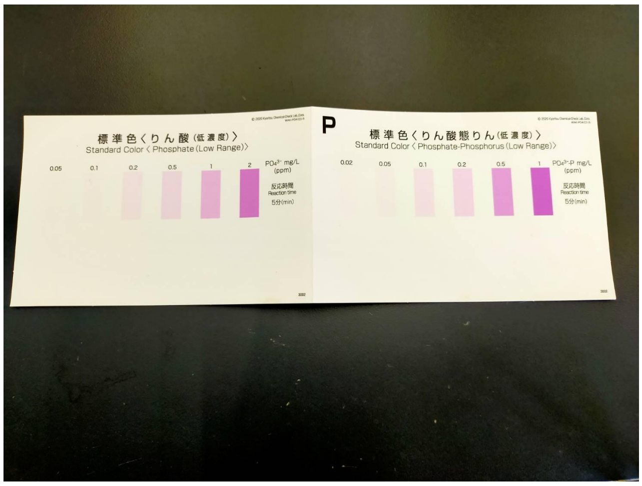

Figure 38: PO_4^{3-} level

This is the PO_4^{3-} level chart that we used in our experiment.

Table 12: PO_4^{3-} level correlation to water quality [18]

Below 0.0163mg/L	Rainwater
0.0163 mg/L~0.0326 mg/L	Water from the upstream area of rivers
0.0326 mg/L ~ 0.3260 mg/L	Water from the downstream area of rivers
Below 0.0652 mg/L	Clean water
0.0652 mg/L ~ 0.3260 mg/L	Chance of contaminated water
0.3260 mg/L ~0.6520 mg/L	Slightly contaminated water
0/6520 mg/L ~ 1.6300 mg/L	Contaminated water
Below 1.6300 mg/L	Severely contaminated water

As Table 12 indicates, clean water has a concentration level of below 0.0652 mg/L. When the level falls anywhere above 0.6520 mg/L, the water is considered to be contaminated. Orthophosphates are found in a wide range of fertilizers, synthetic detergents, and foods, and the higher the value, the more eutrophic it is, which is believed to cause red tides and other problems.

3) NO_2^- test

Nitrite affects all living beings through the degradation by way of the bacteria of protein and ammonium. It is commonly processed in addition to non-toxic nitrate. Typically, if the water is clean, there should not be any sign of nitride, but when there are signs of nitride, it means that the bacterial degradation has been disturbed and the water is contaminated. Especially from a concentration of 0.4 mg/l, it can be very dangerous or even fatal for fish to ingest because nitrite blocks oxygen transportation in the blood. NO_2^- tests can also be used to recognize how badly the ecosystem may be harmed.

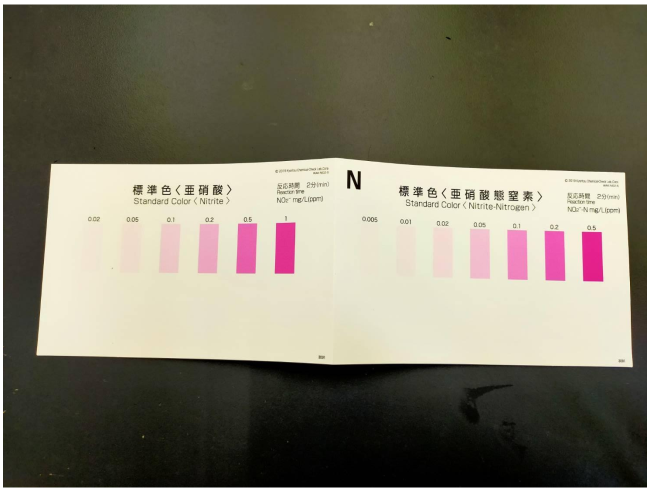

Figure 39: NO_2^- level

This is the NO_2^- level chart that we used in our experiment.

