

1 **Field survey of seawater reverse osmosis (SWRO) usage for overcoming water scarcity on small**
2 **islands in Indonesia**

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4 **Amanatullah Savitri^{1*}, Kazuyoshi Souma², Hiroshi Ishidaira², Jun Magome²**

5 ¹Special Educational Program on River Basin Environmental Science, Integrated Graduate School of
6 Medicine, Engineering, and Agricultural Sciences, University of Yamanashi, Japan

7 ²Interdisciplinary Center for River Basin Environment, University of Yamanashi, Japan

8 *g23dtka1@yamanashi.ac.jp

9

10 **Abstract**

11 The dry season impacts clean water availability in Indonesia, particularly on small islands; however,
12 there are few comprehensive studies of water availability on small islands. The aim of this study was
13 to assess clean water sources and the obstacles to accessing clean water on small islands. We used
14 a combination of structured questionnaires and interviews along with direct observations on two
15 small islands in Indonesia, Belakang Padang Island and Labu Island. On Belakang Padang Island, we
16 interviewed the water resource manager in October 2022 and May 2023, and surveyed 61
17 households in Tanjung Sari subdistrict RT No. 002/RW No. 002 in October 2022. On Labu Island, we
18 interviewed the staff of the seawater reverse osmosis (SWRO) system and surveyed 35 coastal
19 households in September 2023. On both islands, the government has improved residents' access to
20 clean water by constructing SWRO facilities. The small SWRO facility on Labu Island ran more

21 efficiently and stably as it was powered by a generator. The larger SWRO facility on Belakang Padang
22 Island experienced disruptions during periods of unstable electricity generation supplied by the
23 State Electricity Company. The absence of septic tanks pollutes the surrounding area and increases
24 the risk of contaminating underground water and pipe networks (reservoirs and SWRO) during high
25 tides, and seawater used for SWRO's raw water. Our findings recommended the use of generators
26 or sustainable generators for SWRO on small islands to achieve stable SWRO operation, as well as
27 the use of an appropriate septic tank for coastal communities on small islands.

28 Keywords: small islands in Indonesia, field survey, water resources, desalination

29

30 Introduction

31 The global demand for water is growing annually.[1] Ensuring universal access to clean water by
32 2030 is target 6.1 of the United Nations Sustainable Development Goals. However, not all countries
33 are positioned to achieve this goal for various reasons, including population growth and unequal
34 infrastructure distribution.[2,3] The 2015 Paris Agreement acknowledges that small islands are
35 particularly vulnerable to climate change. Small island states face scarce freshwater sources,
36 fluctuating weather patterns, rising sea levels, extreme weather events linked to climate change,
37 and expanding populations.[4,5] Based on Chapter 15 of the Intergovernmental Panel on Climate
38 Change 2022 report, small islands are increasingly impacted by temperature increases, tropical
39 cyclones, storm surges, droughts, shifting precipitation patterns, rising sea level, coral bleaching,
40 and invasive species. Many small islands lack sufficient fresh water supplies to meet residential,
41 commercial, and agricultural needs.[6] On small islands, water supplies may include groundwater,

42 surface water, ocean water desalination, and sparingly harvested rainwater;[7] the restricted
43 availability of water resources poses challenges to development on small islands.[8] Furthermore,
44 the effects of climate change and seawater intrusion present risks to groundwater resources on
45 small islands. Overall, water treatment solutions must cater to the unique potential and challenges
46 of each small island.

47 Indonesia is a Southeast Asian country comprising 17,508 islands, 16,671 of which are officially
48 recognized by the United Nations, located between the Indian and Pacific Oceans.[9] According to
49 climate change projections, rising temperatures and shifting rainfall patterns will gradually reduce
50 the amount of water availability in the majority of the Indonesian Archipelago, especially in small
51 islands.[10] Provinces on Java-Bali Island typically have better access to potable water and sanitation
52 conditions for their households compared to other islands.[11] Due to the political process of
53 decentralization of public services and administration that occurred in the 1980s and 1990s, there
54 has been uneven development throughout Indonesia.[12] Not all areas have access to clean water
55 managed by the central government. The availability of clean water in rural areas or small
56 communities tends to rely on natural clean water sources and is not well managed.[13]

57 During the dry season, hinterlands and small islands have limited access to clean water due to low
58 water availability.[14,15] However, there are few comprehensive studies on the state of water
59 resources on very small islands,[16–18] particularly in Indonesia, where governments tend to focus
60 efforts on larger islands such as Java.[19–22] Indonesia is committed to achieving SDG 6 of the 2030
61 Agenda for Sustainable Development, which is to ensure universal access to safe drinking water and
62 sanitation. The SDG targets have also been incorporated into the national targets in the 2020-2024
63 Rencana Pembangunan Jangka Menengah Nasional (National Medium-Term Development

64 Plan).[23] One strategy adopted by local governments to meet clean water needs is the installation
65 of seawater reverse osmosis (SWRO) systems.[24] Previous studies have focused on desalination
66 facilities on tourist islands.[25–27] A previous study investigated SWRO systems in a few regions of
67 Indonesia; however, these systems were located far apart and/or near tourist destinations.[28] By
68 contrast, small islands on the periphery of Indonesia may be less economically profitable but must
69 still be safeguarded to maintain the integrity of Indonesia's international borders.

