Carrying Capacity Based on Multi-Criteria Evaluation of Marginal Land for Catfish Farming in Gunungkidul Regency, Yogyakarta

Septriani, Nur Indah., Sudarmadji, and Baiquni

Abstract— The purposes of this study was to examine the spatial capacity of the environment, and to map sustainable land use. We used statistical analysis, scoring and weighting, for potential and existing variables, which were water quality, water quantity, slope, soil type, rainfall, land use, and socio-economic potential. We overlayed the variables using Geographic Information System (GIS) application to determine the suitable area for catfish farming.

The prioritized land areas for catfish farming development were 14.02% of the total area of Gunungkidul, with zones 3.23% located in Baturagung, 7.19% in Ledok Wonosari, and 3.58% in Karst Hills of the total area of Gunungkidul. The priority of development of the catfish farming was in Ledok Wonosari, or priority land I, comprising the sub-districts of Playen, Wonosari, Semanu, Paliyan, Karangmojo, Semin, and Ngawen.

Keywords— marginal land, carrying capacity, catfish, map overlay

I. Introduction

THE majority of agricultural areas in Gunungkidul Regency consist of karst lands (marginal lands). The karst area in Gunungkidul covers approximately 53.40% of the entire regency area, Therefore, plant cultivation in the regency is predominantly carried out in dry lands consisting of 68,734 ha of upland crop fields (*tegalan*) and 42,633 ha of home gardens (*pekarangan*). The farming productivity is still low. Low water availability is the main factor that inhibits the development of agriculture. The difficult water access is due to the deep aquifer and physical characteristics.

The society has made attempts to escape the powerlessness by taking advantage of rain water. As a matter of fact, rainfall in the area is reasonably high. Rainfall recording in Wonosari station showed that annual average rainfall for the 1978-2008 period in Gunungkidul is about 1940 mm/year [1]. Based on Soegiharto's study [2], rain water can be used effectively for aquaculture development.

The featured aquacultural production in Gunungkidul Regency is dryland catfish farming using either semi-permanent (sheeting-walled), permanent, or non-permanent pond and extensive, semi-intensive, or intensive technology. Nevertheless, the application of the technology is yet to be optimal as many farmers are not successful in the fish farming. So that, Study using mapping technology and carrying capacity was required to optimize the production of catfish farming. Besides, the zoning approach can provide important information for potential developers/ investors to identify the suitable zone that could meet certain objects for their maximum benefit [3].

Regional planning in terms of aquaculture not concerning environmental capacity and zoning approach will result in environmental problems along with their implicated aspects in the long run. Failure in the harvest of dryland catfish farming in Gunungkidul Regency means it requires better mapping of environmental carrying capacity which region is high, moderate, or low in terms of carrying capacity regarding dry land catfish farming and determine site selection. Site selection is a key factor in any aquaculture operation, affecting both success and sustainability as well as solving land or water use conflicts [4]. This study aims to examine the spatial carrying capacity of the environment, and to map the sustainable land use (site selection).

II. Theoretical Framework

1. Carrying Capacity

Possible form of absolute assessment is using the indicator of sustainability known as carrying capacity [5]. Carrying capacity is the maximum number of individuals or organisms that can be accommodated in a particular area in the long term. Carrying capacity in the ecological sense is defined as the maximum number of fish from resource of a particular habitat can support. Different regions with different characteristics have different levels of carrying capacity [6].

Carrying capacity of water in cultured fish is determined by metabolic loading density kg/l/min or kg food/day/m^3 or food/available oxygen/l/minute, the oxygen consumption rate of the fish and their response to ammonia, carbondioxide and other toxic metabolic produced. Carrying capacity is generally based physiological needs and spatial needs [7].

Carrying capacity of fish farming area with mathematical analysis, such as near-field semi-analytic solutions and rapid assessment using hydrodynamic and semi-analytic solutions [8;9] the weighting system referred to the modification of Multi Criteria Evaluation was used Salam, et al. [10] to

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determine carp farming potential in Barhatta Upazilla, Bangladesh.