Table 13: NO_2^- level correlation to water quality [18]

0.006 mg/L ~ 0.10 mg/L	Water from the upstream area of rivers
Below 0.02 mg/L	Clean water
0.02 mg/L ~ 0.10 mg/L	Slightly contaminated water
0.10 mg/L ~ 0.20 mg/L	Contaminated water
0.20 mg/L ~ 0.50 mg/L	Severely contaminated water
Above 0.30 mg/L	Water from the downstream area of rivers
Above 0.50 mg/L	Sewage water

As shown in Table 13, clean water has a NO_2^- level of below 0.02 mg/L. When the concentration level is higher than 0.02 mg/L the water is contaminated. The water is especially contaminated when the concentration level is higher than 0.50 mg/L. In this way, nitrite nitrogen in water is an important indicator for estimating water pollution, as it is mainly produced by the oxidation process of ammoniacal nitrogen from various industrial effluents, fertilizers, human waste, sewage, and other contaminants.

4) NH_4^+ test

Ammonia is the preferred nitrogen-containing nutrient for plant boom. Ammonia may be transformed to nitrite NO2 and nitrate NO3 by means of microorganisms, and then used by flora. Nitrate and ammonia are the most common varieties of nitrogen in aquatic systems. Nitrate predominates in unpolluted waters. Nitrogen can be an essential element in controlling algal increase when other nutrients, including phosphate, are plentiful. If phosphate is not found in considerable amounts, it is able to restrict algal increase instead of nitrogen. Most of the ammoniacal nitrogen present in the water is generated as a result of the process of decomposition and decomposition of proteins and organic nitrogen compounds derived from sewage, human waste, and industrial wastewater. Clean water with high oxygen content contains a high percentage of nitrate nitrogen, while dirty water with inflow of wastewater contains high organic nitrogen and ammoniacal nitrogen.

Ammonia is a key pollutant because it is particularly common, but it may also be poisonous, causing decreased reproduction or the demise of a species. The neutral, un-ionized shape (NH3) is particularly toxic to fish and other aquatic organisms.

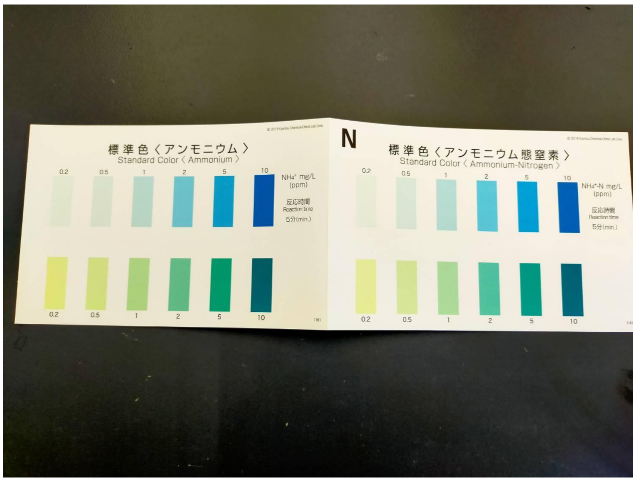

Figure 40: NH_4^+ level

This is the NH_4^+ level chart that we used in our experiment.

Table 14: NH_4^+ level correlation to water quality [19]

0.05 mg/L	Water from the upstream area of rivers, spring water
0.10 mg/L ~ 0.40 mg/L	Rainwater
0.40 mg/L ~ 5.00 mg/L	Water from the downstream area of rivers
5.00 mg/L	Sewage water

As shown in Table 14, an NH_4^+ level of 0.05 mg/L is equivalent to the water of a river near its source. Whereas, an NH_4^+ level of 5.00 mg/L is equivalent to that of sewage water, meaning that it is highly contaminated.

5) pH test

This test is the simplest among the seven here. Basically, living organisms just can't live in overly acidic water or overly basic water. As a reference for the case of humans' drinking or washing water, EPA guidelines state that the pH of tap water should be between 6.5 and 8.5, as shown in Table 15.

