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Hydro-chemical characteristics and evaluation of water quality for irrigation purposes in the Madukismo Sugar Factory area, Kasihan, Bantul

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Abstract

River water is crucial for irrigation requirements although it may be jeopardized by both natural phenomena and anthropogenic activity. The rice fields in Mrisi Hamlet, Tirtonirmolo, Bantul are irrigated by water sourced from the vicinity of the Madukismo sugar factory. This raises worries on the contamination of irrigation water by waste from sugar factories, which would subsequently affect rice fields. This study aimed to (i) examine the quality and hydro-chemical features of irrigation water in the study region, and (ii) investigate the impact of irrigation water on NPK concentration in soil and rice yield. The employed research approach is descriptive quantitative. Laboratory analysis was conducted on samples of water, soil, and vegetation. The analysis of water samples was conducted at the source areas, as well as at the inlet, middle, and outflow points of the tertiary irrigation channel traversing the rice fields. Samples were collected from rice fields irrigated with uncontaminated water and those contaminated by sugar industry effluent. The evaluation of irrigation water quality is founded on PP No. 22 of 2021. A statistical study using the ANOVA test was conducted to evaluate plant development across different locales. The study's results indicated a considerable disparity in irrigation air quality between contaminated and unpolluted areas, as evidenced by the metrics of air temperature, total dissolved solids (TDS), chemical oxygen demand (COD), and biological oxygen demand (BOD). The quality of irrigation water contaminated by sugar industry effluent surpassed the established maximum limit for irrigation water. Nevertheless, the waste from the Madukismo sugar refinery positively influenced plant output. The growth and productivity of rice plants on contaminated soil exceeded those on unpolluted land. The rice yield in the contaminated region was 8,000 kg/Ha, higher than in the control area, which yielded just 4,800 kg/Ha.

INTRODUCTION

Water is a crucial element in agriculture, particularly in irrigation to meet the hydration requirements of plants. Inadequate water supply adversely impacts plant growth, resulting in suboptimal development and a tendency for decline (Manurung et al., 2022). The plant's metabolic processes will be impaired when water deficiency stress intensifies. Water scarcity adversely affects nutrient absorption, impedes cell division and enlargement, diminishes enzyme activity, and causes stomatal closure, thereby hindering plant growth and development (Supriyanto, 2013). Sari (2019) asserted that rice yield will be optimized with enough water availability, attainable by irrigation. Consequently, it is essential to assess the quality of irrigation water, particularly the quantity and composition of soluble salts, since these factors dictate its suitability for irrigation (Zaman et al., 2018).

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Tirtonirmolo Village, located in Kasihan, Bantul, predominantly utilizes its land for rice cultivation, while also being in proximity to industrial areas. The Madukismo Sugar Factory/Spirit Factory (PGPS Madukismo) is a significant industry situated in the agricultural region. The Madukismo Sugar Factory dispose its manufacturing waste into the river, resulting in alterations to the river water's odor and color (Yoga, 2016). Liquid waste contamination results in COD concentrations surpassing irrigation water quality regulations (Sari et al., 2021; Septia, 2021). Well water in the neighboring neighborhood is likewise contaminated, with COD concentrations surpassing the quality criteria established by the Regulation of the Governor of the Special Region of Yogyakarta No. 20 of 2008 about Quality criteria (Marizka and Faidati, 2020; Yoga, 2016).

The quality of irrigation water contaminated by liquid waste might influence the production and sustainability of rice crops. Contaminated water can adversely affect soil and plants, disturb ecological equilibrium, and potentially impair soil fertility and the availability of water supplies for organisms. Consequently, the quality of irrigation water in Tirtonirmolo Village warrants examination to establish a robust basis for the formulation of effective and sustainable environmental protection plans. The aims of this research were (1) to identify the characteristics of irrigation water contaminated by liquid waste from the Madukismo sugar factory and (2) to assess the impact of liquid waste on the NPK content of the soil in the study area, as well as on the growth and productivity of rice.

MATERIALS AND METHODS

Study area

The research was carried out in Mrisi Hamlet and Jogonalan Hamlet, Tirtonirmolo Village, Kasihan District, Bantul Regency. Tirtonirmolo Village is situated at a longitude of 110.20'43" and a latitude of -7.49'43". Tirtonirmolo Village encompasses 483 hectares of agricultural land. The research area of rice fields encompasses 10,000 m^2. Mrisi Hamlet is an area where irrigation channels and land are contaminated by a combination of liquid waste from the Madukismo sugar factory, whereas Jogonalan Hamlet is an area where irrigation channels and land are not contaminated by this waste.

