Population Affected by the Tsunami of the Tohoku Earthquake; March 11, 2011

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Background:

On March 11, 2011 magnitude 9.0 earthquake occurred in the northeast of Japan, resulting in a catastrophic tsunami. This is the largest tsunami ever recorded and caused tremendous damage on the northeast coast of Japan, especially the Oshika Peninsula region.

Goal:

The goal of this project is to analyze the population affected by the Tsunami in the Oshika Peninsula region, Miyagi Prefecture of Japan following the Tohoku Earthquake.

A final map is presented showing the habitable zone (the mean slope is less than or equal to 10 degrees) flooded, inhabitable zone (the mean slope is more than 10 degrees) flooded and the area that remained unflooded by the Tsunami.

This map is accompanied by two reference maps (1) the location of Miyagi Prefecture in Japan and (2) the location of the Oshika Peninsula region and 5 cities with the highest number of death per person (number of death/total population) in Miyagi.

Data Collection:

Data used in the project came from the following sources:

- Spatial data (Administrative Area, Cover, Cover Mask, Elevation, Elevation Mask, Gazetteer, Inland Water, Population, Population Mask, Railroads, Roads): http://www.diva-gis.org/gdata
- DEM: https://asterweb.jpl.nasa.gov/gdem.asp
- Flooded Area (Restoration Support Investigation Archive/Login required/Japanese): http://fukkou.csis.u-tokyo.ac.jp
- Ishinomaki Districts Map (Japanese): https://www.ur-net.go.jp/press/h25/ur2013_press_0902_ishinomaki.pdf
- Ishinomaki Area Map before merged to be Ishinomaki City (Japanese): https://upload.wikimedia.org/wikipedia/ja/5/5c/Monou-Miyagi.png
- "Relationships between Distribution of Japanese Residential Area and Topography" Masumi ZAIKI, Takashi OGUCHI, Yuichi KAGAWA, Akiko TAKAHASHI (The University of Tokyo), Shiro KOIKE and Masakazu YAMAUCHI (National Institute of Population and Social Security Research): www.csis.u-tokyo.ac.jp/dp/dp68/68.pdf

- Ishinomaki Population by District 2010 (Japanese): www.city.ishinomaki.lg.jp/cont/10102000/0040/3914/3-9-2-1612.pdf

- Miyagi Population by city 2010 (Japanese): https://www.pref.miyagi.jp/soshiki/toukei/22gaiyou.html

- The number of deaths and population affected by city (Japanese): www.bousai.go.jp/kaigirep/chousakai/tohokukyokun/1/pdf/3-2.pdf

Data Processing:

Coordinate System: GCS WGS 1984

The JPN_adm shapefiles were projected on the fly when imported into ArcGIS and therefore need not to be projected.
The image for Ishinomaki districts were georeferenced as explained in the following section.

ArcGIS Processing:

I took the following steps to analyze the data imported to ArcGIS to create my final map and table:

Part A

1. Add data
2. Create a new shapefile of the Miyagi Prefecture
3. Create a new shapefile of the cities in the Oshika Peninsula region
4. Create a new shapefile of the Oshika Peninsula region (*"targets"*)
5. Create a mask of the DEM by "*targets*"
6. Create a hillshade of the DEM to "*targets*"
7. Georeference the downloaded image of Ishinomaki districts
8. Cut the polygon of Ishinomaki City in "*Target_area*" to districts
9. Add district names and population to attribute table of "*Target_area*"
10. Merge polygons of flooded area ("*Tsunami_area*") for each city or district
11. Project "*Target_area*" and "*Tsunami_area*" to Cylindrical Equal Area (World)
12. Calculate the flooded area ("*Area_flood"*) and total area ("*Area_total"*) with "*Calculate Geometry*"
13. Calculate the population affected ("*Pop_affect"*) using "*Field Calculator*"

Part B

14. Create a slope raster from the DEM using "*Slope*" tool
15. Reclassify the slope raster into (<=10, 10<) using "*Reclassify*" tool
16. Clip the slope raster to each city and district
17. Calculate the area of habitable zone ("*Area_habit"*)
18. Calculate the population affected ("*PopAffect2"*)
19. Clip the slope raster by "*Tsunami_area*"

Part C

20. Create map (2)

1. Add data to ArcMap
   a. Open a blanc ArcMap document
   b. Connect to project folder (*Project*)
   c. Add data:
      i. *JPN_rails*
      ii. *JPN_water_lines_dcw*
      iii. *JPN_water_areas_dcw*
      iv. *JPN_adm2*
      v. *JPN_adm1*
      vi. *JPN_adm0*

2. Create a new shapefile of the Miyagi Prefecture (*Miyagi*)
   a. Select “*Miyagi”* in “*JPN_adm2”* using “*Select by Attributes”* (“NAME_1” = “Miyagi”)
   b. Export data to create a separate “*Miyagi”* shapefile

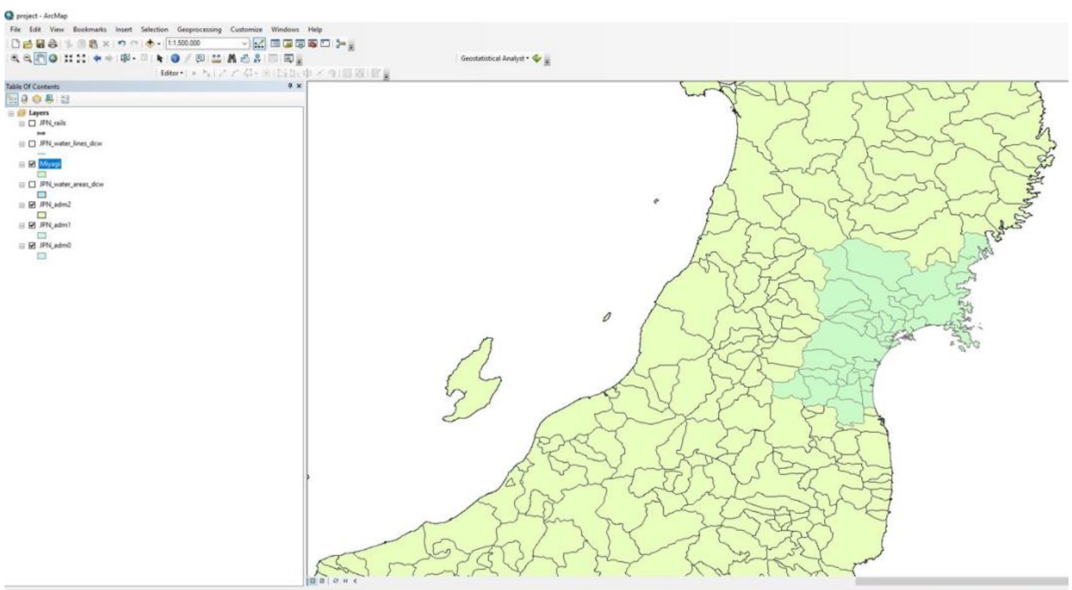


Figure 1: Shapefile “*Miyagi*” showing Miyagi Prefecture

3. Create a new shapefile of the cities in the Oshika Peninsula region
   a. Select “*Matsushima”*, *“Higashimatsushima”, “Ishinomaki”* and *“Onagawa*” in “*Miyagi”*
   b. Export data to create separate shapefiles: “*Matsushima*”, “*Higashimatsushima*”, “*Ishinomaki*” and “*Onagawa*”.

