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Original research article

Vulnerability assessment of small islands to tourism: The case of the Marine Tourism Park of the Gili Matra Islands, Indonesia

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HIGHLIGHTS

- Tourism is one of the actors that is responsible for environmental depletion on small islands, due to the constructions of buildings and tourism activities.
- Gili Matra Islands have a vulnerability status from low into moderate, ranging from 2.25 to 2.75.
- Tourism activities in Gili Matra Islands already at a critical position.
- Vulnerability index which built from coastline, coral reef, live coral, and development area was applicable to assess small island vulnerability in Indonesia, especially for coral island.

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ABSTRACT

The Indonesian government is currently directing its focus of development on the optimum uses of marine and coastal ecosystem services including the marine and coastal tourism. One of the main locus of coastal and marine tourism is the small islands tourism such as Gili Matra Islands among others. Small islands tourism is one of the favourite touristic activities because the destination provides beauty, exotism, aesthetic and a diversity of natural habitats including the warm, clear and attractive water. Tourism is being considered as a development instrument in order to boost a country's economy and has become part of the global industry. However, tourism is also one of the actors that is responsible for environmental depletion, due to the constructions of buildings and tourism activities. This paper aims to study the level of vulnerability in small islands to tourism as a basis of integrated small islands management in Indonesian conservation area. The group of islands in this study consists of three islands namely Gili Ayer Island, Gili Meno Island and Gili Trawangan Island (known as Gili Matra Islands) that were observed using Small Islands Vulnerability Index (SIVI). The results indicate that Gili Matra Islands have a vulnerability status from low into moderate, ranging from 2.25 to 2.75. Gili Ayer Island has the highest

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vulnerability with SIVI of 2.75 (Moderate), followed by Gili Meno Island with SIVI of 2.50 (Low) and Gili Trawangan Island with SIVI of 2.25 (Low). The driving factor of vulnerability is the intensive utilization of marine tourism activities. Tourism is the sole stress to Gili Matra Island's ecosystem due to its direct damaging impact and reducing its environmental quality. The vulnerability index which was built from the coastline, coral reef, live coral reef, and development area was applicable to assess the small island's vulnerability in Indonesia, especially for coral island.

1. Introduction

As the largest archipelagic state in the world, Indonesia has registered amount of 13,466 islands[1] in 2014. Among them are grouped into small islands such as Seribu Islands, Kapoposang Islands, Togean Islands, Wakatobi Islands, Padaido Islands, Waigeo Islands, Raja Ampat Islands, Gili Matra Islands and many others. Similar to other Small Island Developing States (SIDS), small islands in Indonesia are also vulnerable to natural disasters and human activities, such as destructive fishing practices (poison fishing and bomb- or blast fishing), boat anchoring, coral- and sand mining. Small islands are usually high in coastal and marine biodiversity. Thus, detrimental activities are threatening the ecological-, socio and economic sustainability of small islands. Faced with such challenges, the Indonesian government has considered efforts to conserve coastal and marine resources, particularly for the small outermost islands in Indonesia. The Indonesian government is currently directing its focus on the development of small islands as conservation areas in conjunction with tourism industry. These efforts can be seen at Nusa Lembongan Island (Bali), Trawangan Island (Lombok), Pramuka, Macan, Untung Jawa and Pari Island (Jakarta), Asu Island (Nias), Weh and Rubiah Island (Aceh), Banda Island (Maluku), Enggano Island (Bengkulu), Derawan Island (Kalimantan Timur), Moyo Island (Sumbawa), Karimunjawa (Central Java), Bunaken Island (Manado), Waigeo Island (Raja Ampat), etc. Generally, tourism plays an economically significant role as a source of income and employments for the inhabitants of the small islands.

In many small islands worldwide, tourism is considered as a development instrument to boost the economy of a country (Croes, 2006) and as part of the global industry (Eligh et al., 2002; Daby, 2003; Teh and Cabanban, 2007). The preference for small islands is closely related to such factors as their beauty, exoticness, aesthetic, diversity of natural habitats (coral reef, sandy beach and sand dune), the warm, clear and attractive water (Daby, 2003). Compared to other tourism industries, marine tourism industry has grown enormously and become one of the biggest industries in the world (Hall, 2001; Mvula, 2001; Eligh et al., 2002; Gössling, 2002; Pickering and Hill, 2007).

Tourism has provided significant benefits in terms of economy and has led to an increase of community awareness in protecting the ocean environment especially the marine conservation area (Pelletier et al., 2005; Fabinyi, 2008; Abecasis et al., 2013). This can particularly be seen in countries such as: Indonesia in Nusa Lembongan Island (Long and Wall, 1996) and Trawangan Island (Yulianto et al., 2007; Bottema and Bush, 2012; Hampton and Jeyacheya, 2014), Malaysia in Banggi Island (Teh and Cabanban, 2007), Caribbean in Barbados Island (Bunce, 2008) and St. Lucia Island (Barkes and Roberts, 2004), Spain in Gran Canaria Island (García-Falcón and Medina-Muñoz, 1999) and Philippines in Calamianes Islands (Fabinyi, 2008) and Apo Island (Hind et al., 2010). However, tourism is also one of the main contributors that is responsible for environmental depletion, due to building constructions and tourism activities (Pickering and Hill, 2007; Fabinyi, 2008; Hannak et al., 2011). As mentioned by Peng and Guihua (2007), human activities bring implications for quality and quantity of natural resource, such as: (1) the establishment of hotels and resorts, port constructions and boats utilization, (2) reef-walking, snorkelling and diving, (3) fishing, and (4) land-based pollution and sedimentation (Barkes and Roberts, 2004; Hutabarat et al., 2009; Parolo et al., 2009; Hannak et al., 2011).

Those aforementioned developments, commonly found in developing countries were made without any regards to nor consideration that small islands have limited land and clean water making them vulnerable to the extensive pressures (Falkland, 1993; Gössling, 2001, 2002; Tompkins, 2005). Theoretically, according to an ecological resilience perspective, all ecosystems are vulnerable and easily disturbed (Lauer et al., 2013). Kaly et al. (2002) and Tompkins (2005) stated that vulnerability and resilience can be viewed as interconnected systems. Another theory stated that vulnerability is defined as a level in which the human- and nature system experience loss due to external disturbances or pressures (Janssen and Ostrom, 2006), whereas resilience is described as a degree of disturbances that can be absorbed by a system (Holling, 1973) and the recovery time for a system to reach its balance point (Brand and Jax, 2007). Campbell (2009) and Lloyd et al. (2013) stated that vulnerability is the tendency of disturbed and damaged system, while resilience is regarded as the ability of the system to adapt. This means that the less vulnerable the level of the system is, the more resilience it is, and vice versa; this is known as contradictory spectrum.

[1] *Kementerian Kelautan dan Perikanan, Indonesia*/Ministry of Marine Affairs and Fisheries, Republic of Indonesia (KKP), 2013. *Jumlah Pulau Kecil di Indonesia, Statistik Pulau-pulau Kecil*/Number of Small Island in Indonesia, Statistic of Small Islands. http://statistik.kkp.go.id/index.php/statistik/free/388/?entitas_=345&filter=Lihat+Data+%C2%BB.

Small islands can be included as vulnerable entities because of their remote location, limited resources, high dependency on imported goods, high incurring transportation costs and susceptibility to natural disasters (Brookfield, 1990; Barrientos, 2010; Adrianto and Matsuda, 2004; MEA, 2005; Vogiatzakis et al., 2008). Global processes (such as climate change and the associated sea level rise), regional processes (the pollution in developing cities has an influence on small islands located in them), and local processes (environmental and resources degradation as impact of population growth) also contributed in affecting the vulnerability of small islands (Pelling and Uitto, 2001; Barrientos, 2010; Adrianto and Matsuda, 2004; Farhan and Lim, 2011, 2012).

In recent decades, several composite indexes have emerged to quantify vulnerability (Table 1). According to Table 1, there are different dimensions, variables and driving factors of vulnerability as well as various vulnerability equations used. Most of the studied composite indexes are specifically focused on the environmental dimensions of vulnerability to environmental disaster, and rarely has assessed the vulnerability to human activities impacts, especially the impacts of tourism. Vulnerability assessment is not only useful to know the state of region, but also to measure the ocean and coastal sustainability and to build management strategies and policy making (Villa and McLeod, 2002; Farhan and Lim, 2013; Pethick and Crooks, 2000). Vulnerability- and resilience-based management aims to: (1) prevent the system from undesirable shifting due to pressures and disturbances, and (2) maintain and preserve elements that enable the system to renew and reorganize after a massive change (Walker et al., 2002). Holling (1973) emphasized that sustainable economic activities are attained when life supporting ecosystem is resilient.

