WATER QUALITY CHARACTERISTICS TO THE WATER-ENERGY-FOOD (WEF) NEXUS

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ABSTRACT

Upper Citarum Watershed is one of the sources of water that is used to fulfill raw water for agriculture or irrigation, with an area of irrigation reaching 16,659 hectares. There is a close relationship between water security and food security. In general, water resistance is measured through quantity indicators, while quality indicators are still not widely studied. Water quality indicators will also affect energy security. When water quality decreases dramatically with the waste being discharged into the water, energy is needed to manage waste that has been disposed of. If waste is not managed it will have an impact on the quality of the food produced.

This research will show how the characteristics of water quality in water-energy-food-nexus. The research was conducted in the Upper Citarum watershed, by examining the characteristics of metals in water and grain or rice. After knowing the metal characteristics in both of them, water-energy-food-nexus analysis was carried out. The results showed that in areas contaminated with metals, grain or rice also contained metal. The presence of metals in certain concentrations in food has a certain level of danger for consumption. To anticipate the dangers of food consumption due to pollution of water quality, several management practices can be carried out, including the prevention of waste by applying clean production and the manufacture of WWTP installations.

Keywords: Irrigation, Water quality, Water-Energy-Food-Nexus, Clean production, WWTP

1. INTRODUCTION

Generally, water resistance is measured by the quantity indicator such research has been done previously like mapping water provisioning services to support the ecosystem-water-food nexus by taking into account environmental flow requirements for riverin ecosystems using the hydrological model Soil and Water Assessment Tool (Karabut et al., 2016), irrigation water security at river basin areas in Indonesia (Hatmoko, Radhika, Firmansyah, & Fathoni, 2018), understanding and managing the food-energy-water nexus – opportunities for water resources research (Cai, Wallington, Sha, & Marston, 2018).

Water security measured by water quality has not been widely studied. When the quality of water decreases due to waste dumped into the water, energy is needed to manage the waste that has been disposed of. Wastes that are not managed properly can decrease the food quality produced. This study will show the characteristics of water quality in nexus-water-energy-food.

Studies on food-water-energy nexus has attracted multidisciplinary sciences that resulting in a few key implications for policymakers (Shannak, Mabrey, &

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Vittorio,2018), sustainable planning with decision making tools (Bieber et al., 2018), management of the Hindu Kush Himalayan ecosystems region (Rasul, 2014), land and water management strategies (Chen et al., 2018), and many other studies. But studies of water quality related to food-energy-water nexus still rare.

The research was conducted at Citarum Hulu watershed, by examining the characteristics of metals in water and rice, so that a food-water-energy-food analysis can be carried out. The study was conducted in the Citarum Hulu watershed by focusing on surface water sources that have been contaminated with metals used to irrigate agriculture, and the knowledge of the metal content in rice so that a water-energy-food analysis can be carried out.

2. METHODS

2.1 Study Area

The study was carried out in the Citarum Hulu watershed. The Citarum Hulu flow starts from Situ Cisanti to the Inlet of the Saguling Reservoir, passing through several administrative areas including Sumedang District, Bandung Regency, Bandung City, Cimahi City and West Bandung Regency. In this study, sampling of water and rice quality was carried out in 15 locations along the Citarum Hulu river flow (shown in Table1) for columns 1,2,4.