70 The aim of the present study was to assess the sources of clean water and obstacles to meeting
71 clean water demands on small islands. We compared the state of freshwater sources on two small
72 Indonesian islands located closed to one another near Malaysia and Singapore; because of their
73 proximity, the two islands experience similar rainfall patterns.

74

75 **Materials and Methods**

76 **Study sites**

77 We surveyed two small islands, Belakang Padang Island and Labu Island, Riau Islands Province,
78 Indonesia (**Fig 1**). Riau Islands Province is bounded by Vietnam and Cambodia to the north, Malaysia
79 and West Kalimantan Province to the east, Bangka Belitung and Jambi Islands Provinces to the south,
80 and Singapore, Malaysia, and Riau Province to the west. Riau Islands Province contains five
81 regencies, two cities, 52 subdistricts, and 299 villages across a total of 2,408 large and small islands;
82 of these islands, 30% are unnamed and unpopulated.[29] Riau Islands Province is located on one of
83 the world's busiest shipping lanes along the Malacca Strait and Natuna Sea (South China Sea).

84 The areas of Labu Island and Belakang Padang Island are 0.188 km² and 2.317 km², respectively.[30]
85 Both islands fall under the administration of Batam Island, which is the most developed island in
86 Riau Islands Province. During the dry season, both islands have limited access to clean water.[31]
87 Currently, BLUD UPT PAB Batam manages the water resources of both islands. We used a
88 combination of closed-ended structured questionnaires and interviews, along with direct
89 observations of water facilities on both islands.

90 **Fig 1. The study sites of Belakang Padang Island and Labu Island, Indonesia.**

91

92 Water resource manager interviews

93 We obtained information about the state of water resources and government initiatives through
94 direct interviews with local water resource managers on Belakang Padang Island and Labu Island.
95 The interview questions are listed in **Table 1**. The water resource manager on Belakang Padang
96 Island was interviewed for two days on October 2, 2022, and March 15, 2023. The staff of the SWRO
97 facility on Labu Island were interviewed for one day on September 19, 2023. We also met with staff
98 from BWWS Sumatra IV in one day, which manages water resources in Riau Islands Province, on
99 September 20, 2023. Prior to conducting the interviews, we verbally requested consent to use the
100 data for our research in local language.

101 **Table 1. Interview questions submitted to the water resource managers on Belakang Padang**
102 **Island and Labu Island.**

No.	Question
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1	What was the state of water resources before the SWRO facility was built?
2	What has been the state of water resources since the SWRO facility was built?
3	Were alternative solutions proposed before the SWRO system was built?
4	What is the state of the SWRO facility operation and maintenance?
5	What problems occur?
6	What is the price of water produced by the SWRO facility?
7	What is the quality of water produced by the SWRO facility?
8	How has the local community responded to the production of water by the SWRO facility?

103

104 Resident interviews

105 We conducted questionnaire interviews of households on Belakang Padang Island and Labu Island.

106 We posed 20 questions (**Table 2**) to the head of the household on four topics: house condition,

107 socioeconomic conditions, clean water and sanitation, and environmental conditions around the

108 house. We interviewed 35 households in a coastal area of Labu Island for one day on September 21,

109 2023. On Belakang Padang Island, we interviewed 61 households in the Tanjung Sari subdistrict,

110 Kampung Tengah RT No. 002/RW No. 002, on October 3, 2022 for one day (**Fig 2**); The Kampung

111 Tengah has the worst living environment on Belakang Padang Island, and is impacted by tides due

112 to its proximity to the ocean. Prior to conducting the interviews and field surveys, we verbally

113 requested consent to use the data for our research in local language from head of neighborhoods

114 and from all participants.

115

116 **Table 2. Resident interview questions.**

No.	Question
A.	House Condition
A.1	Is the house constructed of concrete and built on land?
A.2	Is the house a stilt house constructed of wood?
A.3	Do any of the house's buildings need repairs?
A.4	Is the house equipped with a toilet or latrine that meets the Indonesian National Standard?
A.5	Does the front of the house have road access for motorcycles and pedestrians?
B.	Socioeconomic Conditions
B.1	Is the household income more than IDR 4,000,000 per month?
B.2	Have you lived on Belakang Padang Island or Labu Island for more than 10 years?
B.3	Is it easy to access necessities such as food, clothing, and shelter?
B.4	Are you healthy and comfortable with your living conditions?
B.5	Does your income meet your daily needs?
C.	Clean Water and Sanitation
C.1	Do you have a clean water source, without clean water shortages?
C.2	Is a reservoir your main water source?
C.3	Do you obtain the water from a rainwater tank and purchase the water from a neighboring island?
C.4	Do you dispose of domestic waste, such as soapy water, laundry residues, and feces, directly into the ocean?

