The application of groundwater availability and quality indices on the pre-selection of sustainable Whiteleg shrimp (*Litopenaeus vannamei*) ponds in the sandy coastal area of Bantul, Indonesia

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Abstract. Improved efficiency in water use is one of the main priorities of the sustainable intensification of aquaculture. This study aims to investigate groundwater suitability in a sandy coastal area, in Bantul, to develop sustainable whiteleg shrimp (*Litopenaeus vannamei*) ponds in pre-selection. The groundwater suitability was evaluated by using the Groundwater Availability Index (GWAI) and Groundwater Quality Index (GWQI). GWAI was used to determine a ratio between the demand and the safe yield of groundwater. GWQI used to analyze groundwater quality consisted in the determination of physico-chemical parameters (salinity, temperature, turbidity, total suspended solids, pH, dissolved oxygen, BOD-5, ammonia, phosphate and organic matter) and a biological parameter (total Vibrio). The result shows that GWAI ranges from 240 to 428, indicating that the groundwater is under the "very critical" condition and its use has faced overexploitation. However, the GWQI ranges from 65.96 to 98.37, explaining that the groundwater quality is good for shrimp farming. Based on these two indices, it is concluded that groundwater in this area is not suitable for the development of shrimp ponds. The next step in the site selection of shrimp ponds can be continued, but focused on regulating shrimp ponds under the physical and production carrying capacity.
Key Words: GWAI, GWQI, vannamei shrimp farming, sustainable development.

Introduction. Within the last decade, shrimp farming has been the fastest growing sector in the agri-food sectors (Henriksson et al 2018; Joffre et al 2018). Since 2014, Indonesia, along with China, Vietnam and India, has been the biggest producer of shrimp in the world (FAO 2018). This business has positive impacts and multiplier effects in society through its role in supplying food, employment, local income and national foreign exchange (Klinger & Naylor 2012; Phillips et al 2016). Nevertheless, uncontrollable expansion and intensification of shrimp farming have brought negative impacts on society, economy and environment (Islam & Tabeta 2016; Phillips et al 2016). Learning from this experience, the development of shrimp farming in the future should be improved through sustainable intensification (Ahmed & Thompson 2017; Henriksson et al 2018; Little et al 2018). It can be achieved by improved governance and management practices (FAO 2016) and the adoption of innovative technology (Joffre et al 2018).

Related to the technology innovation, Indonesia has developed intensive shrimp farming in the sandy coastal area by using biocrete or polyethylene plastic as pond liners (Triyatmo et al 2016; Triyatmo et al 2018). These ponds are called "on-sand shrimp ponds" or "lining shrimp ponds". From an environmental aspect, the development of the on-sand shrimp ponds can improve the efficiency and effectiveness of the marginal land of a sandy coastal area, and at the same time can avoid the destruction of mangrove forests, estuarine and the other intertidal ecosystems. On-sand shrimp ponds are also proven to generate high production and productivity (Priyono et al 2005). Located on the southern coast of Java, Bantul is well-known as the pioneer of on-sand shrimp ponds and recently became the center of Indonesian shrimp production (MMAF 2016). Currently, the farmed shrimp farmed is whiteleg shrimp (*Litopenaeus vannamei*) (Triyatmo et al 2016; Djumanto et al 2016; Samadan et al 2018; Triyatmo et al 2018). The need for brackish water for shrimp is fulfilled by pumping groundwater in the coastal area (Triyatmo et al 2016; Triyatmo et al 2018).

In order to achieve environmental sustainability, the development of on-sand shrimp ponds have to consider the carrying capacity, including an efficient use of water as part of the physical carrying capacity (Ross et al 2013). This is also the main priority in the sustainable intensification of aquaculture (FAO 2016; Ahmed & Thompson 2017). Challenges exist, since intensive shrimp farming tends to use a lot of water (Verdegem & Bosma 2009; Bosma & Verdegem 2011). Therefore, a comprehensive evaluation of the availability and quality of water is needed in developing sustainable shrimp farming. This should be done in the pre-selection stage or before the site selection for shrimp ponds (Beltrame et al 2006; Ferreira et al 2011).