*I imported the DEM file because I forgot to in last section

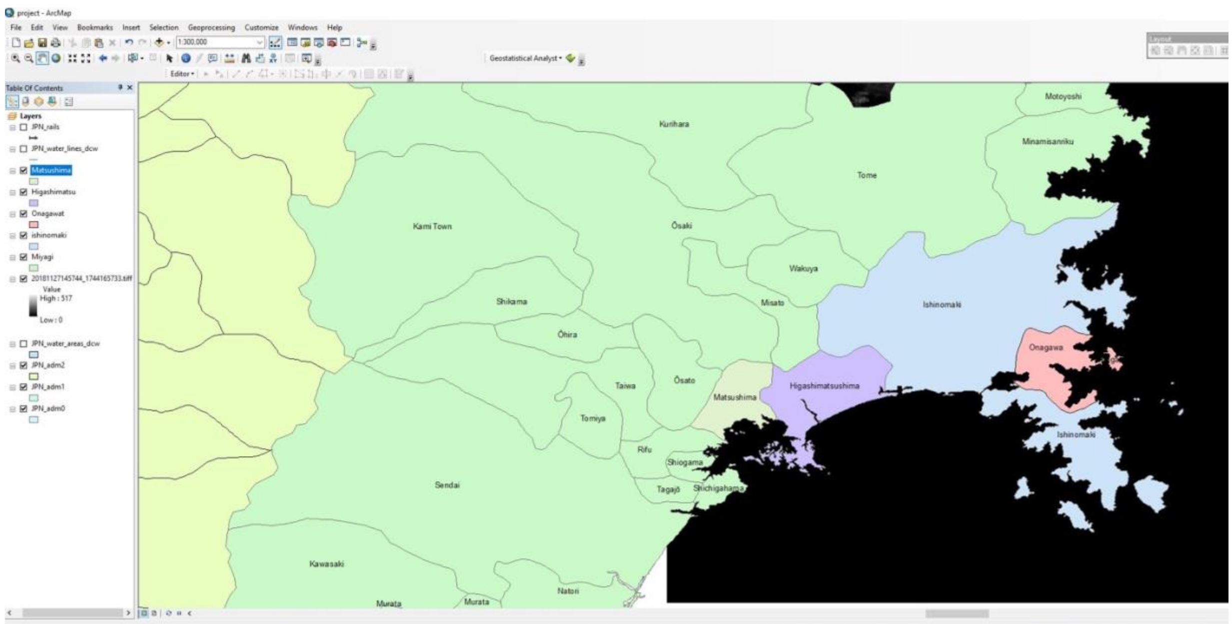


Figure 2: Shapefiles for the target cities

4. Create a new shapefile of the Oshika Peninsula region (*targets*)
   a. Export all the selected data from last section to create a shapefile “*targets”* including all the target cities
   b. Make it hollow and show the border lines.

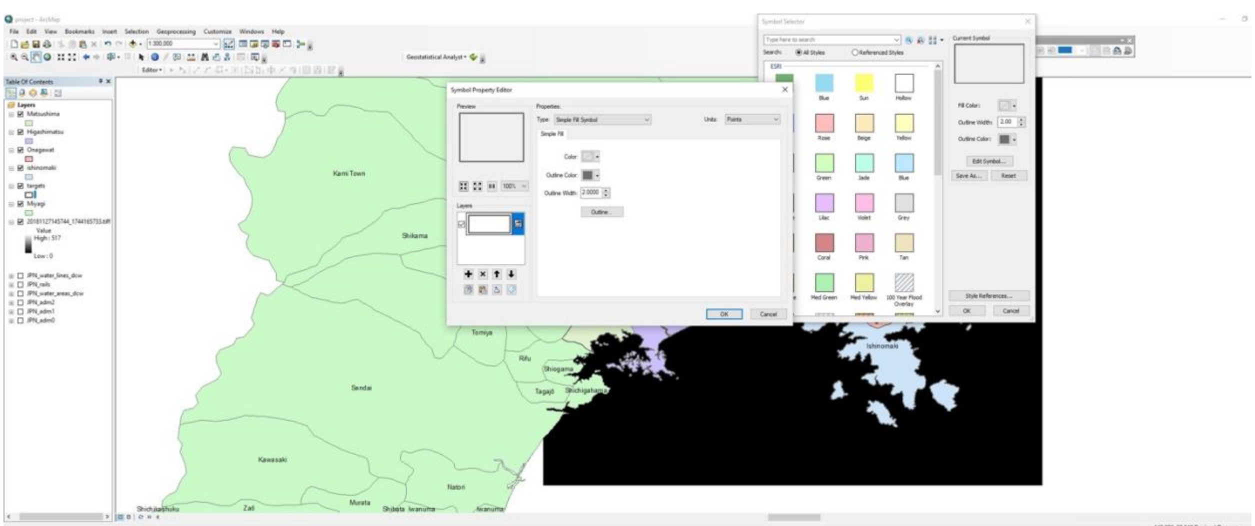


Figure 3: Symbolizing a shapefile for the Oshika Peninsula region

5. Create a mask of the DEM by "*targets*"

a. Use "*Extract by Mask*" tool (use "*targets*" as a mask)

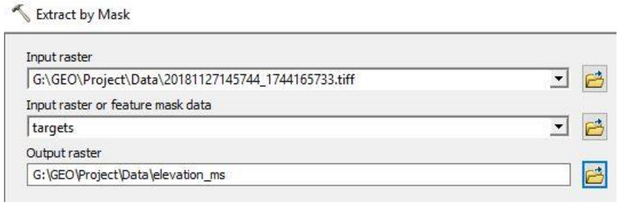


Figure 4: Extract DEM by Mask

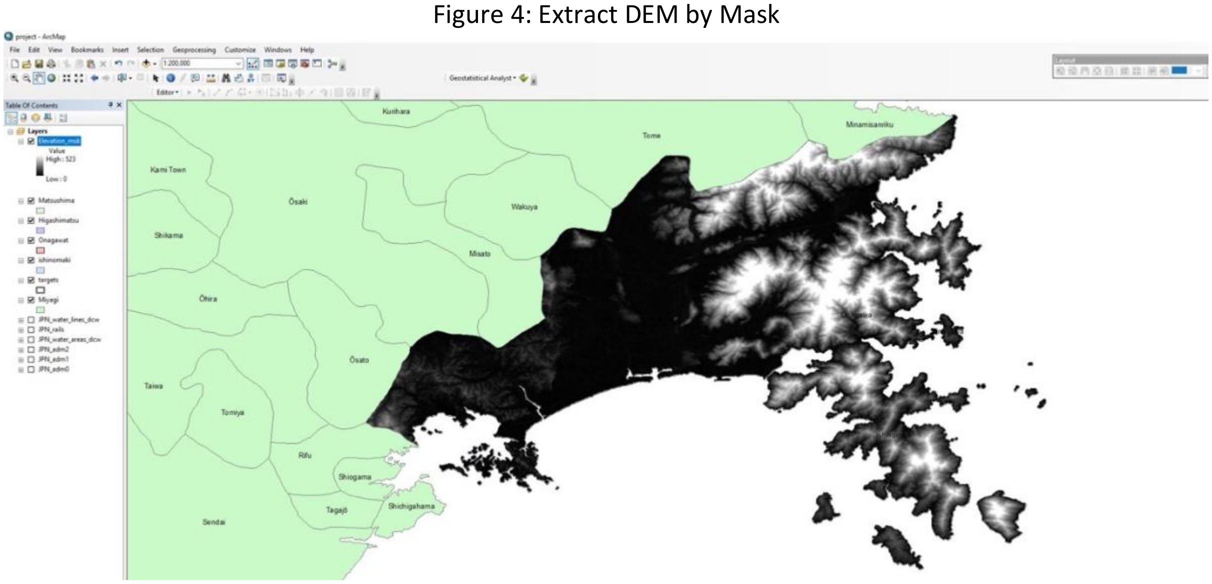


Figure 5: DEM of the Oshika Peninsula region (*elevation_ms*)

6. Create a hillshade of the DEM to "*targets*"

a. Use "Hillshade" tool to create a hillshade of the Oshika Peninsula region

Input: "*elevation_ms*"

z factor: 0.000009

Output: "*hillshade2*"

b. Change the transparency of "*targets*" to 50%.