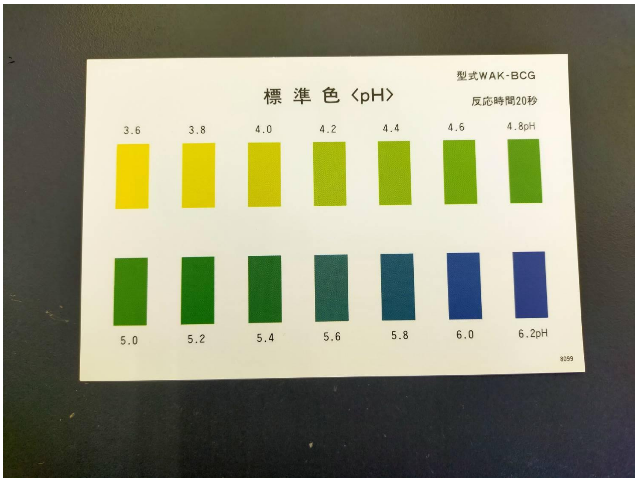

Figure 41: pH level

This is the pH level chart that we used in our experiment.

Table 15: pH level correlation to water quality [20]

Water quality standards	6.5 ~ 8.5
Existing wastewater standard	5.8 ~ 8.6
Water standard of tap water	5.8 ~ 8.6
Comfortable water quality pH level	Around 7.5

6) Turbidity (transparency) test

Water almost typically consists of suspended solids that encompass special debris of diverse size. Some of the particles are large enough and heavy enough to subsequently settle to the bottom of a field if a pattern is left standing (those are the settleable solids). The smaller debris will settle slowly. It is this debris that causes the water to appear turbid.

Many factors will have an impact on the quality of drinking water, so authorized regulations set the quantity of turbidity that is permissible. Now, the most common measurement for turbidity is the nephelometric turbidity unit (NTU). Regarding drinking water, inside the samples accumulated for turbidity dimension, the turbidity must remain less than or identical to 0.3 NTU for at least ninety five percent of those accrued in any month. If a public consuming water machine uses any filtration aside from flocculation or direct filtration then they will be restricted to providing water to their nation, but even those must not exceed a turbidity degree of 5 NTU. Normally, utilities will try to preserve a turbidity level of about 0.1 NTU.

7) Hardness test

Water hardness is determined by the size of the quantity of ions that have lost electrons (divalent cations) dissolved within the tested water and it is, consequently, related to total dissolved solids. The more divalent cations dissolved in the water, the "tougher" the water. Generally, the maximum common divalent cations are calcium and magnesium; however other divalent cations might also make contributions including iron, strontium, aluminum, and manganese. Typically, the alternative divalent cations make little to no changes to the water hardness measurement. Change of hardness in a certain location displays the geology of the catchment's location and every now and then gives a measure of the influence of human activity in a watershed. As an example, some aquatic environments which have lively or abandoned mines close by often have better concentrations of iron ions in the water resulting in a completely excessive hardness diploma. Despite the fact that there is some research indicating that there are no health risks in tough water for humans, many of the results are still inconclusive, and even if the ones consequences are authentic, it doesn't necessarily mean that tough water is safe for all living organisms.

7.2. Method and Materials

1) COD test

Strong oxidant, potassium dichromate, potassium iodate, or potassium permanganate under acidic conditions are often used to measure the COD. A known excess amount of the oxidant is added to the sample, and when oxidation is complete, the concentration of organics in the sample will be calculated from the amount of oxidant remaining in the solution.

2) PO_4^{3-} test

The two not unusual colorimetric methods of measuring orthophosphate are the Ascorbic Acid/"Blue" approach and the Molybdovanadate/"Yellow" approach. Both techniques integrate orthophosphate with molybdate in an acidic environment but they differ in how they form the very last compound, which creates the blue or yellow shade.