2. GIS based on Multi-Criteria Evaluation

GIS based on Multi-Criteria Evaluation was used in Hossain and Das's research [6] to determine the basis of suitability for prawn farming in Noakhali, Bangladesh. Soil and water quality were measured from temperature, pH, Dissolved Oxygen, nitrite, phosphate, TSS, TDS, soil texture, slope, soil pH, organic matter, organic carbon, land use type. Infrastructure factors were measured from distance to road, electricity, market, fry source and labour availability. In Addition, GIS used for identifying suitable sites of Japanese scallop (*Mizuhopecten yessoensis*) to ensure both success and long-term sustainability of providing scallop productions [11]. In Haphong, Vietnam, thirteen base layers (thematic maps) were grouped into four main land use requisites for aquaculture, namely, (1) potential for pond construction (slope, land use type, soil thickness, elevation), (2) soil quality (soil type, soil texture, soil pH), (3) water availability (distance to sea, and water source), and (4) infrastructure and socio-economical status (population density, distance to roads, local markets, and hatcheries) [12]. It was used in Barhatta Upazilla, Bangladesh for aquaculture site selection [10], for sustainable shrimp culture in India [13], in Mahanadi Delta, India [14], identifying and mapping local by catch hotspot of loggerhead sea turtle [15], to identify for marine protection [16], critical regions [17], assessment of soft-shell clam sites [18], spatial pattern and habitat modeling of fish in two Frenc Meditteranean coastal areas [19]. Site selection for shellfish aquaculture on data-poor environment [20] .

Management in fisheries also can be analyzed by using GIS [21]. For example, the study to support fisheries management in the Patos Lagoon Estuary, southern Brazil. Artisanal fishing data were documented through a series of interviews conducted during and after fishing trips at harvest spots, and scientific data. GIS was also used, in what concerns the creation of coherent and well-organized touristic offer about fishing communities cultural heritage [22] , management decisions the Meramec River Basin [23], and sustainable management in lake Chilika [24]. Combining GIS and GAM can identify potential habitats of squid in the Northwestern Mediterranean [25].

3. Marginal Land

Critical land, or often termed marginal land, is a problematic land which requires particular technology in its utilization. According to the term, critical or marginal land is related to limitations, unprofitability, and marginal situation. The productivity of marginal land is highly determined by physical, climatic, hydrological, topographical, and soil-related characteristics. Higher slope gradients will result in even more complex problems as high rainfalls increase erosion rate.

4. Catfish Farming in Gunungkidul Regency

Based on Soegiharto's study [2], marginal lands in Gunungkidul are suitable for the development of catfish farming since this area has average rainfall 28,446 mm/year or 2,370.5 mm/month. The community can make water harvesting area. Based on the potential, the area that can be used for catfish farming is 146,700 hectares out of the total Gunungkidul area (1,485.36 km^2). The percentage of land available for the cultivation of catfish is 2.3% of the total area available, while the land currently used for catfish farming is 23,019 m^2 or 0.16% of the total area with 1,412,544 kg of production. The results of Soegiharto's study become the theoretical basis for this research.

III. METHOD

This research located in Gunungkidul Regency, in southern area of Yogyakarta Province (110°28'12" - 110°50'24" BT dan 7°46'48" - 8°12'36" LS). It consists of 18 Districts and 114 Villages. The districts were Patuk, Nglipar, Gedangsari, Ngawen, Semin, Ponjong, Playen, Wonosari, Karangmojo, Semanu, Paliyan, Purwosari, Panggang, Saptosari, Tanjungsari, Tepus, Girisubo, and Rongkop.

The methods used were the statistical analysis, scoring, weighting and mapping. The study was conducted on potential and existing variables, and overlay maps of water quality, water quantity, rainfall, slope, soil type, land use, and socio-economic potential using Geography Information System (GIS) application as in Longdill et al. [26] to support identification of the most suitable sites for sustainable open coast *P. canaliculus* zoning within the Bay of Plenty, New Zealand. Aplication of Remote Sensing in choosing a site aquaculture for carp farming in urban water bodies of Chittagong, Bangladesh, and for giant prawn (*Macrobrachium rosenbergii* in Companigonj Upzila of Noakhali, Bangladesh grouped as water quality, soil quality, topography, infrastructure and socio-economic [3:4]. Vincenzi et al. [27], use GIS to determine habitat suitability model for commercial yield estimation of *Tapes philippinarum* in a Mediterranean coastal lagoon (Sacca di Goro, Italy). Karthik, et al. [28], identified the potential area for the commencement of sustainable shrimp farming in Palghar Taluk, Thane district of Maharashtra, India, using techniques of remote sensing and GIS. Another application, on actual control of land use through maximal utilization of detailed grid data with advanced GIS functions [29].

