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APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) FOR TSUNAMI POTENTIAL MAPPING IN SIKKA DISTRICT, EAST NUSA TENGGARA

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Summary. This study aims to map potential tsunami areas, evacuation routes and gathering points in Sikka District, East Nusa Tenggara Indonesia. Mapping is carried out using geographic information systems through a tsunami vulnerability analysis approach. The vulnerability approach is conducted using some criteria including land elevation, slope, land use, distance from the coastline, and distance from rivers. Population factors are also used to determine the level of tsunami risk. Overall, the coastal areas of Sikka District are potentially at risk of tsunami. The level of potential is very high in the northern coastal areas of Magepanda Regency, West Alok District, Alok District, East Alok District, Kangae District, Kewapante District, Waigete District, Talibura District and some small islands in the north of Sikka District, namely Pemana Island, Big Island, and Babi Island. Areas with high vulnerability are mostly found on the north coast and a small part on the south coast. These areas with a very high and high level of risk are still relatively small, which is about 6% of the total area of Sikka District. However, these potential areas are in a dense residential area, therefore tsunami mitigation has been developed in the form of comprehensive evacuation routes and gathering points to reduce the negative impact of tsunamis. The earthquake event used as a reference is with a magnitude of 7.3 on the Richter scale at a depth of 114 km north of Sikka District.

Introduction

The Indonesian archipelago is highly prone to earthquakes and tsunamis. Being densely populated, the Indonesian archipelago has more persons exposed to such geophysical hazards than any other country in the world (Dhellemmes et al., 2021; Hall et al., 2022). Some major geophysical disasters have occurred in the region including the 2004 Indian Ocean earthquake and tsunami that killed over 165,000 people of Indonesia, making it one of the deadliest socio-natural disasters in the 21st century (Hall et al., 2022; BNPB, 2012).

To minimize the impact of tsunamis on the community, a number of studies have been conducted to investigate and develop tsunami mitigation models for some regions in Indonesia. Areas covered in the studies include Banda Aceh (Agussaini et al., 2022; Nurhayaty et al., 2015), Palu Bay (Imran et al., 2020), Pangandaran beach-West Java (Faiqoh et al., 2013), Padang city-West Sumatera (Imamura et al., 2012), Manacarra beach-West Sulawesi (Baeda, et al., 2015), and Labuan Bajo-East Nusa Tenggara (Wibowo, 2022). Such studies have provided the society including the government with more obvious tsunami mitigation concept and better mitigation strategies to minimize the negative effects of potential tsunami hazards in the future.

Sikka District, which is a part of the East Nusa Tenggara Province, is an area with a fairly high level of tsunami risk because this area is close to the subduction zone of the Australian and Eurasian tectonic plates and is influenced by active faults along the Flores Island (Fauzy, 2006; Sengaji and Nababan, 2009). Sengaji and Nababan (2009) have made tsunami level map in Sikka region but the authors have not investigated in details the tsunami disaster mitigation efforts, namely the process of seeking various preventive measures to minimize the negative impact of the tsunami disaster. Hence, the purpose of the present work is to map the level of potential Tsunami disaster and map evacuation routes and gathering points of potential Tsunami areas in Sikka District. The map will be made by applying the remote sensing systems and geographic information, which was previously used to map the tsunami potential map in Kupang Regency, East Nusa Tenggara (Rumaal et al., 2018).

METHOD

Database Building

Extensive data processing is carried out by collecting data from various sources which are then processed to obtain each parameter, namely Digital Elevation Model (DEM) data producing slope maps, elevation, distance from rivers and Landsat 8 image data (Band 4, 3, 2, & 8) for land cover maps, and coastline data producing distance maps from the coastline. Meanwhile, the preparation of evacuation route maps and gathering points uses Sikka District Road Network data and local building data. Areas at risk of tsunami impact can also be identified through population density at each monitoring location (Julkarnaen 2008; Sinaga et al., 2011).

Scoring and Weighting of Potential Levels

The rating and weighting system for each parameter corresponds to the influence exerted on the tsunami disaster, the greater the effect, the greater the weight, and vice versa, the smaller the influence, the smaller the weight (Papathoma et al., 2003; Irfani, 2002).