C.5	In the dry season, do you have difficulty accessing clean water?
D.	Environmental Conditions Around the House
D.1	Do the tides reach your stilt house, with water below the house changing daily?
D.2	Do the tides reach your concrete house?
D.3	Are you disturbed by smells originating from domestic waste that has settled beneath the house?
D.4	Is there a rubbish disposal point in front of the house, which is collected by cleaning staff?
D.5	Does flooding often occur during the rainy season?

117

118 **Fig 2. Locations of households interviewed on Belakang Padang Island and Labu Island.**

119 Results

120 1. Water resource manager interviews

121 Belakang Padang Island

122 The government constructed the small Sekanak Reservoir in the 1990s to meet the demand for clean
123 water on Belakang Padang Island; this reservoir was later expanded with the construction of
124 Sekanak Reservoir 2 to meet growing water demand. Because these reservoirs rely solely on
125 rainwater, and water levels drop during the dry season, the local community has frequently
126 struggled to access clean water during the dry season. In response to a severe drought in 2016,
127 which caused hardship to the community, the government built an SWRO facility on Belakang
128 Padang Island that has been operating since 2017; this facility converts seawater into freshwater

129 (hereafter, SWRO water). However, the SWRO facility has experienced operational issues originating
130 from its unstable electricity source; power disruptions have interfered with the engine operation
131 and disrupted water desalination. The procurement of replacement parts, which are ordered from
132 Germany, takes a long time.

133 The SWRO water costs IDR 41,000 per m³, which is expensive for residents; to help offset this
134 expense, the central government subsidizes 50% of the cost. The SWRO system produces potable
135 water that can be consumed directly within the facility; however, water produced by the SWRO
136 system that is transported by pipe networks to households should not be consumed directly. The
137 SWRO facility was originally intended to meet the water needs of residents living at higher
138 elevations, which cannot be supplied by pipes from the reservoirs. However, other communities
139 wanted access to SWRO water to supplement the reservoir water; by 2022, 852 houses were
140 connected to the SWRO facility.

141 Labu Island

142 Before 2022, the residents of Labu Island had no local water source; they had to travel to other
143 islands to either purchase water or collect it from rivers. The water was transported on small
144 wooden boats, posing a risk to the residents' safety. Fishers had concerns about leaving their
145 families without access to water while they worked. The community requested assistance from the
146 government to provide a clean water source on their island; however, the island was too small to
147 build a reservoir and the groundwater quality too poor for wells.

148 The SWRO facility on Labu Island was constructed on land donated by residents and began operation
149 in 2022. The SWRO facility provides 24-hour access to clean water that meets the standards of the

150 Indonesian Ministry of Health. All Labu Island residents have access to SWRO water, although some
151 continue to purchase water elsewhere. Since the start of operation, no major operational problems
152 have occurred. SWRO water costs IDR 44,000 per m³; to help offset the expense, the central
153 government subsidizes 50% of the cost. Overall, the community has benefited greatly from the
154 SWRO facility.

155

156 2. Resident interviews

157 House condition

158 On Belakang Padang Island, among the 61 households of Kampung Tengah interviewed, 82% of the
159 houses were constructed of wood and built on stilts; 18% of the houses were constructed of
160 concrete (**Fig 3**). Approximately 80% of the houses required repairs to fix weakening structures that
161 caused the buildings to tilt. Moreover, 84% of the houses lacked a septic tank and had inadequate
162 toilets; only 16% of houses had a septic tank.

163 **Fig 3. Houses on Belakang Padang Island.**

164 On Labu Island, among the 35 coastal-area households interviewed, all of the houses were built on
165 stilts and lacked a septic tank. Some houses were aging and required repairs. The mosque and health
166 center, located at the center of the island, both have septic tanks. In 2023, the government
167 announced plans to build communal septic tanks, allocating one septic tank for every three to four
168 houses.

169

170 Socioeconomic conditions

171 The socioeconomic conditions of the communities of Belakang Padang Island and Labu Island
172 tended to influence the residents' sanitation conditions. The occupations and monthly incomes of
173 residents of Belakang Padang Island and Labu Island differed substantially (**Table 3** and **Fig 4**).
174 Belakang Padang Island residents participated in more varied occupations, whereas the majority of
175 Labu Island residents were fishers. Fishers usually work at night and their income is uncertain, as
176 poor weather prevents them from working. On Labu Island, most married women become
177 homemakers, and depend on their husbands' income. Despite differences in occupations, the
178 residents of the two islands had similar monthly incomes, between IDR 1,000,000 and IDR
179 3,500,000; this range falls below the minimum standard for Batam City in 2023, which is around IDR
180 4,500,440.[32]

181 **Table 3. Occupations and incomes of residents interviewed on Belakang Padang Island and Labu**
182 **Island.**

Occupation	Belakang Padang Island		Labu Island	
	n	(%)	n	(%)
Laborer	18	30%	5	14%
Fisher	10	16%	25	71%
Civil servant	3	5%	0	0
Self-employed	14	23%	2	6%
Unemployed	11	18%	3	9%
Other	5	8%	0	0

Income	n	(%)	n	(%)
IDR 1,000,000–3,500,000	40	66%	21	60%
IDR 3,600,000–4,000,000	15	25%	9	26%
> IDR 4,000,000	6	9%	5	14%

183

184 **Fig 4. Occupations of residents interviewed on Belakang Padang Island and Labu Island.**

185

186 Clean water and sanitation

187 The sources of clean water differed between Belakang Padang Island and Labu Island (**Table 4**). On
 188 Belakang Padang Island, residents accessed clean water from the SWRO facility and reservoirs, as
 189 well as wells and rainwater tanks (**Fig 5**). The residents of Labu Island relied solely on SWRO water;
 190 well water is too saline for drinking. In terms of sanitation, most residents of both islands lack septic
 191 tanks because the houses surveyed were located in coastal areas. Rather, these communities rely
 192 on tidal water to clean up discarded waste and unclean water.