In this research, aspects in selecting the aquaculture site referred to *Aquaculture Site Selection* published by the *African Regional Aquaculture Centre*, Port Harcout, Nigeria [30] and were classified into non technical (socio-economic, legal, and policy-related) and technical (climate, water availability, water quality, land, topography, system, soil and vegetation) factors. Several methods were used for analyzing environmental carrying capacity of brackish water fish farming (*tambak*) in Indonesia. The determination of the environmental carrying capacity of fish farming area with the weighting system referred to the modification of Purnomo's idea, which was applied by Ratnawati and Asaad in Berau. Formula 1 is the

weighting formulation in the study of environmental carrying capacity.

Score : (Scoring A X Weighting Factor A) + ……

…… (1)

Devices used in the study included RBI map, topography map, soil type map, Gunungkidul rainfall map with the scale of 1:25.000, a GPS device, a digital camera, a water quality checker, software Arc GIS 10.1, a coolbox, a tape measure, sample bottles, and stopwatch. The material to study was spring water sample from Baturagung hills, Ledok Wonosari, and Karst hills; water sample from the fish ponds as the applied technology pilot project; and questionnaires on people's perception on catfish farming development. Fig. 1. describes research framework based on Multi-Criteria Evaluation of Biophysisc and Socio-economic.

RESEARCH FRAMEWORK

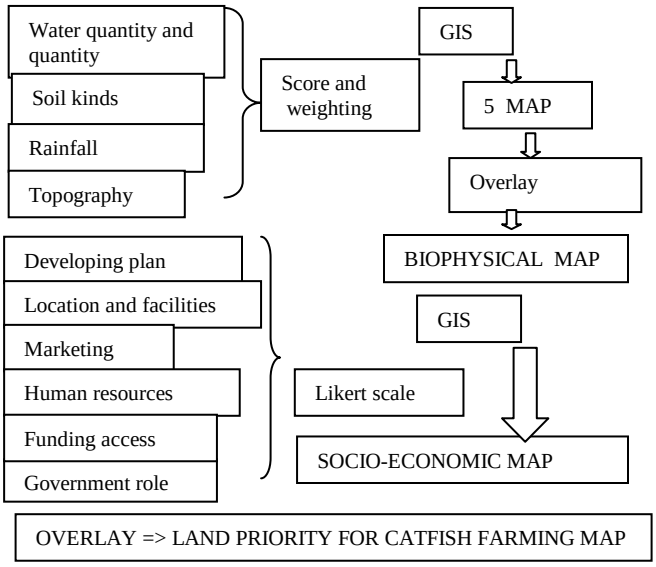

Fig.1. Research framework based on Multi-Criteria Evaluation

IV. RESULT

Biophysical and socio-economic data were obtained from survey and secondary data. Biophysical potential include water quantity, water quality, rainfall, topography and soil map. Socio-economic potential of the fish farming development include people's perception on its impact, developing plan, location, facility and fund accessibility, marketing, human resource and management, and government role.

1. *Biophysical potential*

Water quantity

Water balance is water supply from rain water, ground water, spring, cave, river, lake, and reservoir compared to domestic water consumption. From the water balance analysed in 2007 and the predicted water balance in 2015, 16 villages will be estimated to be water crisis areas. This data was obtained from secondary data. Table 1 shows the villages predicted as the crisis areas.