Spatial analysis is used for the determination of tsunami potential using the CBM method, both to classify and to overlay each parameter obtained. All parameters used will be in a grid format consisting of a set of cells. Each cell has a certain value, the magnitude of which depends on the magnitude of each parameter. In determining the level of vulnerability, calculations are also carried out by assigning scores and weights to each parameter. The score is multiplied by the weight used in each parameter. The value of each class is based on the following formula (Muzaki et al., 2009):

$$N = \sum Bi \; x \; Si \tag{1}$$

where:

N= Total value weight

Bi = Weight on each criterion

Si = Score on each criterion

I = i^{-th} parameter

Furthermore, it is grouped based on its value into five classes (zones) namely very high potential, high, intermediate, low and very low potential. The interval of each class is obtained from the number of maximum value multiplications of each weight and score minus the number of minimum value multiplications which are then divided by the number of parameters used. Mathematically, the interval of tsunami vulnerability level classes is formulated as follows (Muzaki et al., 2009):

$$\textit{Hose width class } (\mathrm{L}) = \sum \frac{(Bi \; x \; Si) \max - (Bi \; x \; Si) min}{n} \tag{2}$$

where:

L = Hose grade width

n = Number of classes

Data Interpretation

Data interpretation is carried out qualitatively and quantitatively by separating each vulnerability map, namely for vulnerability according to land cover map, slope, altitude, distance from coastline, and distance from rivers. The impact of tsunami insecurity in terms of population density is interpreted in a similar way (Eddy, 2006; Muck, 2008).

RESULTS AND DISCUSSION

Map of the Study Area

Sikka District is located between 8°22' to 8°50' south latitude and 121°55'40" to 122°41'30" east longitude. Administratively, the boundaries of Sikka District are north of the Flores Sea, south of the Sawu Sea and the west is bordered by Ende District and east of East Flores District. Sikka District consists of 21 sub-districts covering 13 villages, and has an area of 7,552.91 km^2 consisting of 1,731.90 km^2 of land area and 5,821 km^2 of sea area. The study area is presented in Fig. 1.

Slope

Slope is an important parameter in determining tsunami potential, the steeper a landmass, the higher the lower the rise (Sambah and Miura, 2014). In this study, the slope weighed 20%. The slope is derived from elevation using the Surface analyst function on the analyst's spatial menu. The slope map is visualized in Fig. 2.

The areas of the slope mapping results of Sikka District are depicted in Table 1.

Table 1

Potential Slope Area of Sikka District Elevation

No	Potential Level	Class	Area (km^2)
1	Very Low	> 40%	4.745
2	Low	15 - 40%	672.6
3	Intermediate	6 - 15%	675.87
4	Tall	2 - 6%	220.83
5	Very High	0 - 2%	79.199

The elevation classification is divided into 5 classes, namely very high class (< 10m), high class (10 - 25 m), medium (25 - 50m), low (50 - 150m), and very low (>150m). Fig. 3 shows the elevation map while the area of elevation classes in Sikka District is presented in Table 2.

Table 2

Area of elevation potential of Sikka District

No	Potential Level	Class	Area (km^2)
1	Very Low	>150 m	1389.3
2	Low	50–150 m	126.46
3	Intermediate	25 – 50 m	74.33
4	Tall	10 – 25 m	76.07
5	Very High	>10 m	20.21

