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Assessment of Stream Water Quality in Tropical Grassland using Water Quality Index

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ABSTRACT Water quality is a serious issue in tropical grasslands that must be addressed to ensure the continuity and sustainability of water resources. This study aimed to assess the stream water quality of tropical grassland under long-term moderate (2.7 animal unit ha^{-1} y^{-1} for 34 years) and short-term heavy (5 animal unit ha^{-1} y^{-1} for 2 years) grazing systems at catchment and farm scales in Kuala Lumpur, Malaysia. Water samples were collected in the streams of both grazed and ungrazed grasslands monthly throughout the year. Samples were analyzed for pH, EC, DO, NH_3-N, COD, TSS, BOD_5, fecal coliform (FC) and *E. coli*. Harkins' index was used to classify stream water quality status. Mean values of NH_3 and FC were similar amongst the streams in both catchment and farm (P>0.05). Mean values of TSS, COD, BOD and pH of streams in grazed grassland were higher than those in streams of ungrazed grassland in both catchment and farm (P<0.05). DO concentration was similar amongst the streams in the catchment or farm (P>0.05). Water quality of the streams in grazed grassland was classified as class II, however, the streams in ungrazed grassland had water quality of class I in the catchment. Water quality was not affected by short-term heavy grazing in farm scale. The negative impact of grazing on water quality was prominent in long-term moderately grazed grasslands than short-term heavily grazed grassland.

Key words: *Heavy Grazing, Moderate Grazing, Quality Index, Rangeland Hydrology*

1 INTRODUCTION

Degradation of water resources quality in grassland ecosystems is of growing environmental concern (Hubbard *et al*., 2004). Quality of water from grassland is a function of precipitation, landscape characteristics, soil properties, vegetative cover and animal grazing management strategy (Agouridis *et al*., 2005). The impact of animal grazing on stream water quality in grassland can be varied with management strategies and depends on stocking density, grazing intensity, animal access to streams, availability of off-stream water supplies, location of bedding ground, salt and mineral lick blocks and etc (Scrimgeour and Kendall, 2002). Animal can negatively affect water quality by direct deposition of faeces and urine into the water bodies (Stamm *et al*., 1998; Lowrance and Sheridan, 2005), aggregation in specific locations such as bedding ground near to water bodies, overgrazing, and untimely

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grazing (Relative to rainfall events and soil) wetness) (Hubbard *et al*., 2004; Ohlenbusch *et al*., 2002). Additionally, the use of agro-chemicals by farmers particularly in commercial pasturelands can result in the accumulation of P and N, increasing the potential problem of surface water contamination (Aryal *et al.*, 2012). Grazing animal can also adversely affect surface water through increasing soil erosion and sediment export into water bodies (Lowrance and Sheridan, 2005). Water quality degradation with micro-organisms is another major concern associated with grazing animal in grassland especially when animal have unrestricted access to streams and ponds (Tiedemann and Higgins, 1989; Agouridis *et al*., 2005). Most of these water quality concerns in grassland appear at high stocking density. The impact of animal grazing on surface water quality can also be varied with grazing land size. It seems that when animal are restricted to small scale farm, the impact on water quality is limited at least in short period (Vidon *et al*., 2008). Hubbard *et al*., (2004) emphasized that the impact of grazing animal on surface water quality should be assessed at both farm and catchment scales. At both scales, grazing animal waste is considered as a major source of pollutants like nutrients and micro-organisms (Belsky *et al*., 1999).

Tropical grasslands are subjected to heavy rainfall throughout the year. During storm events, there is little water infiltration into the soil and much of the rain flows into streams via surface runoff. Animal waste deposited on the grazing land and along the stream banks during the dry conditions, can be transferred to adjacent streams by runoff and influence water quality adversely. This will provide detriments to wider community by declining quality of water from grazing lands that enters to other water bodies in downstream (Hall, 2014). Therefore, water quality is a serious issue in tropical grasslands that must be addressed properly. As water quality problems become more serious, water quality monitoring and assessment must be an important part of management actions and research projects.

Assessment of water quality can be defined as the analysis of physical, chemical and biological characteristics of water (Bharti and Katyal, 2011) with various approaches including statistical analyses of individual parameter, multivariate statistical techniques, water quality indexes and etc. A numbers of indexes have been developed all over the world which can easily judge out the overall water quality within a particular area promptly and efficiently (Bharti and Katyal, 2011). Examples are Harkins' objective water quality index (WQI_H) (Harkins,1974), US National Sanitation Foundation Water Quality Index (NSFWQI), British Columbia Water Quality Index (BCWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) and etc. These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source (Khan *et al*., 2003). Among these indices, the Harkin's index is widely used because of its flexibility and simplicity. This index is getting attention in many countries as it can be used to indicate water quality status and to classify the streams by their water quality level (Yusoff *et al*., 1999). The objective of this study was to assess the stream water quality of tropical grassland with different grazing management strategies at both farm and catchment scales.

