Quantifying the Impact: Statistical Analysis of Weather and Paddy Activities on Paddy Effluent Quality

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ABSTRACT

Paddy cultivation is a cornerstone of global agriculture and food production while supporting rural economies worldwide. Nonetheless, the intensive farming methods have adversely impacted water quality due to the poor effluent quality. The objective of this study is to investigate the influence of weather and stages of paddy farming activities on the quality of effluent discharged from paddy fields. A holistic approach was applied to integrate the paddy activities and weather variability into the analysis, uncovering nuanced relationships that have previously been overlooked. The water quality parameters include Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (NH_3-N), Total Suspended Solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN), Arsenic (As) and Aluminium (Al) were comprehensively assessed with statistical methods such as t-tests and ANOVA. The implementation of statistical methods such as t-tests and ANOVA provides a robust framework for quantifying these relationships and determining their significance. Results showed that the stages of paddy farming activities influenced all the measured water quality parameters statistically significant with p-value less than 0.05 were obtained for all the parameters. The weather conditions did not significantly influence the quality of the paddy fields effluent. However, the effect of weather conditions with the combination of paddy farming activities statistically significant towards NH_3-N, TSS and Al with p-value less than 0.05. This research contributes valuable insights to the scientific understanding of paddy agriculture's environmental footprint and informs evidence-based policies for promoting sustainable agriculture and preserving water quality worldwide. By understanding how weather patterns and farming practices impact effluent quality, strategies to mitigate environmental risks and optimize water management practices in paddy cultivation areas can be developed.

Keywords: Paddy effluent; quality; weather; paddy activities; impacts;

INTRODUCTION

Rice is the staple food for over half of the global population and about 90% of the global rice is produced and consumed in Asia. High demand for rice has contributed to the increasing trend for the area of paddy harvested globally which was 165 million tonnes in 2021. As documented by Food and Agriculture Organization (FAO) (2021), 90.5% production of rice were contributed by countries in the Asia region followed by Americas (5.2%), Africa (3.7%), Europe (0.6%) and Oceania (0.1%).

Owing to the increased demand for rice, eleven countries of Asia have contributed about 87% to the total global rice production include China, India, Bangladesh, Indonesia and Malaysia (USDA, 2023). In Malaysia, rice is the third most important crop after oil palm and rubber which is planted twice annually. Paddy cultivation in Malaysia covered up to 689 268 ha in which two third of the total planting area is distributed in Peninsular Malaysia and the remainder is found in Sabah and Sarawak (Firdaus et al., 2020). Most of the rice granaries are managed by the recognized agencies such as Muda Agricultural Development Authority (MADA), Kemubu Agricultural Development Authority (KADA), North Terengganu Integrated Agriculture Development (KETARA), Project Barat Laut Selangor (PBLS), Krian, Seberang Perak, Seberang Perai, Kemasin, Rompin, Kota Belud and Batang Lupar. Apart from that, there are 74 secondary granaries and 172 minor granaries throughout Malaysia (Dorairaj & Govender, 2023). In conjunction striving for better food security in Malaysia, the Malaysian government have initiated the National Food Security Polity and National Agro-Food Policy 2020-2030 (NAP 2.0) to boost rice production so that Malaysia can achieve its Self-Sufficiency Level (SSL) target, which is about 80% in 2030. In accordance with policy, the government plans are to promote the expansion of rice cultivation in rural areas and enhance productivity with modern technology (Ministry of Agriculture and Food Industries, 2021).

Amidst achieving the national aspiration, paddy cultivation requires a significant amount of water. According to Ahmed et al. (2014), in Malaysia, agriculture sector uses approximately 76% the supplied water in which 90% of them is allocated for paddy cultivation. In Malaysia, most of the farmers adopt continuously flooded method which require water up to 2600 litres/kg gross paddy (Han et al., 2022). Considering average standing water of 10 cm, it can be estimated that approximately 689 billion litres of water are utilized for paddy cultivation throughout Malaysia for a season. This significant amount of standing water will eventually become effluent which flows into the nearby water bodies during draining period for pre-planting and pre-harvesting stages. The untreated effluent contains various pollutants such as organic matter, ammonia, suspended solids, nutrients and heavy metals which can degrade the water quality and leading to the water security threatening as a result of poor agricultural practices and over-fertilized (Varol & Tokatlı, 2021).