Within the last decade, the evaluation of water availability has been carried out by using the water availability index (WAI). The first WAI was introduced by Meigh et al (1999), and was defined as the ratio between the yield and total water demand. In another study, Mohammed & Ghazali (2009) used WAI based on the ratio between demand and yield. In the scientific literature, the term "water availability" is frequently defined as water scarcity, water stress or critical water. In the context of aquaculture, there are few studies on this subject, because there is an assumption that the supply of existing water resources is still able to meet water uses. As a result, recent studies only measure water use in aquaculture, without analyzing its availability (Verdegem & Bosma 2009; Sharma et al 2013). To accommodate the two variables, Muis et al (2017) have attempted to evaluate the water uses and their availability within aquaculture. However, the study is perceived as less comprehensive, since the non-aquaculture water uses are not calculated.

An evaluation of water quality has also been carried out by using the water quality index (WQI). WQI is a single value that expresses water quality by aggregating physical, chemical and biological parameters in a mathematical approach (Saeedi et al 2010; Lumb et al 2011). However, to date, the use of WQI in aquaculture is limited only to surface water (Beltrame et al 2006; Ferreira et al 2011; Simoes et al 2008; Ma et al 2013; Tallar & Suen 2016; Mohanty et al 2018). On the other hand, the use of WQI for groundwater is commonly focusing on the need for drinking (Vasanthavigar et al 2010; Rajanankar et al 2011; Kumar & James 2013).

This study aims to investigate the suitability of groundwater in the Bantul sandy coastal area, for developing sustainable whiteleg shrimp ponds in pre-selection by using the Groundwater Availability Index (GWAI) and the Groundwater Quality Index (GWQI).

Material and Method

Study area. This research was conducted in the sandy coastal area of Bantul, which is located in the south of Java. The study covered land areas with a distance of 1 km from the coastline, in the south directly adjacent to the Indian Ocean and in the west and east bordered by the Progo River and the Opak River, respectively. In the north it is bordered by agricultural land and settlements. The allocation of whiteleg shrimp ponds in Bantul was divided into three development areas, namely western, central and eastern regions (Figure 1). The area dominated by sand dunes (Triyatmo et al 2018), with a sand content ranging from 81 to 95% (Priyono et al 2005).

Data collection. The availability of groundwater was estimated through the water stored in the aquifer units or landforms. Groundwater uses were derived from land use in the study area. The determination of the groundwater requirement standard was based on relevant literature and the result of a field survey. For this purpose, landforms and land use maps were created through interpretation and digitization on computer, using the World View 2 image 2018, and supported with a digital version of the Indonesian Topographic Map 2013, within the scale of 1:25.000. ArcGIS 10.2 software was utilized for mapping and spatial analysis.