The aim of this paper is to assess the vulnerability of small islands to tourism as part of an integrated management framework in the conservation area. The study area chosen is called Gili Matra Islands in North Lombok, Indonesia. The analysis focuses on biophysical–spatial changes caused by tourism activities affecting the small island's vulnerability.

2. Study area

Administratively, Gili Matra region is part of Pemenang Sub-district, North Lombok Regency, West Nusa Tenggara Province (Nusa Tenggara Barat/NTB). Based on the Ministry of Forestry Decree No. 85 in 2001, this area has been appointed as a conservation area. This was renewed in 2001 (based on decree No. 99 in 2001) in which it was designated as a Marine Natural Park. By March 4th, 2009, the management of this region is handled by the Ministry of Marine Affairs and Fisheries (KKP) which then changed its status to a National Marine Conservation Area and Marine Tourism Park encompassing 2954 ha (Fig. 1).

The Gili Matra Islands region consists of three islands, namely, Gili Ayer Island, Gili Meno Island, and Gili Trawangan Island. This region can be categorized as semi-open inner islands. Gili Matra region is protected by Lombok Island in the southeastern part, influenced by Java Sea in the northern side, Lombok Strait in the western part and by the Indonesian Throughflow coming from Indian Ocean (Sprintall et al., 2003).

Based on the island's morphogenesis,[2] Gili Matra Islands is categorized as coral island that comprises of rich marine fauna and stable sea floor supporting the islands (Hehanussa and Hartanto, 2005). The islands' stability in Gili Matra region is influenced mostly by fringing reefs ecosystem (Bakti et al., 2012), which protects the beach from the currents and waves. Theoretically, fringing reef is supposed to be able to reduce waves, currents and storms at coastal areas, and also acts as a coastal stabilizer compared to other types of reefs (Moberg and Folke, 1999; Eversole and Fletcher, 2003; Frihy et al., 2004) such as barrier reef, atolls and platform reef (Moberg and Folke, 1999). Storlazzi et al. (2004) stated that fringing reef reduce more than 78% of wave height, 79% of wave period, and 97% of wave energy. This probably leads to an increase of sedimentation and even the creation of new coral reef area (Eversole and Fletcher, 2003; Frihy et al., 2004; Moberg and Folke, 1999; Presto et al., 2006; Storlazzi et al., 2004). Limestones encircling islands are also a great protection against erosion caused by wave and storm (Gallop et al., 2012).

Tourism in Lombok's has started to develop since 1990s, in conjunction with the increase of tourism in Bali Island since 1986 (Dahles and Bras, 1999). As a result, Gili Matra region has become one of the popular destinations and consequentially elevating the development within the said region rapidly. Scuba diving, snorkelling, sun bathing, canoeing, sport fishing and surfing (Fig. 2) are the most chosen tourist activities in Gili Matra region (Yulianto et al., 2007; Dodds et al., 2010).

Overall, the tourism sector has contributed to 16% of revenue for Lombok Island Economy and employed local people, especially in craftsmanship business (Dahles and Bras, 1999). Yulianto et al. (2007) stated that tourism industry has a surplus of over US$ 8,724,613.25 per year by 2006 and has thus led to a population explosion that increased drastically of about 31.75% (2813 people in year 2000 to 3706 people by 2014) as seen in Fig. 3 (primary data Desa Gili Indah/Gili Indah Village, 2000, 2010, 2014). From 2009 to 2013, tourists (both domestic and foreign) have also increased significantly and reached 695.30% (from 54,957 to 437,074 tourists) as seen in Fig. 4 (primary data *Dinas Pariwisata Lombok Utara*/Department of Tourism of Lombok Utara Regency, 2015). As a consequence of the population growth and tourism industry, the marine ecosystem surrounding the region has environmentally degraded specifically the quality of the coral reef ecosystem. From 2000 to 2013, there was a decline of live coral coverage from 25.13% to 16.50% except at Gili Trawangan Island's which actually increased from 15.56% to 21.67% (Fig. 5) as seen in the analysis made by Husni (2001), Sirait (2007) and KKP (2013).

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[2] The formation of landforms and other structures from the geological perspective.

Table 1
Summary of vulnerability assessments, geographical applications, dimensions, variables and driving factors.

Authors	Methods/names of the indexes	Geographical applications	Dimensions	Variables	Driving factors
Abuodha and Woodroffe (2006)	Coastal Vulnerability Index	Global; Illawara coast, Australia	Environment	Dune height, barrier types, beach types, relative sea-level change, shoreline erosion/accretion, mean tidal range, mean wave height	Climate change
Abuodha and Woodroffe (2010)	Coastal Sensitivity Index	Global; Illawara coast, Australia	Environment	Rock type, coastal slope, geomorphology, barrier type, shoreline exposure, shoreline change, relative sea-level rise, mean wave height, mean tide range	Sea-level rise
Adrianto and Matsuda (2002)	Economic Vulnerability Index	Small Islands; Amami Island, Japan	Economics	Gross Island Products	Sea-level rise, natural disaster
Adrianto and Matsuda (2004)	Composite Economic Vulnerability Index	Small Islands; Amami Island, Japan	Economics and environment	Economic exposure, economic remoteness, economic impact of environmental and natural disaster	Sea-level rise, natural disaster
Barrientos (2010)	Social Vulnerability	Small Island States; Grenada	Social and economics	Demography, economic size, economic openness of economy	Natural disaster, international economy changes
Boruff et al. (2005)	Coastal Social Vulnerability Index (Combination of Coastal Vulnerability Index and Social Vulnerability Index)	Global; USA	Environment, social and economics	Social (poverty, age, development density, Asian and immigrants, rural/urban dichotomy, race and gender, population decline, ethnicity (Indian) and farming, infrastructure employment reliance, and income), physical (mean tidal range, coastal slope, rate of relative sea-level rise, shoreline erosion and accretion rates, mean wave height, geomorphology/erodability)	Erosion hazard
Briguglio (1995)	Economic Vulnerability Index	Small Island Developing States	Economics	Exposure to foreign economic conditions, remoteness and insularity, disaster proneness	Environmental disaster; natural disaster
Briguglio and Galea (2004)	Economic Vulnerability Index Augmented by Resilience	Small Island Developing States	Economics and Governance	Economic vulnerability (economic openness, export concentration, peripherality, and dependence on strategic imports), economic resilience (improving the competitiveness of the economy, building a sound macroeconomic environment, improving governance, diversifying the economy to reduce excessive reliance on a narrow range of exports, and strengthening the transport and communications infrastructure)	The characteristics of small island
Briguglio et al. (2009)	Economic Vulnerability and Resilience	Small Island Developing States	Economics, Governance, and Social	Economic vulnerability (economic openness, export concentration, and dependence on strategic imports), economic resilience (macroeconomic stability, market efficiency, good political governance, and social development)	The characteristics of small island
Doukakis (2005)	Coastal Vulnerability Index	Global; Pelleponese, Greece	Environment	Coastal slope, subsidence, displacement, geomorphology, wave height, tidal range	Sea-level rise

(continued on next page)

Table 1 (*continued*)