The Juru River Basin is in the district of Seberang Perai Tengah, Penang, Malaysia. Its upstream originated from the Permatang Rawa River and Ara River which become the confluence of the Rambai River and then flows into the Juru River before being discharged into the Straits of Malacca. The river flows through the commercial, industrial, residential and agricultural areas, and becomes one of the main water sources within the areas (Masthurah et al., 2021). As paddy areas cover up to 67.4% of the agriculture areas and contribute to significant effluent volume to the Juru River, hence control at the paddy fields outlet is crucial to ensure good quality effluent to be discharged into the river (Department of Town and Country Planning, 2018). At the upstream of the Juru River, there are paddy granaries (302.8 ha) which are managed by the Integrated Agricultural Development Area (IADA) Seberang Perai. The presence of the paddy fields at the river upstream has degraded the Juru River quality of the river due to their poor effluent quality. As a result, the Juru River has been identified as a polluted river and classified as Class IV, needing immediate action (Karim et al., 2019).

During paddy cultivation, paddy fields undergo series of filling and discharge water depending on the stages such as irrigation, pre-planting, planting and pre-harvesting (Yamaoka, 2006). The variability of stages and weather conditions throughout the paddy season have led to different pollutants' concentration discharged into the water bodies in the forms of effluent and runoff. These pollutants can adversely impact the environment, leading to eutrophication, reduce dissolved oxygen and severe impacts on water resources and biodiversity (Hadiyanto et al., 2019; Loi et al., 2022; Xu et al., 2022). Therefore, comprehensive research is required to determine the effluent quality from the paddy fields within the district and the factors which influence the variability concentration statistically.

The aims of this research were to investigate the influence of weather and stages of paddy farming activities on the quality of effluent discharged from paddy fields statistically in the Juru River Basin and compare the water quality parameter with the National guidelines.

MATERIALS AND METHODS

Study area

The Juru River basin is one of the main basins in the district of Seberang Tengah, Penang, Malaysia with a total catchment area of 68.3 km^2. The Juru River originates from the Bukit Mertajam Hill (5°22′N and 100°28′E), Penang, Malaysia (Karim et al., 2019). Its upstream starts from the Permatang Rawa River and Ara River which joins to form Rambai River and then flows into the Juru River before being discharged into the Straits of Malacca. The length of the Juru River is about 15km. The Juru River basins consist of six main tributaries which are Permatang Rawa River, Ara River, Pasir River, Kilang Ubi River, Permatang Rotan River and Derhaka Juru River as shown in Figure 1. According to Department of Town and Country Planning (2018), approximately 303 Ha of paddy fields are concentrated at the upstream of the Juru River Basin especially, at Permatang Rawa River. Due to the direct discharge of paddy fields effluent into the downstream of Permatang Rawa River, leading to the severe pollution of the Juru River Basin. According to the Malaysia Environmental Quality Report 2023 by Department of Environment (DOE) (2023) , the Juru River Basin has been classified as polluted with high ammoniacal nitrogen and BOD content.

Figure 1 Juru River location with sampling points

Sampling and analysis

The water quality samplings were carried out to determine the water quality data from paddy fields. The water samples were collected during the main season (October-February 2022) and off-season (May-September 2023) to obtain comprehensive data that covered different paddy stages (irrigation, pre-planting, planting and pre-harvesting stages) and weather conditions (dry and wet conditions). Four sampling locations were set up as shown in Figure 1 which covers the upstream, midstream and downstream of the paddy fields with the purpose of monitoring the variations of the water quality as river flows along the agricultural areas.

