Long term transformation of building locations in 8 villages along the Sanriku coast, tsunami-prone area

Kento Tawada*, Shin Aiba**

** NTT Urban Development Corporation, kento.tawada.uc@ntt-us.com*
*** Professor, Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, aib@tmu.ac.jp*

The Sanriku coastal region of Iwate Prefecture was severely damaged by the Great East Japan Earthquake of 2011. The area has been repeatedly hit by tsunamis since the 1896 Meiji Sanriku Tsunami, the 1933 Showa Sanriku Tsunami, and the 1960 Chile Earthquake Tsunami, and is therefore called a "tsunami prone area" in prior research. However, this discourse has not been verified. In this study, we quantitatively analysed spatial changes in representative 8 villages along the Sanriku coast from the 1960s to 2022. Firstly, we traced aerial photographs taken since the 1960s on GIS, and created data on infrastructure such as roads and the location of all buildings in the villages. Secondly, all residential areas in the villages were categorized into 10 types according to their formation process and whether or not they were inundated by the Great East Japan Earthquake, and the number of buildings, building density, distance to fishing ports, and elevation were calculated to reveal spatial transformations. As a result, it became clear the eight villages can be roughly classified into two groups: those absorbed the increase in the number of buildings in the district from the 60s to the 00s through gentle slope sprawl and planned residential development, and those suffered significant damage from the Great East Japan Earthquake as residential areas spread within past flooded areas. On the other hand, even within the latter, changes contributed to the reduction of damage were identified, such as the concentration around stations and along national roads, and the relocation to higher ground was planned after the Showa Sanriku tsunami. These results support the discourse tsunami prone areas have been learning from past tsunamis. The study also succeeded in extracting a desirable change, sprawl on gentle slopes during the inter-disaster period, which had not been clearly visualized previously.

Keywords: Sanriku Coast, Tsunami Prone Area, historical GIS, inter-disaster period

1. Research Objectives and Methods

Thirteen years have passed since the Great East Japan Earthquake of 2011 caused extensive damage along the Sanriku coast of Iwate Prefecture. This area is known as a "tsunami prone area" and has been repeatedly hit by tsunamis in modern times alone: the 1896 Meiji Sanriku Tsunami, the 1933 Showa Sanriku Tsunami, the 1960 Chilean Earthquake Tsunami, and the 2011 Great East Japan Earthquake. It was said that the repeated damage was caused by people who forgot about the tsunami after a certain amount of time had passed, and repeatedly built and settled in low-lying areas. On the other hand, Aiba, using the Ryori district of Sanriku-cho, Ofunato, clarified that the housing space after World War II was not "located in dangerous places after forgetting the tsunami," but was generally located slowly in safe places, which was influenced by the convenience of urban infrastructure such as roads and railroads that were built after the war. This is due to the convenience of urban infrastructures such as roads and railways that were developed after the war. From a similar perspective, this paper analyses and compares the medium- and long-term changes in the urban infrastructure connecting the eight districts located along the Sanriku coast and in the concentration of housing within the districts. The purpose of this paper is to extract universal knowledge that can be applied to planning techniques from the reconstruction period to the post-reconstruction period or on the eve of the next tsunami through these analyses and comparisons.

In Chapter 2, we focus mainly on roads and railroads, and trace changes in the structure of each community over time due to infrastructure development. Here, among roads, the north-south road in the inland area of Iwate Prefecture is considered the "spine axis," the east-west road running directly parallel to it toward the Sanriku coast is called the "rib axis," and the infrastructure connecting villages located in the coastal area is called the "coastal axis," with particular attention to National Route 45 and the railroad in the coastal axis. The former connects villages scattered along the Sanriku coast as if they were stitched together, while the latter connects the districts relatively more smoothly through the extensive use of tunnels.