The climate at the research area was assessed using the Schmidt and Fergusson methodology. Climate was ascertained by the quantity of wet and dry months annually, followed by the computation of the average. Climate relies was determined using the outcomes of the Q value computation according to Schmidt and Fergusson formula as follows.

$$Q = \frac{\text{number of dry months}}{\text{number of wet months}} \times 100 \quad \text{............(1)}$$

Data collecting

The sample location was determined using the purposive sampling approach. The chosen areas comprised rice fields irrigated with water contaminated by sugar plant effluent (Mrisi Hamlet, Tirtonirmolo Village, Kasihan, Bantul) and uncontaminated rice fields (Jogonalan Hamlet, Tirtonirmolo Village, Kasihan, Bantul).

Hydro-chemical analysis water samples were collected in HDPE bottles. Water sampling was performed using the grab sample method, which entails collecting water samples at a specific site without regard to time or other factors. Subsequently, samples were packed in ice boxes and promptly transported to the laboratory, maintaining a constant temperature of 4°C to preserve their integrity. Water samples were collected from four locations, consisting of the source point, the entry, the middle, and the outflow of the tertiary irrigation canal that traverses the rice fields (Figure 1), with three samples taken from each site. The assessment of irrigation water quality is governed by the Indonesian National Standard (SNI) 06-2412-1991. Field measurements include water EC, pH, and temperature, whereas laboratory tests include color, turbidity, BOD, COD, DO, TDS, Pb, Cu, Zn, NO_3, and P_2O_5 metals.

Soil sampling was conducted in the designated rice fields (Figure 2). At each site, samples were collected from three sample points, each with three replications, resulting in a total of nine samples. Each replication at the identical sample point position was consolidated into one sample. Soil samples were analyzed in the laboratory for moisture content, texture, total nitrogen, available phosphorus, available potassium, soil electrical conductivity, pH in water, potassium permanganate, and organic carbon.

Agronomic observations were conducted to assess plant growth and development as indicators of the state of both contaminated and unpolluted plants.

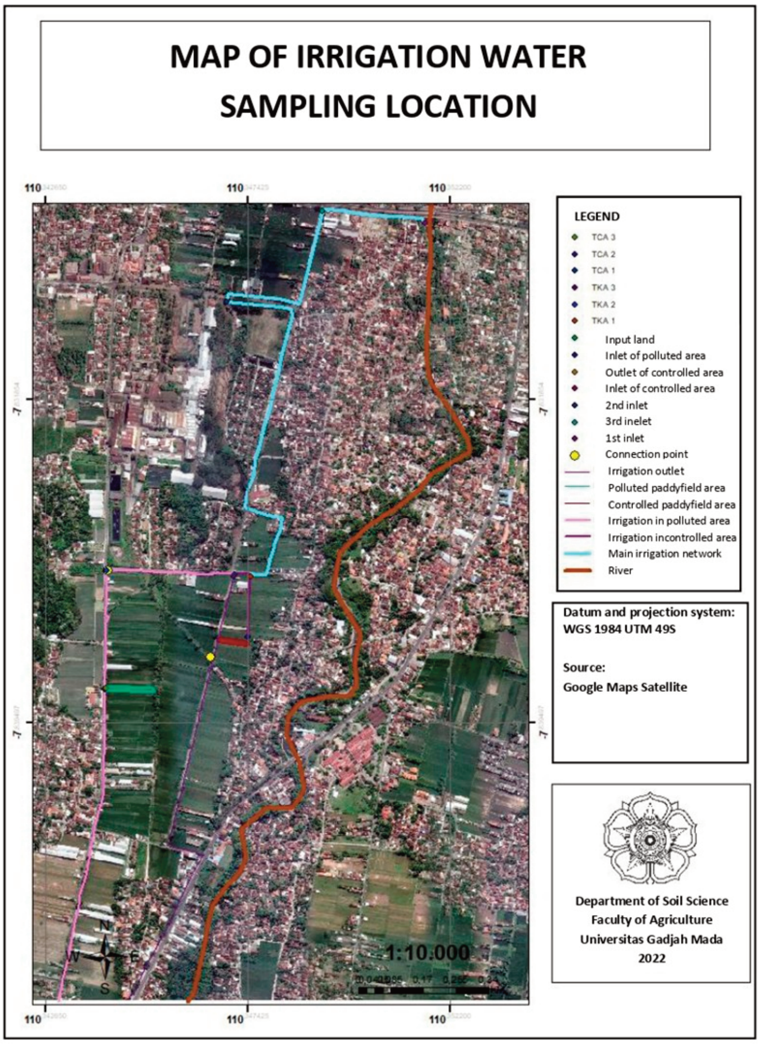

Figure 1. Map of Sampling location of irrigation water in Jogonalan and Mrisi Hamlet