193 **Table 4. Clean water and sanitation conditions of residents on Belakang Padang Island and Labu**
 194 **Island.**

Variable	Category	Belakang Padang Island		Labu Island	
		n	(%)	n	(%)
Clean water source	Reservoir/SWRO	40	65%	35	100%
	Well	12	20%	0	0%

	Rainfall (rainwater tank)	6	10%	0	0%
	Other source	3	5%	0	0%
Septic tank	Available	12	16%	0	0%
	Not available	60	84%	35	100%
Wastewater sewerage	Available	0	0%	0	0%
	Not available	61	100%	35	100%

195

196 **Fig 5. Sample photographs of water resources on Belakang Padang Island: a) SWRO, b) reservoir,**
 197 **c) rainwater tank, d) well.**

198

199 SWRO facility conditions

200 The SWRO facilities differ between the two islands in terms of size, energy source, clean water
 201 production, and operating time. **Table 5** summarizes the results of the interviews and field surveys
 202 on Belakang Padang Island and Labu Island.

203 **Table 5. Clean water and SWRO facility conditions on Belakang Padang Island and Labu Island.**

	Belakang Padang Island	Labu Island
Number of respondents	61 households	35 households
Clean water source	Reservoir and SWRO facility	SWRO facility

Water tariff	Reservoir = IDR 5,000/m ³ SWRO = IDR 20,500/m ³	IDR 22,000/m ³
Electricity source	PLN (State Electricity Company). The central PLN purchases electricity from PLN Batam and transports it to Belakang Padang Island via an underwater cable.	Generator, individual solar panels (PLN plans to construct centralized solar panels)
Water resources		
Reservoir	The Sekanak I and Sekanak II reservoirs connect to 1278 houses, but do not meet water demand during the dry season. No network pipe map is available and some old pipes leak; non-revenue water services over 30.	N/A
SWRO facility size	Large	Small
SWRO facility household connections	852 houses (pipes installed in 2017)	50 houses (pipes installed in 2022)
Water access before SWRO	People depended on reservoirs and rainwater storage. During the dry	People purchased water or collected it from rivers on other

facility construction	season, people purchased water from other islands, particularly residents of Kampung Jawa, where the high elevation impedes water transport from reservoirs.	islands, and transported it on small wooden boats.
SWRO facility water production	Operates 24 h per day, and water production is carried out 7 days per week	Operates 24 h per day, and water production is carried out 2 days per week
SWRO facility energy source	PLN (state electricity company), which is often unstable and disrupts SWRO facility operations	Generator (74 kVA) providing stable electricity
Drinking water	Residents purchase water by the gallon	Residents purchase water by the gallon

204

205 Discussion

206 Before Batam City was established as the site of the local government, Belakang Padang Island
 207 historically hosted the local government. Several government offices and other facilities remain,
 208 which attract local and foreign tourists. Labu Island is a smaller island, with few inhabitants. The
 209 Indonesian government has been working to meet the drinking water needs of residents on small
 210 islands, particularly during the dry season, for example through the construction of reservoirs, water
 211 tanks, and SWRO facilities. SWRO facilities are expensive to operate and maintain. Therefore, the

212 government of Belakang Padang Island first considered alternatives, including an undersea pipeline
213 to supply clean water from Batam City; however, this strategy would have been costly, and risked
214 requiring pipeline repairs and disturbing boat traffic.[33]

215 SWRO system operation requires stable electricity. The unstable electricity supply on Belakang
216 Padang Island disrupts operations, straining the machinery and requiring more frequent repairs.
217 Replacement parts must be shipped from Germany, causing long wait times. From our interview
218 with the water resource manager in 2023, during such waiting periods, residents' water supply is
219 maintained by drawing water from the Sekanak Reservoir.

220 On Labu Island, the community endured decades of hardship due to the difficulty in accessing clean
221 water. Inhabitants requested a solution from the government;[34] in response, the SWRO facility
222 was constructed and began operating in 2022. According to our 2023 interview with the water
223 resource manager, Labu Island is too small for a reservoir, and wells were not a viable solution
224 because the ground water does not meet the standards set by the Indonesian Ministry of Health.
225 The SWRO facility has greatly assisted Labu Island residents. Notably, most workers are fishers, who
226 work at night and now feel secure when leaving their families with the knowledge that they have
227 access to clean water.

