Assessment of water quality from water harvesting using small farm reservoir for irrigation

PAPER • OPEN ACCESS

Assessment of water quality from water harvesting using small farm reservoir for irrigation

To cite this article: W S Dewi *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **129** 012034

IOP Conf. Series: Earth and Environmental Science **129** (2018) 012034 doi:10.1088/1755-1315/129/1/012034

Assessment of water quality from water harvesting using small farm reservoir for irrigation

W S Dewi[1,4], Komariah[1], I Y Samsuri[2] and M Senge[3]

[1] Department of Soil Science, Agriculture Faculty of Universitas Sebelas Maret, Indonesia. Jl. Ir. Sutami No. 36, Kentingan, Surakarta, Central Java, Indonesia.
[2] Alumni of Department of Agrotechnology, Agriculture Faculty of Universitas Sebelas Maret, Indonesia.
[3] Faculty of Applied Biological Sciences, Gifu University, Yanagido 1-1, Gifu 501-1193, Japan
[4] Corresponding author: Email: wsdewi2000@gmail.com

Abstract. This study aims to assess the quality of rainfall-runoff water harvesting using small farm reservoir (SFR) for irrigation. Water quality assessment criteria based on RI Government Regulation number 82 the year 2001 on Water Quality Management and Pollution Control, and FAO Irrigation Water Quality Guidelines 1985. The experiment was conducted in the dry land of Wonosari Village, Gondangrejo District, Karanganyar Regency. SFR size was 10 m x 3 m x 2 m. Water quality measurements are done every week, ten times. Water samples were taken at 6 points, namely: distance of 2.5 m, 5 m, and 7.5 m from the inlet, at depth 25 cm and 175 cm from surface water. In each sampling point replicated three times. Water quality parameters include dissolved oxygen (DO), Turbidity (TSS), water pH, Nitrate (NO_3), and Phosphate. The results show that water harvesting that collected in SFR meets both standards quality used, so the water is feasible for agricultural irrigation. The average value of harvested water was DO 2.6 mg/l, TSS 62.7 mg/l, pH 6.6, P 5.3 mg/l and NO_3 0.16 mg/l. Rainfall-runoff water harvesting using SFR prospectus for increasing save water availability for irrigation.

1. Introduction

Water is a vital natural resource for living things to survive, including crops. Water availability, water scarcity, and water crisis are the widely discussed topics that recently concerned dispite climate change and population growth [1]. It dramatically affects the plants water availability, even water catchment area is threatened by climate change [2]. Increased atmospheric temperature globally has an essential impact on hydrological cycle changes [3], both in tropical and sub-tropical regions. The saturated water vapor pressure in the atmosphere is very sensitive to temperature; therefore climate change will affect the global water cycle disruption that will impact on precipitation and run-off [4]. By hydrological context, climate change accelerates its cycle on a global scale and causes uneven intensity and distribution of hydrological resources. The extreme rain phenomenon in some parts of the world are increasing, yet some areas drought out [5], and rainfall variability is also increasing [1]. The hydrological cycle changes lead to seasonal shifts, longer dry seasons and shorter rainy seasons with higher rain intensity, increased dry season and wet season anomalies, less soil moisture, resulting in farmland prone to drought. It is one of food security threats.

Agriculture is highly dependent on water resources [6]. The agricultural sector is the most significant water user in some countries [7]. Globally, agricultural activities require approximately

3,100 billion m^3, or around 70% to 90% of the total water on the surface and groundwater [8][10], and will increase to 4,500 billion m^3 by 2030 if not efficiently to use. It is a major limiting factor for plant growth in tropical and sub-tropical environments [9]. The seasonal rainfall quantity is not the only major limitation for agricultural production, but uncertain rain phenomena are also an important issue [9]. Climate change guides water availability problems. Water scarcity is a threat to meeting future food demands unless significant improvements in agricultural water productivity can be achieved. Sustainable water management strategies contribute to transforming degraded soils into healthy agroecosystems, and increasing resilience to climate change and variability [6]. Therefore, availability of sustainable and more productive water management technology for agriculture is a very urgent need.