3) NO_2^- test

The nitrate anion is an oxidizer, and many tests for the nitrate anion are based on this property. However, other oxidants present within the analyte might also intervene and deliver faulty outcomes. Nitrate can also be detected through first lowering it to the greater reactive nitrite ion and the use of one in all many nitrite tests.

The most common nitrate test, known as the brown ring check, can be carried out by including iron (II) sulfate to a solution of a nitrate, then slowly including concentrated sulfuric acid such that the acid forms a layer below the aqueous answer. A brown ring will form on the junction of the 2 layers, indicating the presence of the nitrate ion.

4) NH_4^+ test

Ammonium ions can be recognized in a solution by adding dilute sodium hydroxide solution and gently heating the mixture. If ammonium ions are excreted, they'll be converted to ammonia fuel. Ammonia has a characteristic choking odor. It additionally turns damp red litmus paper or damp standard indicator paper blue.

5) pH test

A standard pH meter has fundamental components: the meter itself, which can be a moving-coil meter (one with a pointer that moves towards a scale) or a digital meter (one with a numeric display), and either one or more probes into the water that you are testing. To make electricity flow through something, you have to create a whole electrical circuit; so, to make electricity flow through the test solution, you have to put two electrodes (electric terminals) into it. If your pH meter has probes, each of them is a separate electrode. If it has only one probe, each of the two electrodes inside that one probe.

6) turbidity (transparency) test

The simplest and lowest cost way to measure the turbidity of a sample is a turbidity tube. This is a tube with a black cross at the lowest point and the tester simply continues pouring water into the tube until they cannot make out the black cross, at which point the tester can take a reading using the scale on the outside of the tube in the nephelometric turbidity unit (NTU).

7) hardness test

The hardness test that is easiest to conduct is called the “bottle test”. For easy at-home testing, fill a bottle one-third full, add a few drops of pure liquid soap and shake vigorously for a few seconds. If there is a distinct lack of fluffy bubbles and the water appears cloudy and/or milky, your water is hard. Although this is a very simple method, the more accurate tests conducted under lab conditions work in basically the same way, just with more precision.

8. Results of Phase 2 Experiment

8.1. Results

We tested water from five different sources: tap water, water from Mihama Garden, water from Hamada River, water from Hanami River, and water from an aquarium tank. The tap water and the water from the aquarium were sourced from our school, but the other three sources were collected from outside our school.

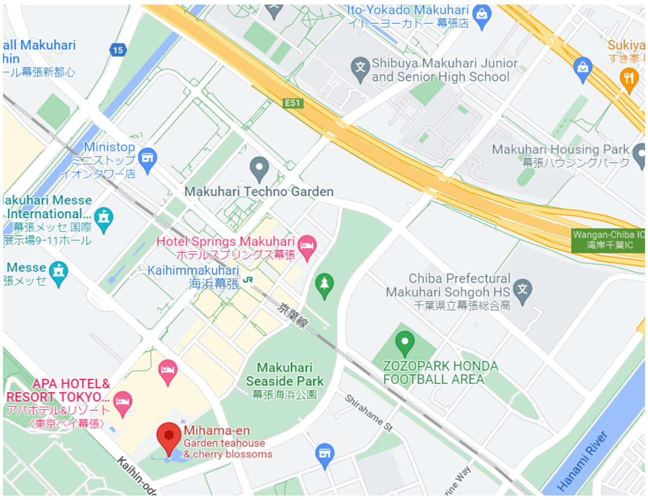

Figure 42: Location of Mihama Garden and its proximity to our school

Figure 43: Location of Hamada River and its proximity to our school

Figure 44: Location of Hanami River and its proximity to our school

As can be seen in Figures 42 to 44, the area that we collected water from is very near our school and would likely be the alternate source of water should a natural disaster occur and there were only a limited amount of available bottled water or safe tap water. However, it should also be noted that this scenario is unlikely to occur given the research that we have done on the effect of a large earthquake on the water system and drainage system. Most of the water systems, even if damaged, are likely to recover soon. Regardless of whether water systems are damaged or not, to the extent that we have limited access to clean water, we still think that it is important for us to evaluate the water quality surrounding our school to understand the environmental aspect of the area and what can be improved.