The water quality samplings were carried out in-situ and ex-situ. For in-situ sampling, the physicochemical parameters such as pH, temperature and turbidity were determined by using the YSI 556 Multi-Probe System (MPS) and turbidity meter. The sampling process were repeated three times for every location which also complied to the American Public Health Association procedures (APHA, 1998). For ex-situ sampling, biochemical oxygen demand (BOD_5), Total Suspended Solids (TSS), ammoniacal-nitrogen (AN), total Kjeldahl nitrogen (TN) and total phosphorus (TP), Arsenic (As) and Aluminium (Al) were conducted based on APHA methods (APHA, 2012). For ex-situ sampling, the water samples were collected with different samples bottles of sterilized high-density polyethylene (HDPE). The bottles were dipped at 5cm below the water surface without disturbing the bed surface. The filled bottles were then kept in a cooler box with temperature less than 4˚C and transported to the laboratory for the analysis within 24 hours.

Statistical analysis

Statistical analysis was conducted to identify the trends and patterns which facilitate understanding the influences of paddy cultivation activities and weather conditions towards the paddy effluent quality. From the statistical analysis, the factors which influence the effluent quality can be statistically determined. In this study, t-test and one-way analysis of variance (ANOVA) were conducted to analysis the result based on the p-value. The statistical analyses were performed by using Minitab.

The t-test was conducted to statistically test is there is significant difference between the means of two independent groups (Golub et al., 2024). This is ideally to be used to examine the influence of weather conditions since there are only two conditions which will be statistically analyzed such as ‘Dry’ and ‘Wet’ conditions. The significance of the t-test is verified when p-value less than 0.05, indicating the difference between the mean is considered statistically significant (Kotronoulas et al., 2023). Hence, indicating that the weather condition is one of the significant factors towards the water quality parameters. The t-test can be performed by referring to the formula (Duncan, 1975):

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where $\overline{X_1}$ is observed mean of first sample, $\overline{X_2}$ is observed mean of second sample, S_1 is the standard deviation of first sample, S_2 is the standard deviation of second sample, n_1 and n_2 are the sample size of first and second samples, respectively.

The one-way ANOVA was conducted to determine whether there are any statistically significant differences between the means of three or more independent groups. In this study, the statistical analysis was carried out to investigate the influence of paddy cultivation activities with four groups (irrigation, pre-planting, planting and pre-harvesting) towards the effluent quality. The group is considered as statistically significant differences when the p-value is less than 0.05. The computation of ANOVA was computed accordingly as discussed by St»hle and Wold (1989).

In this study, the general linear model (GLM) was also applied to investigate the influence of the combined factor (weather conditions and paddy cultivation activities) towards the effluent quality. The idea is to observe the variability of the effluent quality with the combined effects in terms of statistically significant differences. GLM is an ANOVA procedure which describes the statistical relationship using a least squares regression in which two or more independent variables can be combined for the statistical analysis (Feng et al., 2018). The group is considered as statistically significant difference when the p-value is less than 0.05 (Helwig, 2019).

RESULTS AND DISCUSSION

Water Quality Trend

The results obtained from the site sampling of BOD, NH3-N, TSS, TP, TN, Al and As maximum concentrations were tabulated in **Table 1**, providing crucial insights of the paddy effluent quality into the Juru River. From the graphs, it can be observed that the levels of all measured pollutants exceeded the Raw Water Quality Standard established by the Ministry of Health Malaysia (MOH) . The maximum values obtained for BOD, NH3-N, TSS, TP, TN, Al and As were 25 mg/L, 42.53 mg/L, 571 mg/L, 62.84 mg/L, 107.49 mg/L, 24.57 mg/L and 0.092 mg/L, respectively. Moreover, when these results were compared with the National Water Quality Standard by Department of Environment Malaysia (DOE, 2023) , it can be observed that the BOD, NH3-N, TSS, TP, TN and Al levels surpassed the Class IV standard while As concentrations exceeded Class III permissible limits. These results underscore the immediate action is required to control the quality of paddy effluent as it contributed to large amount of wastewater into the nearby water bodies.

A notable trend can be observed based on the spatial distribution of pollutant concentrations along the sampling location (SL). The highest concentrations were consistently observed at SL 4 which was situated at the outlet where paddy effluent discharged into the main river. In contrast, pollutant levels at SL 1 (upstream), SL 2 (midstream) and SL 3 (midstream) depicted comparatively lower concentrations. The concentration gradient indicated that the direct influence of the paddy cultivation towards the quality of the nearby water bodies.