Table 1. Sampling location of water and rice quality

No.	**Location**	**Sourceof Pollutants**	**Coordinate**	
			Longitude	**Latitude**
1	**2**	**3**	**4**	
1	Wanir	Agriculture	7° 4'38.73 "S	107° 44'12.26 "T
2	Wangisagara	Agriculture	7° 3'51.07 "S	107° 45'13.49 "T
3	Biru	Industry	7° 2'36.68 "S	107° 43'54.02 "T
4	Koyod	Industry	6° 59'49.58 "S	107° 43'8.16"T
5	Sapan	Agriculture	7° 1'30.92 "S	107° 42'5.30"T
6	Cimanggung	Agriculture	6° 58'6.00 "S	107° 50'26.16 "T
7	Linggar	Industry	6° 57'59.37 "S	107° 47'17.37 "T
8	Bojongloa	Munificial	6° 58'51.59 "S	107° 45'1.21"T
9	Tegalluar	Industry	6° 59'0.46 "S	107° 41'7.56"T
10	Lengkong	Munificial	6° 58'30.73 "S	107° 38'24.45 "T
11	Dayeuhkolot	Industry	6° 58'51.0 "S	107° 36'07.6"T
12	Katapang	Munificial	6° 59'39.71 "S	107° 35'3.02"T
13	Buahbatu	Munificial	6° 59'26.94 "S	107° 40'5.66"T
14	Kutawaringin	Munificial	6° 58'56.24 "S	107° 32'0.65"T
15	Melong	Industry	6° 55'17.49 "S	107° 32'41.32 "T

The sampling area then simplified into 6 locations with dominance of pollutants sourced from industry. Classification of pollutant sources (Table 1, Column 3) was carried out by analyzing water quality parameters and the land use around the sampling location.

Table 2. Sampling location of water and rice quality in Nexus analysis

New Number	OldNumber fromTable1.	Location	Coordinate	
			Longitude	**Latitude**
1	3	Biru	7° 2'36.68"S	107°43'54.02"T
2	4	Koyod	6°59'49.58"S	107°43'8.16"T
3	7	Linggar	6°57'59.37"S	107°47'17.37"T
4	9	Tegalluar	6°59'0.46"S	107°41'7.56"T
5	11	Dayeuhkolot	6°58'51.0"S	107°36'07.6"T
6	15	Melong	6°55'17.49"S	107°32'41.32"T

2.2 Timeline, Data Sources, And Technical Sampling

This research was conducted by survey method during August 2018 to January 2019. Primary data was obtained through collecting field data regarding heavy metal content in rice through sampling and analysis in the laboratory. Other field data that can support the results of analysis of heavy metal content were also collected from specified sampling location.

The rice samples studied were white rice (Oryza sativa L.) Ciherang variety. This variety is a type of rice that is widely planted in the irrigation area of Citarum Hulu. The purposive sampling method was used for sampling, including the irrigation area of the main Citarum River (order 1) to the irrigation area of the Citarum tributaries (order 2 and order 3). The rice sampling was carried out by composite random sampling in the paddy fields closest to the inlet of irrigation water. Sampling of irrigation water was carried out in a grab sampling based on SNI 6989.57: 2008 Water Sampling Methods.

Analysis of heavy metals in the sample includes elements of iron (Fe), manganese (Mn), zinc (Zn), chromium (Cr), copper (Cu), cadmium (Cd), lead (Pb), and nickel (Ni) using atomic absorption spectrophotometric methods.

2.3 Materials

The material used in this study was rice samples (Oryza sativa L.) obtained from paddy fields. Chemicals were used for laboratory analysis in metals such as HNO3, HClO4, standard metal solutions, filter paper pore size 0.45 µm, and distilled water.

The tools used in this study are knives for sampling rice, simple sampling equipment for water sampling, GPS, sample bottles, sample plastics. While the equipment used for the analysis of heavy metals in the laboratory are porcelain dishes, glassware commonly used in laboratories, pestle and mortar, sieves with 2 mm mesh size, oven dryers, hot plates, analytical scales, and Atomic Absorption Spectrophotometers.

3. RESULTS AND DISCUSSION

3.1 Metal Concentration On The Rice And Water

Sampling locations at the area of Biru, Koyod, Linggar, Tegalluar, Dayeuhkolot, and Melong areas were dominated by industrial areas adjacent to the irrigation water stream before entering the paddy fields. Based on the results of the analysis, rice at the industrial area contained heavy metals with concentrations listed in Table 3.