2 MATERIALS AND METHODS

2.1 Study Site

This study was carried out in the Taman Pertanian University catchment (TPU, 2° 58' North and 101° 43' East) and the Ladang pasture farm (Ladang, 3° 00' North and 101° 42'

East) about 20 km south of Kuala Lumpur, Malaysia. The TPU catchment and Ladang pasture farm extend over a total area of 1317 and 40 ha, respectively. The areas have a humid tropical climate with seasonality in rainfall distribution. It rains comparatively less from May to September (dry season) than October to April (rainy season). The mean annual rainfall and temperature are 2471 mm and 24.5 ºC in the areas, respectively.

Mean elevation of study areas is about 80 m above msl. The topography varies from level terrain to slightly sloping and gently rolling with some steep hills and shallow depressions at TPU catchment. Slope varies 5 to 100% in the TPU catchment. However, most parts of the catchment have slope below 20% which is easily accessible by animal under free grazing system. The Ladang pasture farm was located on a flat terrain.

The TPU catchment and Ladang pasture farm represent a long-term moderate (2.7 animal unit ha^{-1} y^{-1} for 34 years) and a short-term heavy (5 animal unit ha^{-1} y^{-1} for 2 years) rotational grazing systems with cattle, respectively. About 75% of the catchment area is covered by grassland while the rest is covered by oil palm plantation. Grasslands are distributed throughout the catchment as well as along the streams and water bodies. The Ladang pasture farm was useless natural grassland before establishment in 2007. Grazing exclosures were also constructed at the TPU (20 ha) and Ladang (4 ha) sites in 1975 and 2007, respectively. The exclosures were located contiguous to the grazed area and on terrain with similar soils and vegetation.

There were six main streams in the TPU catchment. Four streams, i.e., S1, S2, S3 and S4 were located in grassland under animal grazing and two streams, S5 and S6, in ungrazed exclosure. In Ladang pasture farm, two streams, i.e., S1 and S2 were located inside the farm and another two, i.e., S3 and S4 in grazing exclosure. One sampling station was established in each stream at a representative point and sampling was carried out at the same point throughout the monitoring program.

2.2 Water Sampling

Data collection was initiated in July 2009 in both catchment and farm and continued for 12 months. This period was in accordance with tropical climatic condition to cover both dry and rainy seasons. Water samples were collected during steady period of stream flow or within 48 hr after rainfall event in rainy season (Shelton, 1994; Shah *et al*., 2007). Standard multilayer depth-integrating method was used to obtain the most representative sample (Shelton, 1994) in the catchment. In the Ladang pasture farm where flow rate and depth of streams were low and shallow, representative samples were obtained by immersing an open bottle by hand (dip sample) in the center of stream (Shelton, 1994). One composite sample (depth integrated sample) was collected from water-column in the centre of the streams (OWRB, 2013). Samples were analysed on the same day or following day of sampling.

2.3 Analytical Methods

In Situ water temperature (T), electrical conductivity (EC), dissolved oxygen (DO), and pH value of water samples were measured directly on site. Water samples were analyzed in the laboratory for ammonia cal-nitrogen (NH_3-N), chemical oxygen demand (COD), total suspended solid (TSS), 5-day biochemical oxygen demand (BOD_5), fecal coliform (FC) and *E. coli* with standard method (APHA, 1998). The analytical methods used for measuring of the water quality parameters are presented in Table 1.

Table 1 Analytical methods used for analyzing of water quality parameters in samples from standard method (APHA, 1998)

Variables	Unit	Analytical method
Ammonia (NH_3 -N)	Mg L^{-1}	Salicylate Method
COD	Mg L^{-1}	Reactor Digestion Method
Fecal Coliform (FC)	MPN 100 ml^{-1}	Membrane fecal coliform (m-FC) technique
E. coli	MPN 100 ml^{-1}	IDEXX (COLILERT 18) QUANTI-TRAY ™
Total Suspended Solid	mg L^{-1}	Gravimetric determination
BOD5	mg L^{-1}	Modified Winkler method
Temperature (T)	ºC	Thermometer
Dissolved oxygen (DO)	mg L^{-1}	Portable DO meter YSI model 52
pH	–Log [H^+]	Portable pH meter model Orion 3 star series
EC	µS $cm^{–1}$	Portable conductivity meter YSI model 30

2.4 Data Analysis and Water Quality Index

Assumptions of normality and homogeneity of variance were checked and log-transformed as appropriate. Turkey's multiple comparisons test was applied on water quality data to determine which mean amongst a set of means differ (P<0.05) from others. Box-and-whisker plots of individual variables which their means differ significantly from the other stations were signalized. Box lots show the median, and the first and third quartiles (Q1 and Q3).