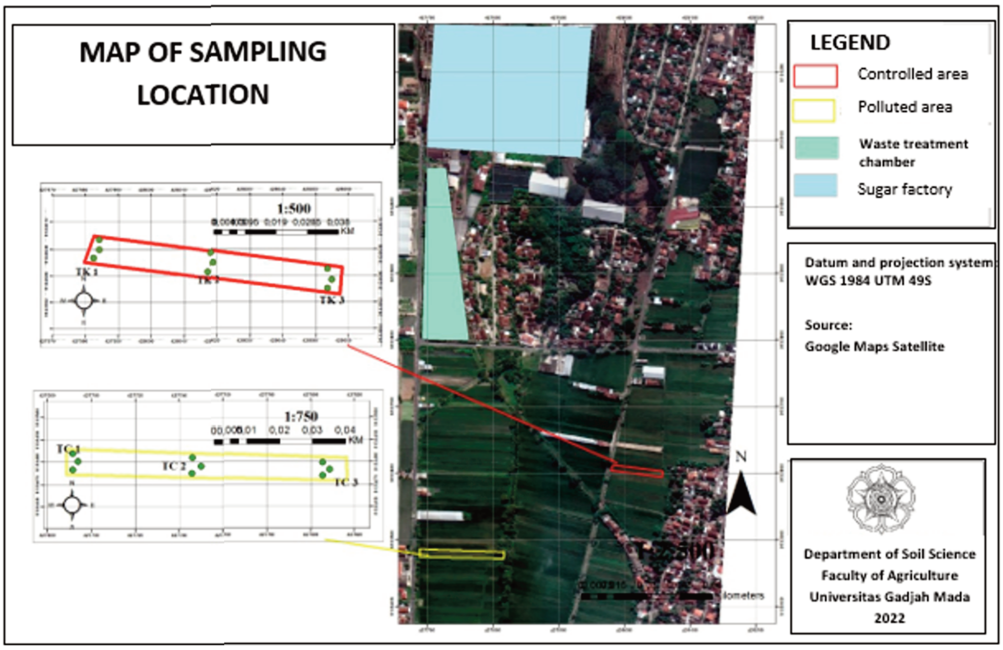

Figure 2. Map of Soil and plant sampling location in Jogonalan and Mrisi Hamlet

Measurements encompassed plant height, biomass (both fresh and dry weight of roots and shoots), and the number of shoots. A statistical study utilizing the ANOVA test was conducted to examine plant development across different locations.

RESULTS AND DISCUSSION

Climate condition

Climate classification in Tirtonirmolo Village according to Schmidt and Fergusson is suitable for agriculture. The Q value obtained is 68.57%, classifying it as climate type D, namely Moderate. Determination of climate classification was performed using rainfall data for 2016–2020 (Table 1).

Evaluation of irrigation water quality

The attributes of irrigation water in areas contaminated by sugar industry effluent exhibit considerable disparities when compared to unpolluted regions. The hydro-chemical parameters examined in Mrisi and Jogonalan are presented in Table 2. The pH is crucial in assessing water's appropriateness for irrigation (Pant et al., 2018). Mrisi exhibited slightly acidic pH values in comparison to Jogonalan, with mean of 6.2 and 7, respectively (Table 2). The electrical conductivity (EC) is a vital water quality metric that assesses the salt risk in irrigation water (Elangovan and Dharmendirakumar, 2013). High EC values may be associated with agricultural runoff, physical erosion, and the weathering of calcium carbonate minerals (Ghimire et al., 2021). Sources of total dissolved solids (TDS) may be either natural or manmade. Natural sources of TDS include precipitation, geological formations, and the weathering of minerals (Singh et al., 2016). Anthropogenic sources, including wastewater discharges and agricultural runoff, may elevate the concentration of ions such as chloride, sulfate, and nitrate (Pant et al., 2018). This investigation revealed that the average EC and TDS values were greater in Mrisi than in Jogonalan. The electrical conductivity (EC) and total dissolved solids (TDS) in Mrisi were double those in Jogonalan. The electrical conductivity (EC) and total dissolved solids (TDS) in Mrisi were around 350 µS/cm and 36 mg/L, respectively, compared to those in Jogonalan, which were 160 µS/cm and 17 mg/L (Table 2). This may be because Mrisi is more impacted by sugar plant effluent. It was concluded that the TDS and EC at both locations did not exceed the maximum permissible limits for irrigation water quality requirements as stipulated by Presidential Decree No. 22/2021, with the exception of the COD parameter.