TABLE 1
VILLAGES ANALYSED AND PREDICTED AS WATER CRISIS AREAS IN 2007, 2010 AND 2015

No	Sub-district	Village	Year 2007	Year 2010	Year 2015
1.	Girisubo	Karangawen	0	-951.3	-7407.5
		Songbanyu	0	-13513.1	-67025.9
2.	Ponjong	Bedoyo	-25910.4	-29334.8	-35236.0
		Gombang	-14620.7	-31553.4	-65369.5
		Karangasem	-29689.6	-35735.9	-46683.2
3.	Purwosari	Giricahyo	-38135.9	-44864.2	-56783.7
4.	Rongkop	Bohol	0	-328.5	-1815.5
		Botodayakan	-29119.7	-44717.2	-73631.0
		Karangwuni	0		-30477.1
		Melikan	-6741.7	-24993.0	-61329.7
		Petir	-1552.7	-13186.4	-34804.1
		Pringombo	-9759.7	-15408.1	-25368.8
		Semugih	-6532.8	-11202.1	-19298.1
5.	Saptosari	Kepek	0	0	-1717710.0
		Krambil Sawit	0	-39219.6	-182266.9
6.	Tepus	Giripanggung	0		-11451.4

Source : Secondary data, Bappeda (2007)

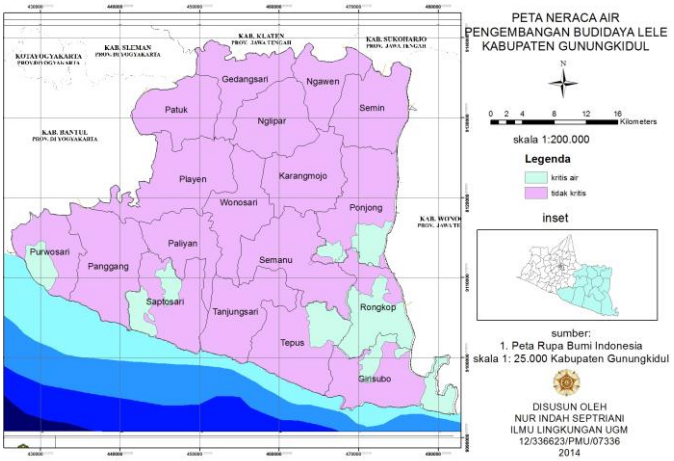

Fig.2. Water balance area of Gunungkidul Regency

Water crisis areas are located on the Karst hills and occur because of the hydrological structure. Water easily passes through the soils on Karst hills, so the soils cannot hold the groundwater. The water flows trough ponor or luweng (cracks), so in this zone no underground river can be found. Water crisis areas are not recommended for dryland catfish farming. Fig.2. Shows water balance of Gunungkidul Regency. The blue colour describes critical land area and the pink one describes surplus water area.

Watr quality

Gunungkidul have unique characteristics because this area is generally karst area consisting of limestones, so that the water contains a lot of $CaCO_3$ (water pH tends to base), more easily contaminated with water pollutants from agriculture, livestock or domestic wastes.

Water quality map was obtained from parameter scoring of water quality such as temperature, turbidity, pH, DO, and the amonium, nitrate and nitrite contents. It was classified into high, medium and low quality. Low water quality is not recommended for dry land catfish farming. Here is an overview of water quality in Baturagung, Ledok Wonosari and Karst hills (Table 2). Based on Camargo [31], fresh water animals, included catfish, appear to be more sensitive to nitrate than marine animal.

TABLE II
WATER QUALITY FOR CATFISH FARMING IN GUNUNGKIDUL

Name of Zone	Parameter	Value	Total	Category	%
Baturagung	Temperature	4.5			
	Turbidity	2.5			
	pH	5			
	DO	4.5			
Name of Zone	**Parameter**	**Value**	**Total**	**Category**	**%**
	Amonia	3			
	Nitrate	4.5			
	Nitrite	5	29	High	82
Ledok Wonosari	Temperature	4.67			
	Turbidity	2.3			
	pH	5			
	DO	5			
	Amonia	4.3			
	Nitrate	4			
	Nitrite	5	30.27	High	86
Karst Hills	Temperature	4.2			
	Kekeruhan	2.2			
	pH	5			
	DO	5			
	Amonia	4.2			
	Nitrate	4.2			
	Nitrite	5	29.80	High	85

Fig. 3 shows water quality map for dry land catfish farming in Gunungkidul Regency