Authors	Methods/names of the indexes	Geographical applications	Dimensions	Variables	Driving factors
Encontre (1999)	Economic Vulnerability	Small Island Developing States	Economics	External shocks	Globalization forces
Farhan and Lim (2011)	Vulnerability Index	Small Islands; Seribu Islands, Indonesia	Environment and social	Settlements area, population density, hard infrastructure, geological process	Coastline changes, urban settlements
Farhan and Lim (2012)	Coastal Vulnerability Index	Small Islands; Seribu Islands, Indonesia	Environment	Land use, coastline changes, island remoteness, coral reef changes, pollutant areas, geological condition	Urban pressures, pollutants
Gornitz (1991)	Coastal Vulnerability Index	Global; USA	Environment	Relief, rock type, landform, vertical movement, shoreline displacement, tidal range, wave height	Sea-level rise
Guillaumont (2010)	Economic Vulnerability Index	Global, Small Island Developing States	Economics and environment	Shocks (the negative impact of instability on growth, instability channels to growth), exposure (major influence of country size), resilience (policy, human capital and the poverty trap)	Natural or external shocks
Hegde and Reju (2007)	Coastal Vulnerability Index	Global; Mangalore Coast, India	Environment and social	Geomorphology, regional coastal slope, shoreline change rates, population	Coastal erosion hazard
Julca and Paddison (2010)	Environmental vulnerability	Small Island Developing States	Economics and environment	Economic vulnerability, international migration and the recreation of vulnerabilities	Natural hazard, climate change
Kumar et al. (2010)	Coastal Vulnerability Index	Global; Orissa, India	Environment	Shoreline change rate, sea-level change rate, coastal slope, significant wave height, tidal rang, coastal regional elevation, geomorphology, tsunami arrival height	Natural disaster
Meur-Férec et al. (2008)	Vulnerability Grip	France	Environment, social and economics	Exposure to risk, management of risk, remembrance of risk, perception of risk	Erosion, submersion
Mimura (1999)	Qualitative assessment, Vulnerability Indexes	Island Countries; South Pacific (Tonga, Fiji, Samoa, and Tuvalu)	Environment and social	Inundation and flooding, beach erosion, saltwater intrusion, impacts on infrastructure and society	Sea-level rise, climate change
Özyurt and Ergin (2010)	Coastal Vulnerability Index	Global; Turkey	Environment and social	Coastal erosion, flooding due to storm surge, inundation, saltwater intrusion to ground water, saltwater intrusion to river/estuary	Sea-level rise
Pendleton et al. (2010)	Coastal Vulnerability Index	Global	Environment	Geomorphology, shoreline change, coastal slope, sea-level rise, wave height Tidal range or ice	Sea- and lake-level changes
Pethick and Crooks (2000)	Coastal Vulnerability Index	Global	Environment	Geomorphology (Recovery-time)	Natural and artificial forces
Rao et al. (2008)	Coastal Vulnerability Index	Global; Andhra Pradesh coast, India	Environment	Coastal geomorphology, coastal slope, shoreline change, mean spring tide, significant wave height	Sea-level rise
Shaw et al. (1998)	Coastal Sensitivity Index	Global; Canada	Environment	Relief, rock type, landform, sea-level change, shoreline displacement, tidal range, maximum wave height	Sea-level rise

(*continued on next page*)

Rapid changes within tourism industry has made the traditional knowledge of Gili Matra known as "*awig–awig*"[3] gradually forgotten by year 2004 (Satria and Matsuda, 2004). In year 1999, *awig–awig* successfully established a coral reef management system by using zonation boundaries prohibiting destructive fishing activities. At that time, the zonation

[3] A local management system of fisheries and resources use.

Table 1 (*continued*)

Authors	Methods/names of the indexes	Geographical applications	Dimensions	Variables	Driving factors
Thieler and Hammar-Klose (1999)	Coastal Vulnerability Index	Global; USA	Environment	Geomorphology, coastal slope, relative sea-level rise change, shoreline erosion/accretion, mean tide range, mean wave height	Sea-level rise
Turvey (2007)	Composite Vulnerability Index	Small Island Developing States	Environment and social	Coastal index, peripherality index, urbanization indicator, vulnerability to Natural Disasters	Physical and human pressures, risks Hazards

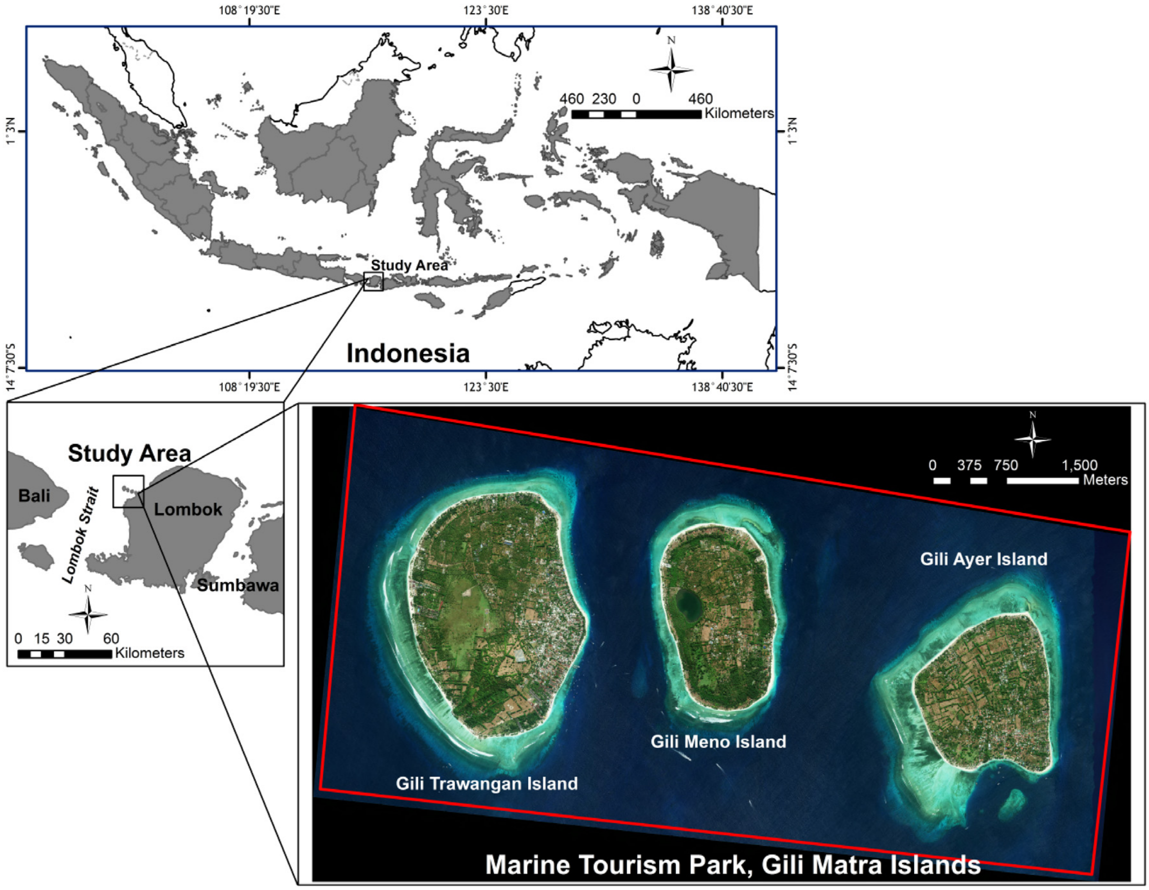


Fig. 1. Study area and location of Marine Tourism Park, Gili Matra Islands in Indonesia.

system was made based on the conditions of the coral reef and its area (Satria and Adhuri, 2010). The first zonation boundary is known as the protection zone. This zone is characterized by abundant coral reef. While snorkelling and diving are allowed inside this zone, net fishing and seaweed cultivation are prohibited. The second zonation boundary is designated as the preservation zone, which is characterized by abundant corals and fishes. Snorkelling, diving and fishing activities are allowed within this boundary. The third zonation boundary is called the utilization zone, this is where all activities are allowed except fishing activities using gill nets and floating net cages.

3. Methodology

This vulnerability study focused on biophysical–spatial aspects of the vulnerability of the small islands and its driving factors. To devise a framework applicable to the Indonesian region, a method for assessing resilience and vulnerability will be employed as suggested by Maclaren (1996) and according to a comparison study that was done by Farhan and Lim (2011, 2012). There are three steps in studying Gili Matra's small island vulnerability (Fig. 6) i.e.:

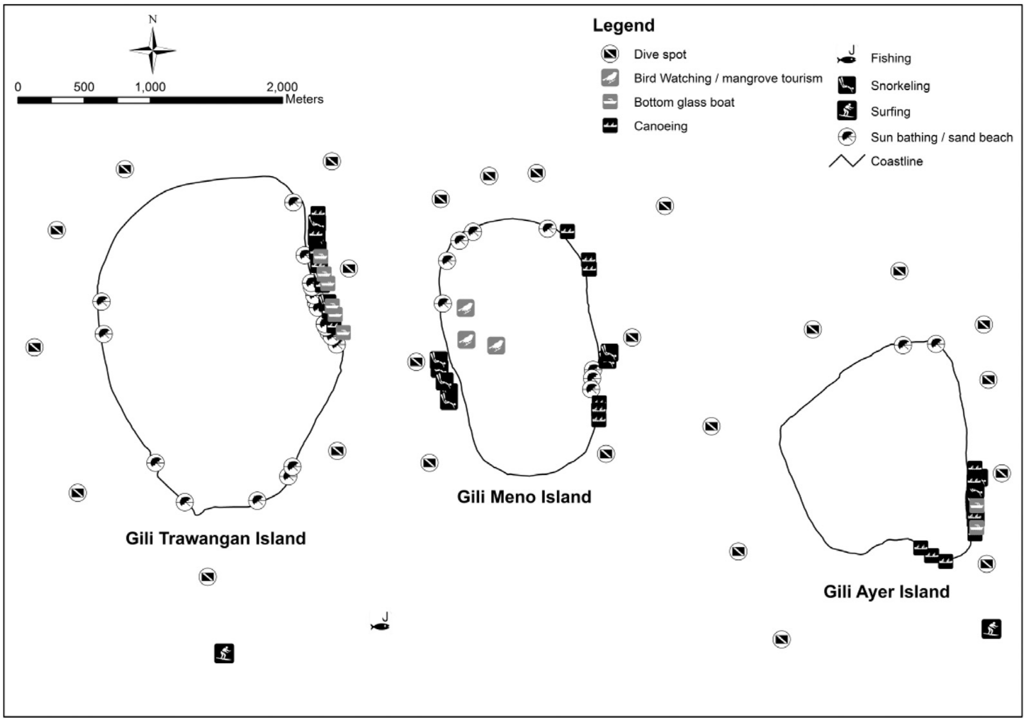


Fig. 2. Tourism spots in Marine Tourism Park of Gili Matra.

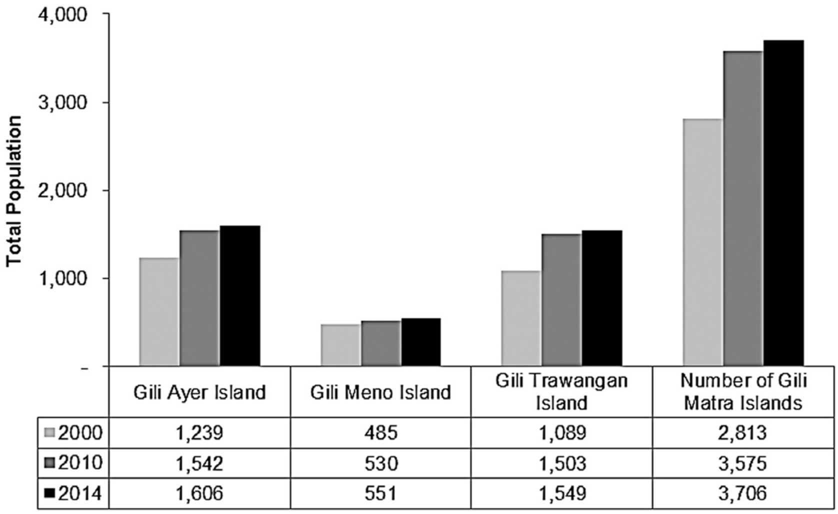


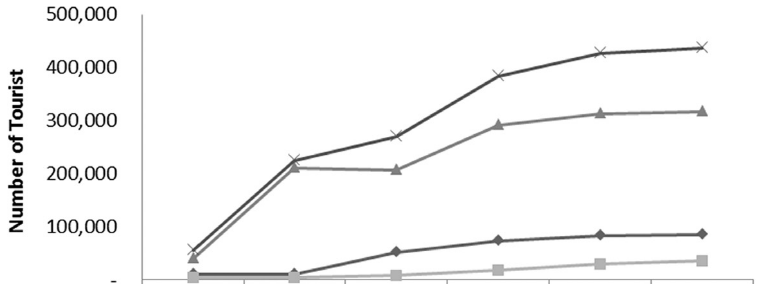
Fig. 3. Population growth in Gili Matra Islands in 2000, 2010 and 2014.

(1) **Step 1: Scoping (literature review, data preparation and choosing indicator frameworks)**

This step consists of three stages, the first stage is literature review of the study area in order to define the approximate vulnerability indicators chosen. It will also determine which/how many indicators will be used and finally, set up a core set of indicators and their associates that can be developed and applied to in small island regions in Indonesia.

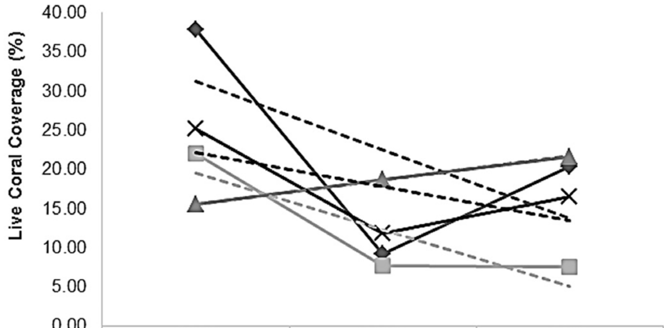
The second process is to develop a baseline data of the study area. The baseline data was built based on Landsat satellite images (year 1972, 1995, and 2013), Quickbird satellite image in year 2010 and GeoEye satellite image in year 2014. Field survey and ground checkpoint were conducted using manta tow equipment in 2014 to measure coral reef and live coral distribution.

Based on these satellite images, the coastline was computed by using a combination of blue, green and near-infrared bands while coral reef and live coral were defined by the Lyzenga Algorithm that was developed by Green et al. (2000), Arsjad et al. (2005) and Siregar (2010). Developed areas such as resorts, ports and houses were inputted using combination



	2009	2010	2011	2012	2013	2014
Gili Ayer Island	10,938	9,387	52,313	73,506	82,974	85,156
Gili Meno Island	3,895	4,446	8,982	19,026	29,604	35,959
Gili Trawangan Island	40,124	210,283	207,362	291,204	313,472	315,959
Number of Gili Matra Islands	54,957	224,116	268,657	383,736	426,050	437,074

Fig. 4. Tourist arrival growth in Gili Matra Islands from 2009 to 2014.



	2000	2006	2013
Gili Ayer Island	37.89	9.23	20.33
Gili Meno Island	21.97	7.65	7.50
Gili Trawangan Island	15.56	18.66	21.67
Gili Matra Islands	25.14	11.85	16.50

Fig. 5. Live coral coverage changes in Gili Matra Region in 2000, 2006, and 2013.

of red, green, and blue band. Ultimately, all results were converted into vector data and overlaid using the ArcGIS 10.2.2 software. The preliminary vulnerability indicators were analysed and deliberated based on study by Gornitz (1991), Shaw et al. (1998), Encontre (1999), Mimura (1999), Thieler and Hammar-Klose (1999), Pethick and Crooks (2000), Boruff et al. (2005), Doukakis (2005), SOPAC–UNEP (2005), Abuodha and Woodroffe (2006), Hegde and Reju (2007), Shaw et al. (1998), Meur-Férec et al. (2008), Rao et al. (2008), Snoussi et al. (2008), Sterr (2008), Campbell (2009), Abuodha and Woodroffe (2010), Kumar et al. (2010), Özyurt and Ergin (2010), Pendleton et al. (2010) and Farhan and Lim (2011, 2012).

(2) **Step 2: Defining indicator selection criteria (identifying potential indicator and indicator analyses)**
This step involves spatial analysis of the bio-geo-physical changes to achieve scientific validation. Each spatial theme is assessed and evaluated based on their influence on the study area. Also each spatial theme is generated and analysed separately in order to build the vulnerable indicators.
Since Indonesia have no standard of a small island vulnerability, constructing the vulnerability index was conducted by comparing other similar studies in terms of small islands region.

(3) **Step 3: Evaluating the indicator and selection of final set (building small island vulnerability indicator (SIVI))**
This step aims to superimpose the GIS spatial themes on the map of the study area. A model builder with spatial joint analysis and an intersection tool were used to compute the vulnerability level together with a set of weighting indicators produced in step 2. The vulnerability calculation and classification will be determined based on the characteristics of each islands and the impacts on them. As a principle, each island will be highlighted individually to identify any specific changes.

4. Results and discussion

Based on spatial analysis and literatures reviews, small island vulnerability indicators in the study area can be categorized based on: coastline changes, coral reef area changes, live coral area changes, and development area.