In order to compare complex and highly individualized communities along the Sanriku coast, it is first necessary to categorize the residential areas within each community according to their respective characteristics. As residential areas that have been developed in a planned manner, we can start with those developed after the Showa Sanriku tsunami (1,2). Although in some cases, such as Tarou in Miyako City, reconstruction of the original site was chosen, most of them chose to relocate to higher ground as part of a project to develop suitable housing sites. According to Okamura, 1,238 housing units were built in 36 villages in Iwate Prefecture. Some of these houses were planned to be built along prefectural roads, national highways, and other arterial roads. Relocation to higher ground was planned to avoid the inundation area of past tsunamis, but many areas were damaged by the Great East Japan Earthquake. Residential areas that were damaged are designated as 1 and those that were not are designated as 2. After World War II, planned developments by developers (3, 4) were also scattered in the area: small developments of about 10 houses, as well as large-scale developments undertaken by the Iwate Housing Supply Corporation and the Japan Workers' Housing Association. These developments were not necessarily built with tsunami risk in mind. Here, residential areas that were damaged are designated as 3, and those that were not are designated as 4. The relocation sites (5) and land readjustment sites (6) developed through the disaster prevention collective relocation promotion project after the Great East Japan Earthquake, as well as residential areas developed by small-scale developers, are extensions of these planned residential development sites. On the other hand, in villages where there are no land use regulations, houses are developed sprawlingly. The residential areas (7,8) spread around the villages and their surroundings, mainly where they are convenient for the fishing industry. In the 1960s, seawalls were built to protect these areas, mainly against storm surges, but the tsunami of the Great East Japan Earthquake overcame these seawalls, so we can distinguish between residential areas that were damaged (7) and those that were not (8). In addition, in the latter half of the Showa period, bypassing of highways and construction of railroads opened up new possibilities for land use, and residential areas spread out in a sprawling manner in some districts. These areas can also be classified into damaged residential areas (9) and unaffected residential areas (10).

In Chapter 3, residential areas are classified into 10 categories according to their relationship with the planning intentions and past tsunami inundation areas, and their medium- and long-term changes are analysed using a geographic information system (GIS). Here, we focus on quantitative (number of buildings and density of buildings) and qualitative (elevation and distance from fishing ports) changes of buildings in the villages to enable a more precise analysis of medium- and long-term changes as described in the previous section.

The GIS data of buildings were created from GIS data in 2022 and aerial photographs taken at four points in the past (1967, 1977, 1999, and 2000). In order to determine whether past tsunamis have affected the medium- to long-term changes in residential areas in the village, we compared the rate of increase in the number of buildings in the inundated area with the rate of increase in the entire village. If the former was relatively small, it was evaluated that lessons from past tsunamis had been learned and induced changes in residential areas in a desirable direction.

2. Changes in the framework of the village due to infrastructure development

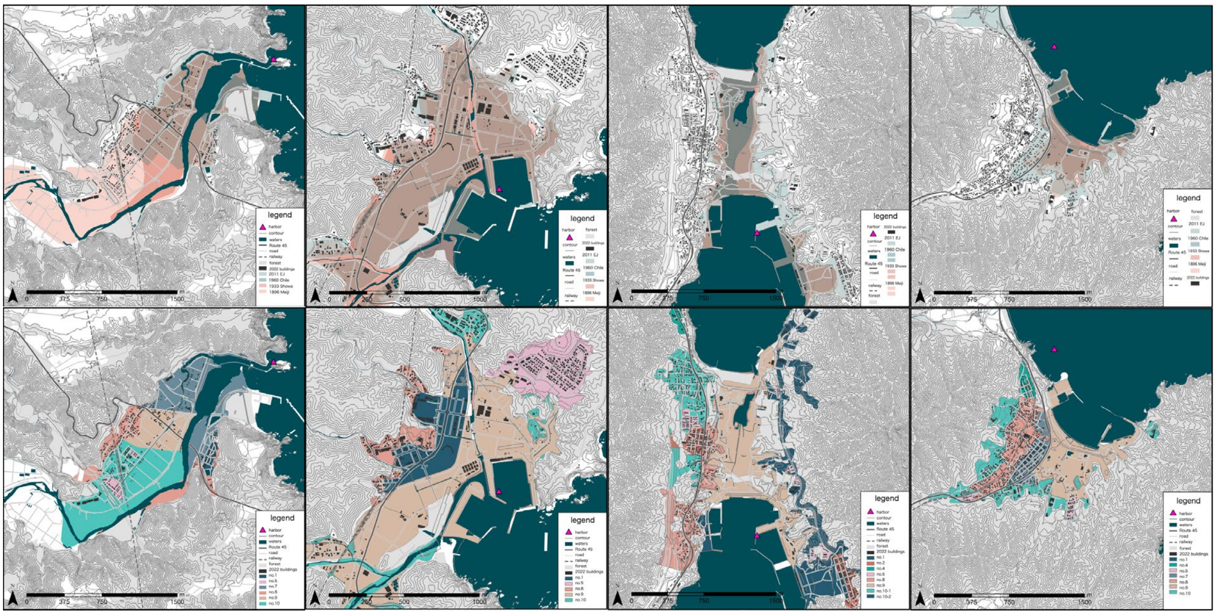

Figure 1 - Past Tsunami Areas and type of residential areas of Omoto, Tarou, Funakoshi, Kirikiri

2-1. Omoto, Iwaizumi

Iwaizumi-cho Omoto is the former center of Omoto Village, which was formed near the mouth of the Omoto River, with the Sanriku Railway station located a little further back. Buildings along the rib axis (National Route 455) along the Omoto River were damaged by the Showa Sanriku Tsunami, and a hill relocation site was built in the southern part of the village. The coastal axis (National Route 45) was constructed to access this relocation site, but the concentration of buildings along the lowland areas damaged by the Showa Sanriku tsunami was also reestablished. Around the same time, a new road, National Route 455, was built across the lowlands, connecting the Sanriku Railway Station and National Route 45 to form the framework of a new village. As a result, the concentration of villages in the lowlands increased, and the area was severely damaged in the Great East Japan Earthquake.