Table 3. Metal concentration in rice

No	Location	MetalConcentration(mg/kg)							
		Fe	**Mn**	**Zn**	**Cr**	**Cu**	**Cd**	**Pb**	**Ni**
1	Biru	745*	92,5	94,6*	46,7*	3,18	<0,002	<0,024	0,979
2	Koyod	380*	56,7	21,1	48,6*	3,86	<0,002	0,397	0,905
3	Linggar	351*	34,6	21,0	56,1*	3,86	<0,002	<0,024	0,658
4	Tegalluar	376*	60,0	34,6	39,0*	4,91	<0,002	<0,024	0,632
5	Dayeuhkolot	518*	74,5	38,5	47,1*	4,89	0,483*	<0,024	1,21
6	Melong	350*	67,8	32,8	35,2*	5,66	<0,002	<0,024	1,84*
Maximum Concentration(FAO)		20	100	60	20	40	0,3	5,0	1,5

1. Metal Concentration Exceed Maximum Boundary Which Recommended by FAO

Irrigation water in industrial areas generally contains heavy metals that are higher than permissible in irrigation water and in human settlement areas. Concentration of heavy metals in water is presented in Table 4.

Table 3. Metal Concentration in water

No	Location	MetalConcentrationLogam(mg/l)							
		Fe	**Mn**	**Zn**	**Cr**	**Cu**	**Cd**	**Pb**	**Ni**
1	Biru	4,03*	1,183*	0,017	0,294*	<0,012	<0,001	<0,009	0,155
2	Koyod	3,68*	0,758*	0,067	0,003	<0,012	<0,001	<0,009	<0,006
3	Linggar	5,16*	0,050	0,043	0,215*	0,021	<0,001	<0,009	0,112
4	Tegalluar	1,23*	0,142*	0,056	0,026	0,015	<0,001	<0,009	0,029
5	Dayeuhkolot	8,12*	0,419*	0,09	0,266*	0,032*	<0,001	0,035	0,152
6	Melong	10,36*	0,254*	0,853*	0,067*	0,015	<0,001	<0,009	0,056
Maximum Concentration (PP82/2001)		0,3	0,1	0,2	0,05	0,02	0,02	0,10	1,0

2. Metal Concentration Exceed Maximum Boundary Which Recommended by PP 82/2001

Rice in each location sampling contains iron. The lowest iron concentration is 350 mg/kg (16.05 mg/l) at location 15 (Melong) and the highest concentration is 745 mg/kg (34.24 mg/l) at location 3 (Biru). These values differ greatly from the levels of Ciherang rice studied by Sakagami et al (2016) which showed 4.6 mg/l iron content of Ciherang rice. The iron content in rice on the six locations when compared with the recommended FAO quality standard, which is 20.0 mg / kg, has exceeded. The high iron content is caused by the input of iron originating from water and accumulating in the soil then translocating into plants. The iron content in irrigation water used to irrigate paddy fields in the sampling location has exceeded the quality standard stipulated in Government Regulation number 82 of 2001, which is 0.3 mg/l. The iron content in the water can accumulate in the paddy fields. In Alloway (1995) it is stated that the iron content limit allowed is around 7,000 to 550,000 mg/kg. Based on this, the iron content in paddy fields has entered into the critical limit. The amount of iron in the soil can be caused by the use of fertilizers for agricultural land.

Manganese concentration in rice at the study site is the minimum concentration 34.6 mg/kg at location 3 and the highest is 92.5 mg/kg at location 1. When compared with the critical limit of Mn in plants, which is 100 mg/kg, the concentration of Mn in rice is still less than the critical limit. Manganese is an essential metal in plants. However, the concentration of manganese can be increased by the presence of manganese metal from other sources, such as water and fertilizers used for plants through absorption. The high manganese content in rice at the sampling location can come from irrigation water used to irrigate rice fields, which are characterized by the presence of manganese in the water. The maximum level of manganese in water designated for agriculture is 0.1 mg/l according to government regulation number 82 of 2001. Based on these regulations, only irrigation water in location 3 does not exceed the quality standard. The high manganese content in the water then accumulates in the soil before some manganese is absorbed by the rice plants.