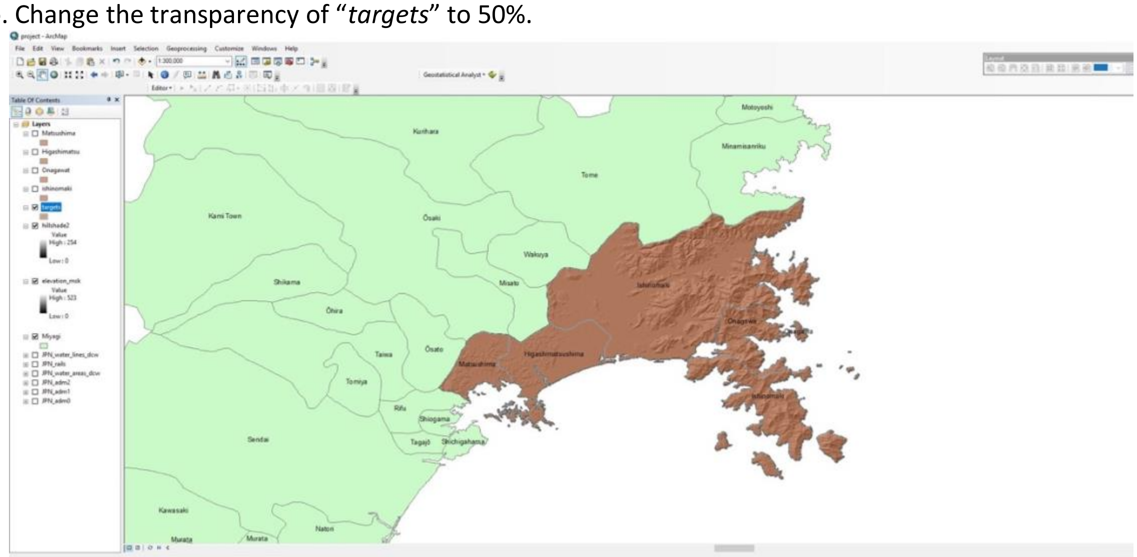


Figure 5: Hillshade of the Oshika Peninsula region (*hillshade2*)

*Since the analysis will be based on the population density, I divide Ishinomaki City into districts to minimize errors.

7. Georeference the downloaded image of Ishinomaki districts
   a. Add the image and shapefile for the Miyagi Prefecture
   b. Make the shapefile layer hollow
   c. Scale the image so that it matches the shapefile layer using “*Georeference”* tool

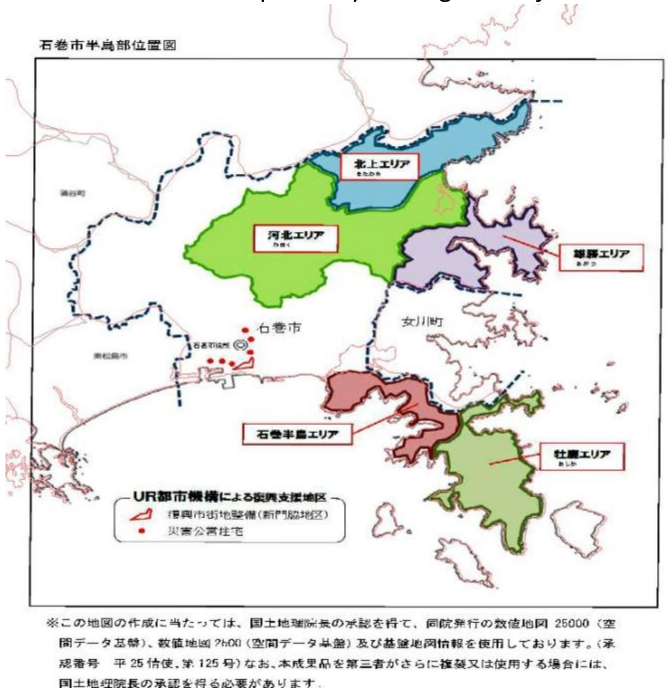


Figure 6: Georeferenced Image of Districts in Ishinomaki

*I changed the name of the layer “*targets*” to “*Target_area*”.

8. Cut the polygon of Ishinomaki City in “*Target_area*” into districts
   a. Add the georeferenced image to the map
   b. Cut the polygon of Ishinomaki City based on the image using “*Cut Polygons*” tool

Figure 7: Cities and Districts in the Oshika Peninsula region

9. Add district names and population to attribute table of “*Target_area*”
   a. Add a field “*Pop2010-4*” (long integer)
   b. Add district names to the field “*VARNAME_2*” in attribute table
   c. Add population to the field “*Pop2010-4*”

Table

Target_area

TYPE_2	ENGTYPE_2	NL_NAME_2	VARNAME_2	Pop2010_4
Shi	City	石巻市	Oshika	4321
Machi	Town	女川町	Onagawa	10032
Shi	City	石巻市	Monou	7582
Machi	Town	松島町	Matsushima	15187
Shi	City	石巻市	Kitakami	3718
Shi	City	石巻市	Kahoku	11578
Shi	City	石巻市	Ishinomaki	129633
Shi	City	東松島市	Higashimatsush	42760
Shi	City	石巻市	Ogatsu	3994

Figure 8: Attribute table of “*Target_area*”

*Since polygons in the shapefile “Tsunami_area” are individual, I merge them for each area.
*Unit of area is m^2.