2-2. Tarou, Miyako

Tarou, Miyako City, is a town that chose to build seawalls and rebuild the original site instead of relocating to higher ground after the Showa Sanriku Tsunami. The first embankment was completed in 1958, followed by the second (1956-65) and third (1973-78) embankments, completing the framework of the embankment. During the reconstruction of the original site, National Route 45 was built through the center of the site to allow for evacuation to relatively higher ground. In conjunction with the completion of the seawalls, sprawl proceeded to the low-lying areas surrounded by the first and second seawalls, and the lowlands surrounded by the first and third seawalls. The Sanriku Railway opened in 1972 at Tarou Station as the terminal station of the JNR line, and the entire line opened to Kuji in 1984, which may have influenced the formation of sprawl in the southern part of the district. Due to its long seawall, the Tarou area was known as a model for tsunami disaster prevention, but in the Great East Japan Earthquake, the tsunami overcame and destroyed the seawall, and all the districts were severely damaged.

2-3. Funakoshi, Yamada

Funakoshi and Tanohama, both located in Funakoshi, Yamada-cho, are known for their contrasting paths of planning for relocation to higher ground after the Meiji Sanriku Tsunami, with Funakoshi in the west realizing the creation of sloping land and Tanohama in the east abandoning the plan. Funakoshi has National Route 45 positioned at the eastern end of the Meiji Era upland relocation site. Later, in the late 1930s, a railroad line was built, and in the 1960s, a new Route 45 was built inside the relocated upland area. Therefore, sprawl and planned development sites spread to higher elevations, and the area suffered almost no damage from the Great East Japan Earthquake. The fact that the lowlands were developed as Funakoshi Park in the 1990s may have also prevented the spread of the sprawl to the lowlands. After the Great East Japan Earthquake, the disaster prevention collective relocation site was developed to connect to the relocation site. The topography is steeper than that of the sprawl, and the development of land development technology and intensive public investment made it possible to relocate to this area. Tanohama is located along the old Tanohama route along the bay. After the Meiji Sanriku Tsunami, the area was abandoned, and after the Showa Sanriku Tsunami, the area was relocated to higher ground through a housing development project, but the relocation was not thorough, and residential areas were formed in the fishing port and surrounding low-lying areas, which were severely damaged in the Great East Japan Earthquake.

2-4. Kirikiri, Otsuchi

Kirikiri, Otsuchi-cho is a district on National Route 45, but National Route 45 is being redrawn inside the district. Before the Showa Sanriku tsunami, there were two routes from Otsuchi in the south to Kirikiri: the Ando route and the Akahama route, and National Route 45 was the Akahama route. Since the accumulations on both sides were damaged by the Showa Sanriku Tsunami, a hillside was relocated to a higher level on the mountain side, and a new National Route 45 was built in the relocated area. At the end of the 1930s, a railroad line was constructed along the Ando route, and a railroad station was built on the mountain side of the relocated site. In this way, the axis was built on top of the higher areas, and residential areas spread out in the sprawl as if pulled by the higher elevations. However, National Route 45 was switched to the Ando route with the opening of the tunnel at the end of the 1960s. In Kirikiri, the previous national highway was bypassed and National Route 45 was built closer to the sea. A large area between Route 45 and the railroad was sprawled, and most of the area, including the Showa relocation site, was damaged by the tsunami of the Great East Japan Earthquake.