228 Although the SWRO facility on Labu Island is small and produces water only 2 days per week,
229 whereas the SWRO facility on Belakang Padang Island is larger in capacity and produces water every
230 day, both facilities provide residents with continuous access to water.[35] However, the Belakang
231 Padang Island SWRO facility has experienced operational difficulties caused by the unstable
232 electricity supply. By contrast, the Labu Island SWRO facility is powered by a generator and has
233 operated stably since operation began in 2022. Labu Island does not have a central source of

234 electricity; rather, Labu Island residents use individual generators and solar panels to meet their
235 daily electricity needs.[36] Our questionnaire revealed that more than 60% of residents had incomes
236 below the minimum standard salary for Batam City. SWRO water is expensive, but the central
237 government subsidizes 50% of the cost, ensuring that it remains affordable. We also found that most
238 coastal residents had poor sanitation conditions because they lack septic tanks, which increases the
239 risk of contaminating underground water and pipe networks (reservoirs and SWRO) during high
240 tides, and seawater used for SWRO's raw water. Drinking water may be contaminated not only by
241 wastewater but also due to seawater intrusion during tidal events.

242 The state of the SWRO facility on Belakang Padang Island may have differed from that on Labu Island
243 because they have been in operation for different durations. An earlier study of the Belakang Padang
244 Island SWRO facility observed that its operation tended to be stable [28]; since that study,
245 challenges have arisen that have negatively impacted both the government and the community.
246 From our interview with water resource manager in 2023, the amount of water produced daily by
247 the Belakang Padang Island SWRO facility has been impacted by an increase in the number of houses
248 connected by pipes. Efforts by the government and Belakang Padang SWRO facility are ongoing to
249 meet residents' water needs by drawing water from the reservoirs for distribution to SWRO water
250 customers. Governments and regions adapt to growing water demands by increasing water stocks
251 and increasing clean water supply through deepening or expanding water sources. However, small
252 islands with limited resources face challenges. For example, newly dug wells may not yield high-
253 quality water, and desalination plants have high investment costs.[37]

254

255 Conclusion

256 This study explored the limitations and control measures for clean water sources on two small
257 islands in Riau Islands Province, Indonesia, using a combination of closed-ended structured
258 questionnaires and interviews, along with direct observations.

259 The government has succeeded in improving residents' clean water access on both islands through
260 the construction of SWRO facilities. On Labu Island, the SWRO facility is supplied by a stable
261 electricity source from a generator, which allows the desalination process to operate uninterrupted.

262 In the future, more sustainable energy sources must be adopted. By contrast, the larger SWRO
263 facility on Belakang Padang Island is often disrupted due to its unstable electricity supply. As a result,
264 multiple water resources are required to provide residents with continuous access to clean water.

265 This facility should be powered by a generator to ensure a stable electricity supply.

266 Desalinated water is expensive, as the desalination process consumes large amounts of energy and
267 has high operating costs. However, on both islands, the cost of SWRO water is partially subsidized
268 by the government, ensuring that residents can afford clean water.

269 We surveyed residents living near the coast, where most houses lack septic tanks. The residents are
270 at risk of illness from exposure to water contaminated by wastewater or seawater intrusion during
271 tidal events. Therefore, it is imperative that septic tanks be installed in small, coastal communities
272 to improve sanitation.