10. Merge polygons of flooded area (“*Tsunami_area*”) for each city or district
   a. Select the polygons for each area using “*Select by Location*” tool
      Target layer: “*Tsunami_area”*
      Source layer: “*Target_area*” (Use selected feature)
      Spatial selection method for target layer feature(s): are within the source layer feature
   b. Merge the selected features using “*Merge*” in “*Editor*”

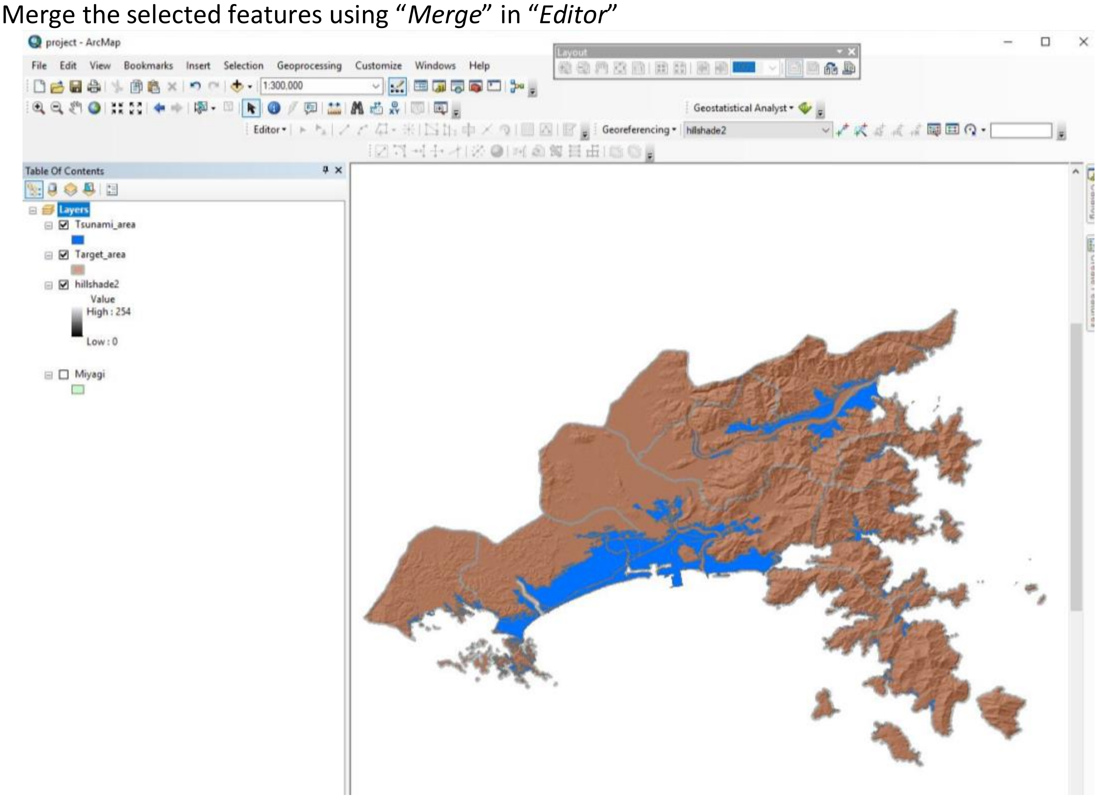


Figure 9: Flooded area in the Oshika Peninsula region

*Since WGS 84 is a Geographic Coordinate System, I should project it into Projected Coordinate System to calculate the geometries. I use Cylindrical Equal Area projection to preserve the area.

11. Project “*Target_area*” and “*Tsunami_area*” to Cylindrical Equal Area (World)

a. Project “*Target_area*” and “*Tsunami_area*” to Cylindrical Equal Area (World) using “*Projection*” tool

“*Target_area*” -> “*CEA_target*”

“*Tsunami_area*” -> “*CEA_tsunami*”

12. Calculate the flooded area and total area with “*Calculate Geometry*”

a. Add fields to attribute table of “*CEA_target*”

“*Pop_affect*”: Population affected (long integer)

“*Area_flood*”: Flooded area (long integer)

“*Area_total*”: Total area (long integer)

b. Add fields to attribute table of “*CEA_tsunami*”

“*Area*”: Area, which is equal to “*Area_flood*” in “*CEA_target*”

c. Calculate “*Area*” in “*CEA_tsunami*” and “*Area_total*” in “*CEA_target*” using “*Calculate Geometry*”

CEA_target

VARNAME_2	Pop2010_4	Pop_affect	Area_flood	Area_total
Higashimatsushima	42760	0	34331602	107566215
Ishinomaki	129633	0	33879823	221083909
Matsushima	15187	0	1705973	51991267
Onagawa	10032	0	3292101	60412651
Ogatsu	3994	0	1441570	45134222
Kahoku	11578	0	13166928	119419261
Oshika	4321	0	2086833	56153588
Monou	7582	0	0	46291020
Kitakami	3718	0	5976468	65001842

Figure 10: Attribute table of “*CEA_target*” showing the flooded area and total area

13. Calculate the population affected (*Pop_affect*) using “*Field Calculator*”

a. Calculate “*Pop_affect*” using “*Field Calculator*”

“*Pop_affect*” = “*Pop2010_4*” * “*Area_flood*” / “*Area_total*”

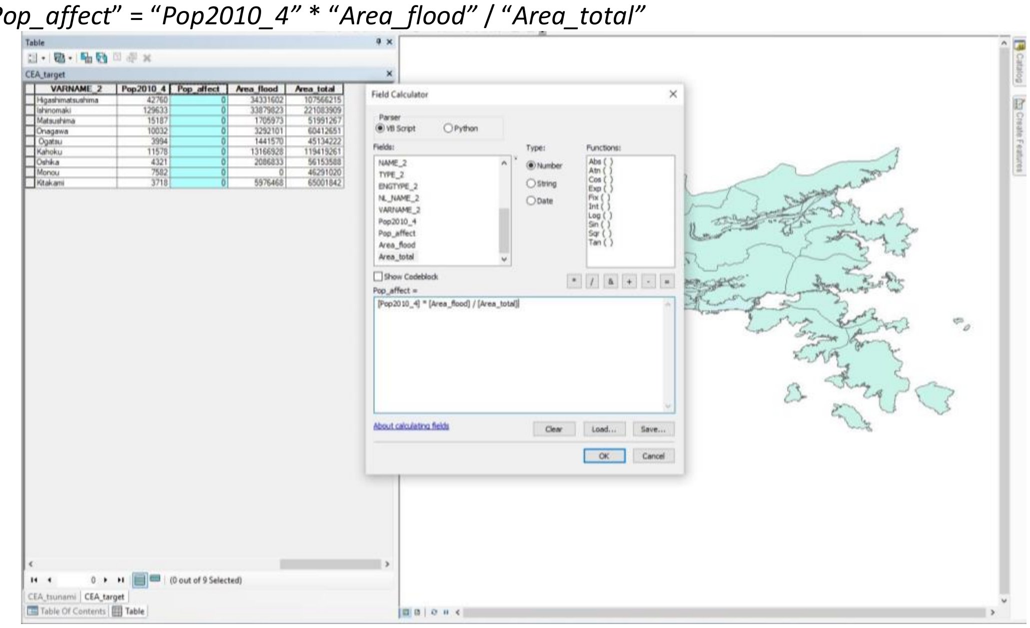


Figure 11: Calculate “*Pop_affect*” using “*Field Calculator*”

Table

CEA_target

	VARNAME_2	Pop2010_4	Pop_affect	Area_flood	Area_total
	Higashimatsushima	42760	13648	34331602	107566215
	Ishinomaki	129633	19866	33879823	221083909
	Matsushima	15187	498	1705973	51991267
	Onagawa	10032	547	3292101	60412651
	Ogatsu	3994	128	1441570	45134222
	Kahoku	11578	1277	13166928	119419261
	Oshika	4321	161	2086833	56153588
	Monou	7582	0	0	46291020
▸	Kitakami	3718	342	5976468	65001842

Figure 12: Attribute table of "*CEA_target*" showing "*Pop_affect*"

*Since this estimation is not accurate, I consider habitable and inhabitable zones.