Table 1 Maximum values for the measured parameters at every sampling location

Sampling Location (SL)	BOD (mg/L)	NH3-N (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	Aluminium, Al (mg/L)	Arsenic,As (mg/L)
1	3	1.55	53	0.09	5.14	0.35	0
2	4	1.92	56	0.24	5.88	0.37	0
3	5	3.1	61	27.74	14.21	0.41	0.022
4	25	42.53	571	62.84	107.49	24.57	0.092

Weather and Paddy Activities Influenced Factors

The mean and p-values of water quality parameters against different weather conditions and paddy activities were tabulated in **Table 2**, assessing the influence of weather conditions and paddy activities on the paddy effluent quality. The results revealed important information related to the factors driving variations in water quality parameters.

Table 2 Mean and statistical analysis of the measured parameters

Parameter	Weather		p-value	Paddy Stages				p-value	Combined Factors
	Wet	Dry		Irrigation	Pre-planting	Planting	Pre-Harvesting		(p-value)
BOD (mg/L)	14	8	0.262	5	18	4	18	0.010	0.229
NH3-N (mg/L)	14.94	8.75	0.616	0.80	20.29	7.95	36.83	0.000	0.011
TSS (mg/L)	282	226	0.631	76	518	46	377	0.000	0.047
TP (mg/L)	35	27	0.435	30	41	8	46	0.003	0.058
TN (mg/L)	46.37	45.23	0.863	4.57	60.33	19.79	98.52	0.000	0.119
Aluminium, Al (mg/L)	8.98	11.71	0.547	6.97	9.39	4.49	20.53	0.002	0.024
Arsenic,As (mg/L)	0.049	0.043	0.621	0.024	0.080	0.026	0.055	0.000	0.057

For the weather condition factor, the analysis indicated that it did not exert a statistically significant influence on the paddy effluent quality as the p-values exceeded 0.05 for all measured parameters. It indicated that the weather alone does not significantly impact the effluent quality without considering the paddy cultivation stages as paddy fields undergoes series of filling and drained standing water which occurred on the predetermined stages. For instance, the mean values for NH3-N, TSS, TN and As recorded almost similar or slightly different results which indicated that the factors alone cannot be used as the benchmark as reference to the severity of the paddy effluent quality.

Paddy activities emerged as a statistically significant factor which influenced the effluent quality with p-values below 0.05 for all the measured parameters. From the table, it can be observed that the pre-planting and pre-harvesting stages exhibited higher mean values compared to the irrigation and planting stages. During pre-planting, sowing and other paddy fields preparation activities have caused land disturbances which lead to the accumulation of pollutants like TSS in the flooded and stagnant water, resulting poor water quality upon discharge. Similarly, pre-harvesting stages involves draining of standing water upon harvesting stage which contained elevated nutrients (BOD, NH3-N, TP, TN) and heavy metals levels due to the application of chemical fertilizers and pesticides for the paddy growth and yield which further increasing the effluent concentration.

The combined analysis of weather conditions and paddy activities revealed that significant influences on measured parameters such as NH3-N, TSS and Al with p-values less than 0.05 and were presented in Figures 2-4, respectively. The influence of weather and paddy activities towards the other parameters concentrations at SL 4 can be observed from the **Supplement Materials**. This highlighted the need to consider both factors comprehensively during the assessment of paddy effluent quality, as different concentrations of water quality parameters were observed for the same paddy stages under varying weather conditions. As the paddy stages directly influence the volume and composition of the effluent, weather conditions play a complementary role in modulating the transport and dilution process of the pollutants. The weather conditions influence the effluent dynamics in which they can enhance dilution of pollutants that can reduce their concentrations in the effluent and can also exacerbate runoff from paddy fields into the nearby water bodies. The effects of the weather conditions depend on the rainfall intensity and duration. Moderate rainfall events normally facilitate the pollutants dilution within the paddy fields which effectively reduces their concentrations in effluent. However, heavy rainfall events pose a higher risk of exacerbating effluent pollution through surface runoff (Shi & Li, 2024).