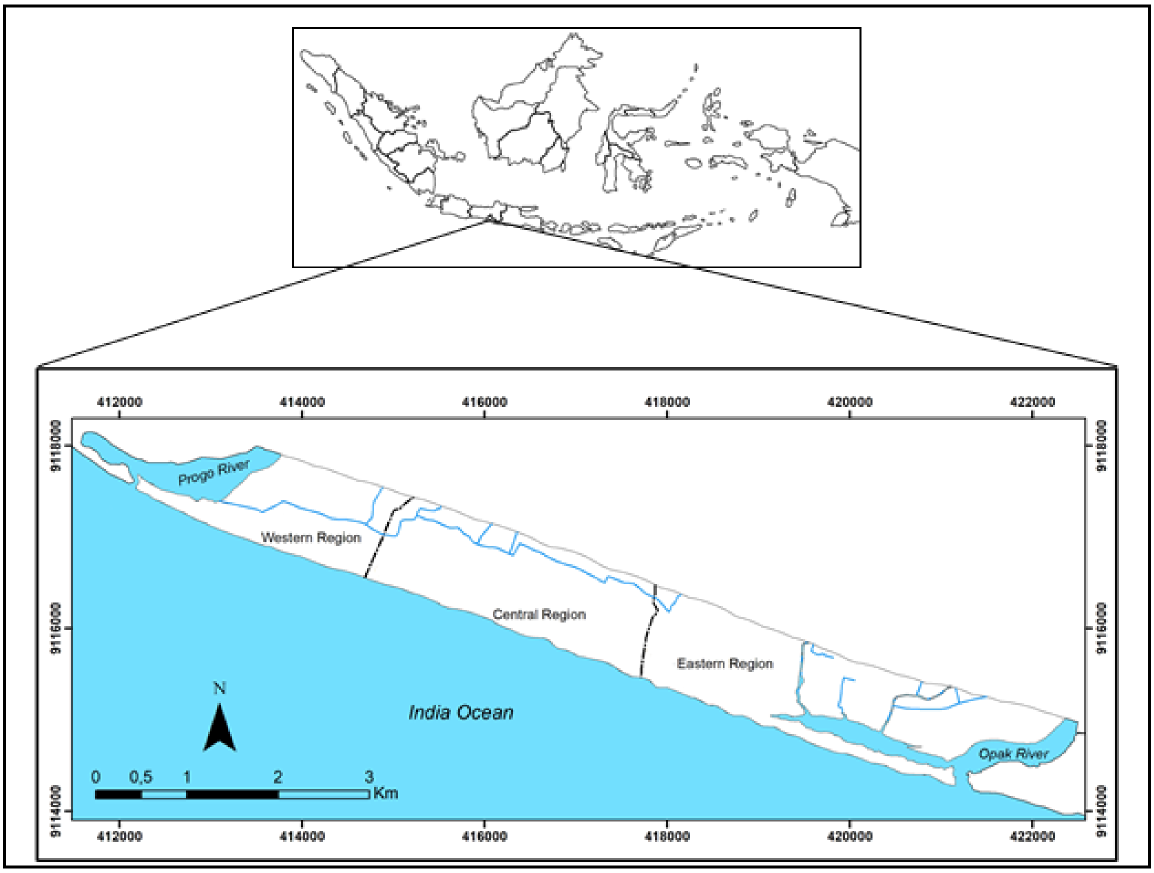

Figure 1. The study area in the sandy coastal area of Bantul, Indonesia.

Samples for water quality determinations were collected from January to February 2017, from three shrimp pond development areas, namely western, central and eastern regions. In each region, the samples were collected from three observation points, around the coastline area, shrimp ponds area and the upper shrimp pond areas. The collection was carried out in the morning (8–11 AM) to avoid the difference from daily fluctuations (Ma et al 2013). Physico-chemical parameters, temperature, salinity, turbidity, total suspended solids (TSS), pH, dissolved oxygen (DO), BOD-5, ammonia, phosphate, and organic matter and biological parameters (total Vibrio) were included in the determinations conducted for groundwater quality. Temperature was measured with a mercury thermometer, salinity with a hand refractometer, pH with a digital pH meter and DO with the Winkler method titration. These parameters were determined *in situ*. BOD-5, determined by the Winkler method titration, and total Vibrio (TCBS culture media) were measured at the Fisheries Department Laboratory Gadjah Mada University. The turbidity, measured with a NTU digital turbidimeter, TSS (determined by gravimetry), ammonia (determined by spectrophotometry), phosphate (determined by spectrophotometry) and organic matter (determined by permanganometry titration) were measured at the Yogyakarta Health Laboratory Center. Sampling, preparation and measurement of groundwater quality parameters were based on APHA (1998) methods.

Groundwater Availability Index (GWAI). In this study, GWAI was defined as a ratio between the demand and availability of groundwater. The availability of groundwater was calculated by static modeling based on the volume of groundwater, which could be released from each aquifer unit (Purnama 2012; Santosa & Adji 2014). The groundwater availability was estimated by the following equations:

$$Wav=AxhxSy$$

$$Wsy= AxFxSy$$

Where: Wav - groundwater availability (m^3 $year^{-1}$); Wsy - safe yield of groundwater utilization (m^3 $year^{-1}$); A - cross-sectional area of the aquifer unit (m^2); h - thickness average of the aquifer (m); F - fluctuation of groundwater-surface level (m); Sy - specific yield or the percentage of groundwater released from the aquifer unit (%).

Table 1

The availability and safe yield of groundwater in the sandy coastal area of Bantul based on the aquifer units

The aquifer units	*Area (m^2)*	*Thickness (m)*	*Fluctuation (m)*	*Sy (%)*	*Availability (m^3 $year^{-1}$)*	*Safe yield (m^3 $year^{-1}$)*
Western:						
Fmp	1059660	100	2.5	15	15894900	397372
Cbr-sd	771200	40	2.5	38	11722240	732640
Total	1830860				27617140	1130012
Cetral:						
Fmp	1248360	100	2.5	15	18725400	468135
Cbr-sd	1855810	40	2.5	38	28208312	1763020
Total	3104170				46933712	2231155
Eastern:						
Fmp	2598670	100	2.5	15	38980050	974501
Cbr-sd	1155110	40	2.5	38	17557672	1097354
Total	3753780				56537722	2071855
Grand total	8688810				131088574	5433022

Note: the aquifer units and area (A) were generated from the interpretation of World View 2 image 2018; the thickness of the aquifer (h), fluctuation (F) and specific yield (Sy) are based on Purnama (2012) and Santosa & Adji (2014); Fmp - fluvio-marine plains; Cbr-sd - complex of beach ridges and sand dunes.