Harkins' water quality index (WQI_H): This objective index is a nonparametric multivariate ranking system which follows a statistical approach based on the rank order of sampling stations compared to a set of control values. Usually a set of water quality standards or recommended limits are used as control values. Then measured water quality variables values are given numerical ranking orders in relation to a set of control values. The information is then used to compute the standardized distance from the control values for each parameter to produce an index of water quality. In this study, Malaysian recommended Interim Water Quality Standard (INWQS) (DOE, 1995) for water quality of class II was used to address the parameters with exceeded value.

Four steps were followed to compute the Harkins' Index (WQI_H):

1. A control value for each parameter and standard classes for each class of water quality were set.
2. All values in a certain column including control value, standard classes and parameter's values were ranked by assigning a rank value. Dissolved oxygen (DO) value was ranked from highest to lowest value (descending). Values of other parameters were ranked ascending. The rank values are used in place of the actual value of the parameter in succeeding computations.
3. Variance V(i) for each rank values were calculated for the i^{th} parameter using the equation (1).

$$V_{(i)} = 1/12n\times[(n^3-n)-\sum(t^3-t)] \quad (1)$$

Where n is the number of observations plus the number of control and classes, k is the number of ties encountered, t_j is frequency of the j^{th} ties and V(i) is variance of each parameter.

Calculated variance for each parameter is used to standardize the computed index. If k = 0 (no ties occur), the corresponding summation is to be regarded as vacuous (Yussoff *et al*., 1999)

4. Harkins' index was computed using the equation (2) to find standardized distance for each observation.

$$HI(n) = \sum_{i=1}^{P} [R_j(i) - R_c(i)]^2 / V(i) \qquad (2)$$

Where R_j (i) is rank for each parameter, R_c (i) is rank of the control value, P is number of parameter (6 parameters in this study) and HI is Harkins' index

WQI_H varies from 0 to a large positive number and gives different values for different sets of observations (i.e. its scale is "relative" rather than "absolute"). Low value of the index indicates high class of quality and the high value represents low class of water quality. Table 2 depicts the classification of the stream water quality based upon Harkin's Index.

Table 2 Classification of the stream water quality based upon Harkin's Index

Harkins' Index	Water quality class
0–28.5	I
< 38.0	II
< 42.5	III
< 45.5	IV
Other values	V

3 RESULTS AND DISCUSSION

3.1 Variations of Water Quality Parameters in the Streams

Mean values of NH_3 and FC were generally similar (P>0.05) amongst sampling stations in TPU catchment. Mean concentrations of TSS and COD were differed (P<0.05) amongst sampling stations in Ladang pasture farm (Table 3). In TPU catchment, pH value of stations in grazed grassland was higher (P<0.05) than that in stations of ungrazed grassland but was within the recommended standard (Table 3). The sampling stations of ungrazed grassland had more acidic water. In Ladang pasture farm, variation in mean pH value amongst stations ranged from 6.31 to 6.67 and all stations had pH value within recommended standard (Table 3).

pH of the aquatic bodies is an important indicator of the water quality and most chemical reactions are based on pH value (Juahir *et al*., 2011). Low pH can be due to the leachate and runoff water from accumulated plant litter and dead materials on ungrazed grassland. Organic acids could be formed by the decomposition of organic matter over time and transfer to surface water by runoff. This is the major factor that causes low pH value in streams (Juahir *et al*., 2011). Unpolluted waters usually illustrate a near neutral or slightly alkaline pH (Jonnalagadda and Mhere, 2001).

Average EC in the stations of ungrazed grassland was lower (P<0.05) than that in the stations of grazed grassland in TPU catchment (Table 3). EC values were generally similar (P>0.05) amongst the stations in Ladang pasture farm (Table 3). The EC values in the sampling stations of both areas were within the recommended standards. The higher EC value in some stations is due to high total dissolved solids and ionised species in the waters (Jonnalagadda and Mhere, 2001).