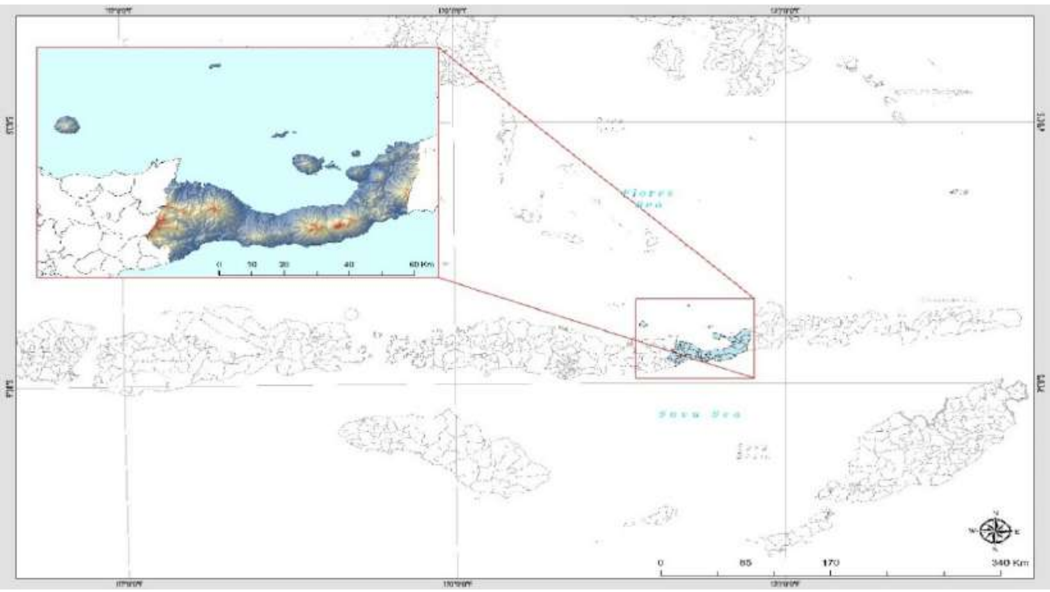

Fig. 1. Map of the study area

Fig. 2. Map of slope research area

Fig. 3. The Elevation map of research area

Land use

Based on data obtained from data processing, land use including forests, community gardens, fields, dry land, settlements, and noise in the form of clouds, is visualized and can be seen in Fig. 4. From Fig. 4, the area of each land use in Sikka District is calculated and depicted in Table 3.

Table 3

Land cover area of Sikka District

No	Types of Land Use	Potential Level	Area (km^2)
1	Forest	Very Low	369.5
2	Citizen Gardens (rice fields and other types of farming)	Low	425.4
3	Garden	Intermediate	436.2
4	Dry Land	Tall	330.2
5	Village	Very High	117.4
6	Cloud	Very Low	8.77

Distance from Coastline

The settlement of residents in Sikka District is directly adjacent to the sea. Therefore, in this study, the distance parameter from the coastline was one of the important factors in the analysis (Faiqoh, et al., 2013). The distance map is processed from the coastline (Fig. 5). Based on the potential class area, the distance from the coastline in Sikka District has been calculated and presented in Table 4.

Distance from the River

Tsunamis that enter the river flow will cause great damage, when the tsunami passes through a narrow area such as a river, there will be an increase in speed and an increase in water mass because the flow of the same water mass must travel a narrow distance at the same time (Pratiwi, 2017). The results of mapping the distance from the river can be seen in Fig. 6 with corresponding areas shown in Table 5.

Table 4

Distance from the coastline of Sikka District

No	Distance	Potential Level	Area (km^2)
1	0 - 500 m	Very Low	102.37
2	500 - 1000 m	Low	78.65
3	1000 - 1500 m	Intermediate	70.74
4	1500 - 3000 m	Tall	184.98
5	> 3000 m	Very High	1233.34

Table 5

Area Distance from river Sikka Regency

No	Distance	Potential Level	Area (km^2)
1	0 - 100 m	Very Low	102.37
2	100 - 200 m	Low	78.65
3	200 - 300 m	Intermediate	70.74
4	300 - 500 m	Tall	184.98
5	> 500 m	Very High	1233.34