The groundwater availability and safe yields are presented in Table 1. The demand for groundwater was estimated by the following equation (NSAI 2002):

$$Wd=Wdo+Wnd+Wag+Wls+Waq$$

Where: Wd - total groundwater demand (m^3 $year^{-1}$); Wdo - domestic groundwater uses; Wnd - non-domestic groundwater uses; Wag - agricultural groundwater uses; Wls - groundwater uses for livestock; Waq - aquaculture groundwater uses.

The standard of domestic water uses is 60 L $person^{-1}$ day^{-1} (NSAI 2002). Non-domestic groundwater uses is limited to tourism activities, where standard water use is 0.2 L $second^{-1}$ ha^{-1}. The tourism activities are assumed to take place only on holidays and there are 115 such occasions within a year. Groundwater uses for agricultural land are allocated for dryland rice fields and drylands. Within a year, the dryland rice fields are used to cultivate paddies for two planting seasons and horticultural plants for one season. On the other hand, the drylands are only able to cultivate horticultural plants for three seasons in a year. Both for paddy and horticultural plants, it is assumed that every planting season (PS) takes 120 days. In this study, the effective area of dryland rice fields and drylands is assumed to be 75% of the total area. The standard of water uses for paddy in dryland rice fields is 9350 m^3 ha^{-1} PS^{-1} and for horticultural plants is 6440 m^3 ha^{-1} PS^{-1} (Dariah & Heryani 2014). Groundwater for livestock is destined to large livestock (cow and buffalo), small livestock (goat and sheep) and poultry (chicken and duck). The standard of water uses for cow and buffalo is 60 L $animal^{-1}$ day^{-1}, for goat and sheep is 6 L $animal^{-1}$ day^{-1}, while for chicken and duck are 0.6 $animal^{-1}$ day^{-1} (NSAI 2002). Water uses for aquaculture activities are intended for shrimp farming. Based on the in-depth interviews, shrimp ponds are used to culture shrimp for three crops in a year, every crop taking 90 days. The effective area of shrimp ponds is assumed to be two thirds, or 66.67% of the shrimp farming area. The standard of water uses for shrimp farming, assuming the pond water depth is 120 cm, is 84000 m^3 ha^{-1} $crop^{-1}$. The groundwater uses are presented in Table 2.

Table 2

Groundwater uses in the sandy coastal area of Bantul

Groundwater uses (m^3 $year^{-1}$)	*Western*	*Central*	*Eastern*	*Total*
Domestic	23652	16644	5256	45552
Non-domestic	10420	18869	2601	31892
Agricultural	1496513	3446283	2727222	7670018
Livestock	4032	1357	229	5618
Aquacultural	3300192	3869712	2248680	9418584
Total	4834809	7352866	4983988	17171663

Note: groundwater uses were obtained from land use maps that generated from the interpretation of World View 2 image 2018 and field survey, and then calculated based on NSAI (2002).

Furthermore, GWAI was calculated from the following formula, a modification of Mohammed & Ghazali (2009):

GWAI = (Wd/Wsy) x 100

The GWAI values generated were grouped into four classes: not critical (<25), quite critical (25-50), critical (50-100), and very critical (>100).

Groundwater Quality Index (GWQI). GWQI calculations were carried out in three successive steps, standardization, weighting and determination of quality rating scale, based on modifications of Banoeng-Yakubo et al (2009); Vasanthavigar et al (2010); Kumar & James (2013). In the first step, the selection of parameters and water quality standards was determined based on the synthesis of optimum water quality recommended in various studies for the survival and growth of whiteleg shrimp (Beltrame et al 2006; Ferreira et al 2011; Carbajal-Hernandez et al 2013; Kasnir et al 2014; NSAI 2006; NSAI 2014). In the second step, each of the water quality parameters was assigned a weight ranging from 1 to 5 based on their importance and effects on shrimp. The maximum weight of 5 was assigned to salinity, as it was the most influential parameter on the survival and growth of shrimp. 4 was assigned to temperature, pH and DO, and 3 was assigned to turbidity, TSS, BOD-5, ammonia and organic matter. Phosphate and total Vibrio were assigned a weight of 2, because these two parameters had the lowest effect compared with the other parameters (modification of Karthik et al 2005; Mustafa et al 2007; Carbajal-Hernandez et al 2013; Hadipour et al 2015). Furthermore, the relative weight of each water quality parameter was calculated using the following equation (Banoeng-Yakubo et al 2009):

Wi=wi/Σwi

Where: Wi - relative weight; wi – each parameter weight; Σwi - total weight of all parameters. In this study, Σwi was 36.