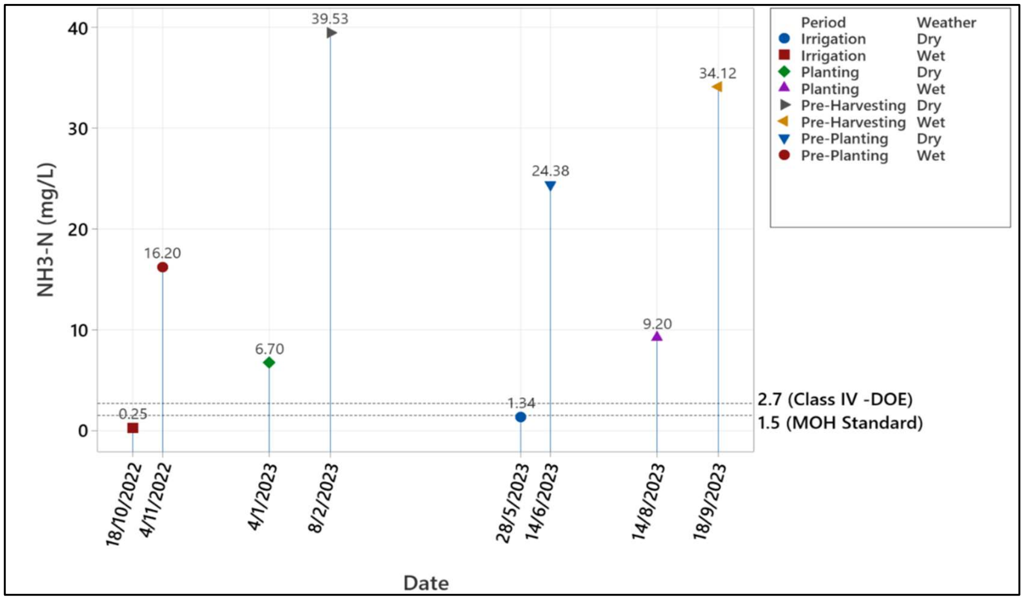

Figure 2 NH3-N concentrations at SL 4

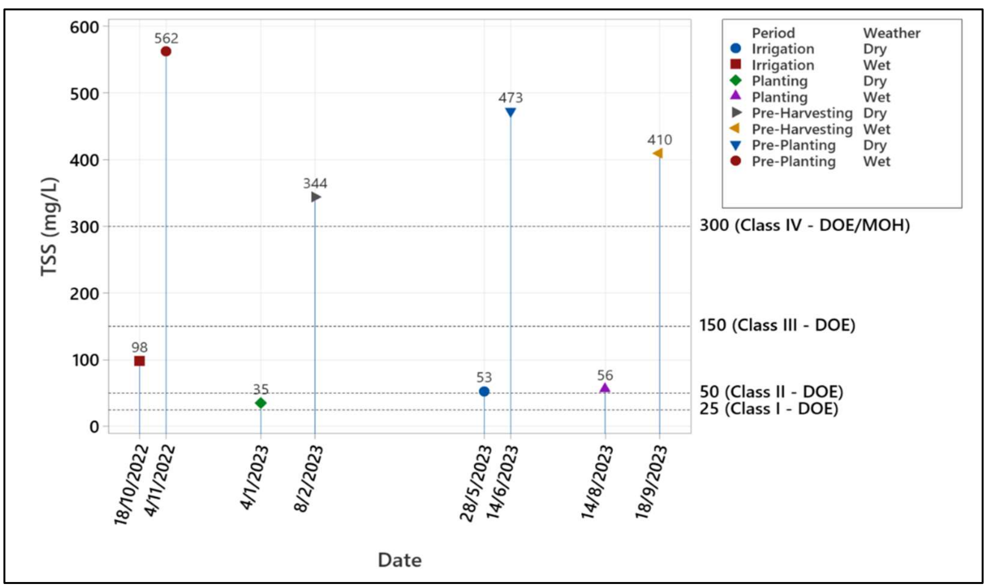

Figure 3 TSS concentration at SL 4

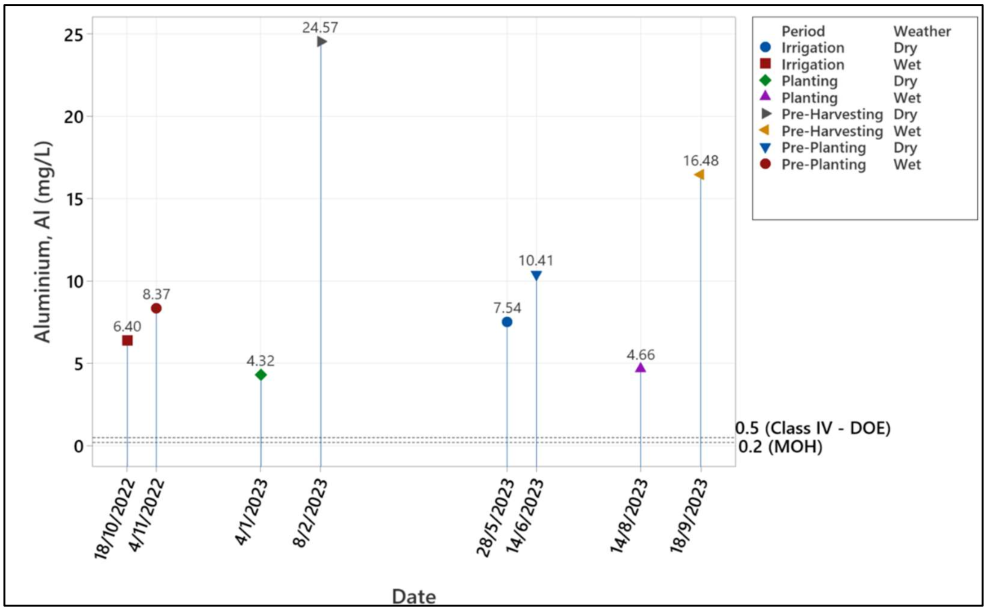

Figure 4 Al concentration at SL 4

Effects to the Environment and Human Health

High BOD discharged from the paddy fields were observed from the effluent especially during pre-planting and pre-harvesting stages. BOD serves as a crucial indicator, representing the oxygen required for organic matter decomposition under aerobic conditions and high BOD value indicated that the effluent was contaminated (Gustinasari et al., 2019). During pre-planting can be caused by the ploughing activity in the paddy plots which led to the accumulation of organic matter in standing water. Similarly, during the pre-harvesting stage, fertilization processes increase bacterial activity, resulting in higher oxygen consumption for organic material oxidation (Ahmad et al., 2014). These observations confirm that paddy field effluents contribute to Juru River contamination, adversely affecting its ecosystem as indicated by Masthurah et al. (2021). Besides, excessive discharge of BOD into the environment can lead to the formation of organic acids in the river consequently reducing dissolved oxygen (DO). Hence, higher concentration of BOD can cause an inhospitable environment for fish and aquatic organisms, endangering their survival. According to the Feisal et al. (2023), the abundance of microbenthic invertebrates (crustaceans and pelecypods) were significantly influenced by the BOD concentration in the Juru River.