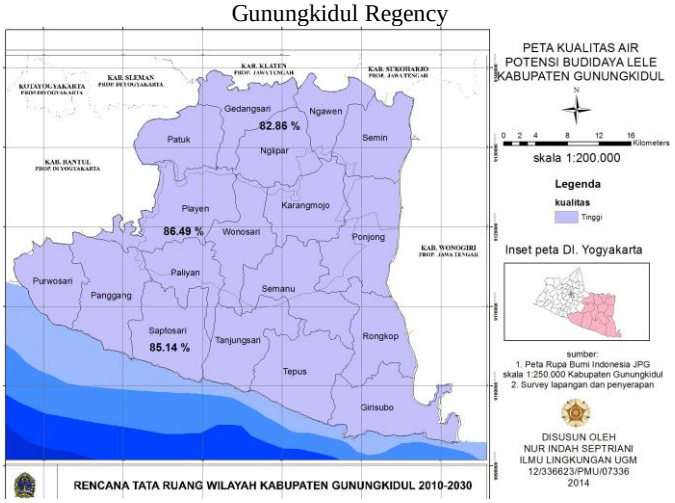

Fig. 3 Water quality for dry land catfish farming in Gunungkidul

Rainfall

Rainfall is an important factor to develop of catfish farming in Gunungkidul. It can be classified into: low rainfall with rainfall < 1500 mm/year, medium rainfall with 1500-2500 mm/year of rainfall and high rainfall with ≤2500 mm/year of rainfall. The area with the lowest rainfall is Semin. Ledok Wonosari has medium rainfall (1500 -<2500 mm/year) without any rainfall variations. The Karst hills area has medium to high rainfalls. Some areas near the seashore had higher rainfalls than the others and it was related with high evaporation. Fig. 4 shows rainfall in Gunungkidul.

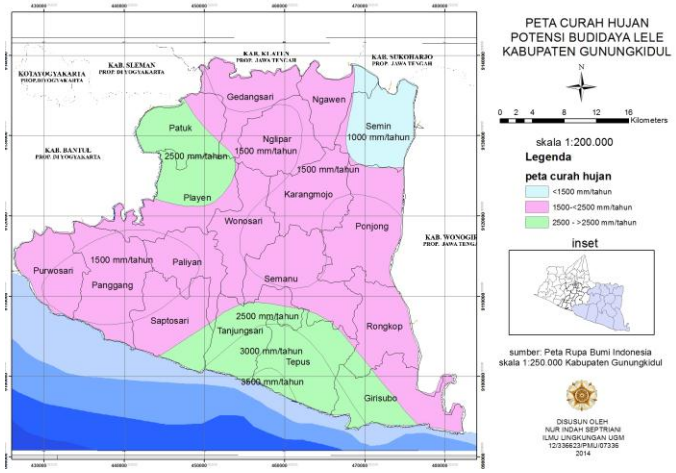

Fig. 4. Rainfall in Gunungkidul Regency

Topography

In terms of topography, the required slope gradient for catfish farming is 0-8%. Slope gradient higher than 8% is difficult to make ponds. Flat areas are more potential for the development of catfish farming because of the small possibility of flooding during heavy rains. Areas with 0-8% slope gradient (flat) are predominantly located in Ledok Wonosari while areas in Baturagung and Karst Hills had steep topography. Fig. 5. shows topography in Gunungkidul Regency