Water harvesting (rainfall-runoff water harvesting) using small farm reservoir (SFR) is one of the strategies for sustainable water management [6]. That technique can reduce the risk of floods and droughts, expand the chance to grow in a dry season, maintain and enhance ecosystem resilience to climate variability and change [6]. Water harvesting techniques using SFR are also applied in Sub-Saharan to address dry spell [9]. Dry spells are a slightly extended dry period, ranging from a week to several weeks, between occurrences of rainy season [9]. Water harvesting is very important for rainfed farming systems, especially for supplement irrigation. Supplement irrigation - irrigation only during periods of growth and critical development - plus rainwater harvesting can increase yields by 2-3 times more than conventional rainwater farming [6].

Increased water scarcity will trace the water harvesting and recycling needs for agricultural irrigation and the low-quality water application [10]. Rainwater is relatively free of dirt unless it carries pollutants from the atmosphere. Pollution may occur at harvest time or during storage. Rainfall harvest from the agricultural catchment area using SFR will mix with run-off, potentially degrading water quality, as it carries various pollutants such as sediment, heavy metals, pesticide residues, organic and inorganic fertilizer residues, plant litter, bird droppings, garbage, insects, even disease-causing microbes. Thermotolerant coliform and E. *coli* are common microbial contaminants present in rainwater harvesting.

Is water harvesting using SFR in Gondangrejo Sub-district, Sragen Regency, Central Java, Indonesia, eligible for agricultural irrigation? Government Regulation No. 82/2001 on Water Quality Management and Water Pollution Control, Article 8, states that irrigation water belongs to classes II, III, and IV with various indicators of physical, chemical, biological and radioactive parameters [11]. In Government Regulation No. 20 of 2006 on Irrigation [12] does not mention the water irrigation quality , while to achieve food security, it is necessary to measure the water harvesting quality for irrigation. Some international standard operate water quality criteria for irrigation, such as Scofield, Oklahoma Water Quality Standard, Colorado Irrigation Water Quality Criteria, FAO, and Guidance for Irrigation Water Quality and Water Management in The United Kingdom of Saudi Arabia [13]. Rainwater harvesting quality using rooftop has been widely published but not much publication about the water harvesting quality using SFR. This paper presents the feasibility of rainfall-runoff water harvesting quality using SFR for irrigation.

2. Material and Methods

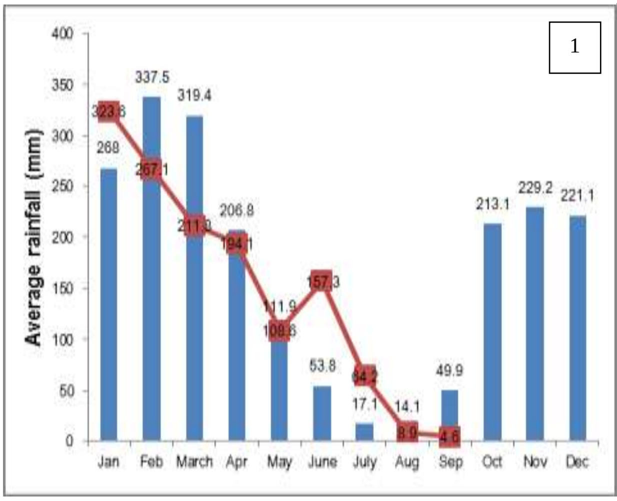
The research was conducted in rain-fed rice field located in Wonosari Village, Gondangrejo District, Karanganyar Regency, from April to June 2013, using SFR with size 10 x 3 x 2 m^3. The SFR site selection based on a place that can accommodate all runoff streams from different directions. The collected water in the SFR is a mixture of rainfall and runoff. Water samples were taken 6 points of SFR, covering 2.5 m, 5 m, and 7.5 m from the inlet, and each at a depth of 25 cm and 175 m from the surface. Water samples were collected every one week, for ten weeks by utilizing techniques which based on the Indonesian National Standard Collection of Public Works on Water Quality [14]. Water quality parameters analyzed include dissolved oxygen (DO), turbidity (TSS), pH, Carbon, Nitrate (NO_3-N), Phosphate, and Potassium based on Land Research Center method [15]. Assessment of water harvesting quality for irrigation based on Government Regulation of the No. 82/2001 on Water

Quality Management and Water Pollution Control, and the Food and Agriculture Organization (FAO) Irrigation Water Quality Guidelines 1985.