Just like manganese, zinc is also an essential metal in rice. The zinc content allowed in food is 60 mg/kg based on FAO (2011) and the critical limit of zinc in plants based on Alloway (1995) is 100 mg/kg. Based on FAO recommendations, the zinc content in rice at location 1, which is 94.6 mg/kg has far exceeded the maximum allowable zinc, while other locations still had below the minimum quality standard. Sources of zinc in addition to plants, can also come from irrigation water and fertilizers that accumulate in the soil. The quality standard of zinc content in irrigation water is 0.2 mg/L (Yusuf, 2014), so that water at location 6 does not meet the criteria for irrigation water standards. Zinc content in rice, soil, and water does not correlate significantly, it is possible that zinc in rice can also come from the fertilizer used. In addition, grab sampling for one time risks showing that zinc input in rice from water cannot describe the true state of the water.

The maximum limit of chromium in food allowed by FAO (2011) is 20 mg/kg. The content of chromium in rice from all these locations has exceeded, with the highest chromium content in grain from location 3, which is 56.1 mg/kg. While based on Alloway (1995) the critical limit of chromium in plants ranges from 2 to 18 mg/kg. The value of chromium in this grain increases due to the input of chromium from other materials such as water, which accumulates in the soil. The concentration of chromium in water that is allowed based on Alloway (1995) is 0.05 mg/l. Only water in locations 2 and 4 still meets irrigation water quality standards.

The critical limit of copper content in plants based on Alloway (1995) ranges from 5-64 mg/kg. Even so, when compared to FAO's recommendations that set a maximum limit of metal content in food 20 mg/kg, then the copper metal content in the rice is still below the maximum limit except for location 6, ie 5.66 mg/kg has begun within the critical limit according to Alloway (1995). The copper content in rice can be derived from the water used to irrigate rice fields seen from the copper content in the water. Generally, these locations meet the feasibility of water for agriculture when compared to water classes for agricultural purposes, which is 0.02 mg/l, except for irrigation water at location 5.

The content of cadmium in rice at location 5 has exceeded the maximum limit set by FAO, which is 0.30 mg/kg, while other locations are below the critical limit. The content of cadmium in rice does not originate from irrigation water, judging by no detection of cadmium content in the irrigation water.

The concentration of lead in rice is still less than the maximum limit of lead in food, which is 5.0 mg/kg, according to FAO. Five locations have undetectable levels of lead metal content in rice and lead content from location 2 is below the maximum limits.

The presence of lead in grain at this location did not originate from irrigation water, judging from the lead content in irrigation water in 5 locations below the detection limit (<0.009

mg/l). Although there is lead in water at location 5, there is no detectable lead in rice. This is because lead is a metal with a low factor transfer value, so it difficult to absorb and translocate lead from the soil into plant parts. This is in accordance with previous research which states that the risk of lead absorption is lowest when compared with Cd, Hg, Mn, Hg, Mn, As, Ni, and Cr (Zeng et al., 2015).

All rice in the sampling location contained nickel. Nickel content in rice is still below the FAO recommended limit for nickel in food, which is 1.50 mg/kg, except rice at location 6. Input of nickel into grain can be derived from the accumulation of nickel in paddy fields. Accumulation of nickel in the soil can be derived from the use of irrigation water that irrigate the fields. The nickel content in the six irrigation water is still below the limit based on Alloway (1995), which is 1.0 mg/l, even at the location 2 nickel is not detected.

3.2 Water Quality To Water-Food Nexus

Generally water security to support food security is measured by quantity, when the amount of water is sufficient will be a measure of the success of food security. Even so, the principle of water security indicators includes aspects: 1) Availability of water; 2) Accessibility; 3) Quality and safety; and 4) Management (Gain, Giupponi, & Wada, 2016). Thus water quality is also a determining factor in food security. Previous research (Mason & Calow, 2012) states that indicators of water security include: 1) Amount of water available; 2) Ratio between storage capacity and the potential of existing reservoirs; 3) Budget allocation of water resources; 4) Use of water; 5) Consumptive use; 6) Percentage of population with good sanitation; industrial sector productivity; 7) Hydropower productivity; 8) Irrigation productivity and water quality that meets the standards. The eighth indicator explicitly emphasizes the existence of Nexus water quality to Water-Food Nexus.