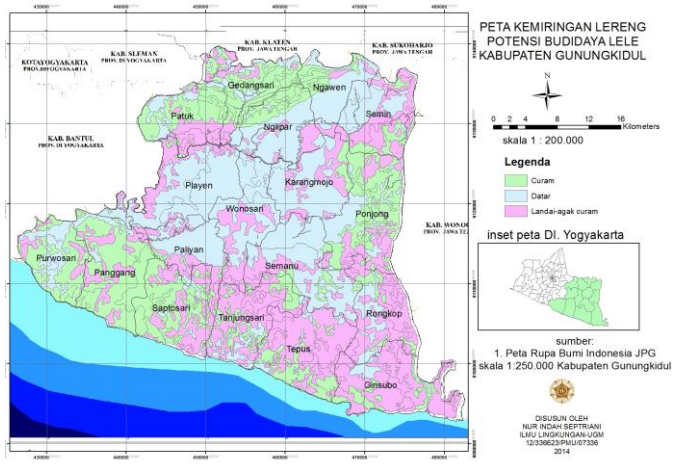

Fig.5. Topography in Gunungkidul Regency

Soil type

With regard to soil type, soils in Gunungkidul regency consist of Black Grumusol, Red Latosol, Lithosol, Lithosol and Red Mediterranean, Rendzina and Red Mediterranean, and Rendzina. For the maintenance of dry land catfish farming, the required soil type is that with low porosity, neutral pH, high content of organic compound, and thick bottom. Based on those characteristics, soils suitable for dry land catfish farming are Black Grumusol and Rendzina. On the map, Black Grumusol was located in the districts of Playen, Wonosari, Semanu, Karangmojo, and Ponjong. Fig. 6. shows soil type in Gunungkidul.

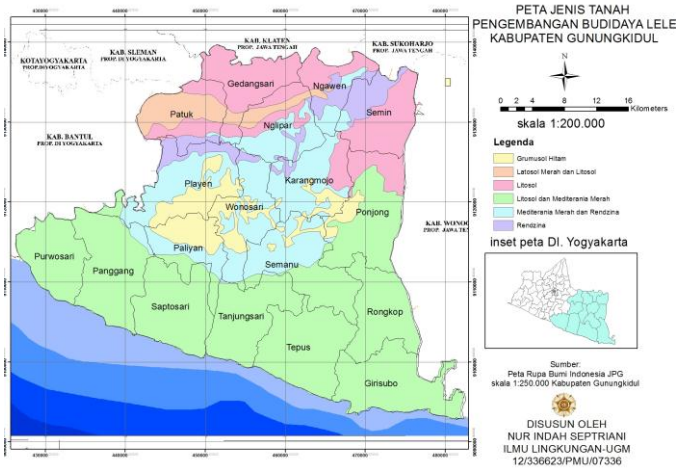

Fig. 6 Soil type in Gunungkidul Regency

Overlay biophysical map

Overlay of biophysical map produced 48 units of land. The land was to be scored and classified into potential categories. The results showed that in terms of biophysical potential for the development of catfish farming, Baturagung scored 66.42% (medium), Ledok Wonosari 75.43% (high) and Kars Hills 62.16% (medium). Fig. 7 shows biophysical potention in dryland catfish farming.

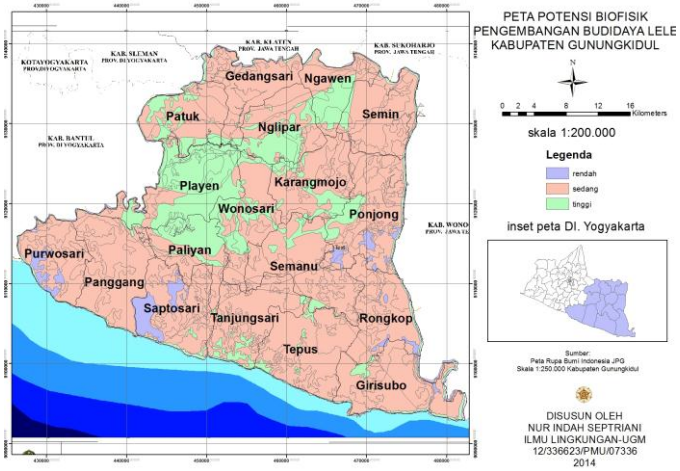

Fig.7. Biophysical potention of catfish farming development in Gunungkidul

2. Socio-economic potential

The socio-economic map was obtained from the societal perception on the impact of farming, developing plan, location, marketing, human resources and management, facilities and funding access, and the government roles. Data were obtained from 30 respondents on each zone consisting of members of the successful Pokdakan (fish farming group), members of the failed Pokdakan and people outside Pokdakan. We found that socio-economic potential was 77.04% in Baturagung, 77.41% in Ledok Wonosari, and 73.04% in Karst hills. Socio-economic condition in Baturagung, Ledok Wonosari and Karst Hills were high, meaning that the society agree about the development of dryland catfish farming in Gunungkidul.