Table 3 Mean value and Tukey's test results for water quality parameters from the sampling stations in the study areas

Water quality variable	TPU catchment						Ladang farm				INWQS (class II)[†]
	grazed grassland				ungrazed grassland		grazed grassland		ungrazed grassland		
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	
Temp	28.78^{a}	27.34^{a}	28.20	27.60^{a}	27.87	27.72	28.21	28.03	27.78	27.95	Normal ± 2
DO	7.22	6.72	5.63^{a}	5.49^{b}	7.42 ^{ab}	7.51^{a}b	6.25	6.34	7.10	7.00	500-7.00
BOD	1.76^{ad}	1.91^{bd}	0.99	0.53^{d}	0.17^{ab}	0.44^{ab}	2.62	4.22	2.59	2.69	3.00
pH	6.35^{a}	6.32^{b}	6.43^{c}	6.10^{d}	5.44^{abcd}	5.89^{c}	6.33	6.67	6.31	6.32	6.00-9.00
EC	34.10^{ac}	65.91^{ab}	76.25^{ac}	44.33b^{c}	30.93^{bc}	31.97^{bc}	39.15	50.63	45.47	40.65	1000.00
TSS	26.00^{abcd}	11.15	20.00^{c}	7.12^{ab}	5.38^{ac}	6.75^{ad}	16.22	26.11^{a}	7.44^{a}	11.56	50.00
COD	19.95	26.87^{a}	26.00^{b}	14.50	5.62^{ab}	6.25^{ab}	39.44	47.55^{a}	20.49	17.89^{a}	25.00
NH_3-N	0.14	0.24	0.13	0.04	0.01	0.09	0.09	0.46	0.07	0.06	0.30
FC	1665.00	880.00	1750.00	677.00	239.00	241.00	5127.00	4715.00	1042.00	3082.00	100.00
E. coli	896.00	1428.00^{a}	1035.00	49.00^{a}	195.00^{a}	383.00	1349.00	1439.00	1176.00	781.00	200.00

Means in rows with the same letter are significantly different at $P<0.05$.
FC and *E. coli* are in geometric mean.
INWQS: Interim Water Quality Standard of Malaysia
[†]Source: DOE (1995)

DO concentration in the sampling stations of ungrazed grassland was higher ($P<0.05$) than that in the stations of grazed grassland in both farm and catchment (Table 3). The flow rate was almost similar in all streams. Consequently, different levels of DO concentration and high discrepancy between grazed and ungrazed stations can be related to low organic sediment in the stations of ungrazed grassland and high organic pollutants in the stations of grazed grassland. In addition, temperature, salinity, stream surface area and etc. can affect DO concentration in surface water (Table 3).

BOD_5 value was within the standard limit in all streams at TPU catchment (Table 3). The lowest (0.17 mg L^{-1}) and highest (1.91 mg L^{-1}) BOD values were recorded in station S5 of ungrazed and station S2 of grazed grasslands, respectively. BOD_5 value of S1 and S2 stations in grazed grassland were significantly higher than that in ungrazed grassland at TPU catchment (Table 3). Higher values of BOD_5 in S1 and S2 stations of grazed grassland is likely related to effluents from goat shed which located in the sub-catchment of S1 stream, milk parlour which located in the sub-catchment of S2 stream, and transportation of deposited fecal materials on grazing land to the streams. Low BOD values in ungrazed grassland stations reflect the small amount of biodegradable organic matter and suspended organic sediments (Yusoff *et al*., 1999) and low burden of organic pollution (Jonnalagadda and Mhere, 2001). There was no discharge of animal waste into streams in ungrazed grassland.

There was no significant difference ($P>0.05$) amongst the stations with respect to BOD concentration in Ladang pasture farm. BOD was lower than recommended standard limit of 3 mg L^{-1} in all stations, except S2, in

Ladang pasture farm. Higher BOD concentration in station S2 is largely related to cattle unrestricted access to this stream which located in the middle of the farm. Higher BOD level in the farm compared with catchment could be related to heavy grazing intensity in the farm compared with moderate grazing intensity in the catchment.

The highest (26.87 mg L^{-1}) and the lowest (5.62 mg L^{-1}) values of COD were recorded at stations S2 of grazed grassland and S5 of ungrazed grassland, respectively, in TPU catchment (Table 3). The average COD concentration in stations S2 and S3 of grazed grassland were higher (P<0.05) than that in ungrazed grassland (Figure 1). In Ladang pasture farm, COD concentration in the streams of grazed grassland was greater than that in ungrazed grassland (Table 3 and Figure 1). Concentration of COD exceeded the recommended limit (25 mg L^{-1}) in stations S2 and S3 of TPU catchment and stations S1 and S2 of Ladang pasture farm. COD is widely used for determining waste concentration and is applied primarily to pollutant mixtures such as sewage, industrial and biological wastes (Marques Da Silva and Sacomani, 2001).