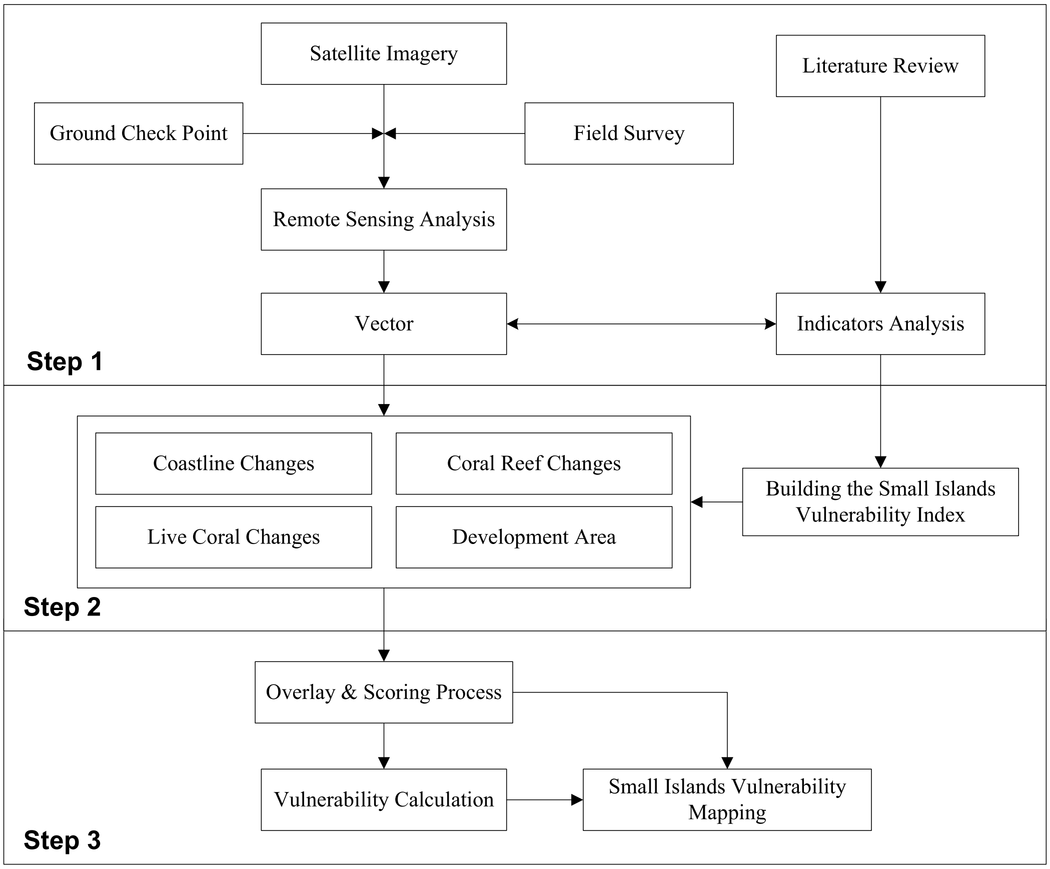


Fig. 6. Methodology.

(a) Coastline changes

Coastline became a major vulnerable entity in small islands as mentioned by Mimura (1999), Thieler and Hammar-Klose (1999), Doukakis (2005), SOPAC–UNEP (2005), Abuodha and Woodroffe (2010), Özyurt and Ergin (2010) and Farhan and Lim (2011, 2012). Coastal dynamic is affected by landward sea wave energy, in which energy is released by oncoming waves. The higher wave contributes for greater strength that hits the coastal (Nontji, 2007). Sedimentation process or coastal erosion depends on the arrival angle of ocean currents (Eversole and Fletcher, 2003; Storlazzi et al., 2004). However, in Gili Matra region, these changes results from constructions or establishment of resorts, restaurant and ports because of the demands of the tourism industry.

(b) Coral reef area

Coral reef area based on bio-geomorphology terms, are the area or habitat of limestone structures with a thin veneer of living organic material, which includes forereef, spur and groove, gorgonian plain, *Montastraea* reef, *Acropora palmata* zone (i.e. branching corals), reef crest, back reef, mixed back reef community (seagrass/corals), algal rubble, *porites* spp. zone, carbonate pavement and patch reef (Green et al., 2000; Sheppard et al., 2009). Coral reef area and composition are included as vulnerability elements as stated by Presto et al. (2006) and Farhan and Lim (2012) because they play a significant role in supporting the small island's dynamic stability. The physical function of the coral reef is as a wave reducer, however such role depends also on the depth and deflection of the currents and waves' direction (Kenneth, 1982); the larger the coral reef area is, the greater is its function as wave reduction in that area.

In addition to its physical function, coral reef also has as an ecological function to provide environmental services to other ecosystems. It can maintain fish diversity (Wilson et al., 2007) and enhance the expansion of coral recruitment (Petersen et al., 2005). These are the reasons why coral reefs are called as a high productivity area bearing structural heritage (Farhan and Lim, 2012).

(c) Live coral area

Live coral area has many functions especially for small islands, such as fishes and biota habitat, food source, contributor of sands at the coastline, coastal accretion and wave reduction (Bascom, 1980; Suharsono, 1995; Moberg and Folke, 1999; Nontji, 2007). Live coral area is one of the criteria in the area or habitat on coral reefs, and used to assess the status of coral reefs by using broad of live coral coverage (Green et al., 2000 and *Keputusan Menteri Negara Lingkungan Hidup Republik Indonesia Nomor 4 Tahun 2001 tentang Kriteria Baku Kerusakan Terumbu Karang*/Minister of Environmental Decree, Republic

Fig. 7. Solid waste generated by residents and tourists in Gili Matra: (a) the buildup of solid waste in coast of Gili Ayer Island; (b) the buildup of solid waste at the landfill area of Gili Trawangan Island.

of Indonesia Number 4 in 2009 about Standard Criteria of Coral Reef Damage (KEP.4/MEN2001)). Vulnerability classification for live coral changes refers to the KEP.4/MEN2001, dividing them into these categories: a. 0%–24.9%, 25%–49.9%, b. 50%–74.9%, and c. 75%–100%, and is classified as non-vulnerable to vulnerable.

(d) Development area

In Indonesia, the development in small island is included as one criteria in the small island vulnerability (Mimura, 1999; Farhan and Lim, 2011, 2012). Houses, resorts, hotels, and other hard infrastructures contribute to water pollution, deteriorate fresh water catchment that leads to seawater intrusion (Falkland, 1993; Gössling, 2001; SOPAC–UNEP, 2005) and solid waste (Fig. 7). Tompkins et al. (2005) also stated that an overpopulated island has a higher risk than a lower one.

However, other studies showed that the development of hard infrastructures and population growth influenced the resilience of small island related to human adaptation in protection efforts, such as breakwater, coastal protection and artificial coral reefs (Mimura, 1999; Farhan and Lim, 2011). Therefore, Bengen et al. (2012) stated that land use for development area in the small islands should be limited to a maximum of 50% development for small island and 30% development for very small island.

The results from the spatial analysis of satellite images taken in 1972, 1995, 2010, 2013 and 2014, show that Gili Matra region has experienced significant changes in term of human activities that has implicated the region's vulnerability. In general, the coastline change of the three islands in Gili Matra region showed erosions. Only a few parts of the coastline showed accretions. From 1972 to 2013, Gili Ayer Island coastline suffered 5.05 ha of land loss due to erosion (from 180.96 ha in 1972 to 175.91 ha by 2013) and Gili Meno Island's loss was 1.79 ha (from 186.42 ha in 1972 to 184.63 ha by 2013). This erosion also occurred in Gili Trawangan coastline incurring a loss of about 1.08 ha of land (from 349.53 ha in 1972 to 348.45 ha by 2013) (see Figs. 8 and 9). Based on the field survey, these changes happened due to sand mining and coral exploitations for development purposes such as houses, resorts, restaurants and others tourism facilities and reclamation for sand leisure (Fig. 10). Reclamation activities occurred at the east coast of Gili Trawangan Island in 1995 and the southeast coast of Gili Ayer Island in 1987.

Coral reefs in Gili Ayer Island showed significant changes compared to other islands; there was an increase of about 13.44 ha within 22 years (from 178.07 in 1995 to 191.50 ha by 2013). The coral reefs in Gili Trawangan Island increased from 202.48 ha in 1995 to 211.92 ha by 2013 (about 9.44 ha), while those in Gili Meno Island increased about 5.36 ha by 2013 (from 104.82 to 110.18 ha) (Fig. 11). Accretion and erosion are very affected by the dynamics of the oceanography and could be different in dry and wet season (Eversole and Fletcher, 2003; Presto et al., 2006). Accretion is assumed to have come from eroded coral reefs because Gili Matra region is far from the mainland rivers as stated in a comparison study conducted by Bothner et al. (2006). During his research at Molokai Islands in Hawaii, they found 70% of sediment materials derived from components of coral reefs, such as algae, sponges, polychaetes, crustaceans, sea urchins, and fishes (Moberg and Folke, 1999; Bothner et al., 2006; Ouillon et al., 2010).