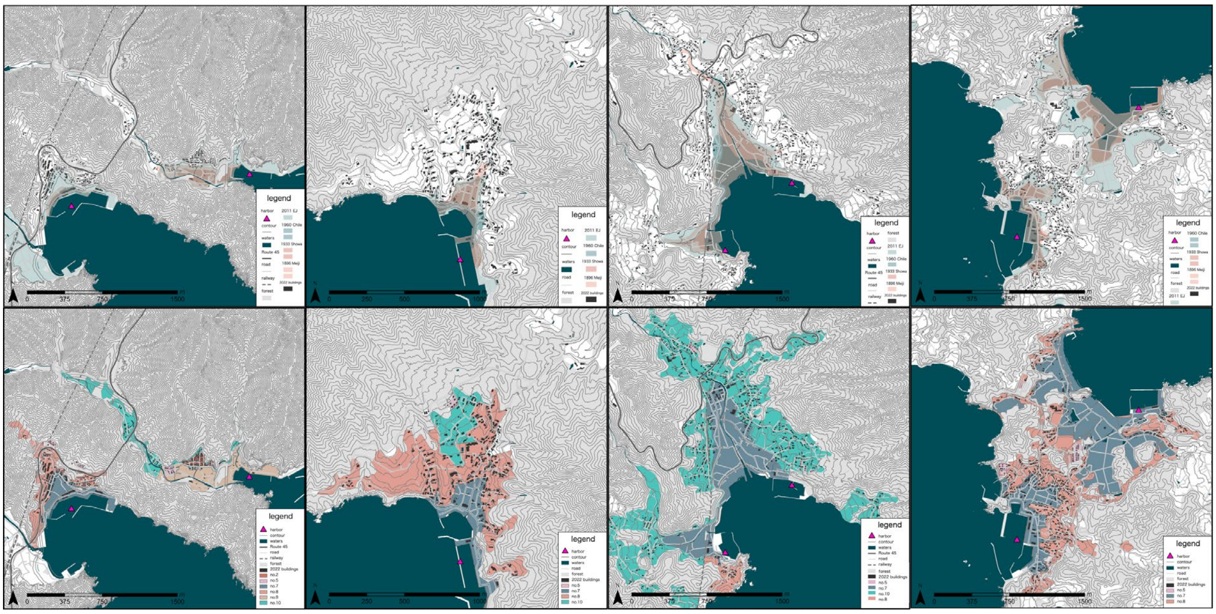

Figure 2 - Past Tsunami Areas and type of residential areas of Touni, Sakihama, Okirai, Hirota

2-5. Touni, Kamaishi

Hongo and Koshirahama, Touni, Kamaishi City, is a district along Route 45. Hongo was severely damaged by the Meiji Sanriku Tsunami, and is known for the mass relocation of residents by building housing lots on the northern slope of the district, which is higher in elevation than the inundation zone of the Meiji Sanriku Tsunami. The only access to both Hongo and Koshirahama from Kamaishi was via the seaside route through Hirata or over a mountain pass following the Kamaishi Kaido inland along the Katagishi River to Koshirahama, but access from the city center was improved with the opening of the Ishizuka Tunnel on National Route 45 in 1969. In the case of Koshirahama, National Route 45 passed through the northern slope, which is higher in elevation than the existing lowland road in the village, and subsequently, a higher elevation built-up area was developed along the road. In the case of Hongo, the prefectural road passing through the relocated area on higher ground merged with National Route 45 at the back of the village, and the internal structure of the village did not change significantly, but in 2006 the Sakura Tunnel leading to the Koshirahama area next to the west was opened, and in 2009 the Sakura-Toge Hirata Line In 2009, the Hongo bypass was constructed, passing through the lowlands to the south of the village and overcoming a tide embankment to the sea. In 1984, Touni Station on the Sanriku Railway's Minami Rias Line was built in the Katagishi district south of Koshirahama, but the concentration around the station was limited and did not have a significant impact on the two districts.

2-6. Sakihama, Ofunato

Sakihama, Ofunato City is located on the northern side of the bay near the eastern end of the Okirai Peninsula, well off National Route 45, but can be seen as a coastal axis along Iwate Prefectural Road No. 209 Sakihama Port Line extending from the adjacent Okirai District. Until now, no major road has passed through the community, but in 1967, with the opening of the Kitasato University Sanriku Marine Biological Laboratory in Yoshihama Bay on the northern side of the community, a road was opened running north-south through the community, connecting Okirai Bay and Yoshihama Bay. This road acts as a rib axis, and residences are clustered at relatively high elevations. There are no train stations in the vicinity of the district, so the opening of the railroad did not have a significant impact.

2-7. Okirai, Ofunato

Okirai, Ofunato City is located at the far end of Okirai Bay, and National Route 45 runs through the base of the village, which is relatively deep. The district used to have a rib axis along the Urahama side of the road, with Prefectural Road No. 9 Ofunato Ryori Sanriku Line leading to Ofunato via Ryori on the south side. In 1960, the Rasho Tunnel was completed, leading to the Yoshihama area to the north of the district, and National Road No. 45, which directly connects to Ofunato on the southwest side, was completed. In addition, the Sanriku Station on the Japan National Railways' Mori Line was built at a relatively high elevation on the southwestern slope of the district, resulting in a concentration of residences at relatively high elevations. In addition, the gentle slopes on the north side of the area have led to the conversion of farmland to residential land at relatively high elevations.