14. Create a slope raster from the DEM using "*Slope*" tool

   a. Create a slope raster from the DEM

      z factor: 0.000009

      output: "*slope*"

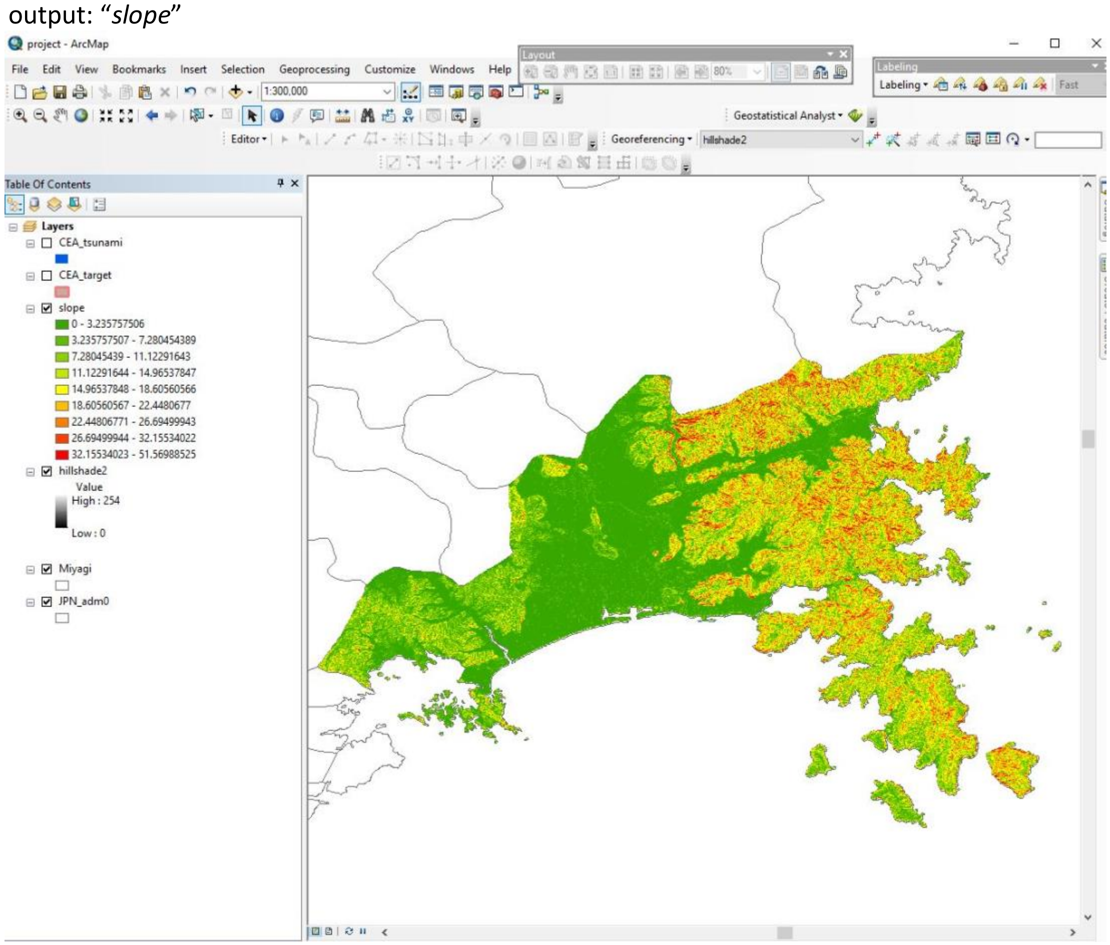


Figure 13: Slope raster of the Oshika Peninsula region

* According to “Relationships between Distribution of Japanese Residential Area and Topography” (Zaiki et al), the mean slope of residential area in Japan is 4.72 degrees, and the maximum mean slope of residential area by city is 8.03. Therefore, it is reasonable to assume that most people are living in area with the slope less than 10 degrees.

15. Reclassify the slope raster into (<=10, 10<) using “*Reclassify*” tool
    a. Reclassify “*slope*” into <=10 and 10< using “*Reclassify*” tool

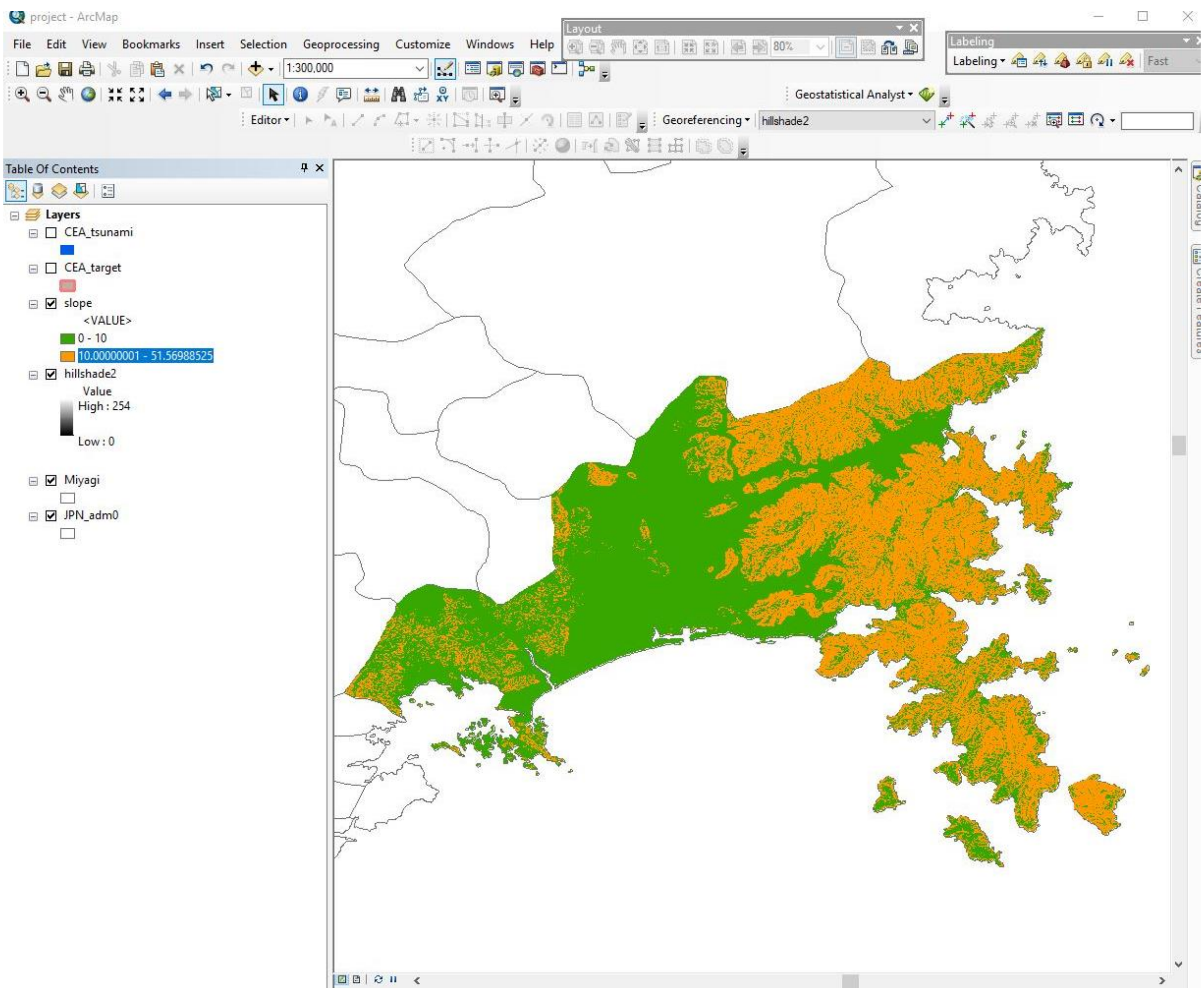


Figure 14: Habitable (green) and inhabitable (orange) zone of the Oshika Peninsula region