3. Result and Discussion

3.1. Description of research location

The research area at Gondangrejo Sub District, Karanganyar was located at 110º48'16,3 "- 110º53'4,36" E and 07º27'17,8 "- 07º32'42,16" S with height 100-200 m asl. It has a total area around 5677 ha with rainfed lowland area approximately 1250 ha. The average rainfall in Gondangrejo based on the last ten years data was below 3000 mm/year, with eight wet months and four dry months (Figure 1). During the wet months (October-April) the rainfall was relatively high, around 213.1 - 337.5 mm, whereas in dry months the rainfall ranges from 14.1 - 53.8 mm. This condition affects the planting pattern in Gondangrejo only two times rice planting. High rainfall needs to be harvested using SFR, which can eventually be used as irrigation water to meet the needs of plant water during a dry spell or the dry season. The soil type present in this region was Vertisol, with sandy clay texture up to clay.



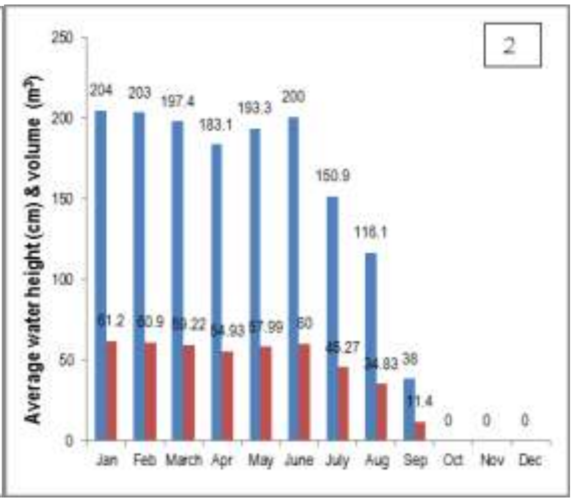


Figure 1. Histogram of average monthly rainfall (mm) in Gondangrejo, the year 2000-2010 (Source: BMKG Central Java). (Note: [blue box] = average 10-year rainfall, [red line] = Average rainfall during the research).

Figure 2. Histogram of average water height (cm) and water volume (m^3) in SFR during the study. (Note: [blue box] = average water height (cm), [red box] = water volume (m^3).

During the research showed that six wet months (January to June), and three dry months (July to Sept). Average rainfall at that time categorized to the wet month (the rainfall between 100-200 mm). The average water density in SFR during April to June was 183.1 cm, 193.3 cm, and 200 cm, respectively (Figure 2). In July, water density in SFR started to fall down, and farmers began for using water from the SFR and lead to reducing the water level in the SFR. In September, the SFR became dry and could not harvest again.

3.2. Water Harvesting Quality in SFR

The average DO, TSS, pH, and nitrate at each point of all sampling points met the quality standards of agricultural irrigation water quality (class III and IV) according to RI Government Regulation no. 82 of 2001 and according to the Food and Agriculture Organization (FAO) Irrigation Water Quality Guidelines 1985 (Table 1).

Table 1. Some parameters of water harvesting quality at SFR (Dissolved Oxygen, Turbidity, pH, Phosphate, and Nitrate)

No.	Parameter	Sampling point	Content (mg/l)	Government Regulation. No. 82/2001		FAO 1985
				Class III	Class IV	
1.	Dissolved Oxygen (DO), mg/l	I A	3.08	3	0	-
		I B	2.30			
		II A	3.10			
		II B	2.28	(minimum threshold)		
		III A	2.93			
		III B	2.02			
2.	Turbidity/ TSS,	I A	58.24	400	400	-
		I B	65.85			
		II A	57.01			
		II B	65.91			
		III A	60.06			
		III B	69.29			
3.	pH	I A	6.61	6 - 9	5 - 9	6.5 – 8.4
		I B	6.50			
		II A	6.60			
		II B	6.57			
		III A	6.60			
		III B	6.64			
4.	Fosfat, mg/l	I A	6.09*	1	5	-
		I B	4.99			
		II A	5.5*			
		II B	5.36*			
		III A	5			
		III B	5.11			
5.	Nitrat (NO_3), mg/l	I A	0.15	20	20	5 - 30
		I B	0.16			
		II A	0.15			
		II B	0.18			
		III A	0.16			
		III B	0.13			