However, this was not the case in terms of live corals. They showed a decline in both Gili Ayer- and Gili Meno Islands. There was a decrease of about 29.97 ha (from 120.78 ha in 1995 to 90.81 ha by 2013) in Gili Ayer Island, followed by 20.30 ha of diminution of live coral area (from 64.09 ha in 1995 to 43.80 ha by 2013) in Gili Meno Island. Surprisingly, however, Gili Trawangan Island indicated that it has an increase of about 26.37 ha (from 78.68 ha in 1995 to 105.05 ha by 2013) (Fig. 12). Those live coral depletion was caused by the increasing tourism activities, particularly swimming, snorkelling and diving as mentioned by Hannak et al. (2011) (Fig. 13). Coral reefs rehabilitation using Biorock material in Gili Trawangan Island has successfully increased the amount of live corals in the area. Biorock material is "composed of natural calcium and magnesium minerals dissolved in seawater that crystallize out on top of conductive metal surfaces that are given a small electrical charge" (Goreau et al., 2013). This rehabilitation effort has started since 2004 conducted by Gili Eco Trust (Non-Governmental Organization) and Center for Environmental Studies, University of Mataram at more than 13 locations. Bakti et al. (2013) said that the growth rate of *Acropora formosa* was 4.39 times faster than the growth away from Biorock, that is 3.42 cm within 8 weeks on Biorock substrate and 0.78 cm away from Biorock, and the growth rate of *Montipora Digitata*

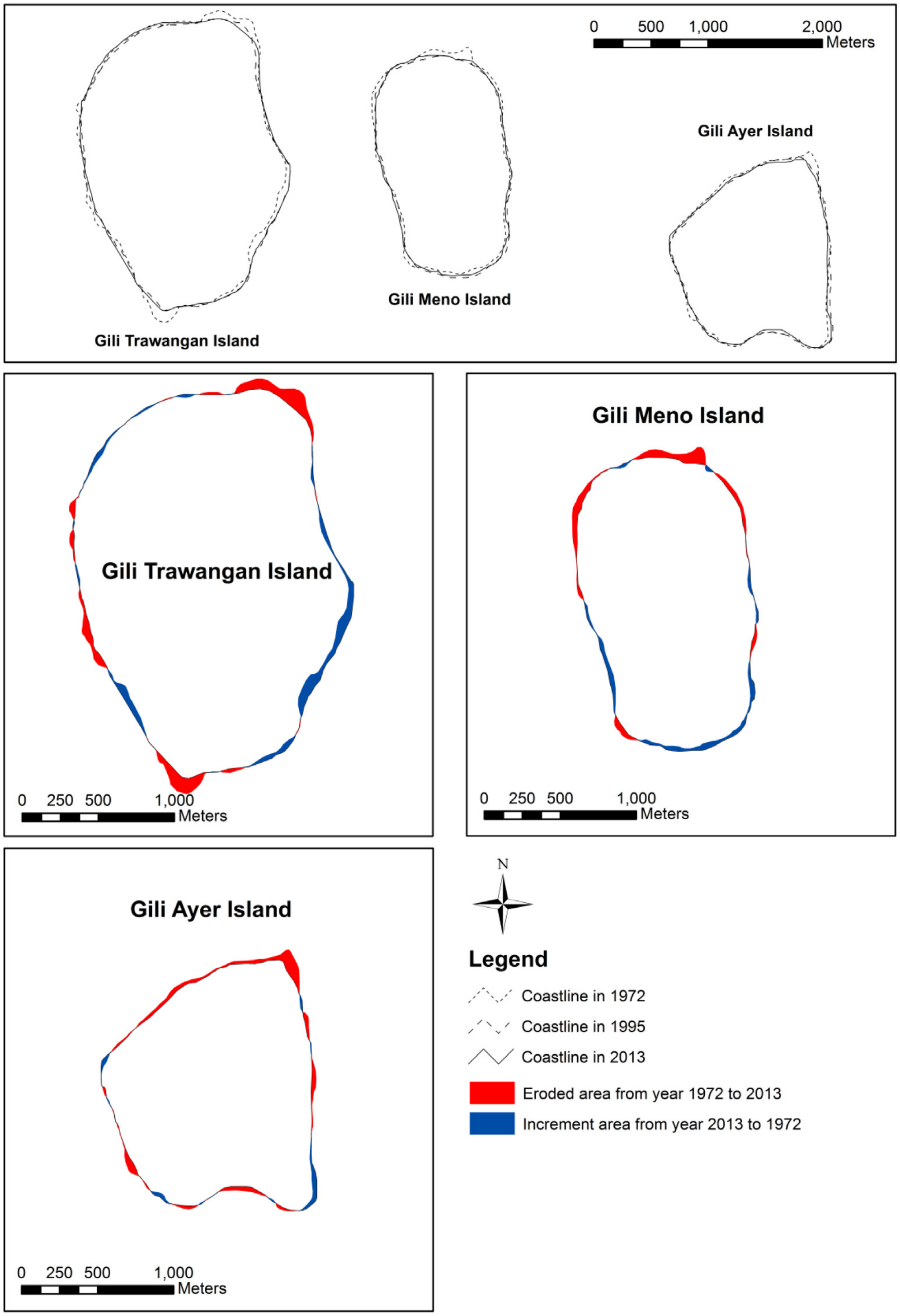


Fig. 8. Coastline changes in Gili Matra Islands.

was 3.34 times faster than the growth away from Biorock, that is 2.40 cm within 8 weeks on Biorock substrate and 0.72 cm away from Biorock.

Along with an upsurge of tourism industry, there is also an increase of development area in Gili Matra, especially for tourism facilities, such as restaurants, internet cafés, beach shelters, bars, shops, laundry sites and accommodations (Hampton and Jeyacheya, 2014). The first accommodation (homestay) were established in 1980s by local entrepreneurs (Bottema and Bush, 2012). Dinas Pariwisata Kabupaten Lombok Utara/Department of Tourism of Lombok Utara Regency

Fig. 9. Coastal erosion and protection using breakwater and vertical sea wall in the north of the Gili Trawangan Island.

Fig. 10. Conditions and development areas around the coastal area in Gili Matra Islands: (a) condition of Gili Trawangan Island as fishing village in 1998 (Source: Indraswara (2008)); (b) resorts and restaurants in Gili Ayer Island; (c) resorts, restaurants and traditional ports in Gili Meno Island; (d) houses, resorts, restaurants and other tourism facilities in Gili Trawangan Island.

(2015) recorded that there were total of 404 accommodations with 2940 beds in Gili Matra region; most accommodations were found in Gili Trawangan Island which has 249 units, followed by 93 units in Gili Ayer Island and 62 units in Gili Meno Island. In 2014, the Gili Ayer Island underwent quite extensive developmental changes up to 50.64 ha or 28.50% of the island, it was developed and expanded significantly to about 86.79% (from 27.11 ha in 2010). Similarly in Gili Meno Island developed more than 34.67 ha or 19.51% of the island area, it also expanded about 56.45% (from 22.16 ha in 2010). On the other hand,