The highest and the lowest concentrations of 26 and 5.38 mg L^{-1} were recorded for TSS in stations S1 and S5 in TPU catchment, respectively (Table 3). TSS concentration in stations S4, S5 and S6 were differed (P<0.05) from station S1 in the catchment. TSS concentration in stations S2 and S3 was differed (P<0.05) in Ladang pasture farm. All stations contained TSS concentration below recommended standard of 50 mg L^{-1}. The stations which were located in grazed grassland showed higher concentration of TSS (Figure 1). This can be due to runoff water from unprotected and eroded soil surface across the grazing land and stream bank erosion caused by animal traffic. In grassland without animal grazing, protection of soil surface and stream bank by dense vegetal cover against water erosion is probably the main reason for low TSS in ungrazed grassland (O' Reagain *et al*., 2005).

Mean FC count was not different (P>0.05) amongst the sampling stations in either grazed or ungrazed grassland at both farm and catchment. However, mean count of FC in S5 and S6 of ungrazed grassland was notably lower than that in the streams of grazed grassland in TPU catchment (Table 1). Mean *E. coli* was significantly differed (P<0.05) amongst stations of S2, S4 and S5 in the catchment. Station S4 followed by S5 showed the lowest level of *E. coli* (Figure 1). Station S4 was located close to ungrazed exclosure grassland and received surface runoff from this site partly. Geometric means of *E. coli* and FC were much higher than recommended standard limit in all stations most frequently, except for *E. coli* in stations S4 and S5 in TPU catchment. In Canada, Miller *et al*. (2010) observed higher *E. coli* in the stream with unrestricted cattle access. Water quality violation from standard limit for all variables is for protection of surface waters for aquatic life. The exception is *E. coli*, which is for protection of surface waters for recreational use (Miller *et al*., 2010). Fecal coliform and *E. coli* count is largely influenced by the animal manure and intensive agricultural activities.