16. Clip the slope raster to each city and district
    a. Clip “*slope*” to each city and district using “*Clip*” tool

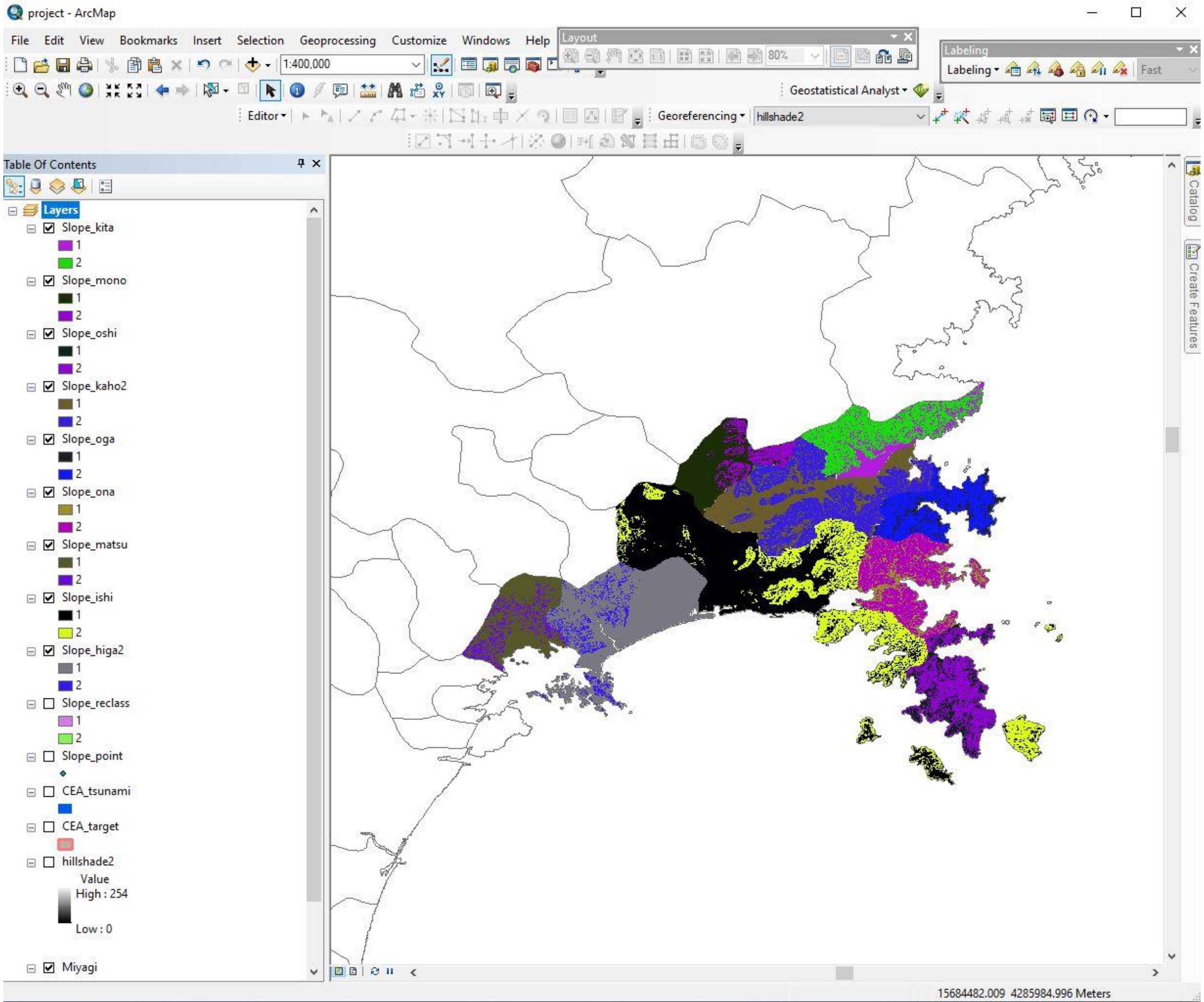


Figure 15: Slope raster clipped to each district and city

17. Calculate the area of habitable zone

a. Add a field "*Area_habit*" to attribute table of "*CEA_target*"

b. Calculate it for each district and city

"*Area_habit*" = "*Area_total*" *(number of points in <=10) / (number of all points)

VARNAME_2	Pop2010_4	Pop_affect	Area_flood	Area_total	Area_habit
Higashimatsushima	42760	13648	34331602	107566215	94803214
Ishinomaki	129633	19866	33879823	221083909	142526379
Matsushima	15187	498	1705973	51991267	39903372
Onagawa	10032	547	3292101	60412651	15238711
Ogatsu	3994	128	1441570	45134222	8123197
Kahoku	11578	1277	13166928	119419261	55791654
Oshika	4321	161	2086833	56153588	18866795
Monou	7582	0	0	46291020	36023812
Kitakami	3718	342	5976468	65001842	21724505

Figure 16: Attribute table of "*CEA_target*" showing "*Area_habit*"

18. Calculate the population affected

a. Add a field "*PopAffect2*" to attribute table of "*CEA_target*"

b. Calculate it for each district and city

*"PopAffect2" = "Pop2010_4" * "Area_flood" / "Area_habit"*

VARNAME_2	Pop2010_4	Pop_affect	Area_flood	Area_total	Area_habit	PopAffect2
Higashimatsushima	42760	13648	34331602	107566215	94803214	15485
Ishinomaki	129633	19866	33879823	221083909	142526379	30815
Matsushima	15187	498	1705973	51991267	39903372	649
Onagawa	10032	547	3292101	60412651	15238711	2167
Ogatsu	3994	128	1441570	45134222	8123197	709
Kahoku	11578	1277	13166928	119419261	55791654	2732
Oshika	4321	161	2086833	56153588	18866795	478
Monou	7582	0	0	46291020	36023812	0
Kitakami	3718	342	5976468	65001842	21724505	1023

Figure 17: Attribute table of "*CEA_target*" showing "*PopAffect2*"