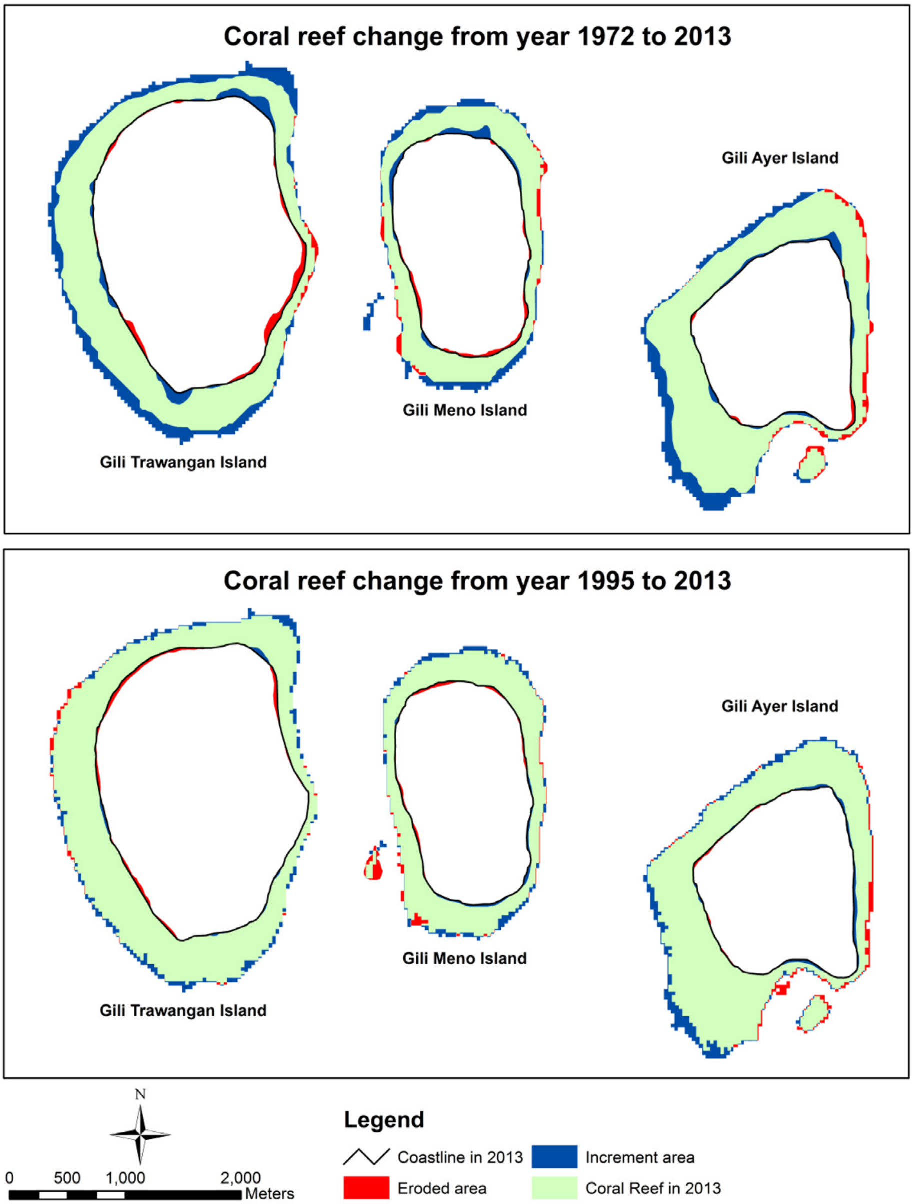


Fig. 11. Coral reef area changes in Gili Matra Islands.

Gili Trawangan Island, the development area is about 99.35 ha or 28.52% of the island, the increase of 34.93% came about in 2010 (Figs. 14 and 10).

Vulnerability classification is divided into five classes each with a scale from 1 to 5 (very low to very vulnerable). Such classification was built by the changes in the values of every island in Gili Matra region. A comparison has been made to Seribu Islands which was classified based on the highest and lowest score for coastline and coral reef changes variable, and also the standard value of Indonesian policy and reference as general provision for both variable of live coral changes and development area. The interval between vulnerability scales was calculated based on an average value in each variable as calculated by Doukakis (2005), Turvey (2007) and Farhan and Lim (2011, 2012).

The SIVI was determined by calculating the average value of the sum of the vulnerability variable value. The final result of the small island vulnerability assessment is then mapped out based on the vulnerability classes for every islands in Gili Matra region. Based on the characteristics of Gili Matra Islands and in comparison with the characteristics of Seribu Islands (Table 2), and based on the standard value of Indonesian policy, then, SIVI is developed (Table 3). From the historical data and data analysis, it showed that Gili Matra Islands as tourism island has a vulnerability level from low (Gili Meno and Gili Trawangan Island) to moderate (Gili Ayer Island) (Table 4). However, tourism activities in Gili Matra are already reaching a

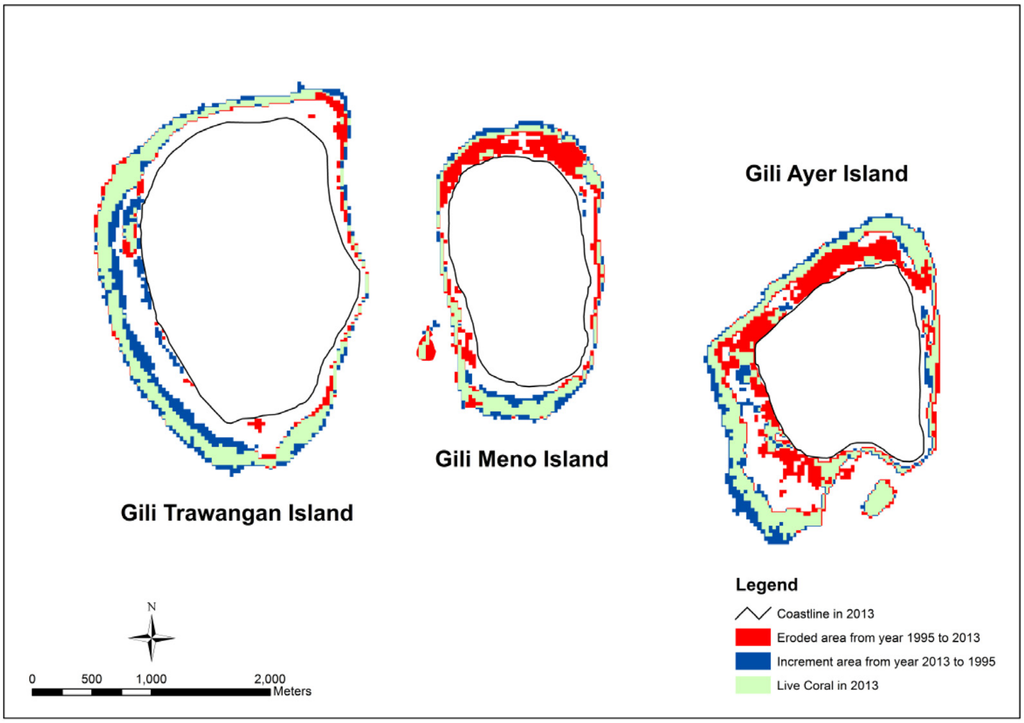


Fig. 12. Live coral area changes in Gili Matra Islands.

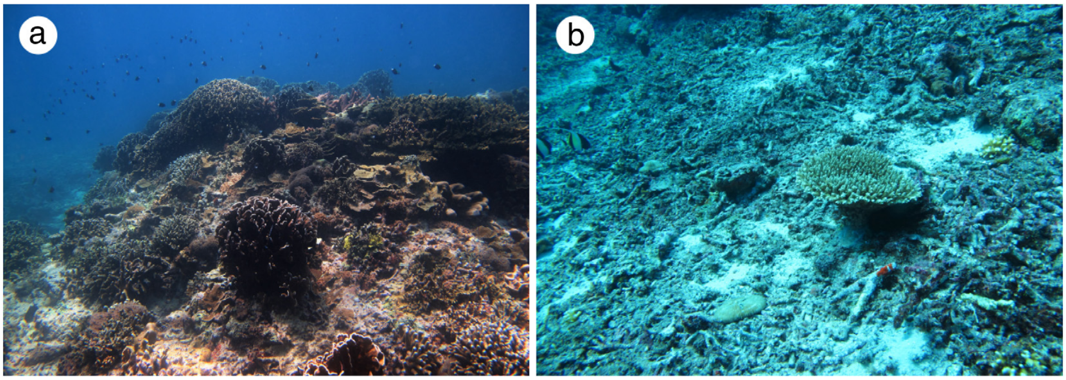


Fig. 13. Coral reef ecosystem of Gili Matra Region: (a) good condition; (b) bad condition in one of the diving spots due to the impact of tourism.

critical position. The islands are currently very crowded, especially in Gili Trawangan Island; as such its vulnerability may increase in the future.

Strickland-Munro et al. (2010) stated that tourism activity can increase the stress to the environment. The need for land expansion for hotel and housing has caused a decrease in the environment functions and an increase of pollution and waste (Falkland, 1993; Gössling, 2001; Bellan and Bellan-Santini, 2001; Pickering and Hill, 2007). Furthermore the increase of development has caused contamination and sea water intrusion into aquifer and surface water (Falkland, 1993; Özyurt and Ergin, 2010). A study conducted by Bakti et al. (2012) proved that the ground water level at Gili Meno and Gili Trawangan Island were relatively shallow averaging from 1 to 3 m and had brackish to salty quality. Therefore, fresh water for daily and tourism utilization was supplied from Lombok Island and delivered there by boat. Tourism activities in the waters, such as diving, snorkelling, swimming and other water tourism activities, pose a threat for the coral reef ecosystem and decrease the live coral coverage (Barkes and Roberts, 2004; Hannak et al., 2011), resulting in a decrease of its function. This is what has occurred in Gili Ayer and Gili Meno Island.