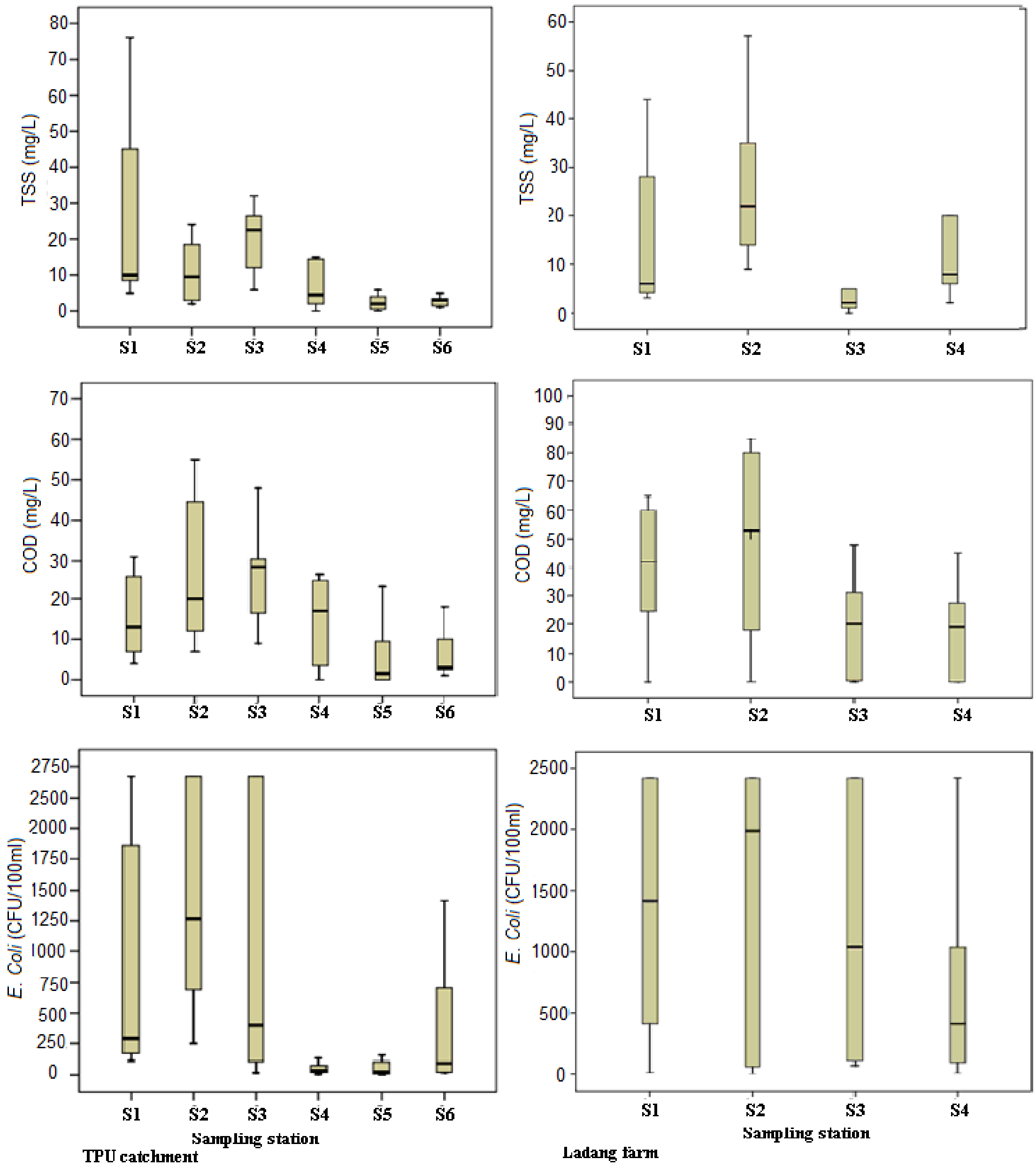

Figure 1 Box-plots of some water quality variables which differ amongst the stations in study area

3.2 Water Quality Index of Streams

The Harkins' index (WQI_H) was computed for sampling stations in both farm and catchment. Water quality of streams was accordingly classified based upon WQI_H value (Table 4). Water quality of streams was unfavourably affected by long-term moderate grazing in TPU catchment. The WQI_H value ranged from 6.42, in station S5, to 22.31, in station S2, at TPU catchment (Table 4). The highest (22.31) and the lowest (6.42) index values were calculated in the station S2 of grazed grassland and in the station S5 of ungrazed grassland (Table 4). The stations can be arranged in the order of S2> S1 > S3 > S4 > S6 > S5 in terms of WQI_H value in the catchment. In TPU catchment, water quality of the streams in grazed grassland was classified as class II, however, the streams in ungrazed grassland had water quality of class I. Class II indicates that water quality in the stream is still good in grassland under long-term moderate grazing.

Low water quality level in station S2 can be related to grazing activity, direct discharge of milk parlour effluents into this stream. Furthermore, a deer farm was in the sub-catchment of stream S2. Therefore, any possible pollution by deer husbandry discharges directly to the tributary of this stream. Discrepancy between the grazed and ungrazed grasslands indicates that surface water in the streams of grazed grassland was adversely affected by animal grazing. The decline of surface water quality could be due to fertilizer application to increase forage production, unrestricted cattle access to streams, in-stream defecation and urination, increased erosion of stream banks by cattle traffic, and increase in re-suspension of stream sediments and deposited fecal loadings by cattle treading. Minimum agricultural practices and anthropogenic interference were carried out in the ungrazed grassland during past three decades in the catchment.

Results showed that streams water quality was not affected by short-term heavy grazing in the grassland of Ladang pasture farm. Water quality of streams was grouped as class II in both grazed and ungrazed grasslands at Ladang pasture farm (Table 4). The highest and the lowest values of WQI_H were 21.64, in station S2, and 5.95, in station S6, in Ladang pasture farm (Table 4). In total, WQI_H value in ungrazed grassland was lower than that in grazed grassland. Low WQI_H value indicates high water quality and vice versa. Consequently, grazed and ungrazed grasslands had similar water quality classes in the farm. This can be explained by grazing period, farm size, and land use type around the farm. Ladang pasture farm was under cattle grazing for short-term (2 years). O'Reagain *et al*. (2005) stated that long periods of grazing are required to detect any responses of surface water to grazing management. Grazing management treatments differences need long time to be emerged and detection of trends in water quality is difficult in short-term. The area of the Ladang pasture farm was 40 ha which divided into four paddocks for rotational grazing purpose. Vidon *et al*. (2008) related that when animal grazing is restricted in a small paddock, the impact of animal on water quality is limited at least in short period. Furthermore, the ungrazed grassland of the farm is located in agricultural area that can be affected by leachate and discharge of adjacent cultivated land (Ohlenbusch *et al*., 2002). However, it can be expected that the streams of grassland with heavy grazing to have lower quality in long term (Lowrance and Sheridan, 2005). In addition, low water quality class in ungrazed grassland can be due to the decomposition of plant residues on grassland (Schepers and Francis, 1982), leaching of soluble nutrients from deposited vegetative materials (White, 1973) and wildlife activity. Increase of grazing inside the exclosures by grasshoppers, rabbits, and rodents may reduce differences between treatments, thus masking the effects of cattle grazing outside the exclosure (Belsky *et al*., 1999). The latter reason is not related to the present study as no considerable presence of wildlife activities was observed in ungrazed grassland.