The predominant chemical oxygen demand (COD) values in the contaminated irrigation water exceeded the limits established by PP No. 22 of 2021. The COD level in the contaminated irrigation water reached 786, whereas the COD levels in the unpolluted irrigation water ranged from 52.1 to 81. The high COD value in the irrigation water from PGPS Madukismo liquid waste signifies that the effluent from the sugar and spirits industries includes substantial organic matter (Sari et al., 2021). High COD levels in the contaminated irrigation water are accompanied by increased biochemical oxygen demand (BOD) (Table 2). BOD levels in this situation have beyond the threshold established by PP No. 22 of 2021. Penn et al. (2009) define BOD as the dissolved oxygen utilized by microbes to oxidize reduced compounds in water. Mardihia and Abdullah (2018) indicate that high BOD levels need a substantial quantity of oxygen for microorganisms to decompose waste.

High biochemical oxygen demand (BOD) levels adversely affect dissolved oxygen (DO) concentrations in the contaminated irrigation water. The dissolved oxygen (DO) concentration in the irrigation water polluted with sugar factory effluent ranged from 0.5

Table 1. Monthly rainfall data (mm) year 2016–2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agt	Sep	Okt	Nov	Dec
2016	208	227	401	137	114	145	113	71	189	272	279	240
2017	193	279	248	138	14	36	0	-	30	57	882	328
2018	365	199	195	58	11	13	-	-	5	0	182	138
2019	189	202	431	173	0	0	0	0	-	0	51	261
2020	520	477	470	510	418	2	3	40	32	237	235	553

Source: BMKG (2021).

Table 2. Water quality analysis in source, controlled, and polluted points

Parameter	Samples						
	Source	TKA 1	TKA 2	TKA 3	TCA 1	TCA 2	TCA 3
Temperature**	27.7	26.9	26.9	26.8	29.1	27.9	27.2
pH	7	7.1	7	6.7	6.7	6	6
EC	159	192	158	150	388	366	299
Color*	3	22	30	34	133	119	110
Turbidity*	4.5	36.6	20	38.3	42.7	60	36.8
TDS**	7	13	17	21	45	37	28
COD**	34.8	81	45.6	52.1	786	448.5	69
BOD**	3	6.4	4.4	4.4	51	147.5	35.3
DO**	6.5	6.5	6.7	6.7	0.7	0.5	0.9
Pb	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
Cu	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060
Zn	<0.0159	<0.0159	<0.0159	<0.0159	<0.0159	<0.0159	<0.0159
Nitrat	12.36	3.81	3.16	3.6	2.36	2.48	0.09
Fosfat	0.41	0.533	0.497	0.552	0.168	0.206	2.094

Remarks: TK = sample in controlled area; TC = sample in polluted area; ** = the variable value is out of standard of PP No.22 Year 2021. Source: Data analysis (2022).

to 0.9 mg/l, while the irrigation water quality requirements stipulate a minimum DO level of > 4 mg/l. The diminished dissolved oxygen content results from the substantial organic material from sugar industrial effluent, high total suspended solids, and higher temperature (Lesmana and Fuady, 2023). Hamuna et al. (2018) stated that an increase in BOD content in water correlates with a greater concentration of organic materials. Dissolved oxygen (DO) is a critical water quality metric, vital for aquatic species in rivers, with high DO levels signifying clean water (Varol and Tokatli, 2023). Additional chemical parameters included encompassed NO_3^-, PO_4^-, and concentrations of heavy metals (Pb, Cu, and Zn). All these parameters are predominantly attributed to anthropogenic activities and serve as significant indicators of water pollution (Varol and Tokatli, 2023).