273

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277

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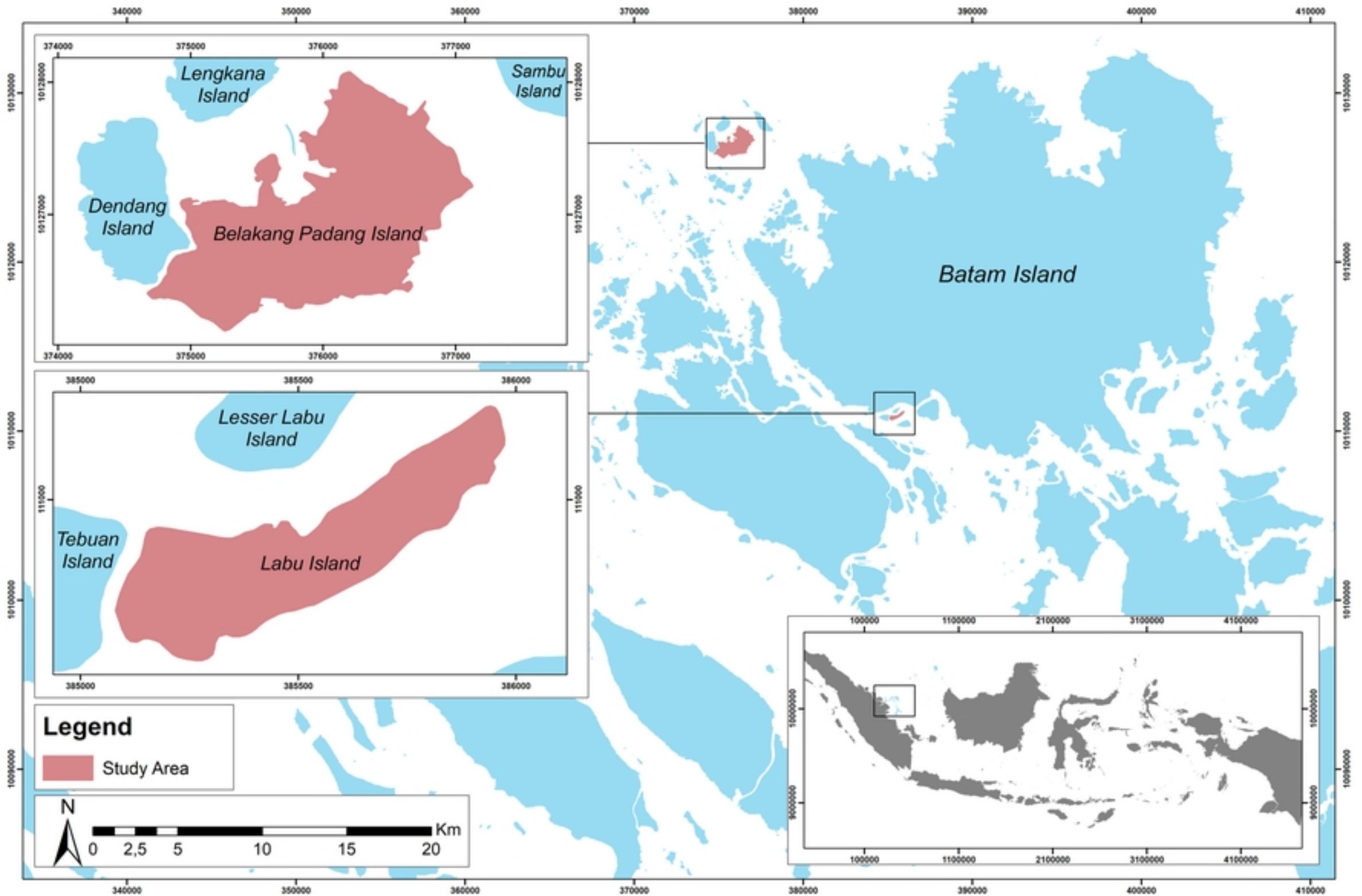