From left to right, we tested the pH level, COD level, NH_4^+ level, NO_2^- level, and PO_4^{3-} level of each of the water samples in that order. Table 16 summarizes our findings.

1) Tap water

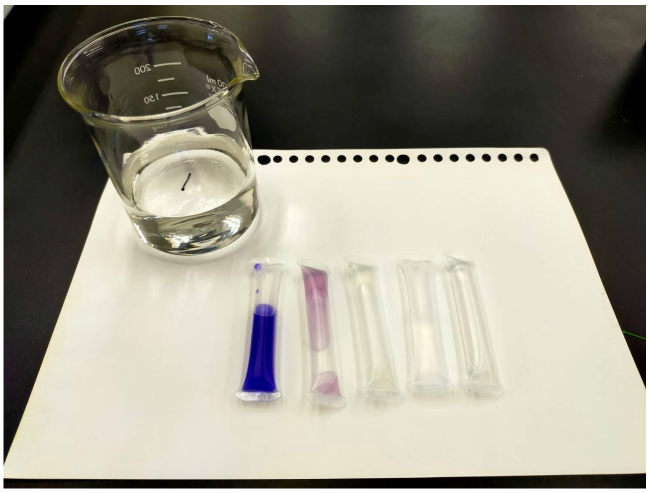

Figure 45: Tap Water

The pH level of the tap water was approximately 6.2. The Chiba Waterworks Bureau guide for clean water suggests that the water should fall between a pH level of 5.8 and 8.6.

This means that the tap water is safe to drink. The COD level of the tap water was 5 mg/L. Under the waterworks law, the standard for potassium permanganate consumption is 10 mg/L or less, which when converted to COD is 2.5 mg/L or less. If the capacity of the water purification process to supply clean water from lakes and marshes is taken into consideration, the standard is 3 mg/L or less. Given this information, we found that the COD level was slightly higher than expected, but it was still safe to drink. The NH_4^+ level of the tap water was 0.2 mg/L. This is about the same level as rainwater, meaning that there is a slightly high concentration of organic nitrogen and ammonia nitrogen. The NO_2^- level was 0.02 mg/L. This means that the water does not contain a lot of nitrite-nitrogen and is therefore clean. The PO_4^{3-} level was 0.02 mg/L. This is about the same level as the upstream water of rivers, meaning that the water is not eutrophicated.

2) Water from Mihama Garden

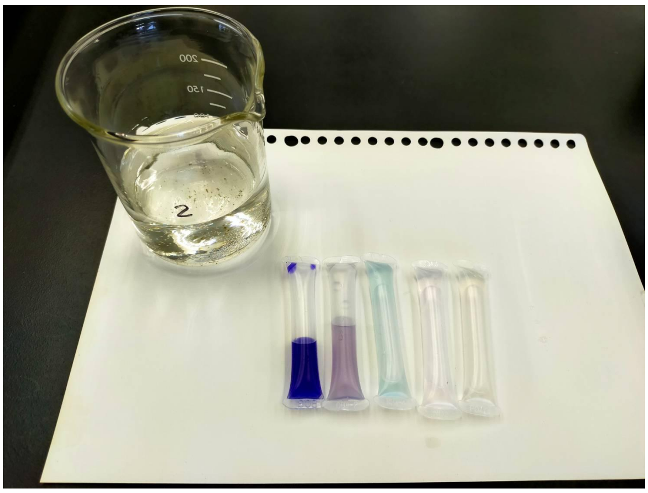

Figure 46: Water from Mihama Garden

The pH level of the water from Mihama Garden was 6.2, meaning that the water is safe to drink. The COD level of the water was higher than that of the tap water at 10 mg/L. This is about the same level as the sewage system, meaning that there is also a lot of dissolved organic matter derived from suspended solids. The NH_4^+ level was 0.5 mg/L. This means that it is of similar level to the downstream water of rivers. This means that there is a higher concentration of organic nitrogen and ammonia nitrogen than tap water. The NO_2^- level was 0.02 mg/L. Like the tap water, the water from Mihama Garden does not contain a lot of nitrite-nitrogen and is therefore clean. The PO_4^{3-} level was 0.02 mg/L. This means that the water is not eutrophicated.