Fig. 4. Land cover map

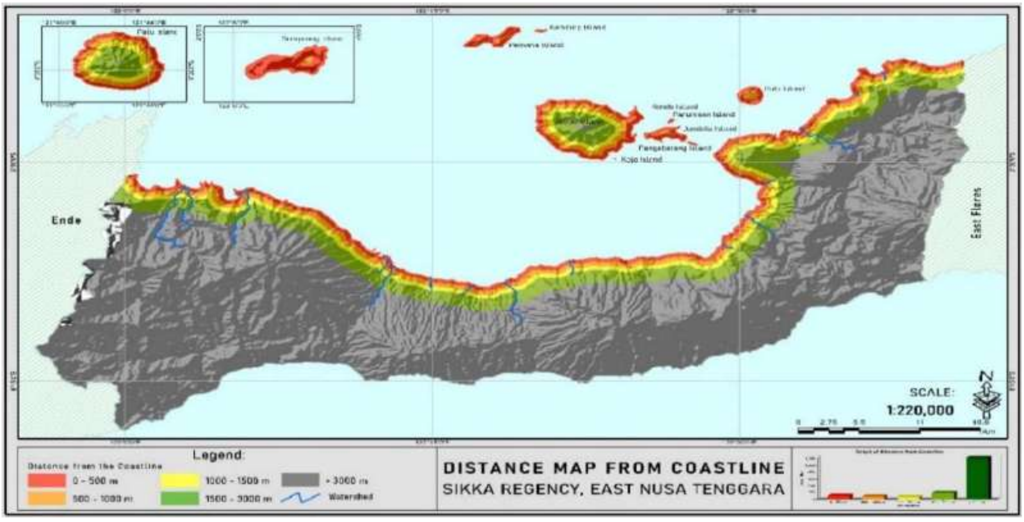

Fig. 5. Distance map from coastline

Fig. 6. Map of potential distance from Sikka Regency River

Analysis of Regional Potential for Tsunami Disaster

Analysis of tsunami potential levels is carried out using the overlay method of all parameters contained in the potential level analysis matrix. The classification of tsunami potential levels in Sikka District consists of 5 categories, namely very high, high, medium, low, very low. The map of the potential level of Sikka District is shown in Fig. 7.

Areas with very low (R5) and low (R4) tsunami disaster potential, namely most of the southern part of the area dominated by highlands with elevation conditions (topography) of 50 m to 1668 m include Nita District, south of Magepanda Regency, south of Waigete Regency, south of Waiblama District, south of Talibura, Hewakloang District, south of Kange District, south of District Nelle, Mego District, Mapitra District, Doreng District, Bola District, Lera District, Paga District. A map of the northern part of Sikka district with potential levels can be seen in Fig. 8.

Very high potential dominates the northern coastal area of Sikka district. This is supported by the state of elevation (topography) of coastal areas ranging from 0 m – 25 m with a slope of 0 – 6%. Areas that have a very large impact supported by population density are the northern coastal areas of Magepanda district, Palueisland, west Alok regency, Alok regency, east Alok regency, Kangae regency, Kewapante district, Waigete regency, Talibura regency and on the northern small island of Sikka district. Based on the calculation of tsunami potential maps, each category has an area (Table 6).

Table 6

Extent of tsunami potential in Sikka District

No	Potential Classes	Potential Level	Area (km^2)	Percentage
1	R5	Very Low	11.76	1%
2	R4	Low	85.70	5%
3	R3	Intermediate	237.27	14%
4	R2	High	1336.72	79%
5	R1	Very High	20.76	1%