All parameters are within acceptable ranges in both Jogonalan and Mrisi. The results demonstrate that the quality of irrigation water remains satisfactory. This aligns with the findings of Sari et al. (2021), stating that the irrigation water characteristics surrounding the Madukismo sugar factory conform to class IV water quality criteria, with the exception of the COD parameter.

The physical properties of irrigation water quality are temperature, color, and turbidity. The physical properties of the irrigation water in areas contaminated by sugar factory effluent exhibit considerable disparities when compared to that in the uncontaminated regions. The water temperature at the contaminated areas was 28.0, whereas at the unpolluted areas, it averaged 26.5. Puspitaningrum et al. (2012) asserted that a temperature rise of 1°C elevates oxygen consumption by as much as 10%. This also impacts the high levels of color and turbidity of the irrigation water in areas contaminated by sugar factory effluent in contrast to those that are unpolluted. The color and turbidity in Mrisi were around 120 and 46 mg/L, respectively, higher than those in Jogonalan, which were 28 and 31 mg/L (Table 2). The high values in Mrisi may be attributed to high concentrations of TDS in the contaminated areas. High TDS levels may originate from suspended particles in water, including biotic components, such as phytoplankton, zooplankton, bacteria, and fungus (Widodo et al., 2022).

Comparison of soil characteristic in the sampling sites

The soil texture at the research area is loam (Table 3). Nonetheless, variations in the proportions of soil fractions at each site result in differing dominance of loam. High concentrations of soil organic matter were observed in the contaminated areas, varying from 2.29% to 17.24% (Table 4). The COD levels in the contaminated irrigation water exceeded those in the unpolluted ones. High COD levels signify an abundance of organic materials. Furthermore, liquid effluent from sugar plants is characterized by high levels of organic materials (Faroni et al., 2022).

Table 3. Soil texture

Sample	Sand (%)	Silt (%)	Clay (%)	Class
TK 1	54	27	26	Sandy clay loam
TK 2	49	32	28	Loam
TK 3	59	28	18	Sandy loam
TC 1	70	3	28	Sandy clay loam
TC 2	47	37	25	Loam
TC 3	45	30	35	Sandy loam

Remarks: TK = sample in controlled area; TC = sample in polluted area. Source: Data analysis (2022).

Table 4. Organic matter

Samples	Organic matter (%)
TK 1	2.82
TK 2	2.23
TK 3	2.40
TC 1	17.24
TC 2	3.25
TC 3	2.29

Remarks: TK = sample in controlled area; TC = sample in polluted area. Source: Data analysis (2022).

Nagaraju et al. (2012) mentioned that the release of sugar factory effluent onto agricultural land significantly impacts the soil's chemical properties, including nutrient levels and organic matter content (Table 4).

The concentrations of total nitrogen, available phosphorus, and available potassium in the soil in contaminated areas exceeded those in the uncontaminated areas (Table 5). The availability of phosphorus in soil is affected by variables like soil pH, microbial activity, organic matter concentration, root-soil contact duration, and temperature. A significant supply of potassium originates from ash emitted by the factory, subsequently accumulating in the soil. Liquid effluent from sugar manufacturing facilities has high concentrations of nitrogen and phosphorus nutrients (Faroni et al., 2022), thereby augmenting nutrient levels in the contaminated areas.

The concentrations of heavy metals, namely total Pb, total Zn, and total Cu, were high in the contaminated areas compared to those in the uncontaminated ones (Table 6). The high Pb levels in this area result from its closeness to a roadway frequented by several motorized vehicles, together with irrigation water identified to contain Pb, which then accumulates in the soil. A contributing factor to the Cu concentration in the soil is the timing of sampling during the wet season. Suriani (2016) asserts that Zn in the soil originates from atmospheric pollution in the vicinity, as well as from the use of agricultural inputs such as fertilizers, pesticides, and fungicides.

Rice plant growth in the research area

The dry and fresh weight of the shoots varied substantially between locations (Figure 3 a-b). The dry weight of the shoots and roots corresponded to the

Table 5. Total N, available P, and available K

Samples	Total N (%)	Available P (ppm)	Available K (ppm)
TK 1	0.05	52.05	0.23
TK 2	0.05	21.89	0.22
TK 3	0.04	20.87	0.19
TC 1	0.06	306.58	0.42
TC 2	0.05	73.61	0.42
TC 3	0.05	54.34	0.34

Remarks: TK = sample in controlled area; TC = sample in polluted area. Source: Data analysis (2022).