Note :
I A: Water sample in 25 cm depth from water level, at inlet nearest point (2.5 m)
I B: Water sample in 175 cm depth from water level, at inlet closest point (2.5 m)
II A: Water sample in 25 cm depth from water level, at midpoint (5 m)
II B: Water sample in 175 cm depth from water level, at the midpoint (5 m)
III A: Water sample in 25 cm depth from water level, at outlet nearest point (7.5 m)
III B: Water sample in 175 cm depth from water level, at outlet closest point (7.5 m)
Class III: water quality criteria for freshwater fish cultivation, livestock, water to irrigate crops.

Class IV: water quality criteria for irrigating crops.
*): the parameters of water samples exceed the threshold of water quality standards for irrigation established by Government Regulation. No. 82/2001.

The phosphate concentration at point IA, IIA, IIB, and IIIB exceeded the predefined standard threshold (> 5 mg/ml), but surrounding soil at SFR was Vertisol which P deficient, therefore a high phosphate content can have a good effect on agricultural production. High levels of phosphate in water harvesting at the SFR affected by the location of the catchment area in the agricultural regions where the average farmer uses a lot of fertilizers, pesticides, and insecticides for the cultivation crop. The agricultural activities impacts will result in the runoff with a high content of nitrate and phosphate sediments [16]. Nutrients or other contaminants transported to SFR along with runoff and rainwater. Phosphate content in SFR that exceeds the needs of organisms has potential lead to eutrophication in a short time.

3.3 Water Quality Dynamics in SFR

To understand the water harvesting quality in SFR safe or not used for irrigation, it was necessary to see the quality as long as it is in SFR, before being used for irrigation. In this experiment, water quality assessment in SFR was conducted weekly for ten weeks, from April to June (Figure 1).