3) Water from Hamada River

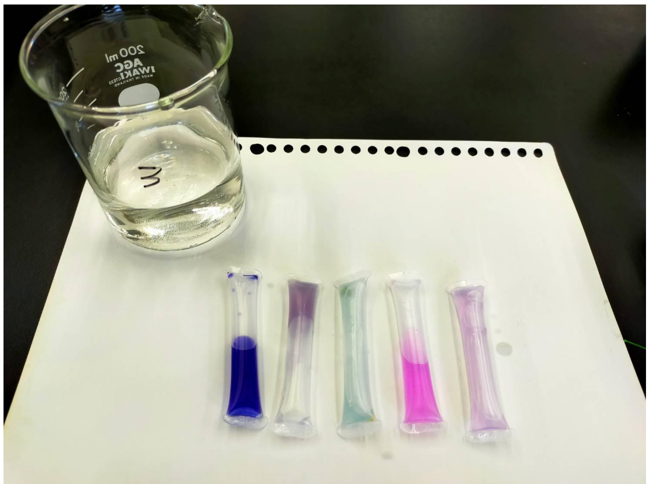

Figure 47: Water from Hamada River

The pH level of the water from Hamada River was 6.2, meaning that the water is drinkable. The COD level of the water was 7 mg/L. This means that the water contains more organic matter than the tap water, but less than the water from Mihama Garden. The NH_4^+ level was 0.6 mg/L, which is similar to the NH_4^+ level in Mihama Garden. This means that the water contains a higher concentration of organic nitrogen and ammonia nitrogen than the water collected from

Mihama Garden. The NO_2^- level was 0.5 mg/L/ This means that the water is slightly contaminated. The PO_4^{3-} level was 0.2 mg/L, also suggesting that there is a high possibility of the water being contaminated.

4) Water from Hanami River

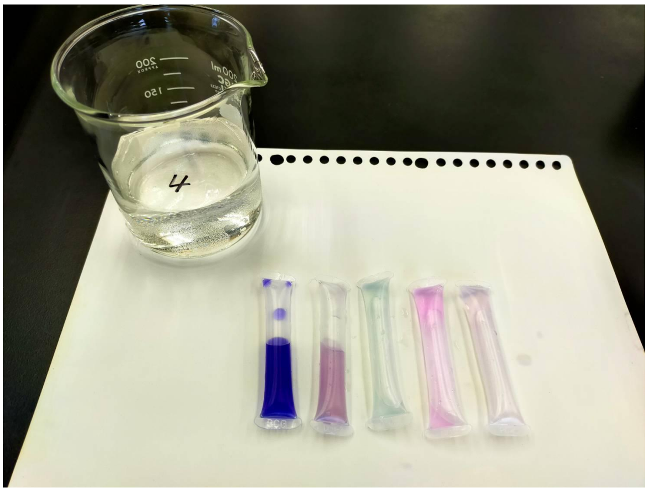

Figure 48: Water from Hanami River

The pH level of the water from Hanami River was 6.2, meaning that the water is safe to drink. The COD level of the water was 8 mg/L. This is slightly higher than the level found in the water sample from Hamada River, and slightly lower than the level found in Mihama Garden. This means that the water contains some organic matter. The NH_4^+ level of the water was 0.3 mg/L which is slightly lower than the level found in the water sample from Hamada River. This means that there is only a slightly high concentration of organic nitrogen and ammonia nitrogen compared to the concentration found in clean water. The NO_2^- level was 0.2 mg/L. This is slightly lower than the level found in the water sample in Hamada River. This means that the water is free from nitrite nitrogen. The PO_4^{3-} level of the water sample was 0.05 mg/L, meaning that it is closer to the level found in tap water and the water sample from Mihama Garden than the level found in the water collected from Hamada River. This means that the water is clean.