2-8. Hirota, Rikuzentakata

Hirota, Rikuzentakata City is a district located in the middle of a peninsula wedged between Ono Bay and Hirota Bay. The district is far removed from National Route 45, which passes through Rikuzentakata at the far end of Hirota Bay. In 1999, the Nitayama Tunnel was opened between the district and Otomo, located to the north, and Iwate Prefectural Road 38, the Ofunato Hirota RikuzentakaTarouute, passes through a ridge-like high point between Hirota Bay and Ono Bay. The district is such that two districts, centered around the Hirota fishing port on the Hirota Bay side and the Mutsugaura fishing port on the north side, are located back-to-back across Route 38. The area is not affected by the railroad, as there are no stations in the neighborhood.

3. Quantitative and qualitative changes within the village

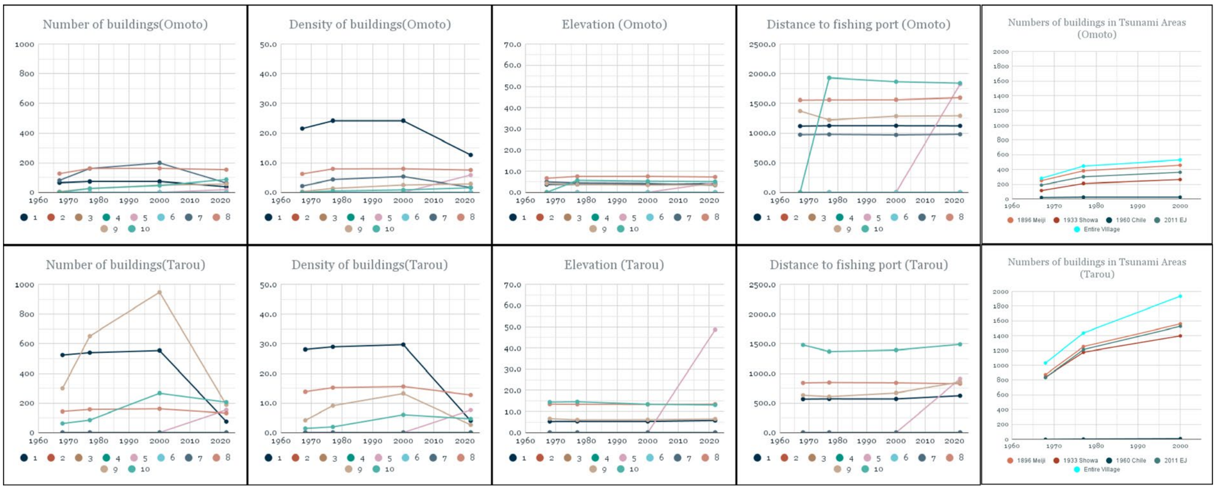

Figure 3 – Four representative indicators (Numbers of buildings, Density of buildings, Elevation, Distance to fishing port) and their transition in each type of residential area, and Numbers of buildings in Past Tsunami Areas in Omoto and Tarou

3-1. Omoto, Iwaizumi

The number of buildings increased until 2000. The number of buildings in 1, which was relocated to higher ground after the Showa Tsunami, did not increase much and was damaged by the Great East Japan Earthquake. Existing village 8 was not damaged by the East Japan Earthquake and the number of buildings did not change much. 7, which was created by sprawl on farmland near fishing ports from the 1960s to the 2000s, suffered damage to more than half of its buildings. As we saw in Chapter 2, the development of National Highway 45 through the lowlands in the 1970s may have encouraged this concentration. The fishing village area that was developed around the station after the East Japan Earthquake is an extension of the sprawl from the 60s to the 00s. Because of the gently sloping lowlands throughout the district, the building elevations have changed little. The same is true for the distance to the fishing port. Since the number of buildings has increased even more in the past inundated areas than the number of buildings in the entire village has changed, it cannot be assessed that the lessons learned from past tsunamis have been applied.

3-2. Tarou, Miyako

The number of buildings increased until 2000. The number of buildings is high in 1, which is the original reconstruction site after the Showa Tsunami, but the increase is levelling off, indicating that the number of buildings is increasing in sprawls 9 and 10. As seen in Chapter 2, 9 is a low-lying residential area that continued to accumulate since the completion of the first seawall in 1958 until the Great East Japan Earthquake in 2011. Looking at the change in the number of houses, 10, which was not damaged by the Great East Japan Earthquake, shows the same increasing trend as 9. This means that changes in residential areas over a long period of time did not necessarily increase damage, but also caused changes that partially improved safety. On the other hand, the 8 areas that were not damaged by the Great East Japan Earthquake were densely populated from 1968 onward, suggesting that the increase in the number of buildings could not be fully absorbed. After the Great East Japan Earthquake, the number of buildings in 5, which was relocated to higher ground, was planned to be about 1/3 of that in 1, while the number of buildings in 6, which was raised and improved, decreased to about half of that in 5. Since the number of houses in the past inundated areas has increased in accordance with the change in the number of houses in the entire village, it cannot be evaluated that the lessons learned from the past tsunami have been applied.