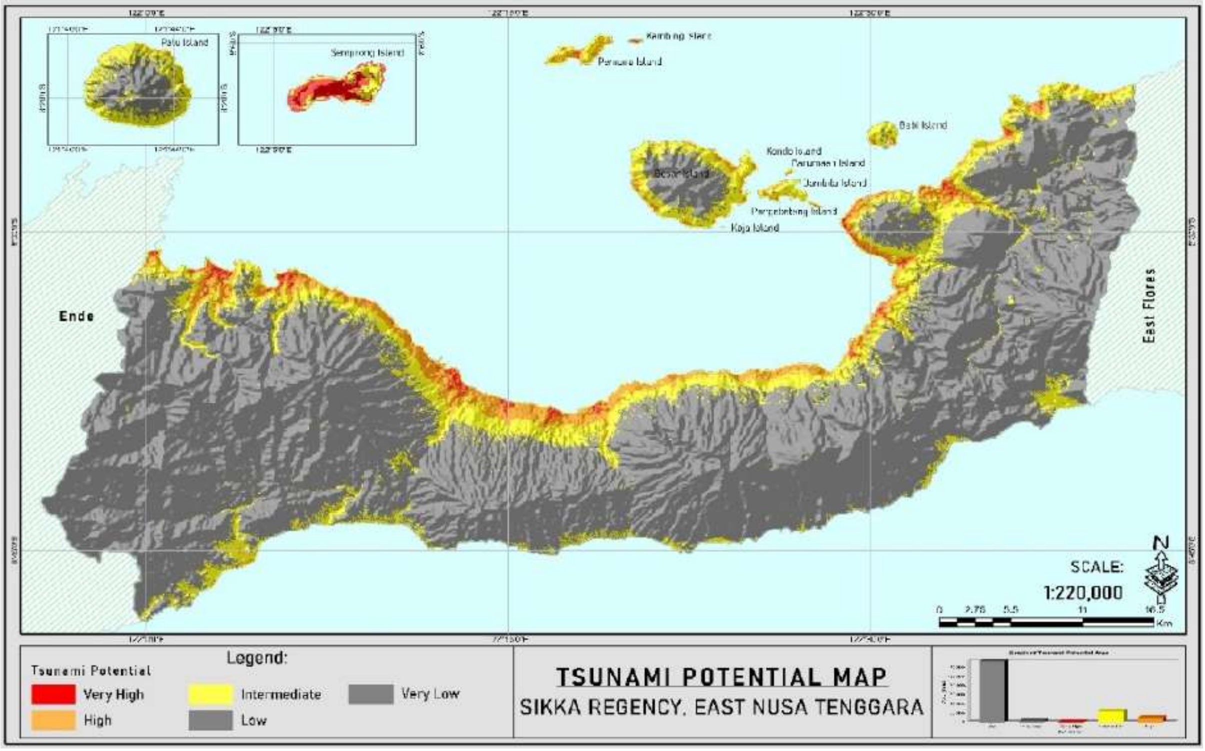

Fig. 7. Sikka District tsunami potential level map

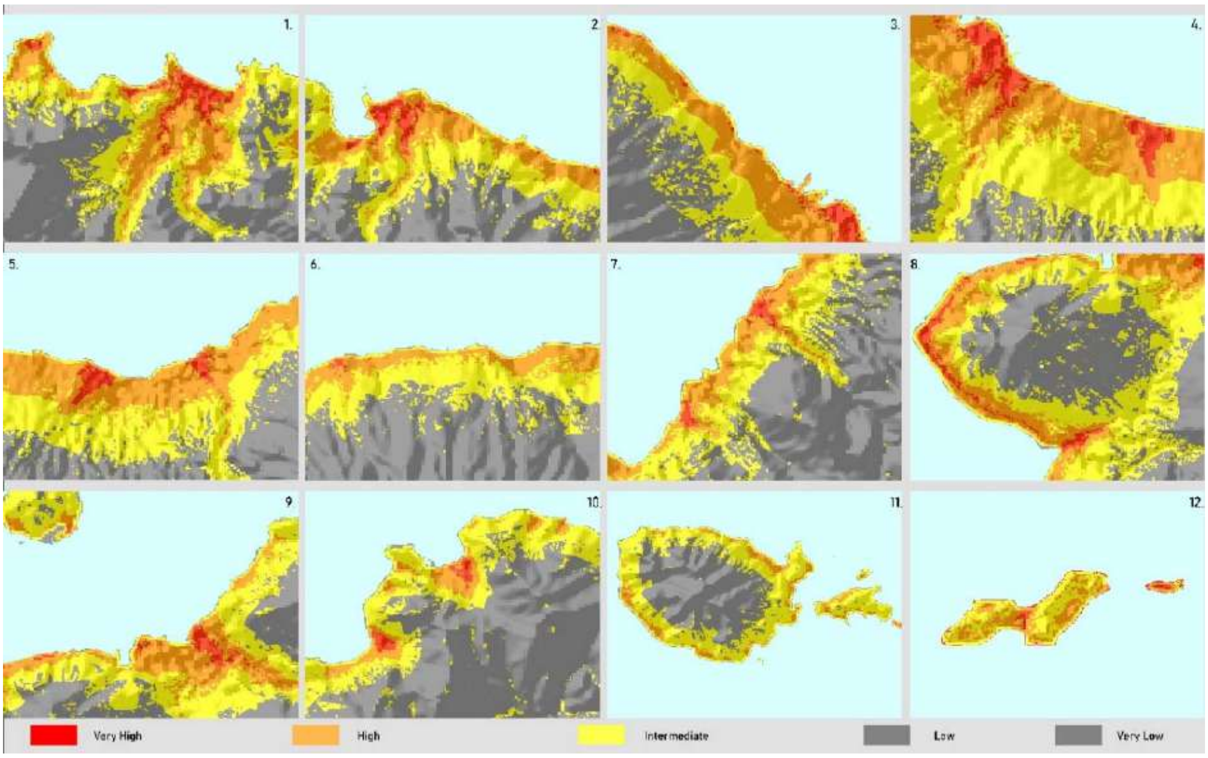

Fig. 8. Map of tsunami potential level of Northern Sikka District

Areas with high (R2) and very high (R1) vulnerability to tsunami disasters are areas with the greatest potential for damage, both in terms of physical damage to the environment and casualties. Environmental damage and loss of life are included in the category of direct damage. Direct damage is defined as fiscal damage or loss that can be quantified in quantity, e.g. casualties, damage to buildings, plantation land, and agricultural land (Pramana, 2015; Primary, 2017). This area has the characteristics of low land elevation (topography), gentle slopes, land use in the form of plantations, rice fields, settlements, distance from the coastline is relatively close, and the presence of large rivers that empty into the sea.