The optimum, standard, weight and relative weight of each water quality parameter for whiteleg shrimp are illustrated in Table 3. In the third step, a water quality rating scale was calculated by the following equation:

qi=(Ci/Si)x100

Where: qi - water quality rating scale; Ci - value of each measured water quality parameter; Si - standard value of each water quality parameter.

Table 3
Optimum, standard, weight and relative weight of water quality parameters for whiteleg shrimp

Parameter	*Optimum*	*Standard*	*Weight (wi)*	*Relative weight (Wi)*
Salinity (ppt)	15-30	20	5	0.1389
Temperature (°C)	28-32	28	4	0.1111
Turbidity (NTU)	<20	20	3	0.0833
TSS (mg L^{-1})	25-150	80	3	0.0833
pH	7.5-8.5	7.5	4	0.1111
DO (mg L^{-1})	>4	4	4	0.1111
BOD-5 (mg L^{-1})	<3	3	3	0.0833
Ammonia (mg L^{-1} N-NH_3)	<0.1	0.1	3	0.0833
Phosphate (mg L^{-1} P-PO_4)	0.1-5.0	0.2	2	0.0556
Organic matter (mg L^{-1})	55-90	55	3	0.0833
Total Vibrio (CFU mgL^{-1})	<1000	1000	2	0.0556
			Σwi=36	ΣWi=1

Note: optimum and standard values of the water quality parameters were synthesized from Beltrame et al (2006), Ferreira et al (2011), Carbajal-Hernandez et al (2013), Kasnir et al (2014), NSAI (2006) and NSAI (2014); weights (wi) were modified from Karthik et al (2005), Mustafa et al (2007), Carbajal-Hernandez et al (2013) and Hadipour et al (2015); NTU - Nephelometric Turbidity Unit; TSS - total suspended solids; DO - dissolved oxygen; BOD-5 - bio-chemical oxygen demand within five days; CFU - colony forming unit.

To calculate GWQI, the subindex was calculated first for each water quality parameter using the following equation:

$$SI = Wi \times qi$$

$$GWQI = \Sigma SI$$

Where: SI - subindex of each water quality parameter; ΣSI - total of subindex from all water quality parameters; GWQI - Groundwater Quality Index.

The resulted GWQI values were grouped into five classes: excellent (<50), good (50-100), poor (100-200), very poor (200-300), and unsuitable (>300).

Results and Discussion

Yield and demand for groundwater. The eastern region has the greatest groundwater availability, of 43.13%, followed by the central region with 35.8% and the western region with 21.07%, from the total groundwater availability of 131088574 m^3 $year^{-1}$. The groundwater safe yield in the western, central and eastern regions is 1130012 m^3 $year^{-1}$, 2231155 m^3 $year^{-1}$, and 2071855 m^3 $year^{-1}$, respectively. The total groundwater safe yield in the area is 5433022 m^3 $year^{-1}$ (Table 1). The highest groundwater uses are for aquaculture (i.e. shrimp farming) and agricultural purposes. The total groundwater uses for both in the western, central and eastern regions are 4796705 m^3 $year^{-1}$ (99.21%), 7315995 m^3 $year^{-1}$ (99.50%), and 4975902 m^3 $year^{-1}$ (99.83%), respectively. It indicates that the groundwater uses besides these, for domestic, non-domestic and livestock, has the overall amount of around 0.17-0.79% (Table 2). Based on the ratio between the demand and the safe yield of groundwater utilization, the Groundwater Availability Index (GWAI) value is generated. The highest GWAI is found in the western region, with a value of 428, followed by the central region with 330, and eastern region with 240 (Table 4). The GWAI values are above 100, indicating that the condition of groundwater in the study area is very critical or, in other words, the groundwater has experienced overexploitation.