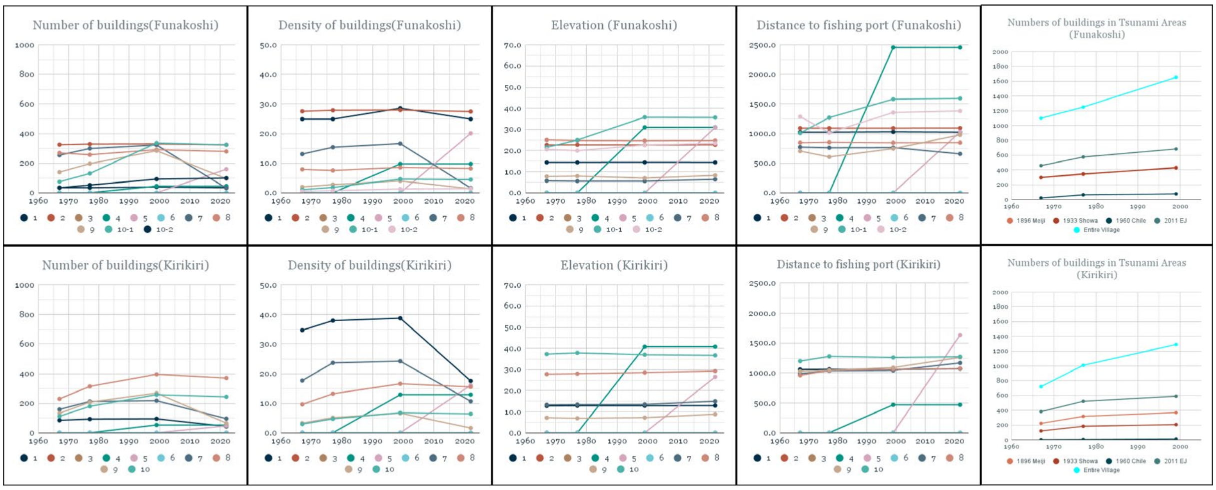

Figure 4 – Four representative indicators (Numbers of buildings, Density of buildings, Elevation, Distance to fishing port) and their transition in each type of residential area, and Numbers of buildings in Past Tsunami Areas in Funakoshi and Kirikiri

3-3. Funakoshi, Yamada

The number of buildings increased until 2000. There was no change in the number of buildings in the area relocated to higher ground (2) after the Meiji and Showa tsunamis, suggesting that the increase in the number of households was absorbed by the high sprawl on the Funakoshi side (10-1), where the increase was particularly large, and the village and its vicinity on the Tanohama side (7). The small planned development (4) is located relatively far from the fishing port and at a higher elevation. As we saw in Chapter 2, Route 45, which passed through the district in the 1960s, may have encouraged agglomeration. The density of the number of houses (2) is high and shows little change, while the other sprawl villages and their surroundings have relatively low densities. Residential area 5, which was developed as an elevated relocation site after the Great East Japan Earthquake, has a similar building density and elevation to 2, indicating that it is an extension of 2. The number of houses has not increased significantly since the Chilean earthquake because the slope sprawl absorbed a certain number of the increase in the number of houses in the entire village. Therefore, it can be evaluated that the lessons learned from past tsunamis have been applied.

3-4. Kirikiri, Otsuchi

The number of buildings increased until 1999. The increase in 8, which is an expansion to the western slope, is particularly large and is thought to have absorbed the continuous increase in the number of households. The small planned development (4) is located at a relatively higher elevation. The density of buildings is higher in 1, which was planned development during the recovery period from the past tsunami. As we saw in Chapter 2, the number of buildings has increased in 8 along Route 45, which runs along the ocean side, while the number of buildings has also increased in 8, which already had a relatively high density, which partially improves the safety of the area. 8 around the station and 10, which sprawls on a gentle slope, show a similar increasing trend, absorbing the increase in the number of buildings in the village and not being damaged. Elevation increases in 4 along the national road, which is considered to have been systematically developed since the 1980s, and the same is true for the distance to the fishing port. The increase in the number of houses in the village as a whole has not been significant since the Chilean earthquake because the slope sprawl absorbed a certain number of the increase in the number of houses. Therefore, it can be evaluated that the lessons learned from past tsunamis have been applied.