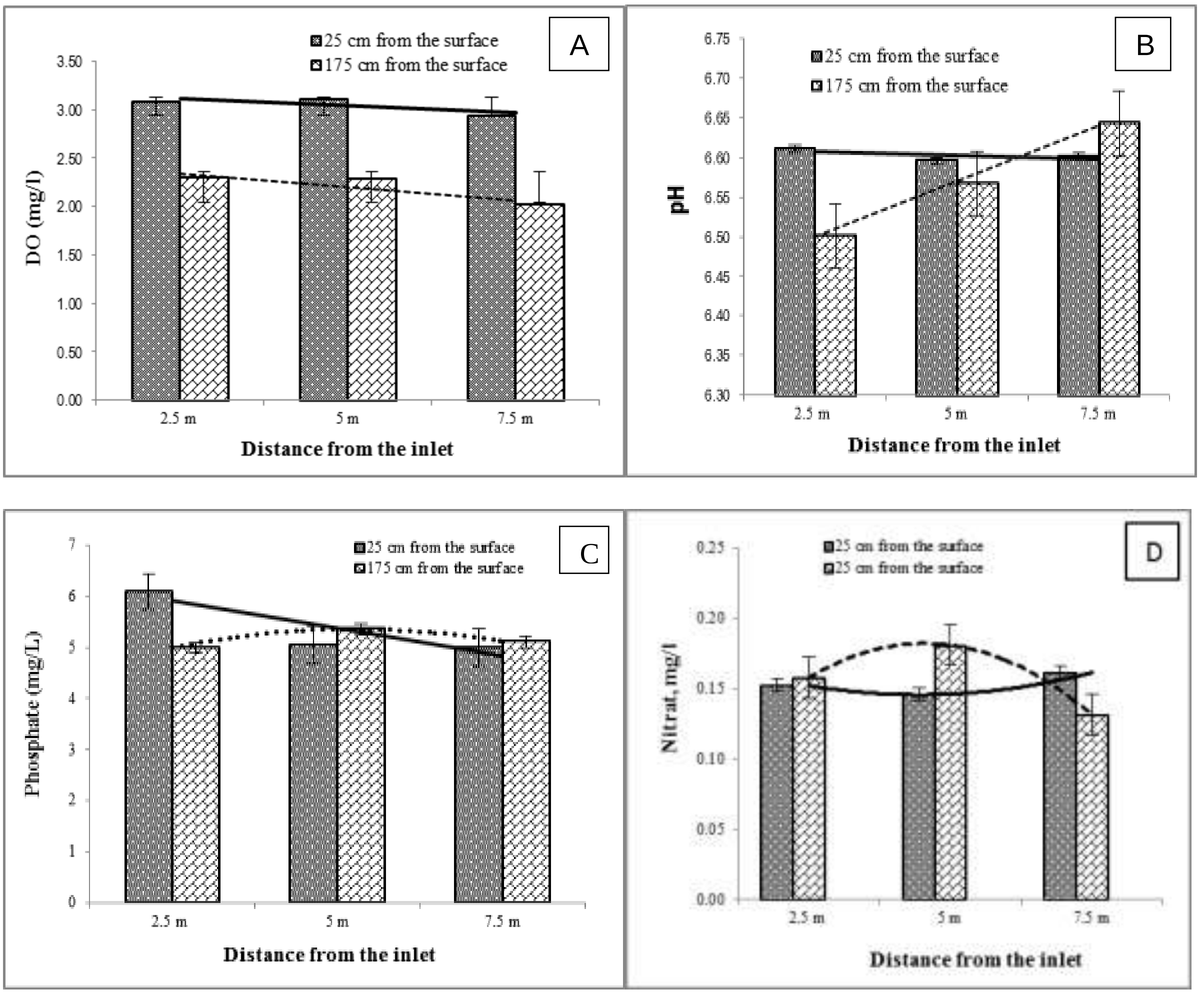


Figure 3. Dynamics of several water quality parameters during harvest in SFR: Dissolve Oxygen (DO) (A), pH (B), Phosphate (C), and Nitrate (D)

During the experiment, the harvesting water stayed for ten weeks in SFR. The average DO near the surface (25 cm from the surface) was 3.02 mg/l, higher and significantly different ($p < 0.05$) with DO at a depth of 175 cm from the surface of 2.02 mg/l (Figure 3A). Dynamics of DO changes were occurred because of diffusion process between water and free air, and photosynthesis process by algae. The farther from the water surface, there was a decrease in dissolved oxygen levels (Fig. 3A). Its related to declining of photosynthesis process and oxygen which widely used for respiration and oxidation of organic and inorganic materials by microorganism [17]. The unorganized organic matter, when discharged into water bodies, will be decomposed by bacteria that need oxygen to decaying material. Because the oxygen solubility in the water was relatively low, high level of organic waste affects reducing DO faster.

There was a significant difference ($p<0.05$) between DOs nearest and farthest from the inlet. The DO decreased with farther distance from the inlet. The average DO closest (2.5 m from inlet) was 2.69 mg/l, while the most distant (7.5 m from the inlet) was 2.48 mg/l (Fig. 3A). Decreasing DO due to the buildup of sediments and organic matter at the outlet area was carried by the runoff stream. Microorganism decomposed organic matter in sediment using oxygen was contained in the upper water layer. The high natural material was trapped in the SFR sediment which affects the increasing decomposition process by aquatic microorganisms and lead decreasing oxygen content in SFR. Reducing DO in sediment was affected by natural respiration and biochemical processes by bacteria against the organic matter input which ambushed in the sediments. Besides, oxidation processes such as nitrification that convert ammonia to nitrate also contribute to the decrease oxygen levels in sediments. The most significant oxygen consumption in the waters was in deposits and water columns near the residues, where there was an organic matter accumulation and active bacterial and benthic metabolism [18].