Areas with low (R4) and very low (R5) vulnerability categories are areas that are safe from being hit by tsunami waves. This area has the characteristics of high land elevation (topography), steep slopes, land use in the form of forests and settlements that are not too dense, and the distance from the coastline and rivers is relatively far.

Disaster Mitigation

To reduce the impact received by tsunami hazards in coastal areas, efforts to reduce the vulnerability of tsunami disasters in Sikka District are one of them through efforts by making maps of evacuation routes and gathering points so that they can help the community in dealing with tsunami disasters (Cutter, et al., 2008; Di Mauro, et al., 2013; Syamsidik, et al., 2021). In terms of reducing fatalities from the impact of the tsunami disaster, here is a map of the evacuation routes of Sikka District as shown in Fig. 9 and maps of evacuation routes and gathering points of the northern coastal area of Sikka District as presented in Fig. 10.

Table 7

Location of Tsunami Disaster Evacuation Points

Number	Name	Elevation
1	Catholic College of Philosophy	217m
2	SMPK Hewerbura Watublapi	455m
3	Hewokloang Village Office	437m
4	Umagera Village Office	185m
5	Nelle District Office	138m
6	Scalabrinian monastery	102 m
7	Convent of the sisters of Mercedaria Solm	52 m
8	Korean Sister	279m
9	Church of St. Gabriel Ladubewa	97m
10	St. John's Chapel Blidit Stasi Bath	142 m
11	Santissima Runut Catholic Church	412 m
12	Church of St. Catholic John the Baptist	401 m
13	Capela Hubin Tekaiku	340m
14	Holy Cross Parish Church Kloangrotat	551 m
15	Sacred Heart of Jesus Catholic Church	170m
16	St. Arnold Jansen Catholic Church	131 m
17	St. Catholic Church of Mary Immaculata Habi	58m
19	Napungete Dam	246m

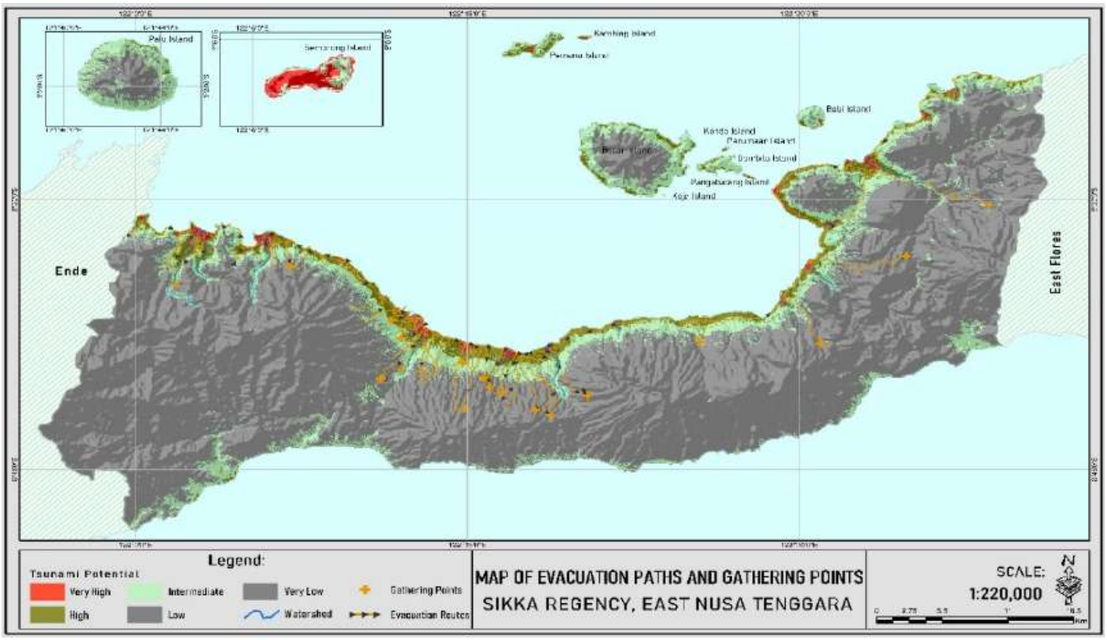

Fig. 9. Map of evacuation routes and gathering points in the northern part of Sikka District