19. Clip the slope raster by "*Tsunami_area*"

a. Clip "*Slope_reclass*" by "*Tsunami_area*" using "*Clip*" tool

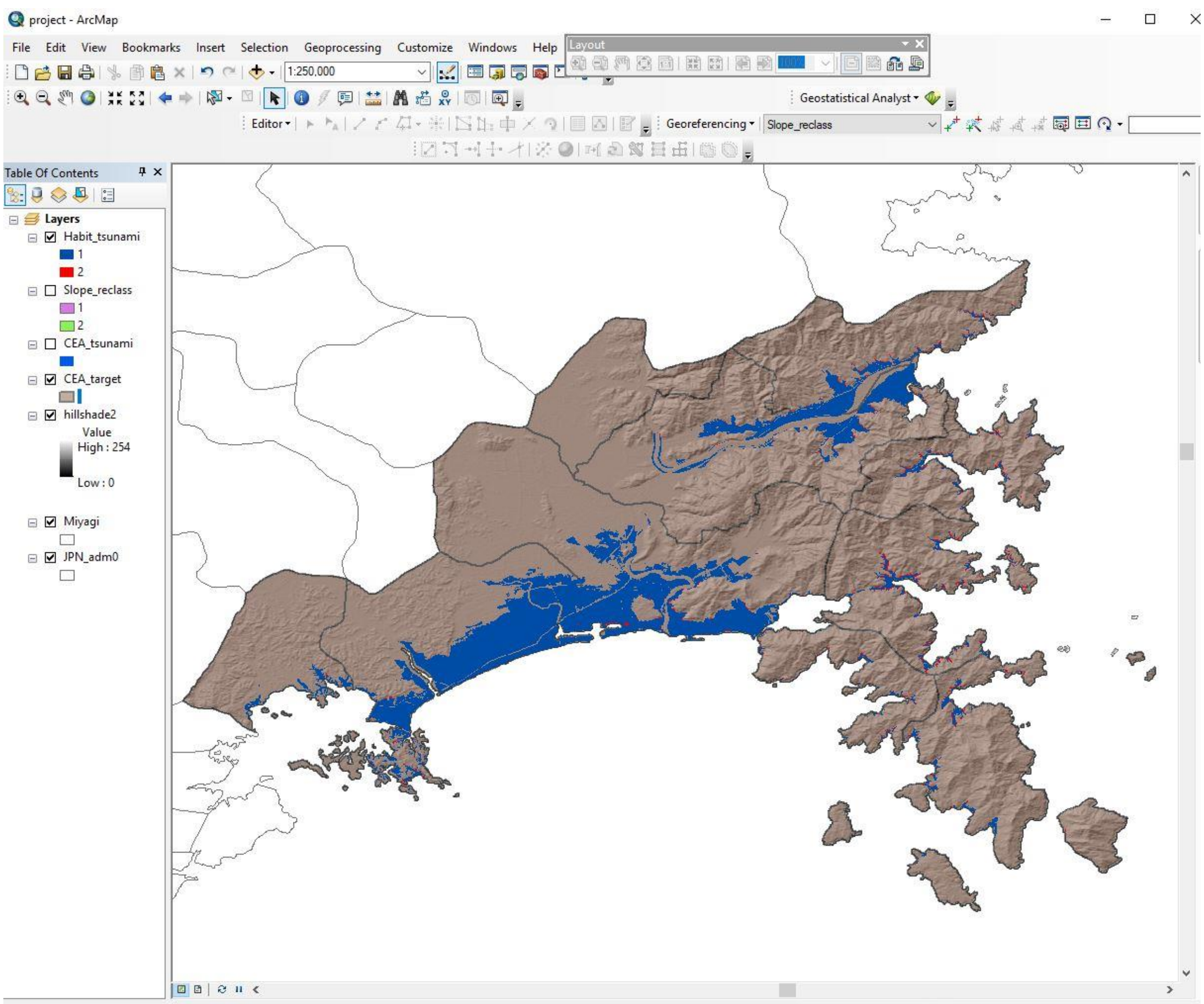


Figure 18: Flooded habitable (blue) and inhabitable (red) zones in Oshika Peninsula region

20. Create map (2)

a. Add fields "*Pop_dead*", "*Population*" and "*Dead_ratio*" in attribute table of "*Miyagi*"
b. Input values for "*Pop_dead*" and "*Population*"
c. Calculate values for "*Dead_ratio*" using "Field Calculator"
   "*Dead_ratio*" = "*Pop_dead*" / "*Population*"
d. Select the 5 cities with highest ratio and export them as a new shape file

Result:

	Higashimatsushima	Ishinomaki	Matsushima	Onagawa	Ogatsu	Kahoku	Oshika	Monou	Kitakami
Total area (km^2)	107.566	221.084	51.991	60.413	45.134	119.419	56.154	46.291	65.002
Habitable area (km^2)	94.803	142.526	39.903	15.239	8.123	55.792	18.867	36.024	21.725
Flooded area (km^2)	34.332	33.880	1.706	3.292	1.442	13.167	2.087	0.000	5.976
Population in 2010	42,760	129,633	15,187	10,032	3,994	11,578	4,321	75,82	3,718
Population affected by tsunami	13,648	19,866	498	547	128	1,277	161	0	342
Population affected by tsunami considering slope	**15,485**	**30,815**	**649**	**2,167**	**709**	**2,732**	**478**	**0**	**1,023**

Figure 19: Calculated Populations affected by the tsunami in Oshika Peninsula region of Miyagi, Japan

From this project, I have concluded that the populations affected by the tsunami are: 15,485 in Higashimatsushima, 649 in Matsushima, 2,167 in Onagawa and 35,757 in Ishinomaki (including 30,815 in Ishinomaki district, 709 in Ogatsu district, 2,732 in Kahoku district, 478 in Oshika district, 0 in Monou district, 1,023 in Kitakami district).
Totaling to 54,058 people.

My first estimate "*Pop_affect*" is not a good one because it assumes the population center is same as the geographic center and population is equally distributed through the area. Since the target area is Ria and mountainous, most people are living in the coastal area. Therefore, the actual population center is far from the centroid of the area. As a result, I underestimated the population affected. For better estimations, I should get detailed population information for every small area.

In order to improve the estimate, I took slope into consideration. From the slope information, I obtained habitable area, which has slope less than or equal to 10 degrees. As a result, the estimate was improved a lot for the east side of the region, but not for the west because the west side is generally flat as shown in the Figure 14. Since my calculation ignores the area of inhabitable zone flooded (i.e. it is supposed to be [population] * ([flooded area] – [inhabitable flooded area]) / [habitable area], but I did [population] * [flooded area] / [habitable area]), it slightly overestimates the population affected, but it is negligible because the inhabitable flooded area is very small compared to habitable flooded area as shown in the Figure 18 and Final Map.
I compared my estimate with the official report by the Japanese government. As shown in the Figure 20, I underestimated the population affected. It is probably because I did not consider other important factors. For example, most jobs in this region is related to fishery, therefore, people tend to live close to the shoreline. I should either get more detailed population data or give some weight on the population to make its center close to the shoreline. However, the numbers I obtained for "*PopAffect2*" follow the general trend of the numbers reported by the government, while the ones I obtained for "*Pop_affect*" do not. Therefore, using habitable zone as a factor when there is not detailed population information available can be a good approach.