The Water-Food Nexus is reinforced by the results of the analysis in this study. i.e. irrigation water that has been contaminated with metal will affect the rice produced. Irrigation water that has been contaminated with metal contamination will accumulate metals in rice (Table 5). Iron accumulation in iron reaches 1.55-14.02 times the concentration compared to the concentration of the metal in water which is used as a source of irrigation. Manganese accumulation reached 3.43 - 31.73 times, Zinc 1.76 - 255.14 times, Chromium 7.28 - 742.78 times, copper 7.01 - 17.30 times, Cadmium 0.09- 22.15 times, Lead 0.03 -2.02 times, and Nickel 0.29 - 6.92 times in rice compared to metal concentrations in irrigation water sources.

Table 4. Acumulation metal concentration from water to crop

Number	**Location**	**Increase of metal concentration from water to crop.**							
		Fe	Mn	Zn	Cr	Cu	Cd	Pb	Ni
1	Biru	8.48	3.59	255.14	7.28	12.15	0.09	0.12	0.29
2	Koyod	4.73	3.43	14.44	742.78	14.75	0.09	2.02	6.92
3	Linggar	3.12	31.73	22.39	11.96	8.43	0.09	0.12	0.27
4	Tegalluar	14.02	19.37	28.33	68.78	15.01	0.09	0.12	1.00
5	Dayeuhkolot	2.92	8.15	19.61	8.12	7.01	22.15	0.03	0.36
6	Melong	1.55	12.24	1.76	24.09	17.30	0.09	0.12	1.51

Metal contaminated water will result in metal accumulation in rice. The presence of heavy metals in rice at certain minimum limits can pose a risk to human health. The main composition of 81.9% rice grains is endosperm, 3.1% husk, and the rest is a small portion of the embryo (He, Yang, & Cha, 2000), so heavy metals are abundant in endosperms consumed and only a small portion of metal is contained in husk.

If heavy metals are consumed by humans through consumption of rice, there are some disadvantages that have an impact on health. Safe limits on food consumption are indicated by a Hazard Quotient value of less than one (<1). Iron and Manganese metals have passed the Hazard Quotient value in all locations, while the Cadmium HQ exceeds 1 at location 5, lead at location 2, and Nickel at locations 1,2,5 and 6 have a HQ value exceeding 1.

Table 5. Hazard Quotient from metal

Number	**Location**	***Hazard Quotient***							
		Fe	**Mn**	**Zn**	**Cr**	**Cu**	**Cd**	**Pb**	**Ni**
1	Biru	3,460*	5,732*	0,733	0,578	0,172	0	0	1,299*
2	Koyod	1,765*	3,515*	0,164	0,602	0,210	0	2,954*	1,201*
3	Linggar	1,631*	2,143*	0,163	0,695	0,209	0	0	0,873
4	Tegalluar	1,747*	3,715*	0,268	0,484	0,266	0	0	0,839
5	Dayeuhkolot	2,404*	4,614*	0,298	0,583	0,265	4,983*	0	1,602*
6	Melong	1,628*	4,203*	0,254	0,436	0,307	0	0	2,436*