Additionally, nutrient discharge from paddy fields, including NH3-N, TN, and TP, exceeds Class IV standards, primarily due to extensive fertilization practices. According to the Food and Agriculture Organization (FAO) (2013), chemical and organic fertilizers are the major sources of nutrients in paddy fields. Based on the rice crops manual by IADA, fertilization was done at least six times for every season to ensure high yield and better quality of paddies (IADA, 2024). During rainfall and pre-harvesting stages, TN and TP were highly discharged as flooded water that mixed with fertilizers was drained out from the paddy fields. Small return period rainfalls had caused pollutants cannot be rapidly dissolved in the rainwater runoff and washed away, causing high nutrients concentrations in the effluent (Shi & Li, 2024). This led to severe algae blooms, eutrophication and oxygen depletion, ultimately harming aquatic organisms (Sagasta et al., 2017). As reported by Al-Shami et al. (2011), in the Permatang Rawa River, due to the paddy fields effluent, the aquatic fauna and sensitive species were rapidly affected while the moderately sensitive animals disappeared gradually at later stages, causing the abundance of the tolerant species such as *Chironomus* spp. which survived the environmental deterioration. Furthermore, elevated nutrient levels in water, particularly in rivers used for drinking water and fish consumption, pose significant risks to human health such as skin rashes, kidney damage, respiratory problems and birth defects (Ward et al., 2018).