In small islands management, it was understood that vulnerability is an intrinsic aspect of changes and conditions that occur from any disturbances in all dynamic system. Even though adaptation can never erase the vulnerability completely, it is yet enough to shift the spatial, temporal or kind of disturbance differently (Lauer et al., 2013). Tompkins (2005) stressed that adaptation can be different in adapting the risks and is dependent on the on driving factor's load. Therefore, adaptive

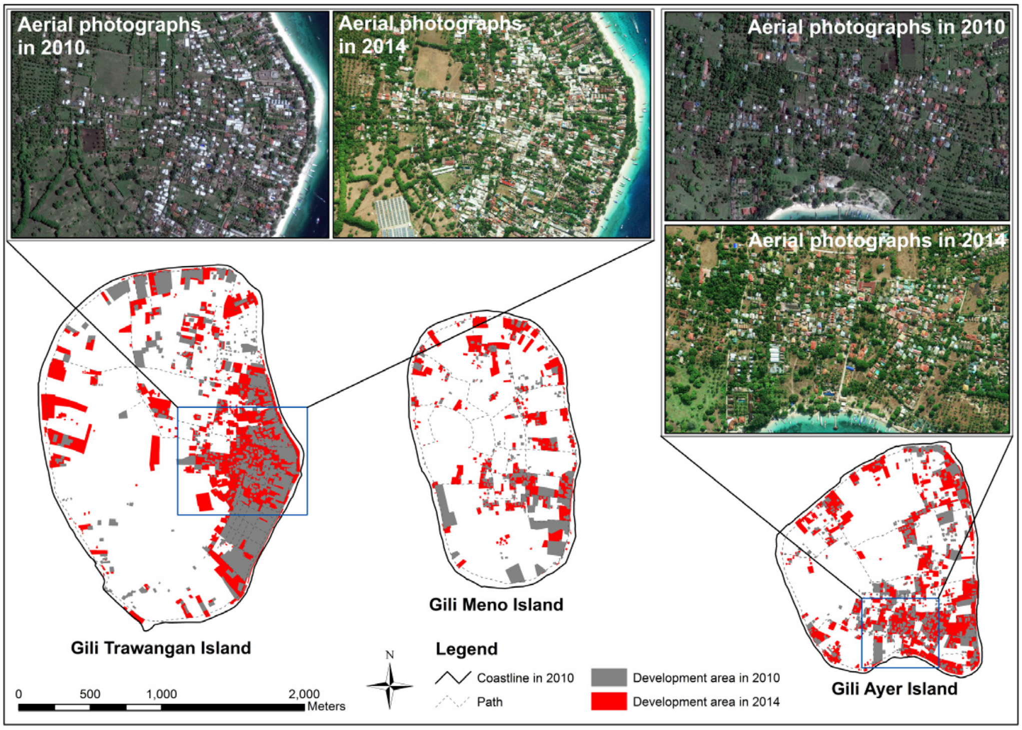


Fig. 14. Development area in Gili Matra Islands.

Table 2
Coastline and coral reef changes in Seribu Islands.

Islands	Coastline changes (%)	Coral reef Changes (%)
Ayer Besar[b]	−29.31	−24.05
Bidadari[b]	−6.50	−9.01
Bokor[b]	−12.43	−38.36
Burung[b]	196.66	4.18
Damar Besar[b]	−1.84	−35.06
Damar Kecil[b]	−35.8	−43.08
Dapur[b]	−20.01	−85.11
Karya[a]	9.15	–
Kayangan[b]	−45.77	−66.68
Kelor[b]	−66.74	−42.39
Kongsi Barat[b]	−35.67	−4.18
Kongsi Tengah[b]	100.00	−4.18
Kongsi Timur[b]	38.35	−4.18
Laki[b]	−30.17	−50.9
Lancang Besar[b]	−43.96	−15.13
Lancang Kecil[b]	−32.98	−15.13
Nyamuk Kecil[b]	−69.76	−61.09
Onrust[b]	−8.11	−19.06
Panggang[a]	−1.69	–
Pari[b]	3.94	4.18
Pramuka[a]	2.49	–
Rambut[b]	−3.84	4.18
Tengah[b]	21.96	4.18
Tidung Besar[a]	−9.38	–
Tidung Kecil[a]	37.18	–
Tikus[b]	24.49	14.86
Untungjawa[b]	−21.16	−36.61

Source:.
[a] Farhan and Lim (2011).
[b] Farhan and Lim (2012).

capacity must be built, both internally and externally (Schwarz et al., 2011; Lauer et al., 2013), so that a new vulnerability scale is newly formed and provides a good social–ecological system.

Table 3
Indicators, classes, scores and SIVI classifications.

No.	Indicators	Vulnerability class				
		Very low	Low	Moderate	High	Very high
1.	Coastline changes (%)	>+20	>+10 to +20	+10 to −10	>−10 to −20	>−20
2.	Coral reef changes (%)	>+20	+10 to +20	+10 to −10	−10 to −20	>−20
3.	Live coral changes (%) (–)	Stable; increment	0–24.9	25–49.5	50–74.9	>75
4.	Development area (%)	<20	21–30	31–40	41–50	>50; 0 (uninhibitation)
Vulnerability index score		1	2	3	4	5
Vulnerability classification class		1–1.5	>1.5–2.5	>2.5–3.5	>3.5–4.5	>4.5–5

Table 4
Vulnerability classes in Gili Matra Islands.

Islands	Changes (%)				Vulnerability class				SIVI	Description
	Coastline	Coral reef	Live coral	Development area	Coastline	Coral reef	Live coral	Development area		
Gili Ayer	−2.87	12.98	−33.00	28.50	3	3	3	2	2.75	Moderate
Gili Meno	−0.97	12.54	−46.34	18.86	3	3	3	1	2.50	Low
Gili Trawangan	−0.31	19.22	25.10	28.52	3	3	1	2	2.25	Low

In addition, significant consideration must be given in Gili Matra Islands to coral reef as an important ecosystem to maintain and enhance the resilience by putting in efforts on ecosystem conservation (Moberg and Folke, 1999), including land use management and zoning system. Spatial planning is an important tool in development management and land use utilization to achieve sustainable development in small islands. Consideration also must be given to provide balanced social as well as economic demands in conjunction with the ecological function (Douvere and Ehler, 2009). Spatial variations of temporal dynamic are importantly needed as spatial feedbacks between spatial variation and processes of a system (Cumming, 2011).

The manager is a person who plays a main role in the management of the establishment to ensure that the development is conforming to provide resiliency in the small islands. The organizational cost form, government officials and participatory approach are the additional factors that contribute towards the social–ecological resilience and sustainability of the resources utilization. Resilience and sustainability can be observed from the existing ecosystem, livelihood, process and also institutional process (Plummer and Armitage, 2007).

5. Conclusions

According to the above case studies, the vulnerability index which was built from the coastline, coral reef, living coral reef, and development area was applicable to assess the small island's vulnerability in Indonesia, especially for coral island. Based on the vulnerability index built, currently, Gili Matra Islands has a vulnerability status of low to moderate level, ranging from 2.25 to 2.75. Gili Ayer Island has the highest vulnerability with a SIVI of 2.75 (Moderate), followed by Gili Meno Island with a SIVI of 2.50 (Low), while Gili Trawangan Island has a SIVI of 2.25 (Low). The vulnerability's driving factor derives from intensive utilization of tourism. Tourism is the sole stress to Gili Matra Island's ecosystem due to its direct damaging impact and reducing its environmental quality. Gili Trawangan Island has a good understanding and social awareness on the impacts and benefits of tourism. This is turn has created a good adaptation system on the island, such as conducting coral reef ecosystem rehabilitation and conservation which provide great goods and services.

In this paper, SIVI was built focusing only on the biophysical (ecological) and spatial aspects. Further study that concentrates on other aspects such as physical oceanography, social and management aspects is needed. Moreover, in building Indonesia's vulnerability index comprehensively, further studies need to be done at more small islands at different locations with have different characteristics than the one at Gili Islands. The vulnerability assessment can be a guidance to observe the spatial resiliency of small island and to understand the adaptive capacity and changes that occur in small islands, be it both positive or negative trends, and whether those changes were altered by natural- or human factors, so it can be seen the tendency of a system is vulnerable or resilient.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2016.04.001.

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