Table 4

Value and classification of GWAI in the sandy coastal area of Bantul, Indonesia

Development area	*Safe yield (Wsy)*	*Groundwater demand (Wd)*	*GWAI (Wd/Wsy)x100*	*Class*
Western	1130012	4834809	428	very critical
Central	2231155	7352866	330	very critical
Eastern	2071855	4983988	240	very critical
Total	5433022	17171663	316	very critical

Groundwater quality. The groundwater quality in the three shrimp pond development areas in Bantul is presented in Table 5. The overall salinity in the eastern region and the upper region of the shrimp pond areas are classified as low, within a range of 2-6 ppt. Temperature and pH are generally in the optimum range for the survival and growth of shrimp. Temperatures range from 28 to 31°C and pH ranges from 7 to 8.6. The groundwater conditions in the study area are classified as very clear, with a turbidity of 0.10-4.51 NTU and a TSS of 0.68-4.51 mg L^{-1}. DO in the western region is below the standard, ranging from 1.80 to 2.12 mg L^{-1}, while BOD-5 in the eastern region is quite high, ranging from 4.06 to 6.26 mg L^{-1}. The values of ammonia in the eastern region, especially around the coastline area and in the shrimp pond area, are 0.459 mg L^{-1} and 0.295 mg L^{-1}, respectively, above the standard. A high phosphate content, of 1.257 mg L^{-1}, was found in the central region, precisely in the upper region of the shrimp pond areas. The value of the organic matter in the western region is above the standard, especially around the coastline area and in shrimp pond areas, 59.15 mg L^{-1} and 56.46 mg L^{-1}, respectively. The total Vibrio content in the three regions is very low, ranging from 0 to 56 CFU mg L^{-1}.

GWQI analysis in the three shrimp pond development areas in Bantul as a whole produced GWQI values ranging from 65.96 to 98.37 (Table 5). The mean GWQI in the western, central and eastern regions was 76.75, 72.94 and 86.16, respectively. Based on the classification according to Banoeng-Yakubo et al (2009) and Vasanthavigar et al (2010), the GWQI value is in the range of 50-100, indicating that the groundwater quality in the regions is good for whiteleg shrimp farming.

GWAI analysis. Groundwater in the sandy coastal area of Bantul is supposed to meet the necessities of domestic, non-domestic (tourism activities), agricultural, livestock and aquaculture. The total groundwater uses for aquaculture (i.e. shrimp farming) and agricultural activities reaches more than 99%. For agriculture, groundwater is required to compensate for the losses during field preparation, evaporation, transpiration, seepage, percolation and the discharge of watering application. Groundwater for aquaculture is essential for filling shrimp ponds at the early stage of culture, replacing water loss due to evaporation and seepage and water replacement to maintain water quality (Verdegem & Bosma 2009; Bosma & Verdegem 2011). Based on the calculation, the total water uses for shrimp farming amounts to 84000 m^3 ha^{-1} $crop^{-1}$.

Groundwater in the coastal area has to be utilized carefully since the water can be used for many purposes (Voudouris 2006) and it is susceptible to pollution and seawater intrusion due to excessive exploitation (Ferguson & Gleeson 2012; Bouderbala et al 2016). Consequently, the groundwater management system must consider the safe yield concept, which is the amount of water that can be pumped from the aquifer without causing unwanted impacts (Alley & Leake 2004; Voudouris 2006). Based on our results, the total safe yield in the study area is 5433022 m^3 $year^{-1}$, or only 4.14% from the total groundwater availability of 131088574 m^3 $year^{-1}$. This result is similar to those of previous studies for all regions in Bantul Regency, which state that the safe yield of groundwater is 4.01% (Purnama 2012) and 4.04% (Santosa & Adji 2014).

Table 5

Groundwater quality and GWQI value in the sandy coastal area of Bantul, Indonesia

Parameter	Western			Central			Eastern			Optimum
	C	P	U	C	P	U	C	P	U	
Sal	28	30	3	20	26	6	5	5	2	15-30
T	31	31	29	31	31	28	30	30	30	28-32
Tur	0.32	0.97	1.56	0.45	0.1	0.41	4.51	2.5	2.11	<20
TSS	5.06	6.24	0.92	1.28	1.02	0.28	0.68	0.58	0.16	25-150
pH	7.0	7	7.2	7.9	7.9	8.6	7.2	7.3	7.1	7.5-8.5
DO	1.8	2.12	1.8	3.72	4.02	6.6	6.48	7.88	7.8	>4
BOD-5	3.48	0.26	1.92	3.55	3.12	0.8	4.06	5.12	6.26	<3
Amm	0	0.048	0.008	0	0	0.007	0.459	0.295	0.052	<0.1
Pho	0.178	0.214	1.881	0.102	0.05	1.257	0.01	0.01	0.034	0.1-5.0
OM	59.15	56.46	4.74	29.09	27.11	9.16	15.27	11.23	5.19	55-90
TV	33	8	7	56	0	0	48	31	23	<1000
GWQI	71.53	69.71	89.01	65.96	67.21	85.66	98.37	90.16	69.96	
Class	good	good	good	good	good	good	good	good	good	