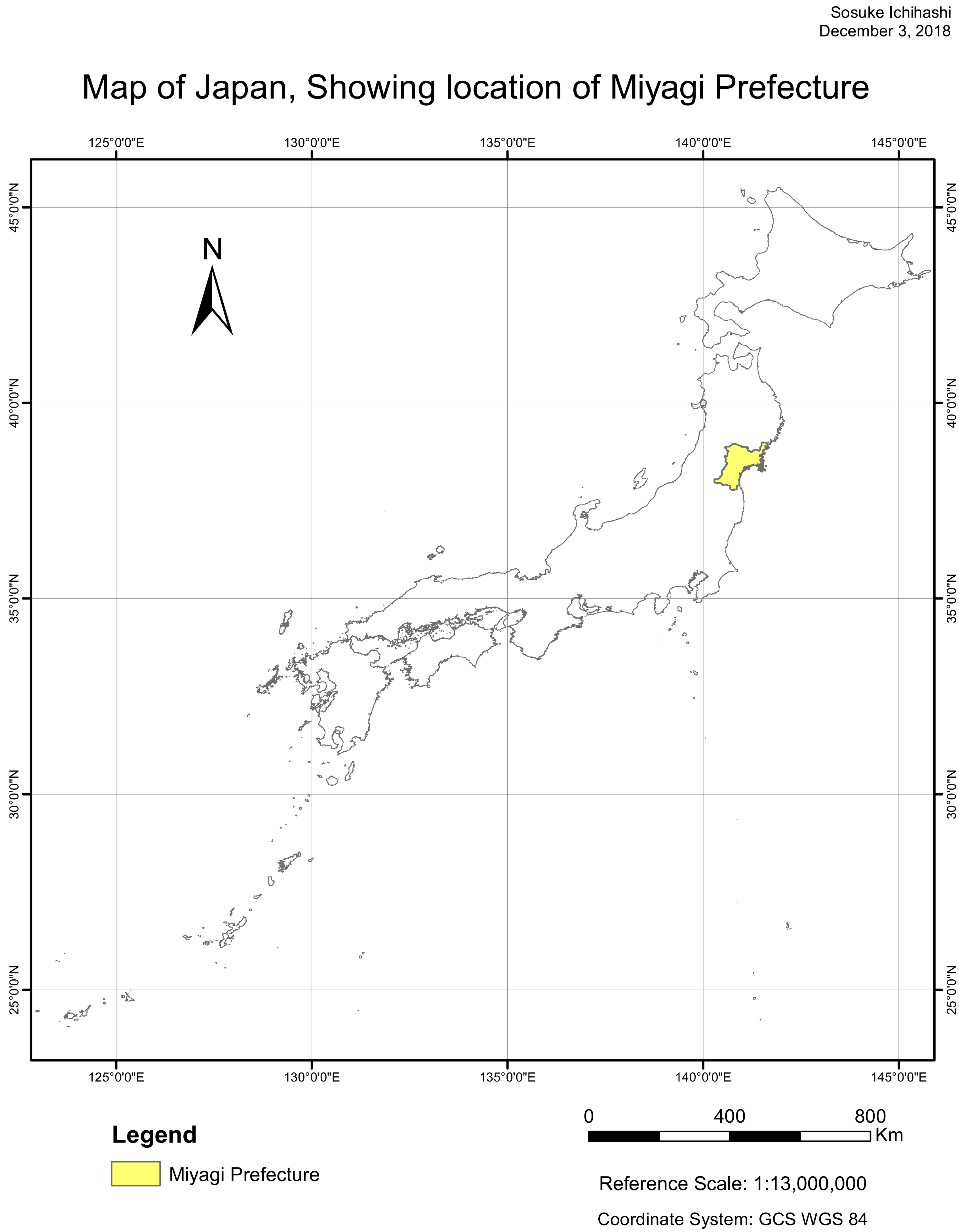
	Higashimatsushima	Ishinomaki	Matsushima	Onagawa
My estimate	15,485	35,757	2,167	2,167
Official report	34,014	112,276	4,053	8,048

Figure 20: Population affected by the tsunami of the Tohoku Earthquake

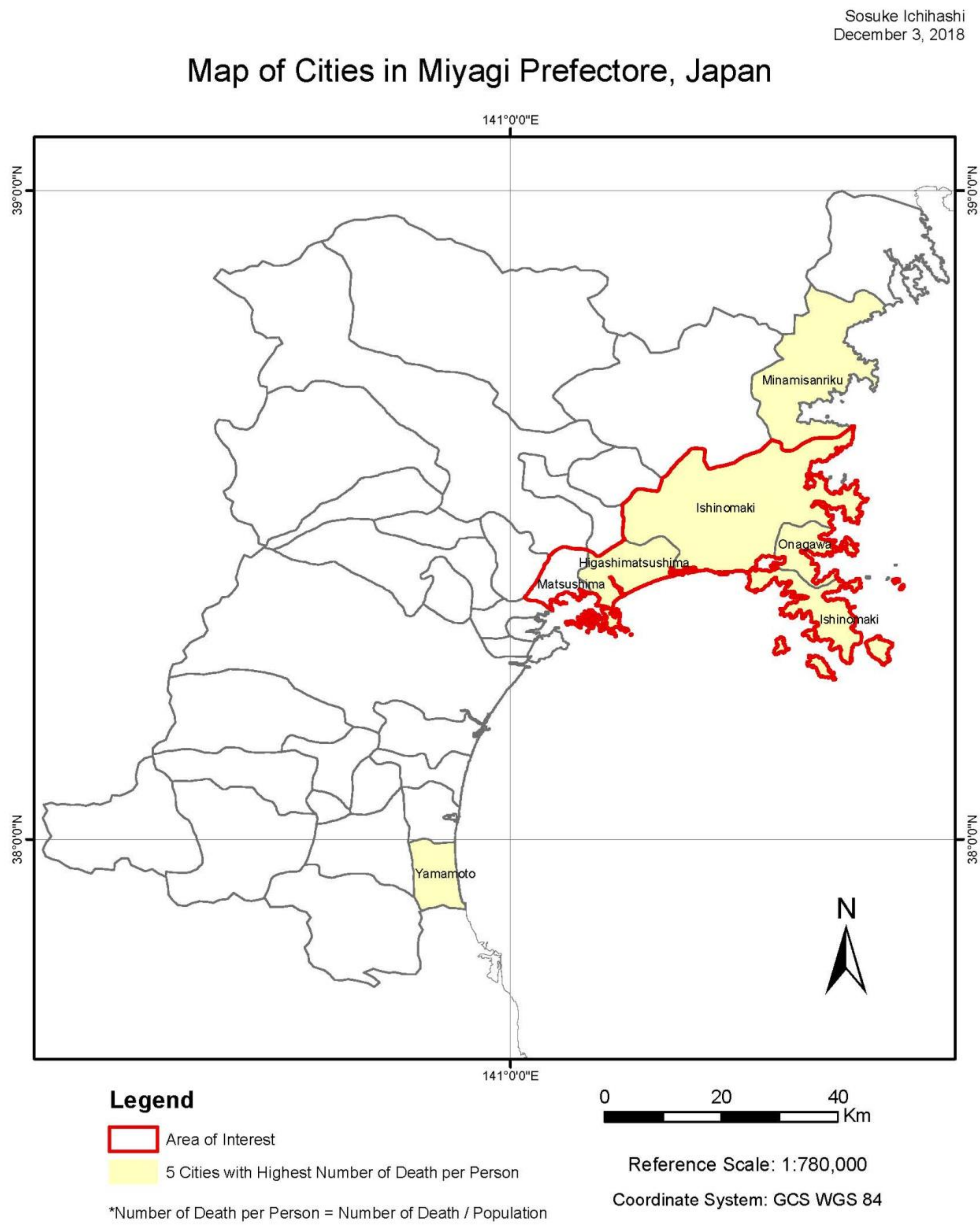
In conclusion, I estimated the population affected by the tsunami of the Tohoku Earthquake, and it was not precise enough though I got the similar trend with the official report. As shown in the final map, most flooded area is habitable zone, and my underestimation indicates people tend to live in the coastal area in this region. They can be the reasons why the tsunami caused this large number of deaths though it is beyond my topic here.

Deliverables (Maps)

1. Map of Japan to show location of Miyagi Prefecture



2. Map of cities in Miyagi Prefecture to show the area of interest and cities with high death rate



3. Final Product Map: showing the habitable and inhabitable zones flooded by the tsunami in the Oshika Peninsula region, Miyagi Prefecture, Japan