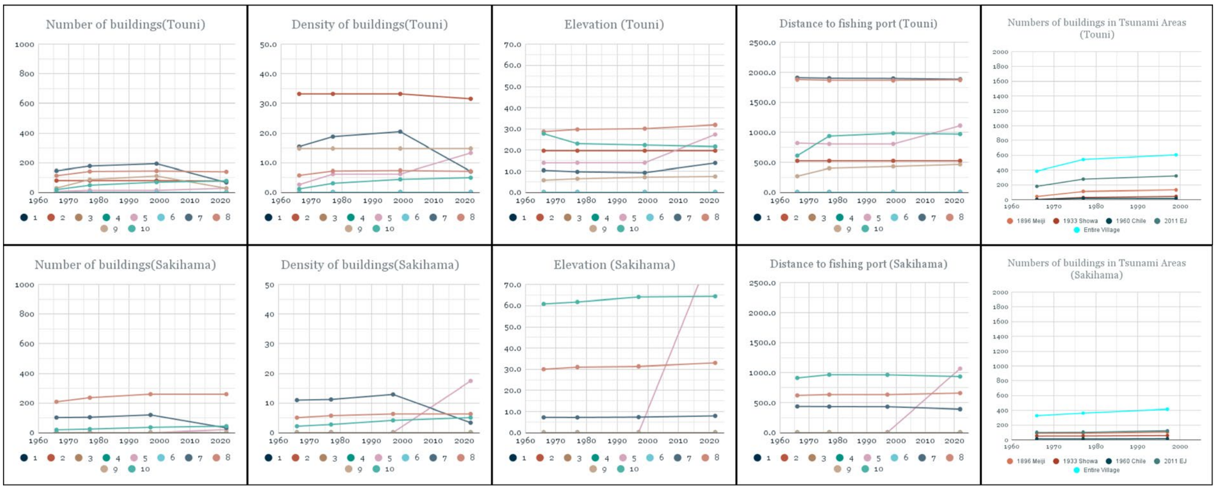

Figure 5 – Four representative indicators (Numbers of buildings, Density of buildings, Elevation, Distance to fishing port) and their transition in each type of residential area, and Numbers of buildings in Past Tsunami Areas in Touni and Sakihama

3-5. Touni, Kamaishi

The number of buildings increased until 1999. 2, which is the site of the relocation to higher ground after the Meiji Tsunami, has remained stable at an extremely high density with no change in the number of buildings since the beginning. 9, located in the low-lying area of Hongo, and 7, located in the low-lying area of Koshirahama, were both damaged. It is slowly sprawling to 10 along National Highway 45. Since the number of buildings has increased in the past inundation areas more than the change in the number of buildings in the entire village, it cannot be evaluated that the lessons from the past tsunamis have been applied. However, the relocation to higher ground that was established after the Meiji Sanriku Tsunami was not damaged by the tsunami at all afterwards, so it can be evaluated as having had a certain effect.

3-6. Sakihama, Ofunato

The number of buildings has increased through 1997 but has not changed significantly. As seen in Chapter 2, sprawl 8 and 10, which spread out on a relatively gentle slope pulled by Kitasato University, located to the north, is increasing steadily. The number of buildings has not increased significantly since the Chilean earthquake because the sprawl on the slope absorbed a certain number of the increase in the number of buildings in the entire village. Therefore, it can be evaluated that the lessons learned from the past tsunamis have been applied. The number of buildings has increased through 1997 but has not changed significantly. Sprawl 8 and 10, spread on gentle slopes, have increased steadily. The number of buildings has not increased significantly since the Chilean earthquake because the sprawl on the slope absorbed a certain number of the increase in the number of buildings in the entire village. Therefore, it can be evaluated that the lessons learned from the past tsunamis have been applied.