Overall, water quality of streams was almost negatively affected by long-term moderate grazing in grassland of TPU catchment. Nonetheless, it seems that decline in water quality of streams in grazed grassland was not much important to influence aquatic life. Because streams still have water quality of class II, indicating good quality of water in stream.

Table 4 Classification of stream water quality in study areas by using of the Harkins' index

TPU catchment				Ladang farm			
sampling station	grassland	Harkins' Index value	class	sampling station	grassland	Harkins' Index value	class
S1	grazed	16.16	(II)	S1	Grazed	11.17	(II)
S2	grazed	22.31	(II)	S2	Grazed	21.65	(II)
S3	grazed	14.69	(II)	S3	Ungrazed	11.23	(II)
S4	grazed	10.74	(II)	S4	Ungrazed	5.96	(II)
S5	ungrazed	6.43	(I)	-			-
S6	ungrazed	6.43	(I)	-			-

Waters with quality of class II can be used for recreational, aquaculture and animal consumption purposes. In case of using class II water for drinking purpose, conventional treatments are needed very much in advance

3.3 Seasonal Water Quality Index of Streams

It is expected that the stream water quality status to be influenced by seasonal variation of rainfall. Water samples of all stations in both farm and catchment were divided into dry (May to September) and rainy (October to April) season samples to detect seasonal variation of WQI_H value. In TPU catchment, water quality in stations S1, S2, S3 and S4 in dry season was classified as class II, however, the stations in ungrazed grassland, i.e., S5 and S6 had water quality of class I in dry season (Table 5). The stations can be arranged in the order of S1 > S2 > S3 > S4 > S5 > S6 in terms of WQI_H value in dry season. The highest and the lowest WQI_H values in dry season were 18.38, in station S1, and 6.89, in station S6, respectively, in TPU catchment (Table 5). All stations were classified as class II in rainy season, except station S6, in the catchment (Table 5). The stations can be arranged in the order of S2 > S3 > S1 > S4 > S5 > S6 in terms of WQI_H value in rainy season. Consequently, station S6 had the highest water quality amongst the stations followed by the station S5 in either dry or rainy season in TPU catchment. These stations are situated in grasslands without any animal grazing and anthropogenic interferences. The stations S2, S3 and S5 showed lower WQI_H values in dry season compared to rainy season, which means streams contained better water quality in dry season. In contrast, stations S1, S4 and S6 had lower index values and subsequently better water quality in rainy condition.

Table 5 Water quality classification of streams in study areas with the Harkins' index value based on rainfall seasonal variation

TPU catchment						Ladang farm					
		dry season		rainy season				dry season		rainy season	
sampling station	grassland	Harkin's Index value	class	Harkin's Index value	class	sampling station	grassland	Harkin's Index value	class	Harkin's Index value	class
S1	Grazed	18.38	(II)	13.56	(II)	S1	Grazed	14.34	(II)	16.63	(II)
S2	Grazed	16.86	(II)	19.97	(II)	S2	Grazed	18.97	(III)	21.35	(II)
S3	Grazed	15.16	(II)	15.73	(II)	S3	Ungrazed	4.91	(I)	5.46	(II)
S4	Grazed	13.66	(II)	7.56	(II)	S4	Ungrazed	7.46	(II)	7.88	(II)
S5	Ungrazed	7.43	(I)	8.11	(II)	-	-	-	-	-	-
S6	Ungrazed	6.89	(I)	6.15	(I)	-	-	-	-	-	-

In Ladang pasture farm, water quality of stations S1, S2, S3 and S4 were classified as class II, III, I and II in dry season, respectively (Table 3). The stations can be arranged in the order of S2 > S1 > S4 > S3 in terms of WQI_H value in dry season. The highest and the lowest WQI_H values in dry season were 18.97 (station S2) and 4.91 (station S3) in the farm, respectively (Table 5). All stations were classified as class II at rainy season at the farm. The stations can be arranged in the order of S2 > S1 > S4 > S3 in terms of index value in rainy season. The highest and the lowest WQI_H values in rainy season were 21.35 (station S2) and 5.45 (station S3) in the farm, respectively (Table 5). Low water quality in station S2 can be related to cattle unrestricted direct access to the stream in the middle of the farm where the station S2 was located. Station S3 had the highest water quality amongst stations followed by the station S4 in either dry or rainy season in the farm. These stations are situated in grassland without animal grazing and with moderate anthropogenic interferences. All stations showed lower WQI_H index values in dry season compared to rainy, which means streams contained better water quality in dry season in the farm. The classification of streams by rainfall variation indicates that surface water quality can be affected by variations of rainfall. Yussof *et al*. (1999) indicated that water quality of the small streams varies depending on the rainy and dry condition. Rainfall events cause the dilution of pollutants and, hence, variations in water quality (Marques Da Silva and Sacomani, 2001). The effect of seasonal variation hinges on other factors such as stream flow rate, anthropogenic activities level in the sub-catchment of stream, agricultural activities, presence or absence of domestic animal grazing and etc. Most of the streams had water quality of class II, indicating that water quality in the streams of the farm was good. Water with good quality (class II) can be used for recreational, aquaculture and domestic purposes and is not appropriate for human consumption unless very intensive treatments to be applied in advance.