Figure 1

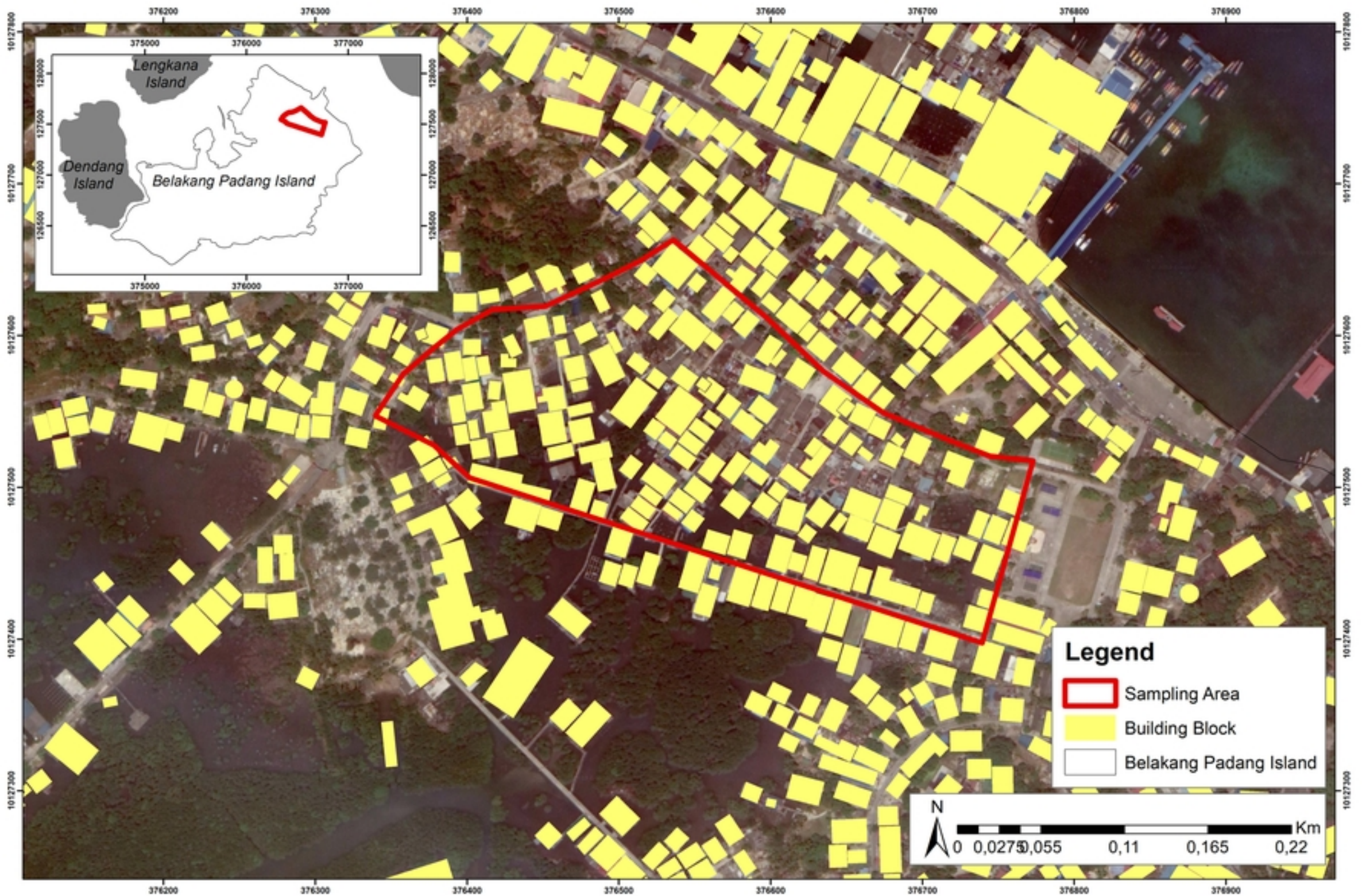


Figure 2 (a)

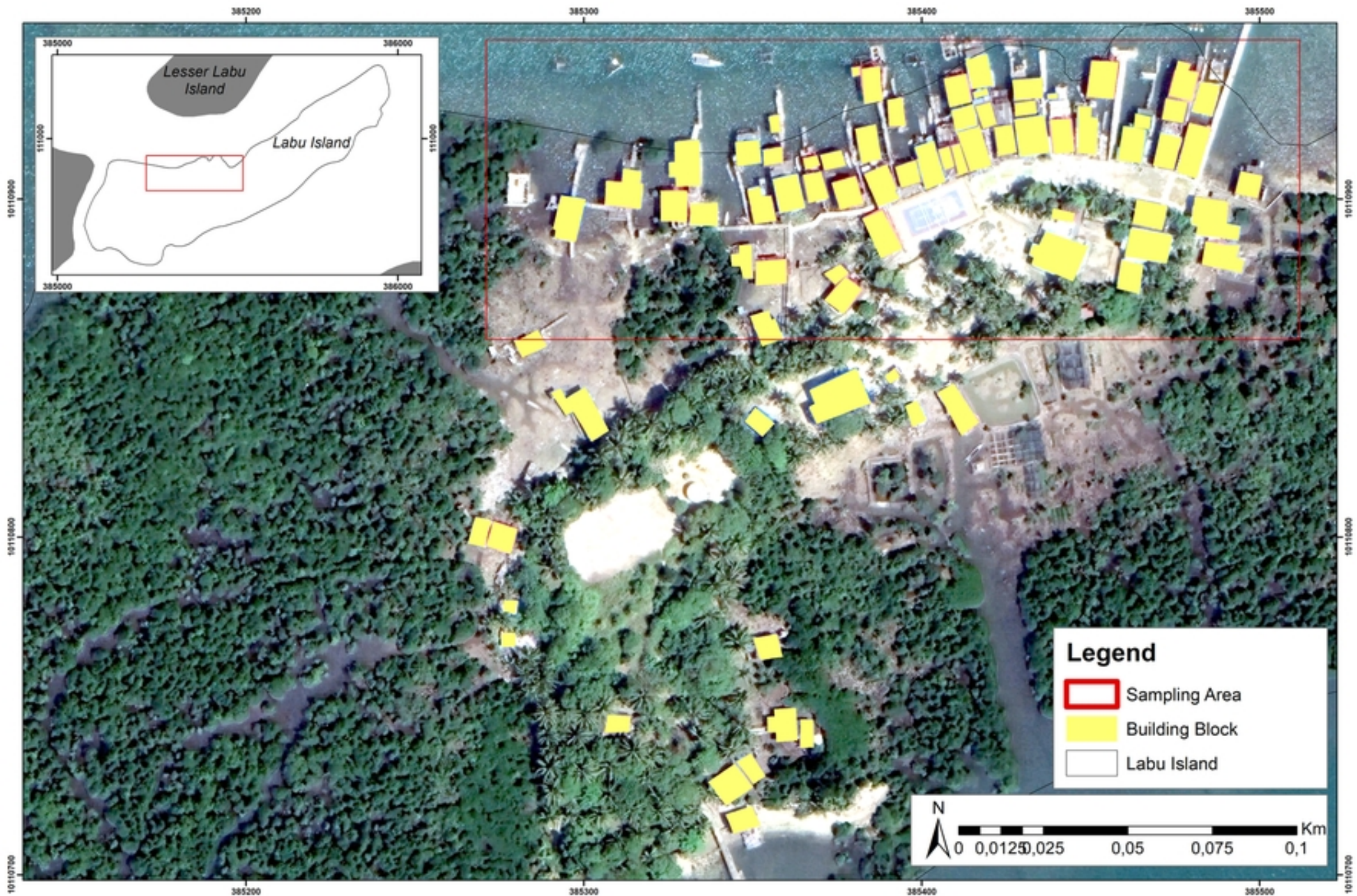
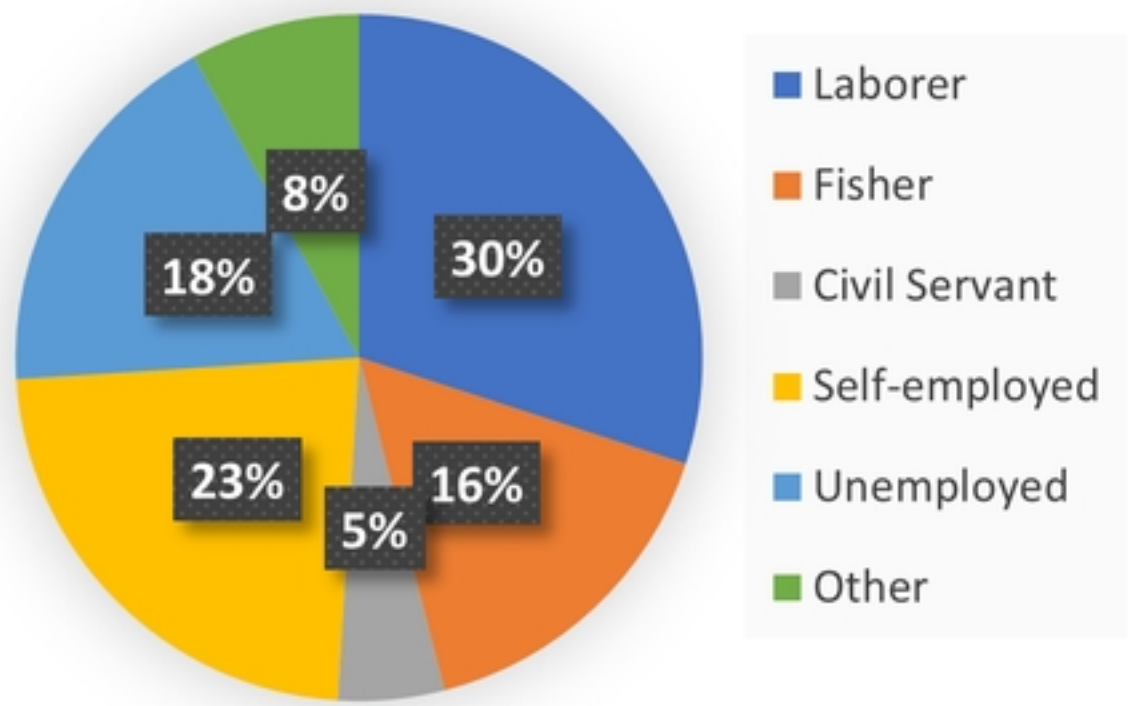