The socio-economic constraints in developing the catfish farming in Baturagung included access of marketing, and management and implementation of the proper fish farming guidelines or CBIB (*Cara Budidaya Ikan yang Benar*). In Ledok Wonosari, the market price was not proportional with the cost. In the Karst area, the constraints included the difficulty to get building materials, equipment and feed cost, difficult market access, and the low market price disproportionate with the cost. We concluded that there were problems with the marketing strategy, the management, and the water access in dry season but they could be overcome with technology and intensive monitoring. Fig. 8. Shows socio-economic of dry land catfish farming development in Gunungkidul Regency.

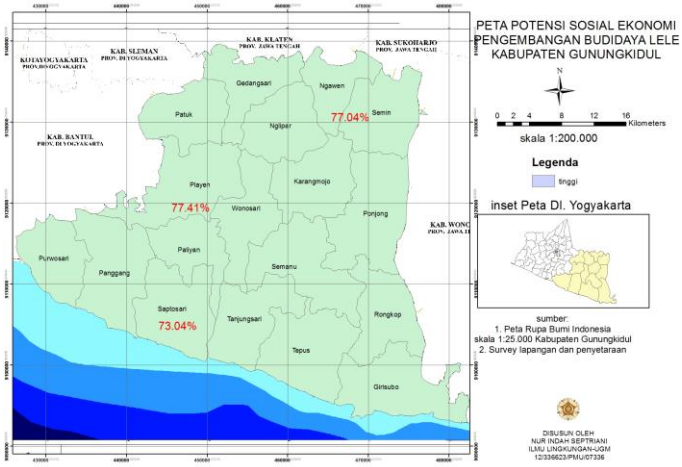

Fig. 8. Socio-economic of dryland catfish farming development in Gunungkidul Regency

Overlay of the biophysical and the socio-economic potential

Overlay of the biophysical and the socioeconomic potential is aimed to get the total of environmental carrying capacity and land priority map. The environmental carrying capacity was71.73% in Baturagung, 76.42% in Ledok Wonosari, and 67.59% in Karst Hills. The prioritized land areas for catfish farming development were 14.02% of the total area of Gunungkidul, with zones were 3.23% located in Baturagung, 7.19% in Ledok Wonosari, 3.58% in Karst Hills of the total area of Gunungkidul. High carrying capacity was 11.30% of the total area of Gunungkidul, medium carrying capacity

2.72% of the total area of Gunungkidul, and non-priority area 85.98% of the total area of Gunungkidul. Fig. 9. shows carrying capacity or total potention of dry land catfish farming in Gunungkidul Regency.

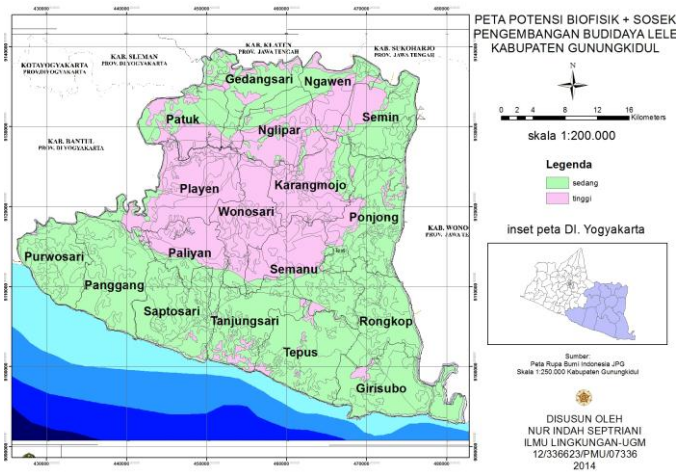

Fig. 9. Carrying capacity or total potention of dry land catfish farming in Gunungkidul Regency.

After that, the potential map was overlayed with land use map which resulted land priority for dry land catfish farming development. Fig. 10. Shows land priority of dry land catfish farming in Gunungkidul Regency.