The average pH of SFR is 6.59. The pH near the water surface tends to be constant, both far to near from the outlet, which was about 6.60 (Figure 3B). While in the deeper water layer (175 cm from the surface), pH increases significantly ($p<0.05$) from the inlet to outlet, i.e., from 6.50 to 6.64. The increased pH was positively correlated with the amount of rainfall during the study ($r = 0.43^{**}$). Rainwater that falls on the catchment affect run-off flows that carry dissolved sediments, both organic and inorganic. The soil type in the water catchment area was Vertisol which has a near-neutral pH so that the deposits taken along with the run-off flow were likely to carry relatively high Ca-containing materials thereby increasing the pH. The Vertisols have neutral to slightly alkaline pH [19]. Besides, organic sediments on the bottom of the SFR from far to near the outlet tend to increase. Natural substances decomposition may increase or decrease the pH depending on the organic material type. Respiration process affects pH dynamic, the more carbon dioxide was produced by respiration process reducing pH, but if higher photosynthesis activity leads increasing pH [20].

Phosphate levels was decreased significantly ($p < 0.05$) from the surface to deeper water layer in SFR, i.e., from 5.38 to 5.15 mg/l. Likewise, there was a significant decrease ($p < 0.05$) of P concentration from the nearest inlet to the outlet, from an average of 5.54 to 5.06 mg/l (Figure 3C). A decrease in P content related to low P content in sediment carried along with runoff flow. Paddy fields have low P content [21]. Water catchment areas were also far from residential areas, so run-offs carry little domestic waste. Household waste, like detergent, affect soluble phosphates in SFR [22]. The soluble P can also be derived from the decomposition of organic matter in a water body. It still found in the deeper layers of water surface. The SFR bottom layer was contained a rich nutrients, both derived from sediments and decomposition of organic compounds [23].

The nitrate concentration at all sample points was not significantly different ($p > 0.05$). Average nitrate levels in SFR ranged from 0.13 to 0.34 mg/l. The nitrate concentration at 175 cm depth was slightly higher compared to the nitrate level at 25 cm depth from the surface (Figure 3D). The soluble nitrate in SFR can be derived from the N fertilizer contaminated with runoff, as well as the organic compounds decomposition which was accumulated in SFR. The higher nitrate concentrations close to the bottom layer related with nitrates in the surface layer were more used or consumed by phytoplankton [24]. Slightly more elevated nitrate concentrations near the bottom also were affected by sediment. Nitrate in deposit resulted from the biodegradation of natural materials into ammonia and oxidized to nitrate. Based on nitrate concentration levels, its oligotrophic waters SFR categorizes of which means poor nutrients because the nitrate content in the SFR was between 0-1 mg/l [18].

The climate change guided precipitation patterns transformation, consequently leaded to frequent short drought (dry spell) in Karanganyar Regency, Indonesia [25], wherein the research area that was implemented. Water harvesting was a good strategy for adaptation to climate change, especially in the arid region. SFR was one of the techniques for harvesting water that can be done by farmers around the cultivation area, therefore it can be utilized in a more accessible way for agricultural irrigation. Rainfall-runoff water harvesting was using SFR prospectus for increasing save water availability for irrigation.

4. Conclusions

The harvested water in SFR was feasible for agricultural irrigation because it meets the water quality standard for agricultural irrigation based on class III, and IV according to RI Government Regulation No. 82 of 2001 and according to the Food and Agriculture Organization (FAO) Irrigation Water Quality Guidelines 1985. The average value of harvested water in SFR was DO 2.6 mg/l, TSS 62.7 mg/l, pH 6.6, P 5.3 mg/l and NO_3 0.16 mg/l. Harvested water in SFR was useful for irrigation and supplements irrigation during dry spelling. Water harvesting technology which using SFR was one of the most important climate change adaptation strategies, especially for dryland areas.

Acknowledgments

The authors would like to thank the Japan Society for the Promotion of Science (JSPS) that funded this research in the fiscal year 2015.

References

[1] Cooper P J M, Dimes J, Rao K P C, Shapiro B, Shiferaw B and Twomlow S 2008 Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment* **126**: 24–35

[2] Immerzeel W W, van Beek L P H and Bierkens M F P 2010 Climate Change Will Affect the Asian Water Towers *Science* **328**: 1382-85

[3] Barnett T P, Adam J C and Lettenmaier D P 2005 Reviews Potential impacts of a warming climate on water availability in snow-dominated regions *Nature* **438**: 303-09.

[4] Milly P C D, Dunne K A and Vecchia A V 2005 Global pattern of trends in streamflow and water availability in a changing climate *Nature* **438**: 347-350.