Table 6. Total Pb, Cu, and Zn

Samples	Total Pb (ppm)	Total Cu (ppm)	Total Zn (ppm)
TK 1	0.91	14.58	98.07
TK 2	0.40	11.93	83.93
TK 3	0.03	10.43	65.88
TC 1	4.41	33.28	274.59
TC 2	1.85	13.15	77.49
TC 3	1.68	10.04	66.26

Remarks: TK = sample in controlled area; TC = sample in polluted area. Source: Data analysis (2022).

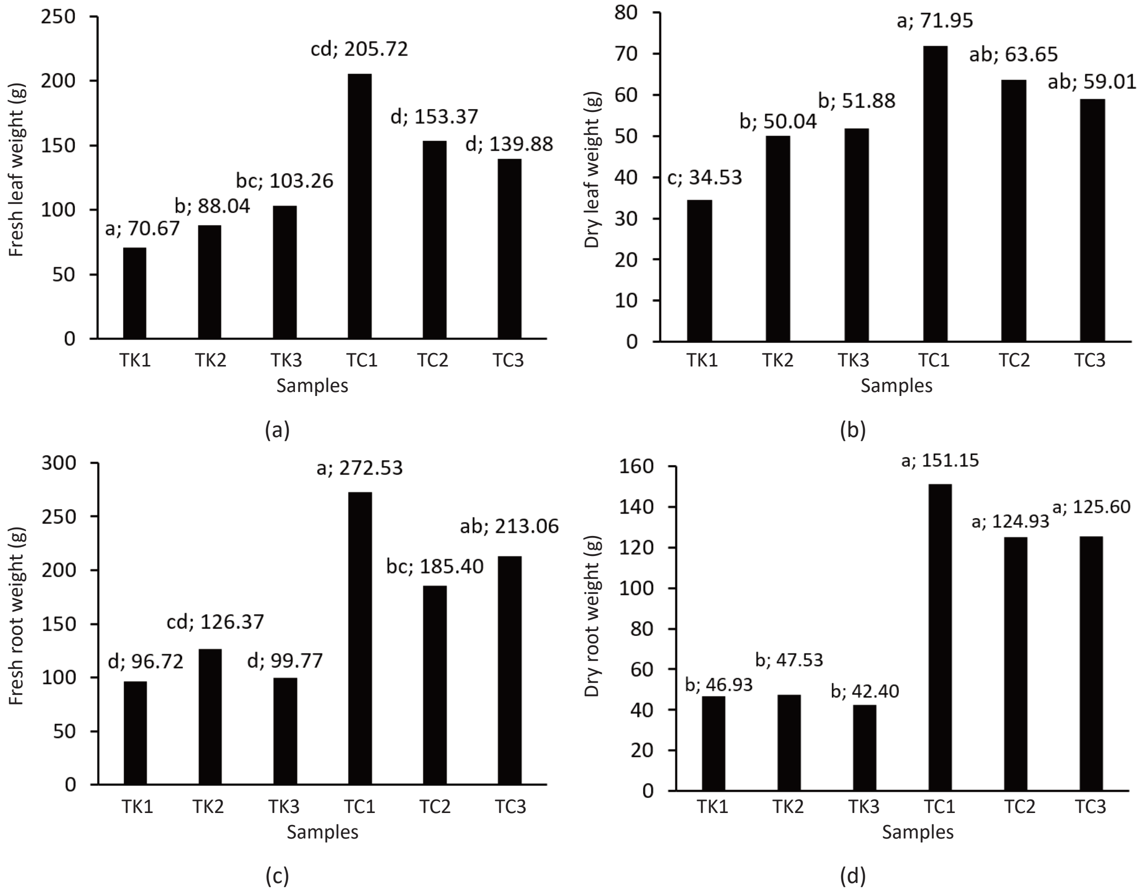

Figure 3. Effects of location on the fresh and dry weight of laves and roots

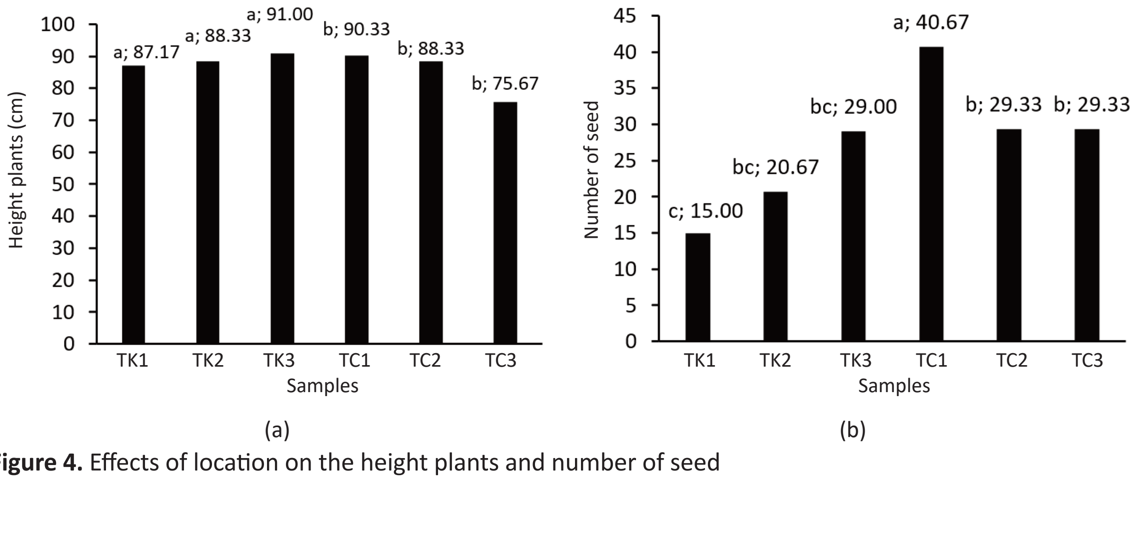

Figure 4. Effects of location on the height plants and number of seed

fresh weight of the shoots and roots. The contaminated areas exhibited greater dry and fresh weight of the shoots in comparison to the uncontaminated ones. Similar results were observed in the dry and fresh weight of plant roots. The dry and fresh weight of plant roots varied substantially between locations (Figure 3 c-d). The contaminated areas showed greater dry and fresh weight of roots compared to the uncontaminated ones. This assumption arises from the fact that rice fields in the contaminated areas also obtain organic material from the metabolism of liquid waste produced by sugar factories. The chemical components in sugar factory effluent are rich in organic material derived from the metabolism of carbon from glucose, thereby supplying nutrients to the land.

The plant height across locations exhibited no statistically significant differences (Figure 4a). No substantial difference was seen in plant height between rice fields irrigated with the contaminated water and those irrigated with the uncontaminated one. This condition contrasts with the findings of Riniarti et al. (2013), reporting that agro-industrial waste influences plant height.

Nonetheless, the number of tillers in the contaminated areas was significantly different from that in the uncontaminated areas. This results from the high soil organic matter concentration in areas irrigated with the contaminated water. Arifiani et al. (2018) mentioned that organic matter enhances soil aeration, hence optimizing nutrient absorption by roots and facilitating the development of a greater number of tillers.