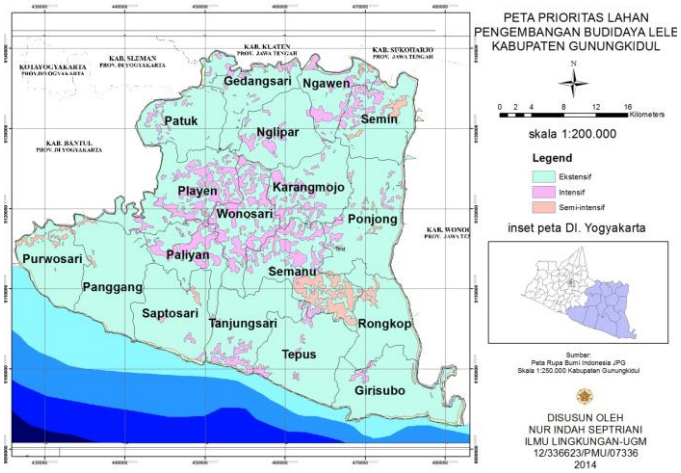

Fig. 10. shows land priority of dryland catfish farming in Gunungkidul Regency.

V. Discussion

The majority of highly prioritized lands for the development of catfish farming were in Ledok Wonosari. Highly prioritized lands were predominantly in Ledok Wonosari, the characteristics of which include close water sources, flat topography, and short distance to the center of local government; therefore, the people were of high economic status.

The distribution of the fish farming groups (*Pokdakan*) was not proportional with the land potential. However, in Playen sub-district,it was suitable with the land potential as this sub-district had been designated as the area for the pilot project of *minapolitan* (fishery zone). Meanwhile, many *Pokdakans* in other sub-districts were laid off. Therefore, it is also necessary to prioritize the catfish aquaculture development in terms of administration. First priority area should be more than 20% of the entire region, including high-priority zones for catfish farming. Second priority area should have catfish farming zone less than 5-20%. Conservation region is the area with less than 5% of the catfish farming priority zones.

Included in the first priority areas are the sub-districts of Playen, Wonosari, Semanu, Paliyan, Karangmojo, Semin, and Ngawen. The second priority areas include the sub-districts of Tanjungsari, Nglipar, Ponjong, Gedangsari, Patuk, Girisubo and Saptosari. Meanwhile, areas prioritized for water conservation comprise the sub-districts of Rongkop, Purwosari and Panggang. Based on the existing, findings, the application of technology is not quite compatible with the land potential. So, for optimizing the budget, we must give attention to the development of catfish farming according to the land potential. The relationship between the number of *Pokdakans* and the land priorities in each district is shown in Fig. 11.

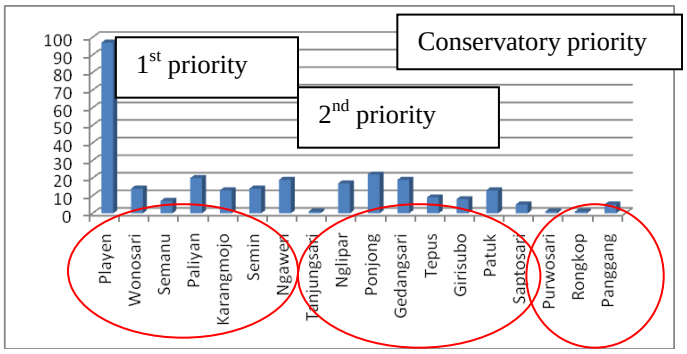

Fig. 11. The relationship between the number of *Pokdakans* and the land priorities in each district

VI. Conclusion

Environmental carrying capacity was 71.73% in Baturagung, 76.42% in Ledok Wonosari, and 67.59% in Karst Hills. The priority of land area for catfish farming development was14.02% of the total area of Gunungkidul with 3.23% of them were in Baturagung, 7.19% in Ledok Wonosari, and 3.58% in Karst Hills.

The priority of development of catfish farming was in Ledok Wonosari, namely the priority land I, comprising the sub-districts of Playen, Wonosari, Semanu, Paliyan, Karangmojo, Semin, and Ngawen.

Acknowledgment

The authors would like to thank DIKTI for funding this research. Mr. Riptanto Edi Widodo, Mr. Deddy Budiono, Mr. Anjal Anie Asmara, Mr. Adhita Sri Prabakusuma, Dr.Titik Soegiharto, Mr. I Nyoman Radiarta, Prof. Rustadi and Dr. Eko Haryono who help the researcher to collect data and to consult the research concept.

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