Note: Sal - salinity (ppt); T - temperature (°C); Tur - turbidity (NTU); TSS - total suspended solids (mg L^{-1}); pH – acidity; DO - dissolved oxygen (mg L^{-1}); BOD-5 - biochemical oxygen demand within five days (mg L^{-1}); Amm - ammonia (mg L^{-1} $N\text{-}NH_3$); Pho - phosphate (mg L^{-1} $P\text{-}PO_4$); OM - organic matter (mg L^{-1}); TV - total Vibrio (CFU mg L^{-1}); C - around the coastline area; P - shrimp ponds area; U - the upper of the shrimp ponds area. Optimum values of water quality parameters for whiteleg shrimp were synthesized from Beltrame et al (2006), Ferreira et al (2011), Carbajal-Hernandez et al (2013), Kasnir et al (2014), NSAI (2006) and NSAI (2014).

GWAI analysis shows that the condition of the groundwater in the study area is classified as very critical, meaning that the groundwater has experienced overexploitation. This condition can lead to a depletion of groundwater availability and quality, soil salinization and seawater intrusion (Voudouris 2006; Ferguson & Gleeson 2012; Bouderbala et al 2016). Based on field observations, the phenomenon of seawater intrusion reflected by increasing groundwater salinity has been recognized in the western region. This is confirmed by the result of the salinity measurement in this region, which presents the highest value among all regions.

GWQI analysis. Water quality is a crucial variable for the survival and growth of whiteleg shrimp. The monitoring of physico-chemical and biological parameters allows the control and even predicts the occurrence of unfavorable conditions for shrimp, so it can prevent shrimp farming from environmental damage and financial losses. Therefore, in the context of a sustainable shrimp farming development, water quality should be evaluated in water sources in the pre-selection of shrimp ponds (Beltrame et al 2006; Ferreira et al 2011).

So far, the evaluation of water quality still often uses traditional approaches, through partial analysis of each water quality parameter. Traditional reports on water quality tend to be technical and detailed, presenting monitoring data on individual substances, without providing a comprehensive and interpretable water quality condition (Carbajal-Hernandez et al 2012; Carbajal-Hernandez et al 2013). Because it is too complex, the traditional approach will make it difficult to make decisions. To overcome this problem, the general water quality index (WQI) and groundwater quality index (GWQI) specifically applied to groundwater are developed to integrate water quality parameters (Saeedi et al 2010). WQI analysis in aquaculture is still limited to surface water, such as the feasibility of lagoon waters for shrimp farming (Beltrame et al 2006; Ferreira et al 2011), pollution rate of river waters because of aquaculture waste (Simoes et al 2008), reservoir waters feasibility for freshwater fish farming (Tallar & Suen 2016) and monitoring and evaluation of water quality in shrimp ponds (Ferreira et al 2011; Ma et al 2013; Mohanty et al 2018). The use of GWQI, in general, is still limited to drinking water (Vasanthavigar et al 2010; Rajanankar et al 2011; Kumar & James 2013).

When compared with previous studies that evaluated the suitability of water quality for shrimp or freshwater fish farming, the present study is more comprehensive, so the results should also be more representative. This is reflected in the number of parameters used in the analysis. In this study, 11 water quality parameters were evaluated, consisting of physico-chemical parameters (temperature, salinity, turbidity, TSS, pH, DO, BOD-5, ammonia, phosphate and organic matter) and biological parameters (total Vibrio). Beltrame et al (2006) and Ferreira et al (2011), evaluating the feasibility of lagoon water for shrimp farming, involved 4 parameters, salinity, turbidity, pH and DO. In another study, Tallar & Suen (2016) who evaluated reservoir water feasibility for freshwater fish farming, also used 4 parameters, DO, pH, ammonia and fecal coliform.