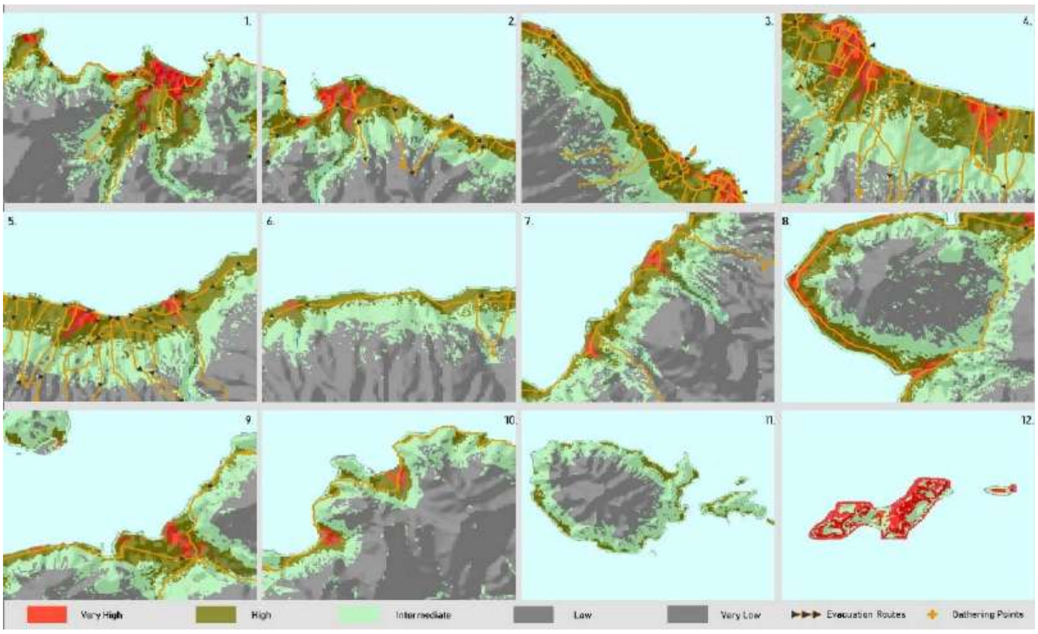

Fig.10. Map of evacuation routes and gathering points of Sikka District

Figs 9 and 10 illustrate evacuation routes and gathering points in Sikka District where the above mentioned data is obtained from spatial data, namely road networks and government facilities, religious facilities, and educational facilities. The evacuation route is a rescue route specifically designed by connecting the entire area to a safe area as a Gathering Point for residents or communities in the area. Evacuation routes serve to direct residents from the threat of danger to a safer place in the event of a disaster. The evacuation routes above include all roads that are in areas with high levels of vulnerability to safer areas or areas with very low levels of vulnerability. The gathering point between them is summarized in Table 7.

Table 7 is dominated by safe evacuation places or points and among them there are 3 temporary evacuation sites, namely the Convent of the sisters of Mercedaria Solm with an altitude of 52 m above sea level, the Catholic Church of St. Mary Immakulata Habi with an altitude of 58 m above sea level, and the Convent of the Sisters PACR Wolonmaget with an altitude of 32 m above sea level.

CONCLUSION

A map of tsunami potential, as well as evacuation routes and gathering points in Sikka District with varying degrees, have been obtained in the present work. Areas that have very high and high levels of tsunami potential include the northern coastal areas of Sikka District while areas affected by the tsunami disaster when the earthquake occurred are the north coast of Magepanda Regency, Palue Island, West Alok Regency, Alok District, East Alok District, Kangae District, Kewapante District, Waigete District, Talibura District and some small islands north of Sikka District, namely Pemana Island, Big Island, and Pig Island. Meanwhile, emergency gathering points during the tsunami were St. Gabriel Ladubewa Church, St. Mary Immaculate Habi Catholic Church, Mercedaria Solm Sisters Monastery.