Rice plant productivity in the research area

The cultivation of rice with contaminated irrigation water gives greater yields than that of uncontaminated one. The findings of conversations with farmers at both locations support this claim. At the contaminated site covering an area of 2.5 m × 2.5 m, a yield of 5 kg was recorded, corresponding to a yield of 8,000 kg/ha. Simultaneously, at the original site with a same tile area, a yield of 3 kg was recorded, corresponding to a yield of 4,800 kg/ha.

Greater crop production in rice fields irrigated with contaminated water is due to the high content of organic matter and nutrients in the soil. The decomposition of organic matter is facilitated by energy derived from carbs, which are plentiful in sugary liquid waste. The degradation of organic matter in water transforms O_2 into CO_2 and H_2O, resulting in a depletion of oxygen in the water. The decomposition of organic matter in water produces litter that facilitates the reactivation of soil microorganisms. This microbial activity enhances primary metabolism, thereby optimizing plant development.

CONCLUSIONS

The research findings indicate that the features of Madukismo sugar factory's liquid waste irrigation water exceeds the limits established by PP No. 22 of 2021; yet, it remains suitable for agricultural use. The liquid waste from Madukismo sugar factory significantly affects the quality of irrigation water. The liquid waste from sugar plant contains chemical compounds with high organic matter derived from the metabolism of carbon from glucose, thereby offering beneficial nutrients for the soil, particularly high levels of phosphate. Consequently, plant development in areas irrigated with water contaminated with sugar factory effluent demonstrates superior outcomes, leading to increased rice plant yield.

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