5) Water from aquarium tank

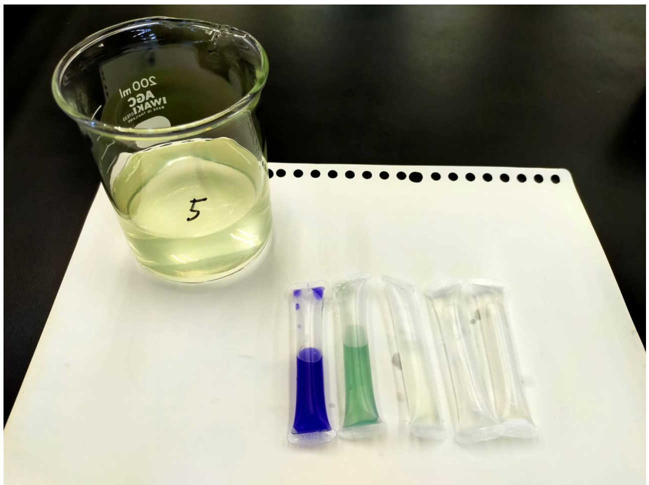

Figure 49: Water from aquarium tank

The pH level of the water sample was 6.2. This indicates that the water is safe to drink. The COD level of the water was 20 mg/L. This is significantly higher than the level found in all four of the other water samples. A COD of 20 mg/L is nearly the same level as the sewage water, meaning that there is a high concentration of dissolved organic matter. The NH_4^+ level was 0.2 mg/L which is the same concentration as the tap water. This means that there is a slightly high concentration of organic nitrogen and ammonia nitrogen. The NO_2^- level was 0.02 mg/L, which is of the same level as the tap water and the water collected from Mihama Garden. This means that the water does not contain a lot of nitrite-nitrogen and is therefore clean. The PO_4^{3-} level was 0.05 mg/L. This is the same level found in Hanami River and indicates that the water is clean.

Table 16: Results in a graph

	PH	COD	NH_4^+	NO_2^-	PO_4^{3-}
1. Tap water	6.2	5	0.2	0.02	0.02
2. Water from Mihama Garden	6.2	10	0.5	0.02	0.02
3. Water from Hamada River	6.2	7	0.6	0.5	0.2
4. Water from Hanami River	6.2	8	0.3	0.2	0.05
5. Water from aquarium tank	6.2	20	0.2	0.02	0.05

8.2. Key Findings from the Phase 2 Experiment

The key findings of the experiment are as follows:

- The pH level of all the water sources indicate that the water is drinkable.
- Water from the aquarium was the most eutrophicated.
- The NH_4^+ level of water from Mihama Garden and water from Hamada River were similar. This could be because the water sources are located close to each other.
- Tap water had the same NO_2^- level as water from Mihama Garden and water from the aquarium tank. This was surprising as tap water should be purer than water from a river or a garden.
- The PO_4^{3-} level of the water from Hanami Garden and the water from the aquarium tank was the same. This could have been because both had living organisms living in the water.

Overall, the water collected from the five locations were not as severely contaminated as we thought they would be. This is great news because it means that the environment of Makuhari is mostly unpolluted.