1. Hazar Quotient Value More Than 1

Some of the disadvantages that have an impact on health, including health problems in the body. Excess iron in the body can cause complications such as cirrhosis, diabetes, weakening of the heart muscle, and arthritis (Monachese, Burton, & Reid, 2012). Excess manganese in the body through consumption leads to chronic poisoningwhich causes a weak impact on the legs, dull facial muscles, and subsequent effects such as slow speech and hyper reflexes. In addition, manganese poisoning in humans affects the respiratory tract and brain causing hallucinations, forgetfulness, and nerve damage. Acute toxicity due to chromium metal can cause vomiting, diarrhea, bleeding, and blood loss in the digestive tract. While chronic toxicity due to chromium such as liver / kidney necrosis, irritant dermatitis, nasal septal ulceration and perforation, and nasal, pharyngeal, and gastrointestinal carcinoma (Monachese et al., 2012). Cadmium can be carcinogenic to humans causing prostate, liver, kidney, and hematopoietic cancers (Tchounwou et al., 2012). The high lead on grain when consumed can cause the risk of acute toxicity such as headache, mild fatigue, nausea, vomiting, and neurobehavioral problems. In addition it can also be at risk of chronic toxicity from lead such as hemoglobin cystic disorders, impaired renal function, deafness, blindness, retardation, decreased IQ, and memory loss (Monachese et al., 2012). Nickel causes lung damage, abnormal lung function, renal tubular necrosis, anemia, and eosinophilia. Nickel inhibits ATPase activity causing neurological disorders, seizures and coma. Chronic nickel exposure causes reduced nicotinamide which then interferes with oxidative phosphorylation reactions (Cameron, Buchner, & Tchounwou, 2011).

3.3 Water Quality To Water-Energy-Food

Water quality affects water as a source of energy and food security, when water quality decreases due to metal pollution resulting in reduced food security, this will also reduce energy security. In order for food to be of quality, water quality must meet the standards, if metal contamination has occurred in the waters in this upstream Citarum River, then industrial areas must absolutely have WWTP to restore water quality so that it meets the standards for irrigation use thereby indirectly increasing return to the quality of grain produced in the Upper Citarum River Basin. The existence of WWTP requires absolute energy, the survey results show that some industries do not have WWTPs.

On the other hand, the land to build WWTPs has already been limited, so that the fulfillment of WWTP is carried out through a more modern concept, namely limited land use by making multilevel WWTPs. This multilevel WWTP will require special costs for energy allocation, for example pumps, aerators and some other equipment. The use of this energy is absolutely necessary to manage the production waste so that when exiting the installation WWTP has met the standard effluent.

Another effort that can be made to restore water quality for this irrigation is by preventing waste entering the river by implementing clean production. When implementing clean production it is necessary to improve the existing system in managing production, for example the pattern of zero metal waste production, by changing the main material of production, and of course requires certain energy to process it. Energy to process for WWTP or clean production takes place so that water to support food security is inseparable from the use of electricity, while the largest generation of electricity comes from water.

For example, Brisbane in Australia has used energy intensity of 0.68 kWh/m3 for water supply and 0.57 kWh/m3 for wastewater treatment systems (Lee, Keller, Chiang, Den, & Wang, 2017). With the existence of holistic management starting from WWTP or clean production system, the obtained water that is suitable for irrigation and the end result is that the produced grain is safe for consumption, is the interconnection of water-energy-food nexus.

4. CONCLUSIONS

Surface water sources in six locations along the Citarum Hulu watershed have been contaminated with metals: iron in all locations, manganese in almost all locations except location 3, zinc at location 6, chromium at locations 1, 3, 5 and 6, and copper at location 5. The contamination of water sources used to irrigate agriculture that has been contaminated with metals causes accumulation of rice at that location, with accumulation varying from 0.03 - 742.78 times in rice compared to irrigation water sources. If heavy metals are consumed by humans through consumption of rice, there are some disadvantages that have an impact on health. Safe limits on food consumption are indicated by a Hazard Quotient value of less than one (<1). Iron and Manganese metal has passed the Hazard Quotient value in all locations, while Cadmium is only in location 5, lead is only located in location 2, and Nickel in locations
1, 2, 5, and 6. To anticipate the dangers of food consumption due to pollution of water quality, some management can be done prevention of waste by implementing clean production and manufacturing of WWTP installations. Management requires certain energy that can be consumed.

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