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ПРИМЕНЕНИЕ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ И ГЕОГРАФИЧЕСКИХ ИНФОРМАЦИОННЫХ СИСТЕМ (GIS) ДЛЯ КАРТИРОВАНИЯ ПОТЕНЦИАЛА ЦУНАМИ В РАЙОНЕ СИККА, ВОСТОЧНАЯ НУСА ТЕНГГАРА

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Резюме. Индонезийский архипелаг очень подвержен землетрясениям и цунами. Данное исследование направлено на картирование потенциальных зон риска цунами, маршрутов эвакуации и мест сбора в районе Сикка, Восточная Нуса-Тенгара, Индонезия. Картирование выполняется с использованием географических информационных систем с применением подхода анализа уязвимости к цунами. Этот анализ проводится на основе нескольких критериев, включая высоту над уровнем моря, наклон местности, использование земель, расстояние до побережья и расстояние до рек. Также учитываются факторы населенности для определения уровня риска цунами. В целом, прибрежные зоны района Сикка потенциально подвержены риску цунами. Уровень этого риска очень высок в северных прибрежных зонах района Маджепанда, Западный Алок, Алок, Восточный Алок, Кангаэ, Кевапанте, Уайгете, Талибула, а также на некоторых мелких островах к северу от района Сикка, таких как остров Пемана, Большой остров и остров Баби. Зоны с высокой уязвимостью в основном расположены на северном побережье и частично на южном побережье. Эти зоны с очень высоким и высоким уровнем риска составляют всего около 6% от общей площади района Сикка. Однако потенциальные рисковые зоны находятся в плотнозаселенных районах, поэтому для снижения негативного воздействия цунами разработаны комплексные маршруты эвакуации и места сбора. В качестве эталонного события было выбрано землетрясение магнитудой 7.3 по шкале Рихтера на глубине 114 км к северу от района Сикка.

Ключевые слова: *Потенциал цунами, дистанционное зондирование, смягчение последствий, географическая информационная система, район Сикка*

SİKKA RAYONU, ŞƏRQİ NUSA-TENQARADA POTENSİAL SUNAMİ RİSK ZONALARININ XƏRİTƏLƏNDİRİLMƏSİ ÜÇÜN MƏSAFƏDƏN ZONDLAMA VƏ COĞRAFİ İNFORMASİYA SİSTEMLƏRİNİN (CİS) TƏTBİQİ

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Xülasə. İndoneziya arxipelaqı zəlzələlərə və sunamilərə qarşı olduqca həssasdır. Bu tədqiqat, İndoneziyanın Şərqi Nusa-Tenqaradakı Sikka rayonunda potensial sunami risk zonaları, təxliyə marşrutları və toplanma məkanlarının xəritələndirməsinə yönəlib. Xəritələndirmə sunami təhlükəsinə qarşı həssaslıq analizinə əsaslanan coğrafi informasiya sistemlərinin istifadəsi ilə həyata keçirilir. Bu analiz dəniz səviyyəsindən yüksəklik, ərazi meyli, torpaqdan istifadə, sahilə və çaylara olan məsafə kimi bir neçə kriteriyaya əsaslanır. Həmçinin əhalinin sıxlığı faktoru da nəzərə alınır ki, sunami risk səviyyəsi müəyyən edilsin. Ümumiyyətlə, Sikka rayonunun sahil zonaları potensial olaraq sunami təhlükəsinə məruz qalır. Bu risk səviyyəsi Madjepanda, Qərbi Alok, Alok, Şərqi Alok, Kangae, Kevapante, Uaygete, Talibula rayonlarının şimal sahil zonalarında, həmçinin Sikka rayonunun şimalında yerləşən Peman adası, Böyük ada və Babi adası kimi bəzi kiçik adalarda çox yüksəkdir. Yüksək həssaslığa malik zonalar əsasən şimal sahillərində və qismən cənub sahillərində yerləşir. Bu çox yüksək və yüksək risk səviyyəsinə malik zonalar Sikka rayonunun ümumi sahəsinin cəmi 6%-ni təşkil edir. Bununla belə, potensial risk zonaları əhalinin sıx yaşadığı ərazilərdə yerləşir, buna görə də sunaminin mənfi təsirini azaltmaq üçün kompleks təxliyə marşrutları və toplanma məkanları hazırlanmışdır. Etalon hadisə kimi Sikka rayonunun şimalında 114 km dərinlikdə, 7.3 bal gücündə Rixter şkalası üzrə zəlzələ seçilmişdir.

Açar sözlər: *sunami potensialı, distansion zondlama, təsirlərin azaldılması, coğrafi məlumat sistemi, Sikka rayonu*