A notable increase in TSS especially during pre-planting and pre-harvesting stages had exceeded Class IV and Raw Water Standard set by the MOH. TSS consists of inorganic materials (sediments and silt) and organic materials (Fondriest Environmental Inc, 2014). The discharge of high suspended solids, particularly sediments, from paddy fields is attributed to ploughing activities, unsustainable land use practices, and improper tillage, leading to heightened erosion and sediment runoff into adjacent rivers, especially during heavy rainfall. Clay and silt in sediments can adsorb various chemicals, including nutrients and heavy metals, thereby facilitating their transport into the nearby water bodies(Sagasta et al., 2017). For instance, insoluble forms such as phosphorus adsorbed to the solid particles, resulting in excess amount of phosphorus in the aquatic ecosystems (Eisa & Mohammad Reza, 2024). The accumulation of high TSS levels can have detrimental effects on aquatic organisms, such as blocking fish gills, impairing watercourses, altering delta formation and dynamics, hindering water navigability, and disrupting water supply for domestic and industrial purposes (Egesi et al., 2023; Kennish, 2023; Zabinski et al.). As reported by Feisal et al. (2023), high concentration of TSS had led to the abundance of phytoplankton in the Juru River and from this study it can be proven that the concentration of TSS was highly driven the untreated paddy effluents. The accumulation of TSS can create turbidity in water, reducing light penetration and affecting aquatic plant growth.

Heavy metals such as Al and As were found to exceed the Class IV and III standard, respectively and exceeded Raw Water Standard established by MOH in the paddy effluent. These metals are introduced into the river through drainage water and runoff from paddy fields. During the planting stage, the extensive use of pesticides and chemical fertilizers containing these metals contributes to their elevated levels in the effluent. Comparing both weather conditions, it can be observed that the concentrations of the metals were lower during wet conditions as both of the metals are soluble in water (Botté et al., 2022; Kastury et al., 2024). Higher rainfall and increased runoff volume facilitate the dilution process of heavy metals before they are transported into the river. The elevated level of Al can pose a threat to aquatic organisms, leading to contamination in the fish's tissues which eventually will be consumed by human(Boopathi et al., 2024). Contaminated with As is concerning as it is associated with severe health consequences such as liver failure, kidney damage and skin cancer (Zhang et al., 2023). Hence, the quality control of paddy effluent is essential to ensure safer and sustainable environment especially, the health of rivers and the well-being of the communities.

CONCLUSION

This study indicated that the paddy effluents have a significant impact on the Juru River quality. Water sampling results revealed that levels of BOD, NH3-N, TSS, TP, TN and Al levels surpassed the Class IV standard while As concentrations exceeded Class III permissible limits based on the NWQS standards by DOE. Additionally, all measured pollutants exceeded the Raw Water Standards established by MOH, indicating the river is severely contaminated. From the statistical analysis results, weather conditions alone did not significantly influence effluent quality, as evidenced by p-values greater than 0.05. However, paddy cultivation activities emerged as the primary contributor to the effluent quality degradation, with p-values less than 0.05 for all the measured parameters. Furthermore, combined analysis of weather conditions and paddy activities revealed significant influences on measured parameters such as NH3-N, TSS and Al, emphasizing the importance of comprehensive assessment considering both factors. From the study, it can be stated that the paddy effluent quality must be strictly controlled as it significantly affected the ecosystem and sustainability of the Juru River.

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