The GWQI analysis in the 3 shrimp pond development areas in Bantul presents values between 50 and 100, indicating that the groundwater quality belongs to the "good" category for whiteleg shrimp farming. This confirms the results of Boyd (2012), who stated that the aquifers in sand or gravel formations present good quality for aquaculture. This is also confirmed by the fact that currently, no industry in the regions disposes of waste in the environment. A lower GWQI value indicates a better groundwater quality. On this basis, it can be said that the western and central regions have better groundwater quality compared with that of the eastern region. Groundwater in the coastline area tends to have better quality than in the shrimp ponds area and above the shrimp ponds area.

Implications for sustainable shrimp farming. In the context of the development of sustainable shrimp farming, the evaluation of water sources must be carried out at the pre-selection stage or even before the site selection of shrimp ponds (Beltrame et al 2006; Ferreira et al 2011). In the sandy coastal area, water variables (availability and quality of groundwater) have a vital role compared to land variables (topography, elevation and slope). It is because the variable for sandy land can be easily modified or engineered, if the conditions are not appropriate and vice versa. Based on the importance of the variable groundwater, it is very important to have an appropriate evaluation of the availability and quality of groundwater, as well as an appropriate approach to integrate both into aquaculture management. In this case, GWAI and GWQI can be used as indicators as well as tools to detect unfavorable groundwater conditions for shrimp, so that negative impacts on the environment and financial losses can be avoided. The use of these two indices is very practical because the interpretation of data can be done quickly and easily, and does not require high costs. Besides, the results obtained are also very simple, simplifying the decision-making process. The application of the two indices is not limited to aquaculture management, opportunities for other production systems being also open.

The results of the GWAI analysis indicate that groundwater in the study area is already in a very critical condition (GWAI>100) and its utilization has experienced excessive exploitation. Meanwhile, the results of the GWQI analysis show that groundwater quality is good for whiteleg shrimp farming (50<GWQI<100). Based on these two indices, it is concluded that groundwater in this area is not suitable for the development of shrimp ponds. The next stage in the site selection of shrimp ponds can be continued, but focused on regulating shrimp ponds. In this case, the opening of new shrimp ponds in the study area should be stopped, while old shrimp ponds that are not operating and are no longer productive can be closed. Furthermore, shrimp ponds that are still operating must be rearranged considering the physical and production carrying capacity (Ross et al 2013).

Since groundwater use for shrimp farming is the highest compared with the other water uses, the efficiency of water use in this sector should be given the highest priority. This is in line with the concept of sustainable intensification of aquaculture, which emphasizes on water efficiency (FAO 2016; Ahmed & Thompson 2017). In this study, water uses for shrimp farming in a sandy coastal area, with a stocking density of about 110 shrimps m^{-2} and a cultured period of 90 days, is 84000 m^3 ha^{-1} $crop^{-1}$. If the average production of shrimp is 15 tons ha^{-1}, the efficiency of water use is 5.60 m^3 kg^{-1} shrimp biomass. This water use is classified as wasteful and inefficient, because according to Mohanty et al (2018), shrimp ponds with a stocking density of 50 shrimps m^{-2} and a cultured period of 120 days only use water as much as 34200 m^3 ha^{-1} $crop^{-1}$, with an efficiency of water use of 1.93 m^3 kg^{-1} shrimp biomass. To increase the efficiency of groundwater uses, in the future, the development of sustainable shrimp farming in this region should be focused on being able to implement better water management through reducing water uses (Verdegem & Bosma 2009; Mohanty et al 2018). These efforts can be achieved by increasing pond aeration (Avnimelech et al 2008), implementing recirculation aquaculture systems (Klinger & Naylor 2012), and increasing pond productivity with biofloc technology (Bosma & Verdegem 2012).

Conclusions. Based on the ratio between the demand and the safe yield, the groundwater in the sandy coastal area of Bantul, Indonesia, is in a very critical condition with GWAI ranging from 240 to 428. It means that the groundwater has experienced overexploitation. However, the area has good groundwater quality for whiteleg shrimp farming with GWQI ranging from 65.96 to 98.37. Based on these two indices, it is concluded that groundwater in this area is not suitable for the development of shrimp ponds. The next step in the site selection of shrimp ponds can be continued, but focused on regulating shrimp ponds under the physical and production carrying capacity. In summary, it can be stated that GWAI and GWQI are practical tools that can be used for a quick and easy data interpretation, for aquaculture management and other production systems.

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