Figure 2 (b)



Figure 3

Belakang Padang Island



Labu Island

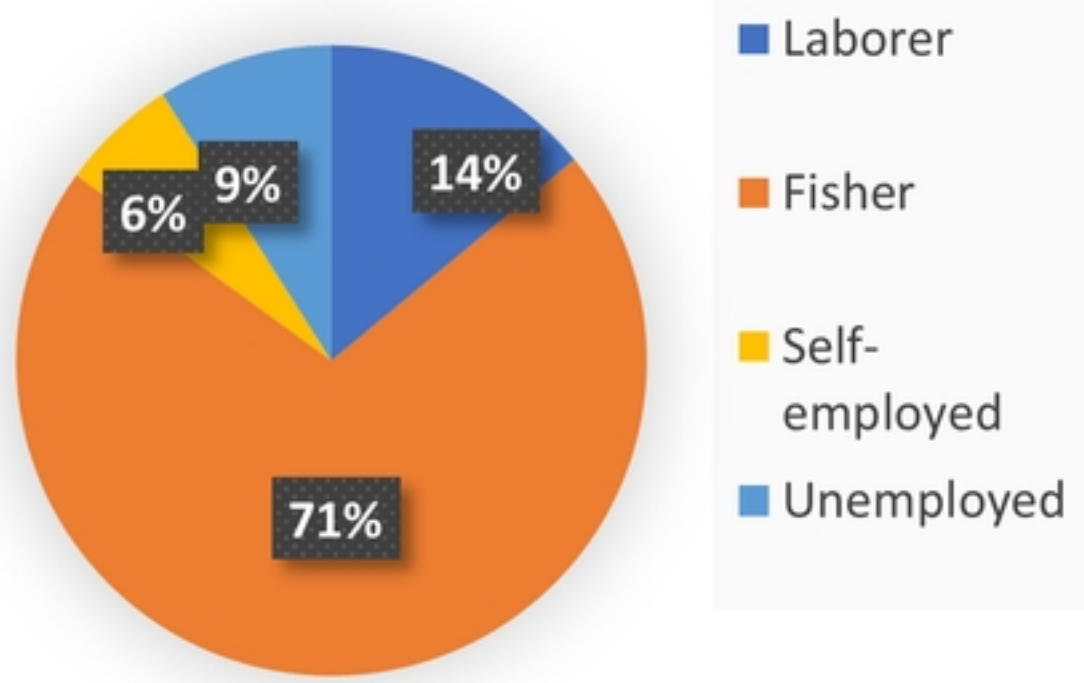


Figure 4



Figure 5