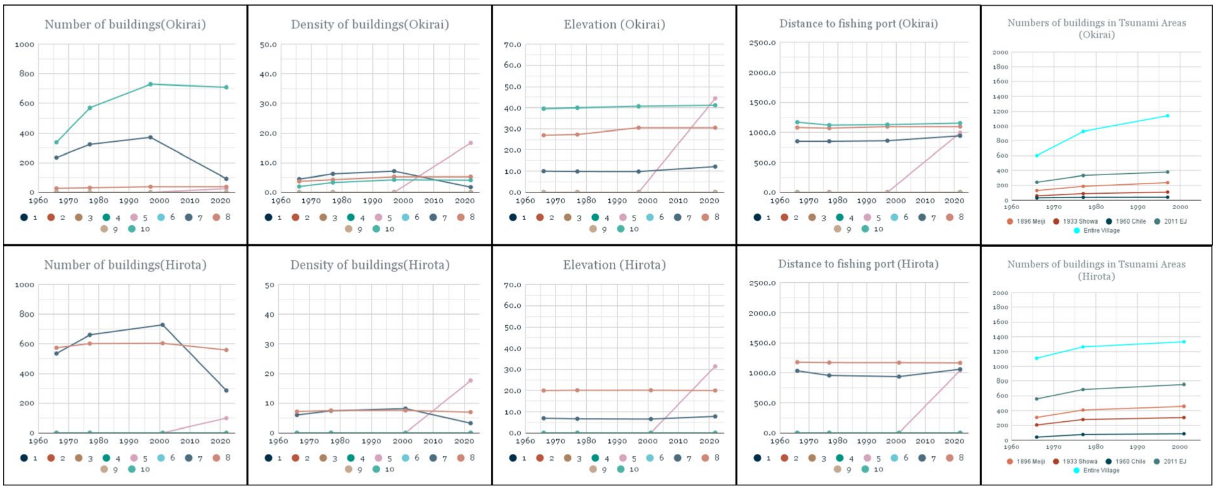

Figure 3 – Four representative indicators (Numbers of buildings, Density of buildings, Elevation, Distance to fishing port) and their transition in each type of residential area, and Numbers of buildings in Past Tsunami Areas in Okirai and Hirota

3-7. Okirai, Ofunato

The number of buildings increased through 1997. The largest increase is observed at 10, which is sprawling on a gentle slope. It also increased at 7, which is closer to the fishing port, but the increase was milder than at 10, suggesting that sprawl partially absorbed the increase in the number of buildings in the village as a whole. Since the slope sprawl absorbed a certain number of the increase in the number of buildings in the entire village, the number of buildings has not increased significantly since the Chilean earthquake. It can be evaluated that the lessons learned from the past tsunamis have been applied.

3-8. Hirota, Rikuzentakata

The number of buildings increased until 2001. Major damage occurred for 7, which are clustered in the lowlands near the fishing port. No significant change has occurred from the 60's to the 00's for 8, which is spread on gentle slopes. Since the number of buildings has increased in the past inundation areas more than the change in the number of buildings in the entire village, it cannot be evaluated that the lessons from past tsunamis have been applied.

4. Medium- and long-term changes in the villages and lessons

As a result of the analysis of medium- and long-term changes in residential areas in the eight districts, it is clear that there are two types of districts: those that absorbed the increase in the number of buildings from the 1960s to the 2000s by sprawl on gentle slopes and planned residential development, such as Funakoshi, Kirikiri, Sakihama and Okirai districts, and those that suffered major damage from the Great East Japan Earthquake, such as Omoto, Tarou, Touni and Hirota districts, which had residential sprawl in flooded areas in the past. The former is the area that was inundated by past tsunamis. In the former, the rate of increase in the number of buildings in the past tsunami inundation area is less than the rate of increase in the number of buildings in the entire community, indicating that the community has learned from the past tsunami. The latter, on the contrary, has not learned from the past tsunamis, since the rate of increase in the number of buildings in the area inundated by past tsunamis was higher than that of the entire community. On the other hand, at the micro level, there are some changes that have worked to reduce damage in the medium- to long-term, such as the concentration around the station located at a relatively high elevation in the Omoto district, the concentration along the national highway in the Tarou district since the 1980s, and the relocation to higher ground developed after the Meiji Sanriku tsunami in the Touni district.

In this paper, we have conducted a more precise analysis of medium- to long-term changes in residential areas in tsunami-hit areas, which were previously regarded simply as "returning to lowlands," by focusing on infrastructure and using a quantitative method. As a result, it became clear that while there are commonalities in the inducement of agglomeration by infrastructure on a macro level, the degree of influence differs greatly from one village to another. It was also found that no single settlement changes uniformly, but is a complex patchwork of various residential areas. Furthermore, we succeeded in extracting lessons from the desirable changes during the inter-disaster period, such as sprawl on gentle slopes and agglomeration near elevated stations and national highways, which was the objective of this paper. In order to elucidate the mechanism of agglomeration, it is necessary to study hard lessons, such as the planning intentions of infrastructure development at the time, and soft lessons, such as the existence or non-existence of traditions within villages.

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Image sources

Figure 1, 2:

Source: the 1:25,000 Topographic Map by Geospatial Information Authority of Japan (2022)

Source: the Aerial Photograph by Geospatial Information Authority of Japan (1966, 1967, 1968, 1977, 1999, 2000, 2001)