4 CONCLUSION

Water quality of streams in grassland was degraded to lower class due to animal grazing in the long-term rather than short-term in this study. Although adverse impact of heavy grazing was greatly expected in the study, the negative impact of moderate grazing on surface water quality was prominent in long-term moderately grazed grasslands.

Water quality of the streams in long-term moderately grazed and ungrazed grasslands of TPU catchment was classified as classes II and

I, respectively. These classes indicated good and excellent water quality in the catchment. Therefore, the degree of water quality degradation in the catchment was so small. All streams were grouped in class II in short-term heavily grazed Ladang pasture farm, indicating good water quality in the farm. On the flat land of Ladang pasture farm with high percentage of vegetal cover, animal grazing were more compatible for achieving water quality targets, provided that sufficient levels of ground cover to be maintained over time. Dense vegetal cover and flat terrain in Ladang pasture farm had significant role in the reduction of nutrients and sediment export from the farm. In contrast, sediment and nutrient loss on steeper and more erodible land types of TPU catchment led to relatively serious concern. Consequently, surface water degradation was relatively serious issue on hills and steep slope grassland of TPU catchment, in spite of moderate grazing intensity, than in flat and smooth land of Ladang pasture farm, in spite of heavy grazing intensity.

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ارزیابی کیفیت آب آبراهه‌ها در علفزارهای استوایی با استفاده از شاخص کیفیت آب

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چکیده کیفیت آب مسئله مهمی در علفزارهای استوایی است که جهت پایداری و استمرار منابع آب باید به آن توجه شود. هدف این مطالعه، ارزیابی کیفیت آب آبراهه‌ها در علفزارهای استوایی تحت چرای متوسط در بلند مدت و چرای سنگین در کوتاه مدت به‌ترتیب در مقیاس حوزه آبخیز و چراگاه (مزرعه) بود. مطالعه در حوزه آبخیز تی پی یو و چراگاه لادانگ در اطراف شهر کوالالامپور کشور مالزی به ترتیب تحت چرای متوسط بلند مدت (۲/۷ واحد دامی/هکتار/سال به مدت ۳۴ سال) و چرای سنگین کوتاه مدت (۵ واحد دامی/هکتار/سال به مدت ۲ سال) انجام شد. نمونه‌گیری آب در آبراهه‌های علفزار چرا شده و چرا نشده به‌طور ماهانه در طول یک سال در هر دو منطقه (حوزه آبخیز و مزرعه) انجام شد. مقادیر pH، EC، DO، NH_3-N، COD، TSS، BOD_5، باکتری‌های ای کولای و کلیفرم در نمونه‌های آب اندازه‌گیری شدند. شاخص هارکینز برای تعیین کلاس کیفیت آب آبراهه‌ها استفاده شد. میانگین مقادیر NH_3-N و باکتری کلیفرم در بین همه آبراهه‌های حوزه آبخیز و آبراهه‌های چراگاه یکسان بود ($P >$ ۰/۰۵). میانگین مقادیر pH، COD، TSS وBOD آب آبراهه‌های منطقه تحت چرای دام بیش از مقادیر این متغیّرها در آبراهه‌های منطقه حفاظت شده از چرا هم در حوزه آبخیز و هم در چراگاه بود ($P <$ ۰/۰۵). غلظت اکسیژن محلول (DO) در بین همه آبراهه‌های حوزه آبخیز و چراگاه لادانگ یکسان بود ($P >$ ۰/۰۵). کیفیت آب آبراهه‌ها تحت تاثیر چرای سنگین کوتاه مدت در چراگاه لادانگ قرار نگرفت. تأثیر منفی چرای دام بر کیفیت آب آبراهه‌ها در علفزار تحت شدت چرای متوسط در بلند مدت مشهودتر از چراگاه تحت شدت چرای سنگین کوتاه مدت بود.

کلمات کلیدی: چرای سنگین، چرای متوسط، شاخص کیفیت، هیدرولوژی مرتع