[5] Rana A, Foster K, Bosshard T, Olsson J and Bengtsson L 2014 Impact of climate change on rainfall over Mumbai using distribution-based scaling of global climate model projections. *Journal of Hydrology: Regional Studies* **1**: 107–28.

[6] "Agricultural water management water and development strategy implementation brief", usaid.gov, 2017. [Online], Available: https://www.usaid.gov/sites/default/files/documents/1865/Ag%20Water%20Management_Implementation%20Brief_Jan%202015.pdf. [Accessed: 16-Oct-2017].

[7] Amarasinghe U A and Smakhtin V 2014 *Global Water Demand Projections: Past, Present and Future* [Sri Lanka: International Water Management Institute].

[8] Wisser D, Frolking S, Douglas E M, Fekete B M, Vörösmarty C J and Schumann A H 2008 Global irrigation water demand: variability and uncertainties arising from agricultural and climate data sets *Geophysical Research Letters* **35**: 1-5.

[9] Fox P, Rockstrom J and Barron J 2005 Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya *Agricultural Systems* **83**:231–50.

[10] Jensen P K, Matsuno Y, Hoek W V and Cairncross S 2001 Limitations of irrigation water

quality guidelines from a multiple use perspective *Irrigation and Drainage Systems* **15**: 117–28.
[11] The Republic of Indonesia, Government Regulation 2001 *Government Regulation No. 82 the year 2001 on the Management of Water Quality and Control of Water Pollution* (Jakarta: Government of Indonesia)
[12] The Republic of Indonesia, Government Regulation 2006 *Government Regulation No. 20 the year 2006 on Irrigation* (Jakarta: Government of Indonesia)
[13] Yusuf I A 2014 Review of water quality criteria for irrigation *Jurnal Irigasi* **9(1)**: 1-15.
[14] The National Standardization Agency of Indonesia 1990 *SNI 06-2412-1991 on sampling methods of water quality* (Jakarta: BSN).
[15] Soil Research Institute 2005 *The chemical analysis of soil, plants, water, and fertilizer* (Bogor: Agency for Agricultural Research and Development, Ministry of Agriculture).
[16] Casali J R, Gimenez J, Alvarez M J D V, Lersundi M, Goni M A, Campo Y, Chahor R, Gastesi J and Lopez 2010 Sediment production and water quality of watersheds with contrasting land use in Navarre (Spain) *Agricultural Water Management* **97**: 1683-94.
[17] Dugan P R 1972 *Biochemical Ecology of Water Pollution* (New York: Plenum Press) p 159
[18] Wetzel JT 1975 *Limnology* (Philadelphia: Sounders).
[19] Getahun M, Selassie Y G 2017 *Characterization, Classification and Mapping of Soils of Agricultural Landscape in Tana Basin, Amhara National Regional State, Ethiopia*. *In*: Stave K, Goshu G and Aynalem S (eds) Social and Ecological System Dynamics. AESS Interdisciplinary Environmental Studies and Sciences Series (New York: Springer)
[20] Kordi K M G H 2000 *Cultivation of Crab and Milkfish in Pond Polyculture System* (Jakarta: Dahara Prize Publisher)
[21] Dewi W S 2015 Improvement soil biology characteristics of paddy field by system of rice intensification *Journal of Soil Science and Agroclimatology* **12 (2)**: 67-75.
[22] Effendi H 2003 *Water Quality Study for the Management of Resources and Water Environment*. (Bogor: Canisius Publisher).
[23] Edward, and Tarigan M S 2003 The season effects on fluctuations of phosphate and nitrate levels in the Banda Sea *Journal of Makara Science* **7 (2)**: 73-82.
[24] Sarangi R K 2011 Remote-sensing-based estimation of surface nitrate and its variability in the southern peninsular Indian waters *International Journal of Oceanography* **2011**:1-16.
[25] Rachmadiyanto A N 2014 Crop water productivity (CWP) with the small farm reservoir (SFR) as a supplemental irrigation for cash crop on rainfed area in Karanganyar Regency, Indonesia *Global Advanced Research Journal of Agricultural Science* **3(6)**:158-64.