9. Different applications of the Results of the Experiment

9.1. Decreasing Groundwater Acidity

As section 4 and section 5 of phase 1 explain, earthquakes open fractures that can release and shift gasses and fluids, discharging groundwater from aquifers and altering streamflow on the surface. This is known as liquefaction. Additionally, these earthquakes can, at least temporarily, expose groundwater to pollution and change its makeup. Such shifts typically correlate with earthquakes larger than magnitude 3.5. According to a report published by researchers who conducted their research at the Grimsel Test Site in Switzerland, while the team was observing the site, draining and refilling of the reservoir triggered microearthquakes.[21] Pulses of groundwater propagated from the quake locations, through the local fracture network, and toward the tunnels. Observations in tunnel boreholes showed that the earthquakes did not change groundwater pressure or solute chemistry. However, they did reveal that the small quakes made the groundwater temporarily more acidic, with a pH change equivalent to the difference between tap water and vinegar. Measurements suggested that the pH returned to its normal level within 24 hours, once the pulse of acidic water had passed. Due to potential heavy metal contamination, it is not recommended to drink acidic water, as it can lead to heavy metal poisoning or toxicity. Therefore, we have researched methods to decrease the acidity of the tap water that is sourced from water systems that use groundwater. There are mainly three ways to decrease the acidity of tap water.[22]

1) pH adjusting agent

Using a pH adjusting agent allows the water to become less acidic and more neutral. This makes the water safer to drink. However, this agent may not be available in many homes.

2) Natural materials

When the water is acidic, using a neutralizing filter containing calcite or ground limestone (calcium carbonate) or magnesia (magnesium oxide) can raise the pH.

3) Adding an alkaline substance

When the water is acidic, adding an alkaline substance such as baking powder allows the water to neutralize.

9.2. Water Purification Methods

As the results from the previous section showed, the COD levels differed greatly according to where the water was sourced from. The water sourced from the aquarium tank was especially high in COD levels. While it may seem unimaginable now, if a deadly natural disaster prevents water systems from functioning for several days or even several months, we may have to resort to drinking water from an aquarium tank. We researched two methods that we can carry out with readily available resources to purify water from such sources after a disaster. These methods are explained below.[23]

1) Boil water

It is important to use clean containers when carrying out these procedures.

- Strain the water through a clean cloth, coffee filter or paper towel into a container to remove any sediment or floating matter.
- Boil the water for at least 1 minute.
- After it cools, the water is ready to use. To improve the taste, adding a pinch of salt to each quart of boiled water, or pouring the water back and forth from one clean container to another several times can help.

2) Liquid Chlorine Bleach

The bleach used should be common, unscented household laundry bleach.

- Add bleach to the water and stir or shake the container thoroughly.
- Let the water stand for 30 minutes. If there is the smell of a slight chlorine odor, the water should be safe.
- If the smell of a slight chlorine odor is absent, repeat the dosage and let the water stand for 15 more minutes before using it.

10. Areas of Further Study

10.1. Spreading to Different Localities

In phase 1, we researched the geographical landscape of Makuhari and the impact liquefaction has had on the region. We have also researched about the impacts of other water-related disasters on Makuhari. However, we were only able to briefly compare Makuhari to other reclaimed lands in section 3 of phase 1. If we had been able to conduct research on other areas of reclaimed land and on the impact natural disasters would have on the wider region, we may have been able to compare the strength of reclaimed land based on when the land was formed and how it was formed. Further research along these lines may open discussion about how reclaimed land should be built. Therefore, extending to different localities is something that we will certainly seek to do if we have a chance to research this topic further.

10.2. Increasing Accuracy of Water Testing

As it was our intention to use readily available materials in our school to conduct our experiment, we used pack tests that were available in the biology department. However, looking back at the results, we think that the accuracy of measurements of the pH level could have been improved if we had used better testing methods. Moreover, because we were not able to compare our data with credible research conducted by the Chiba Prefecture Waterworks Bureau, the results were not as accurate as we hoped they would be. If we have a chance to redo this experiment, we will use better testing methods to increase the accuracy of the results.

11. Conclusion

The purpose of this research was to identify the potential damage caused by water-related natural disasters that may devastate Makuhari. Based on our analysis, it can be concluded that there is a high possibility of liquefaction resulting from a large earthquake. Future exploration into water-related natural disasters in other regions and countries could be useful in finding out more about the potential impact such disasters will have on the area surrounding Makuhari.

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